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RELAP5/MOD3 Code Manual

Summaries and Reviews of Independent Code Assessment Reports

Prepared by
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ABSTRACT

Summaries of RELAP5/MOD3 code assessments, a listing of the assessment matrix, and a chronology of the various versions of the code are given. Results from these code assessments have been used to formulate a compilation of some of the strengths and weaknesses of the code. These results are documented in the report. Volume 7 was designed to be updated periodically and to include the results of the latest code assessments as they become available. Consequently, users of Volume 7 should ensure that they have the latest revision available.

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TABLES

EXECTIVE SUMMARY

Volume 7 was created to:

- Support the efforts of the U. S. Nuclear Regulator Commission (USNC) to determine the ability of advance thermal-hydraulic codes to appropriately represent important physical phenomena and support the quantitative determination of the accuracy of these codes.

- Share user experience on code assessment and to present a well documented assessment data base.

- Share experience on code errors and inadequacies and cooperate in removing the deficiencies to maintain a single, internationally recognized version of each code.

- Establish and improve user guidelines for applying the code.

Summaries of assessments performed on the RELAP5/MOD3.0 and RELAP5/MOD3.1 codes show it gives reasonable calculations of many postulated thermal-hydraulic tranients of light water reactor systems. However, the code does have shortcomings. Based on the assessments completed to date, the resulting matrix shows regions of the thermal-hydraulic behavior and phenomena that require investigation.

1 INTRODUCTION

1.1 Objective

The purpose of this volume of the RELAP5 manual is to provide, in a single location, summaries of all the code assessment reports for RELAP5/MOD3. Additionally, this document summarizes the code deficiencies identified in the reports and indicates how those deficiencies can affect various calculations. This document is intended to be used as a reference by code users for the following purposes:

- To ascertain current code capabilities and limits for various types of calculations.
- To determine if problems they encounter have been identified previously and if those problems have been solved in a later version of the code.
- To gain from the experiences of other code users in the areas of nodalization and other sensitivities.
- To evaluate the RELAP5/MOD3 code assessment database from an overall perspective.

This effort is an adjunct product of the U. S. Nuclear Regulatory Commission (USNRC) Code Assessment and Maintenance Program (CAMP) in which code assessment reports are submitted by the international CAMP members. The reviews contained herein adhere to the format adopted under the CAMP program. The need to gather all code assessment reports in a single document arose because, prior to this work, there was no single document that summarized all RELAP5 code assessments and discussed the impact of code errors, deficiencies, and resulting new user guidelines.

The code assessment reports summarized in this document are reports:

- Submitted to CAMP for review.
- Identified by a literature search.
- Submitted to INEL by the performing organization.

The ideal is to have contributions from all organizations using the code, including the USNRC, CAMP members, the U. S. Department of Energy (DOE), etc.

1.2 Organization of Volume VII

This volume is divided into a number of "living" sections, where each section contains a summary of the code assessment results for a particular code version up to the time of the latest volume update. As new code versions are released, a section will be added for the code assessment results for each. Further, existing sections of the document will be updated periodically as new code assessment reports are received and reviewed. Thus, the product is a "living" document, where reviews of new reports are added and the results summaries revised accordingly. Documents can be distributed either by hard copy or electronic file transmittal.

Section 1.3 discusses general guidelines for the range of conditions and phenomena for which code assessment is performed.

Main sections 2 and 3 summarize the assessment of RELAP5/MOD3.0 and RELAP5/MOD3.1, respectively. Each of these sections are subdivided into six subsections. The first subsection gives a brief description of the code version being assessed to help the user quickly identify the characteristics, since new versions contain error corrections, elimination of deficiencies, or model enhancements which can make a significant difference in results. The second subsection presents a matrix of the code assessment studies reviewed to date. The third subsection contains summary reviews of each code assessment report for separate effects experiments, integral effects experiments, and plant transients. The fourth subsection summarizes the results of the code assessment studies and discusses the impact of the identified code deficiencies on different types of calculations, including steady-state, LBLOCA, SBLOCA, and operational transients. The fifth subsection describes nodalization sensitivities and new or revised user guidelines developed in the code assessment studies. The sixth subsection presents conclusions and observations based on the code assessement results.

It should be noted that the references reviewed in this volume are identified in each individual section containing the review. This method of documenting references was chosen because: (a) references made in an individual report summary/review are most appropriately referenced in that location, and (b) because the report will be continually updated and new references included.

1.3 General Range of Code Assessment

Code assessment should cover a broad range of conditions and phenomena for which the code is expected to perform. A set of useful guides to this range is the OECD/CSNI code assessment matrices (**Reference 4.0-1**). In those matrices, the following are shown: phenomena vs. test type, phenomena vs. test facility, and test facility vs. test type. The merged OECD assessment matrices are given in **Table 1.3-1** through **Table 1.3-3**.

These matrices can be referred to as "functional" code assessment guides, which in this context means a matrix of phenomena/models/etc. vs. various experimental facilities or plant data. Many of the code assessment reports summarized herein fall within the OECD matrices, while others expand the matrix by adding test facilities. In the section for the assessment for each code version, there is a subsection presenting, in a form similar to the OECD matrices, the assessment studies accomplished to date. Comparison of these assessments with **Table 1.3-1** through **Table 1.3-3** provides a perspective of the overall level of assessment reached at any point in time (i.e., each time this document is updated).

Table 1.3-1 OECD code assessment matrix for PWR LBLOCAs.

MATRIX I
Cross-reference matrix for large break in PWRs

Phenomena versus test type
- ● simulated
- ○ partially simulated
- – not simulated

Phenomena versus test facility
- ● suitable for code assessment
- ○ limited suitability
- – not simulated

Test facility versus test type
- ● already performed or planned until 12/84
- ○ performed or planned until 12/84 , but of limited use
- – not simulated

		Test type			Test facility												
					Systems							Sep. effects					
					1:25[a]	1:50	1:100	1:34	1:430	1:712	1:600	1:1	1:25	1:25			
		Blowdown	Reflood	Refill	CCFTL	LOFT	BETHSY	PKL	SPES	LOBI	SEMISCALE	UPTF	CREARE	SCTF	Marviken	BCL	SUPPER MOBY DICK
Phenomena	Break flow	●	●	●	–	○		○		○	○		–	–	●	–	●
	Phase separation	○	●	●	●	●		●		●	●		–	–	○	–	–
	Mixing and condensation during injection	○	●	●	○	○		○		○	○		●	●	–	●	–
	Core wide void + flow distribution	○	●	●	○	○		○		–	–		–	●	–	–	–
	ECC bypass and penetration	○	○	●	●	●		○		–	–		●	○	–	●	–
	CCFL (UCSP)	○	●	●	○	○				○	–		–	●	–	–	–
	Steam binding (liquid carry over, etc)	–	●	●	○	○		●		–	○		–	–	–	–	–
	Pool formation in UP	–	●	○	○	○		○		–	○		–	●	–	–	–
	Core heat transfer incl. DNB, dryout RNB	●	●	●	○	●		○		○	○		–	○	–	–	–
	Quench front propagation	○	●	●	○	●		○		–	○		–	○	–	–	–
	Entrainment (Core, UP)	○	●	○	○	○		○		○	○		–	●	–	–	–
	Dentrainment (Core, UP)	○	●	○	○	○		○		–	○		–	●	–	–	–
	1-and 2-phase pump behavior	●	○	○	–	○		○		●	●		–	–	–	–	–
Test Facility Systems	CCTF	–	●	●													
	LOFT	●	●	●													
	BETHSY																
	PKL	○	●	●													
	SPES																
	LOBI	●		●													
	SEMISCALE	●	●	●													

a. Volumetric scaling.

Important test parameter
leak location/leak size
pumps off/pumps on
cold leg injection/combined injection

Note: Uncategorized facility data = blank

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Table 1.3-2 OECD code assessment matrix for PWR SBLOCAs.

MATRIX II
Cross-reference matrix for small and intermediate leaks in PWRs

Phenomena versus test type
● simulated
○ partially simulated
– not simulated

Phenomena versus test facility
● suitable for code assessment
○ limited suitability
X expected to be suitable
– not simulated

Test facility versus test type
● simulated
○ partially simulated
– not simulated

	Test type							Test facility														
								Systems								Sep. effects						
								1:1[a]	1:50	1:50	1:100	1:134	1:430	1:712	1:1600	1:1	1:15	1:50				
Phenomena	Stationary test addressing energy transportation on primary side	Stationary test addressing energy tranp. on sec. side	Small leak overfeed by HPIS secondary side necessary	Small leak w/o HPIS overfeeding, secondary side necessary	Intermediate leak secondary side not necessary	Pressurizer leak	U-tube rupture	PWR	LOFT	LSTF	BETHSY	PKL-I	SPES	LOBI-II	SEMISCALE	UPTF	THL	GEST GUEN	Patricia GV-1	Patricia GV-2/GEN 3x3	G-2	Pressurizer Test (CISE)
Natural circulation in 1-phase flow, primay side	●	●	●	●	–	●	●	●	●			●		●	●		–			–	–	–
Natural circulation in 2-phase flow, primary side	●	–	○	●	●	○	–	–	●			●		●	●		–			–	–	–
Reflux condenser mode and CCFL	●	–	–	●	●	–	–	–	○			○		○	○		–		●	–	–	–
Asymetric loop behavior	–	–	○	●	–	●	●	–		x	x	–	x	○	○		–			–	–	–
Leak flow	–	–	●	●	●	●	●	–	●			○		●	●		●			–	–	–
Phase separation without mixture level formation	●	–	○	●	●	●	○	–	○			○		●	○		○			–	–	–
Mixture level and entrainment in vert. comp. s.g.[b]	–	●	●	●	●	●	●	–	–			○		○	–		–	x		●	–	[illegible]
Mixture level and entrainment in the core	●	–	–	●	●	●	–	–	○			○		○	○		–			–	●	[illegible]
Stratification in horizontal pipes	●	–	–	●	●	–	–	–	●	x	x	○		○	○		●			–	–	–
ECC-mixing and condensation	–	–	○	●	●	●	●	–	○			○		○	○		–			–	–	–
Loop seal clearance	–	–	–	●	●	○	–	–	●			○		●	●		–			–	–	–
Pool formation in UP/CCFL (UCSP)	●	–	–	○	●	●	–	–	○	x		○		–	○	x	–			–	–	–
Core wide void and flow distribution	●	–	–	○	●	●	–	–	○	x		–		–	–		–			–	–	–
Heat transfer in covered core	●	●	●	●	●	●	●	○	●			●		●	●		–			–	–	–
Heat transfer partially uncovered core	●	–	–	○	●	–	–	–	●			○		○	○		–			–	●	–
Heat transfer in SG primary side	●	○	○	●	●	○	○	–	○			○		●	○		–	x	●	–	–	–
Heat transfer in SG secondary side	○	●	●	●	●	●	●	–	○			○		●	○		–	x		●	–	–
Pressurizer thermohydraulics	○	–	○	○	●	●	●	○	○			–		○	–		–			–	–	●
Surgeline hydraulics	○	–	–	○	●	●	○	–	○			–		○	○		–			–	–	●
1-and 2-phase pump behavior	–	–	–	○	●	–	–	○	○			–		●	●		–			–	–	–
Structure heat and losses[c]	●	–	○	●	●	○	○	–	○			○		○	○		–			–	–	–
Noncondensible gas effects	●	–	–	–	–	–	–	–	–			○		●	○		–			–	–	–
Phase separ. in T-junc. and effect on leak flow	–	–	–	●	●	–	–	–	○			–		○	–		●					

Test Facility Systems	Stationary test addressing energy transportation on primary side	Stationary test addressing energy tranp. on sec. side	Small leak overfeed by HPIS secondary side necessary	Small leak w/o HPIS overfeeding, secondary side necessary	Intermediate leak secondary side not necessary	Pressurizer leak	U-tube rupture
PWR	–	–	○	–	–	●	●
LOFT	–	–	●	●	●	●	–
LSTF							
BETHSY							
PKL-I	●	●	–	●	●	●	–
SPES							
LOB-II	●	●	●	●	●	●	●
SEMISCALE	○	○	●	●	●	●	●

a. Volumetric scaling ratio
b. Secondary side
c. Problem for scaled test facilities

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Table 1.3-3 OECD code assessment matrix for PWR transients.

MATRIX IV
Cross-reference matrix for transients in PWRs

Phenomena versus test type
- ● simulated
- ○ partially simulated
- – not simulated

Phenomena versus test facility
- ● suitable for code assessment
- ○ limited suitability
- – not simulated

Test facility versus test type
- ● already performed or planned until 12/84
- ○ performed or planned until 12/84, but of limited use
- – not simulated

		Test type									Test facility systems							
		ATWS	Loss of feedwater, non ATWS	Loss of heat sink, non ATWS	Station blakout	Steam line break	Feed line break	Cooldown primary feed and bleed	Reactivity disturbances	Over-cooling	PWR 1:1[a]	LOFT 1:50	LSTF 1:50	BETHSY 1:100	PKL-1 1:134	SPES 1:430	LOB-II 1:712	SEMISCALE 1:1600
Phenomena	Natural circulation in 1-phase flow	●	●	●	●	●	●	●	○	○	●	○			○		●	●
	Natural circulation in 2-phase flow	●	●	●	●	–	–	○	○	–	–	○			○		●	●
	Core thermohydrualics	●	●	●	●	○	○	○	●	○	○	●			–		●	●
	Thermohydraulics on primary side of SG	●	○	○	●	○	○	●	○	●	○	○			–		●	○
	Thermohydraulics on secondary side of SG	●	●	●	●	●	●	●	○	●	○	○			–		●	○
	Pressurizer thermohydraulics[b]	●	●	●	●	○	○	○	○	●	●	○			–		○	○
	Surgeline hydraulics (CCFL, choking)[b]	●	●	●	●	○	○	○	○	○	○	○			–		○	○
	Valve leak flow[c]	●	●	●	●	●	●	●	●	●		○			○		○	○
	1- and 2-phase pump behavior	●	●	●	●	○	○	○	○	○	○	○			–		●	●
	Thermohydraulic-nuclear feedback	●	–	–	–	–	–	–	●	–	●	●			–		–	–
	Structural heat and heat losses[d]	○	○	○	○	○	○	○	○	○	–	○			○		○	○
	Boron mixing and transport	–	–	–	–	○	–	–	–	○	–	–			–		–	–
	Separator	○	–	–	–	–	–	–	–	–	–	–			–		–	–
Test Facility Systems	PWR	–	–	–	–	–	–	–	–	○								
	LOFT	●	●	●	○	–	–	●	●	●								
	LSTF																	
	BETHSY	–	–	–	–	–	–	–	–	–								
	PKL-I																	
	SPES																	
	LOBI-II	○																
	SEMISCALE	–	○	○	○	○	○	○	–	○								

a. Volumetric scaling ratio
b. For phenomena separate effects. pressurizer behavior. refer to small leak cross-reference matrix.
c. Valve flow behavior will be strongly design-dependent, specific experimental data should be used if possible.
d. Problem for scaled test facilities.

NOTE: Uncategorized facility data= blank.

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2 SUMMARY OF RELAP5/MOD3.0 CODE ASSESSMENT THROUGH SEPTEMBER 30, 1995

2.1 Brief Code Description

RELAP5/MOD3.0 was released for general use in March, 1990. (At that time, the version nomenclature was somewhat different; this version was originally released as RELAP5/MOD3 version 5m5.) It was the first released version in the RELAP5/MOD3 series and contained model changes distinguishing it from the prior series, RELAP5/MOD2, as documented extensively in Volume 1 of this manual. A chronology of code changes are given in the Appendix "Summary of RELAP/MOD3 Code Versions–Version 5m5 to Present." The major differences between the MOD2 and MOD3 series of the code are (as listed in the RELAP5/MOD3 Code Manual, Volume 1):

- New models
  - The Bankoff CCFL correlation, which is based on actual geometry and can be activated by the user at each junction in the system model.
  - The ECCMIX component for modeling the mixing of subcooled ECCS liquid and the resulting interfacial condensation.
  - A zirconium-water reaction model to model the exothermic energy production on the surface of zirconium cladding material at high temperature.
  - A surface-to-surface radiation heat transfer model with multiple radiation enclosures defined through user input.
- Modifications to existing models
  - New correlations for interfacial friction for all types of geometry in the bubbly and slug flow regimes in vertical flow passages.
  - Use of junction-based interphase drag.
  - An improved model for vapor pullthrough and liquid entrainment in horizontal pipes to obtain correct computation of the fluid state convected through the break.
  - A new CHF correlation for rod bundles based on tabular data.
  - An improved horizontal stratification inception criterion for predicting the flow regime transition between horizontally stratified and dispersed flow.
  - A modified reflood heat transfer model.
  - An improved vertical stratification inception logic to avoid excessive activation of the water packing model.

- The addition of a simple plastic strain model with clad burst criterion to the fuel mechanical model.

- The addition of a radiation heat transfer term to the gap conductance model.

- Modifications to the noncondensable gas model to eliminate erratic code behavior and failure.

- Improvements to the downcomer penetration, ECC bypass, and upper plenum deentrainment capabilities.

- Modifications that place both the vertical stratification and water packing models under user control so they can be deactivated.

• User conveniences

  - Code speedup through vectorization for the CRAY X-MP computer.

  - Code portability through the conversion of the FORTRAN coding to adhere to the FORTRAN 77 standard.

  - Code execution and validation on a variety of systems. [The installation script is supplied with the transmittal for the CRAY-XMP (UNICOS), DECstation 5000 (ULTRIX), DEC ALPHA workstation (OSF/1) IBM workstation 6000 (UNIX), SUN workstation (UNIX), and HP workstation (UNIX). It has been installed on the CDC Cyber (NOS/VE), IBM 3090 (MVS), and IBM PC (DOS). It should be installable on all 64-bit machines (integer and floating point) and any 32-bit machine that provides for 64-bit floating point.].

2.2 Code Assessment Matrix

The RELAP5/MOD3.0 code assessment studies applicable to non-Soviet, commercial light water PWR systems reviewed to date are shown in **Table 2.2-1** and **Table 2.2-2**. These tables indicate the phenomena for LBLOCA and SBLOCA and the degree to which each is simulated in each facility

These tables adhere primarily to the format of the OECD code assessment matrices given in **Table 1.3-1** through **Table 2.4-1**; however, because of the more extensive data set available for SBLOCA-related phenomena, the correlations between test type and phenomena as well as the test type versus the test facility systems tests are shown only for SBLOCAs and not for LBLOCAs.

The code assessment studies reviewed to date include all current CAMP/ICAP assessment reports as well as two other formal reports. A total of 18 studies have been reviewed. Ten are separate effects experiments; six are integral effects experiments; one is a plant transient; and one uses a databank for comparison. It should be noted that the code assessments were all completed using version 5m5 unless otherwise noted.

Table 2.2-1 RELAP5/MOD3.0 code assessment matrix for PWR LBLOCAs.

MATRIX I

Cross-reference matrix for transients in PWRs

Phenomena versus test type

● simulated
○ partially simulated
– not simulated

Phenomena versus test facility

● suitable for code assessment
○ limited suitability
– not simulated

		Test type			Separate effects test facility		
		Blowdown	Reflood	Refill	RIT	UPTF	Marviken
Phenomena	Break flow	–	–	–	–	–	●
	Phase separation	–	–	–	–	–	–
	Mixing and condensation during injection	–	–	–	–	–	–
	Core wide void + flow distribution	–	–	–	–	–	–
	ECC bypass and penetration	–	●	●	–	–	–
	CCFL (UCSP)	–	–	–	–	–	–
	Steam binding (liquid carry over, etc.)	–	–	–	–	–	–
	Pool formation in UP	–	–	–	–	–	–
	Core heat transfer incl. DNB, dryout, RNB	–	●	●	○	●	–
	Quench front propagation	–	–	○	–	○	–
	Entrainment (Core, UP)	–	–	–	–	–	–
	Deentrainment (Core, UP)	–	–	–	–	–	–
	1-and-2-phase pump behavior	–	–	–	–	–	–
	Important test parameter leak location/leak size pumps off/pumps on cold leg injection/combined injection						

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Table 2.2-2 RELAP5/MOD3.0 code assessment matrix for PWR SBLOCAs.

MATRIX II
Cross-reference matrix for small and intermediate leaks in PWRs

Phenomena versus test type
● simulated
○ partially simulated
– not simulated

Phenomena versus test facility
● suitable for code assessment
○ limited suitability
– not simulated

Test facility versus test type
● simulated
○ partially simulated
– not simulated

		Test Type			Test Facility: Systems			Test Facility: Sep. effects							Test Facility: Plant Transients
		Stationary test addressing energy transportation on primary side	Stationary test addressing energy tranp. on sec. side	Small leak w/o HPIS overfeeding, secondary side necessary	BETHSY 1:100[a]	LSTF 1:50	SEMISCALE 1:1600	Northwestern	KAERI	Marviken	WSRC	UPTF	KRESING (Piping)	ROYAL Inst. of Tech.	KORI Unit 3
Phenomena	Natural circulation in 1-phase flow, primary side	●	●	●	●	●	●	–	–	–	○	–	–	–	●
Phenomena	Natural circulation in 2-phase flow, primary side	●	●	●	●	●	●	–	–	–	○	–	–	–	–
Phenomena	Reflux condenser mode and CCFL	●	●	●	●	●	○	–	●	–	–	●	–	–	–
Phenomena	Asymmetric loop behavior	–	–	●	–	–	○	–	–	–	–	–	–	–	●
Phenomena	Leak flow	–	–	●	●	●	●	–	–	●	–	–	●	–	–
Phenomena	Phase separation w/o mixture level formation	●	–	●	●	●	○	–	–	–	–	○	–	–	–
Phenomena	Mixture level and entrainment in vert. comp s.g.[b]	●	●	●	●	–	–	–	–	–	–	–	–	–	●
Phenomena	Mixture level and entrainment in the core	●	–	●	●	○	○	–	–	–	–	–	–	–	–
Phenomena	Stratification in horizontal pipes	●	●	●	●	●	○	○	–	–	–	●	–	–	–
Phenomena	ECC-mixing and condensation	–	–	–	–	–	–	○	–	–	–	–	–	–	–
Phenomena	Loop seal clearance	–	–	●	●	●	●	–	–	–	–	–	–	–	–
Phenomena	Pool formation in UP/CCFL (UCSP)	●	●	○	○	○	○	–	–	–	–	–	–	–	–
Phenomena	Core wide void and flow distribution	●	●	○	○	○	○	–	–	–	–	–	–	–	–
Phenomena	Heat transfer in covered core	●	●	○	●	●	●	–	–	–	–	–	–	–	●
Phenomena	Heat transfer partially uncovered core	●	●	○	●	●	○	–	–	–	–	–	–	○	–
Phenomena	Heat transfer in SG primary side	●	●	●	●	●	○	–	–	–	–	–	–	–	●
Phenomena	Heat transfer in SG secondary side	○	●	●	●	●	○	–	–	–	–	–	–	–	●
Phenomena	Pressurizer thermohydraulics	–	–	–	–	–	–	–	–	–	–	–	–	–	●
Phenomena	Surgeline hydraulics	–	–	–	–	–	–	–	–	–	–	–	–	–	●
Phenomena	1-and 2-phase pump behavior	–	–	–	–	–	–	–	–	–	–	–	–	–	○
Phenomena	Structure heat and losses[c]	●	●	●	○	○	○	–	–	–	–	–	–	–	
Phenomena	Noncondensable gas effects	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Phenomena	Phase separ. in T-junc.and effect on leak flow	–	–	●	○	○	○	–	–	–	–	–	–	–	–
Test Facility Systems	BETHSY	●	●	●											
Test Facility Systems	LSTF	–	–	●											
Test Facility Systems	SEMISCALE	–	–	●											

a. Volumetric
b. Secondary
c. Problem for scaled test facilities

jen1195-001.nod

Twenty reports of RELAP5/MOD3 code assessment studies were located in a literature search. Foreseeing the lack of time of funding to review all 20 for the draft version of the RELAP5 Manual Volume 7, only four of these reports were selected for review and inclusion (two unreviewed ICAP reports and two formal reports). It is recommended that the remaining reports be reviewed and included in a subsequent version of the volume.

Given the constraints on the possible number of reports to be included in the draft, prioritizing was necessary. Priority was given to code assessment studies submitted to the ICAP program that subsequently became NUREG/IA reports. Five such reports were found in the literature search, two of which were not yet reviewed.

For the remaining reports, priority will be given to those that were published as formal reports or journal articles, rather than conference papers. This is based on the assumption that information in conference papers is less finalized and complete than that of journal articles or formal reports. Seven reports meet these criteria; reviews for two are included in this volume. Reviews of the journal articles will be included in a later release of this volume if the reported information is still relevant.

Finally, each conference paper will be evaluated and a determination made as to whether adequate information is available to perform a useful review and if the report contains still relevant information. If so, that paper will be reviewed and the review included in a later release of this volume. If not, the paper will be disregarded or the author contacted for further information.

2.3 Summary Reviews of the Code Assessment Reports

2.3.1 Separate Effects Experiments

The separate effects experiment assessments are reviewed in Section 2.3.1.1 through Section 2.3.1.10 and cover the following areas of code capabilities:

- Thermal hydraulic instability in slight boiling systems with natural circulation - Section 2.3.1.1, **Reference 4.0-2**.
- Low flow natural circulation - Section 2.3.1.2, **Reference 4.0-3**.
- Accumulator component - Section 2.3.1.3, **Reference 4.0-4**.
- CHF - Section 2.3.1.4, **Reference 4.0-5**.
- Piping loads during safety and relief valve discharge - Section 2.3.1.5, **Reference 4.0-6**.
- Downcomer penetration for LBLOCAs - Section 2.3.1.6, **Reference 4.0-7**.
- Countercurrent flow in PWR hot legs - Section 2.3.1.7, **Reference 4.0-8**.
- Direct contact condensation during horizontal stratified flow - Section 2.3.1.8, **Reference 4.0-9**.
- Counter-current flow limiting - Section 2.3.1.9, **Reference 4.0-10**.

- Critical flow - Section 2.3.1.10, **Reference 4.0-11**.

2.3.1.1 Flow Instability.

Report reviewed:

P. A. Leppik, G. L. Urusov, and A. I. Vladimirov, "RELAP5/MOD2/MOD3 Post-Test Instability Analysis for Slight-Boiling Systems of AST-500 Type with Natural Circulation," Russian Research Center-Kurchatov Institute, October, 1992.

Objectives

The objective of the study was to assess the ability of RELAP5/MOD2 and RELAP5/MOD3 to calculate the thermal hydraulic instability in slight boiling systems with natural circulation.

Summary description of the experiment and the input model

The experiments consisted of five series of instability tests in two natural circulation (NC) loop facilities. One facility was a small loop at VTI; the other was a large loop at the Kurchatov Institute of Atomic Energy (KIAE). In the experiments the inlet subcooling varied from 0-100 K; the core mass flux varied from 300-1300 kg/m^2/s, the outlet quality varied from 0-0.035; and the pressure was 1.6 and 2.0 MPa. The tests were carried out because it is necessary to calculate self-induced flow rate oscillation and instability boundaries for slight boiling systems with natural circulation, such as the AST-500 design.

The heated section in the small NC loop (0.75 m) was represented by 10 volumes. The heated section in the large NC loop (3 m) was represented by 15 volumes. The calculations were run on a 386 PC.

Results significant for code assessment

Only those results directly pertaining to RELAP5/MOD3 will be summarized. The overall conclusion of the study was that there was good qualitative agreement and satisfactory quantitative agreement for the parameters of instability boundaries, oscillation amplitude, and oscillation frequency. The areas of quantitative discrepancies were:

- The width of the instability domain and the oscillation amplitude were overpredicted when the average heat flux was between 0.11 and 0.14 MW/m^2.

- The oscillation amplitude and domain width were overpredicted, with the error increasing with decreasing power level. This problem, it was suggested, could be solved if the effect of density wave damping in the riser was taken into account.

- There was a tendency to overpredict core inlet temperature and core outlet quality at the points of instability onset and disappearance, but the shift was not great in comparison to possible errors in measurement.

Author recommendations

It was recommended that the effect of density wave damping in the riser with relatively large cross-sectional area be taken into account to reduce the overprediction of amplitude and the width of the instability domain.

Limitations of the study

More explanation/discussion of graphs is needed to support the conclusions. All graphs are referenced, but few are specifically explained.

Additional significant study findings

None.

Other comments

This code assessment, based on the AST-500 type reactor system illustrates that RELAP5/MOD3 has a wide range of usefulness. However, no plans are in place to improve the code's calculation capabilities with respect to the AST-500 type reactor system.

2.3.1.2 Low Flow Natural Circulation.

Report reviewed:

R. P. Martin and B. K. Taylor, "Benchmarking Assessment of RELAP5/MOD3 for the Low Flow and Natural Circulation Experiment at the WSRC," WSRC-TR-92-088, paper presented at the NURETH-5 Meeting, Salt Lake City, UT, September 21-24, 1992.

Objectives

The objective of the study was to assess the ability of RELAP5/MOD3 to calculate the phenomena associated with low flow and natural circulation flow in a loop with an annular heated section.

Summary description of the experiment and the input model

The test facility consisted of a heat exchanger, pump, venturi flowmeter, standpipe, and a heated single annulus test section through which light water circulated. The heated test section consisted of two concentric 3.81 m (12.5 ft) long tubes. The inner tube was stainless steel and was uniformly heated. The outer tube, Lexan was unheated. Measured parameters included flow rate, fluid temperature, and differential pressure.

Nine sets of test data were used for comparison. These covered the range of stable test variables: inlet temperature of 298 K (77 °F) and 323 K (122 °F); zero power, 25 kW, 45 kW, and 0-21 kW; pressures of 1.01×10^5 MPa (14.7 psia) and 1.17×19^5 (17.0 psia) and both forced and natural circulation. For the model, the test section was divided into 11 volumes, 8 of which were heated.

Results significant for code assessment

The following were observed in the calculations:

- For the zero power, forced flow case, the calculated test section pressure drop agreed very well with the data at the flow rate for which the form losses were determined, but diverged somewhat at lower and higher flow rates.

- For the 45 kW forced flow case, the calculated test section pressure drop exceeded the measured data. This was attributed to the lack of a model in RELAP5 to account for the radial fluid temperature gradient extending outward from the heated wall that causes fluid at the heated wall to have a much lower viscosity than the colder bulk fluid. The lower viscosity reduces the wall friction contribution to the pressure drop.

- Also for the 45 kW, forced flow case, the calculated point of the Onset of Flow Instability (OFI) agreed very well with the measured value. (OFI is the minimum of the pressure drop versus channel flow rate beyond which the two phase pressure drop increases dramatically).

- For the variable power, natural circulation case, the calculated pressure drop underpredicted the measured values. This was attributed to two factors. The first is that the circular pipe geometry assumption in RELAP5 causes the laminar flow wall friction to be significantly underpredicted for an annulus. As stated by the authors, for laminar flow, the annulus wall friction is 50% greater than for a circular pipe. The second is that because the form losses were determined based on forced flow data, they were significantly underpredicted (a hand calculation indicated by as much as 45%) for the low flow conditions of natural circulation.

- Problems were encountered in the calculations when the flow began to transition from single- to two-phase. Mass error would increase greatly during condensation and, leading to slowdown and often failure of the calculation. The solution was to run with very small time steps.

Author recommendations

The following recommendations were offered:

- The friction factor needs to be modified to extend to the laminar and transition regions. It also requires modification for non-circular geometry.

- Future code assessment should investigate the calculation of interfacial phenomena (heat and mass transfer and drag) in non-circular geometry.

- A correction factor based upon viscosity ratio could be incorporated in the friction factor for a heated surface.

- The practice of applying absolute form loss values (for valves, pipe bends, etc.) should be changed such that this loss is assessed, based on "equivalent length" values that are determined with the friction factor, and a new form loss is derived.

- Correlations associated with phasic heat and mass transfer in condensation need to be reevaluated.

Limitations of the study

None identified.

Additional significant study findings

None.

Other comments

None.

2.3.1.3 Accumulator.

Report reviewed:

W. L. Howarth and R. A. Dimenna, "SRS Supplemental Safety System Injection (Gas Pressurizer) Test," Westinghouse Savannah River Company, WSRC-MS-92-519, *1993 RELAP5 International Users Seminar, Boston, MA, July 6-9, 1993.*

Objectives

The objective of the study was to assess the ability of RELAP5/MOD3 to model sudden depressurization phenomena (as indicated by heat transfer, pressure, and temperature conditions) using the pipe and accumulator components.

Summary description of the experiment and the input model

The test rig simulates the Supplementary Safety System (SSS) of the K reactor at the Savannah River Site which uses a gas pressurizer for injection of a neutron absorbing poison. The experiments were conducted in support of the New Production Reactor-Heavy Water Reactor (NPR-HWR) program. The system consists of a tank of water pressurized with nitrogen that discharges to a set of pipes leading to catch tanks. The tests were initiated by opening a control valve, leading to breakage of rupture disks in the outlet piping.

Code calculations were performed for six tests--five using water, one using heavy water. The tank was modeled two different ways: as a pipe with 18 volumes and using the accumulator component. Calculations were run with and without wall-to-fluid heat transfer for both the pipe and the accumulator models.

Results significant for code assessment

Given the criteria that the gas pressure and gas temperature must be within 10 percent of the test data, the pipe model was acceptable and the accumulator model was not. The accumulator model failed to meet the criteria because of a lower limit of 250 K (-9 °F) for the gas temperature. Also, the Bayley's wall-to-fluid heat transfer correlation for turbulent free convection underpredicted the heat transfer coefficient by a factor of two. The interfacial heat transfer for the pipe model without wall-to-fluid heat transfer substantially increased the heat input to the gas during its expansion. This caused the calculation of artificially high gas temperature.

Author recommendations

It was recommended that the lower limit of 250 K for accumulator gas temperature be removed. Also, it was recommended that an improved heat transfer correlation more appropriate to a gas pressurizer be used in code versions specifically for the NPR-HWR.

Limitations of the study

None identified.

Additional significant study findings

None.

Other comments

The lower limit of 250 K for accumulator gas temperature was removed in later code versions.

2.3.1.4 CHF Correlations and Dryout.

Report reviewed

L. Nilsson, "Assessment of RELAP5/MOD3 Against Twenty-Five Post-Dryout Experiments Performed at the Royal Institute of Technology," STUDSVIK/NS-90/93, October, 1991.

Objectives

The objective was to assess the code's ability to calculate heater-rod thermal response during core dryout.

Summary description of the experiment and the input model

In the experiments, wall temperatures were measured on an electrically heated 7 m long tube with an inner diameter of 14.9 mm. The tube was cooled by upward flow of water with mass fluxes from 500 to 2000 kg/m^2s. The cases selected for this assessment covered pressures ranging from 3 to 14 MPa, heat fluxes from 400 to 1060 kW/m^2 and inlet subcooling from 8.5 to 12 K.

The RELAP5 model for the tube was comprised of 47 axial fluid cells. A fine nodalization was employed for the upper part of the test section where post-dryout conditions took place.

Results significant for code assessment

The calculations showed reasonable agreement with the measured CHF location using the Groeneveld lookup table method. The prediction is generally non-conservative, i.e. the calculated dryout position falls in most cases downstream of the actual measured point. The code's calculation of CHF is judged to be reasonable.

The calculated heater temperature, as a function of axial elevation, was generally low compared to the data. The code always underpredicts the axial heater temperature magnitude and quite often gives an unrepresentative axial temperature distribution above the CHF point. The impact of this is that code may undercalculate a heater rod temperature following CHF and may also give the improper axial temperature distribution. Thus the code probably would not give a conservative estimate of the heater rod behavior based on the evidence presented in this assessment.

Author recommendations

None.

Limitations of the study

None identified.

Additional significant findings

Nodalization studies with longer test section cells show that increasing the length from 0.10 to 0.5 m did not remarkably impair the temperature predictions. The larger cell length, typical in nuclear reactor simulations, led of course to less resolution for the calculated axial dryout point and for regions with steep temperature gradients. However the net result was the same. (Note: The axial power profile used for this experiment was constant as a function of length. Since the axial power profiles characteristic of typical nuclear fuel rods are not constant as a function of length, further nodalization studies should be performed to verify this result for typical plant fuel configurations.)

Other comments

None.

2.3.1.5 Discharge Piping Hydrodynamic Loads.

Report reviewed:

E. J. Stubbe, L. Vanhoenacker, and R. Otero, "RELAP5/MOD3 Assessment for Calculation of Safety and Relief Valve Discharge Piping Hydrodynamic Loads," TRACTEBEL, October, 1990.

Objectives

The objectives were to assess the potential of RELAP5/MOD3 to predict safety and relief valve discharge piping hydrodynamic loads, propose modeling guidelines for calculating piping loads, and highlight the effect of various physical models present in RELAP5 on calculating piping loads.

Summary description of the experiment and the input model

The experimental data of a hot water loop seal discharge through a Crosby valve was used for comparison. This test is a part of the EPRI Safety and Relief Valve Test Program (**Reference 4.0-12**) and was conducted at the Kreisingt test facility. Hydrodynamic loads were measured for each segment of the loop seal. Other measurements include fluid temperature at the valve inlet, pressure at the valve discharge, and flow rate through the venturi.

The thermal-hydraulic phenomena addressed is rapid acceleration of a liquid slug in a loop seal, the subsequent steam discharge, and the eventual establishment of two-phase steady flow in the discharging piping. Two-phase choked discharge, interphase drag, heat transfer to pipe walls, and two-phase flow at abrupt expansions were considered.

A base case model and eight sensitivity cases were reported. The code options tested were: interfacial friction model, horizontal stratification at junctions, sudden expansion and contraction, heat slab modeling, vertical orientation of pipe segments, choking model downstream, and phase velocity option. Peak loads (positive and negative) for all the cases were tabulated for comparison with test data and with RELAP5/MOD1 results. The loads were computed by RELAP5's control blocks which were put together by Tractebel's preprocessor code TROPIC.

Results significant for code assessment

In general, the pressure was underestimated by RELAP5/MOD3. However, the maximum peak load and to a lesser extent, the negative load were reasonably estimated by RELAP5/MOD3, although the computed peak loads were delayed. No temperature and mass flow rate comparisons were given.

The authors have stated that the code calculates the peak loads to occur at later times than the measured values due to an undercalculation of the coupling between the liquid and vapor phases. That is, the authors contend that because the interphase drag is underestimated for this application the calculated liquid slug velocities are less than those in the experiment. Thus the times of peak loading are delayed. The reviewers have not finished the confirmatory calculations required to verify the author's point. The impact is that the calculated liquid slug velocity is less than measured and the peak loads are thus delayed.

The inclusion of a transition zone between the subcooled and two-phase flow regimes produces a characteristic two-bump valve mass flow that is reflected on the loads of the downstream piping.

With all the modeling guidelines followed, the calculated "positive" forces agree with the measured values. A margin of 10% covers all experimental points. The calculated "negative" forces exceed the measured values except for one pipe segment where the measured forces exceed the calculated ones by 80%. This exception is probably due to the lower stiffness of supports for this pipe segment. With a suitable margin to estimate the negative forces, the RELAP5/MOD3 results are acceptable.

Author recommendations

The authors made use of user's guidelines provided in a study completed earlier by the Electric Power Research Institute using RELAP5/MOD1 for calculating safety valve discharge piping hydrodynamic loads (**Reference 4.0-13**). The authors of this assessment study followed, modified, and added to the EPRI guidelines as follows:

EPRI guidelines

- The length of control volumes must be between 0.15 m and 0.3 m for a correct slug and pressure front tracking calculation.
- The time step must be limited externally to the material Courant limit of approximately 0.2 m/s.

- The no-choking option must be imposed at all the junctions downstream from the test valve.

- Cold water loop seals (< 373 K) should be located initially downstream from the test valve.

Modified EPRI guideline

- Heat transfer to pipe walls is not required for computing the hydrodynamic loads on the discharge piping due to water loop seal discharges.

New guidelines

- Include the orientation (horizontal or vertical) for pipes downstream of the valve.

- Use the nonhomogeneous (two-velocity) option for the valve junction.

Limitations of the study

None identified.

Additional significant study findings

None.

Other comments

None.

2.3.1.6 Downcomer Penetration Studies During LBLOCAs.

Report reviewed:

K. Schneider, Siemens AG, "Assessment of RELAP5/MOD3/V5m5 Against Upper Plenum Test Facility Test No. 6, Run 131, 132, 135, and 136 Downcomer Countercurrent Flow," April, 1991.

Objectives

The objective was to assess the ability of RELAP5/MOD3 version 5m5 to model emergency core cooling system water downcomer penetration and lower plenum refill during end-of-blowdown and refill phases of a double-ended break in the cold leg of a typical PWR.

Summary description of the experiment and the input model

The data used for this assessment came from the Upper Plenum Test Facility (UPTF) Test No. 6, Runs 136, 133, 132, 131, and 135. It is a full scale model of the cooling system of a four-loop 1300 MWe PWR. Test No. 6 is a quasi-steady state test designed to investigate the ECC downcomer penetration and lower plenum refill behavior at different steam rates. Five test runs were made, each had a different but constant rate of steam injection to the core simulator. Strong heterogeneous and multidimensional flow existed in the downcomer. The ECC delivery to the lower plenum was intermittent.

Two assumptions were used in establishing the nodalization: (a) not the entire facility, but only components relevant to Test No. 6 need to be nodalized, and (b) represent the downcomer by a "split downcomer" nodalization. The rationale behind this nodalization was that Test No. 6 was a separate effect test. Thus, only a small number of components need detailed representation in the model. The "split downcomer" assumption was motivated by the multi-dimensional nature of the flow in the downcomer. A total of 45 RELAP5/MOD3 simulations were made.

Results significant for code assessment

From the base case results, the author identified, that the code overestimated the ECC bypass and, correspondingly, underestimated the lower plenum liquid inventory. The discrepancies were caused by an overprediction of liquid entrainment by the steam upflow in the downcomer. The discrepancies were greater at higher steam injection rates.

To improve the calculation, a series of sensitivity studies were performed, on which the guidelines discussed below are based. Calculations using those guidelines agreed with the test results of UPTF Test No. 6. The delay of penetration by the filling of the loops was correctly predicted. The extent of ECC downcomer penetration in the early phase of refill is satisfactory. During the final phase of refill, the liquid inventory in the lower plenum is sufficiently correct.

Author recommendations

The author found significant sensitivity of the model results to nodalization. The author's and reviewer's investigations suggested the following user guidelines for this type of problem:

- A split downcomer nodalization has to be applied in order to account for the strongly non-homogeneous flow distribution in the downcomer.

- Loss coefficients of 500 for the azimuthal junctions between the two halves of the split downcomer should be used for both forward and reverse flow. The artificially large coefficients damp out oscillations but do not significantly affect the ECC bypass and ECC downcomer penetration.

- An axial division of the lower plenum into two nodes with equal volume is required during the filling of the lower plenum.

- The ECC injection ports should be modeled by branches instead of ECC mixer components.

Limitations of the study

The reviewers think that further nodalization studies are necessary to conclusively determine the best nodalization for this type of problem.

Additional significant study findings

None.

Other comments

None.

2.3.1.7 Countercurrent Flow in PWR Hot Leg.

Report reviewed:

F. Curca-Tivig, and Siemens AG, "Assessment of RELAP5/MOD3/V5m5 Against the UPTF Test No. 11 (Countercurrent Flow in PWR Hot Leg)," KWU E412/91/E1002, March, 1991.

Objectives

The objective was to assess the ability of RELAP5/MOD3 version 5m5 to model countercurrent flow of steam and saturated water in the hot leg of a typical PWR during reflux condensation and reflood conditions.

Summary description of the experiment and the input model

The data used for this assessment came from the Upper Plenum Test Facility (UPTF) Test No. 11, Runs 30 to 45 (16 runs total). It is a full scale model of the cooling system of a four-loop 1300 MWe PWR. Test No. 11 was a quasi-steady state, separate effect test. It was designed to investigate the conditions for the countercurrent flow in the hot leg. Two test series were conducted at different pressures. During the 1.5 MPa test series, the hot leg break valve was partially open and a bypass valve was used to maintain the system pressure. During the 0.3 MPa test series, the break valve was fully open and the containment simulator pressure was kept at 0.3 MPa.

RELAP5/MOD3 simulations were made to establish the result sensitivity with respect to: (a) system pressure level (0.3 MPa versus 1.5 MPa), (b) imposition of the CCFL option at the middle of the hot leg riser, (c) the slope of the flooding curve when the CCFL option was used, and (d) the abrupt area change model for the Hutze to pipe transition.

Results significant for code assessment

Without using the new CCFL model, RELAP5/MOD3/5m5 overestimated the mass rate of water downflow by as much as 35% (1.5 MPa runs) and 43% (0.3 MPa runs). At complete liquid carry over and for the 1.5 MPa runs, RELAP5 predicted a steam mass flow rate of 46 kg/s as compared with 40.2 kg/s in the experiment. For the 0.3 MPa runs, RELAP5 predicted steam flow rate of 21.3 kg/s at complete liquid carry over while the experimental value was 20.5 kg/s.

Very good agreement with the 1.5 MPa experimental data (which are relevant for SBLOCA conditions) could be obtained by using the code's new CCFL option at a junction in the middle of the inclined part (riser) of the hot leg. The flooding correlation used was of the Wallis type with an intercept C of 0.664 and a slope m of 1. With this CCFL correlation, the 40.2 kg/s steam mass flow rate at complete liquid carry over was calculated by the code.

Using the same CCFL correlation for the simulation of the 0.3 MPa test series, which is typical for reflood conditions, RELAP5/MOD3 underestimated the steam mass flow rate by 44% at complete liquid carry over.

Unphysical results were obtained when using the counter current flow limiting (CCFL) model with intercept C of 0.644 and slope m of 0.8 for the 1.5 MPa test series. A programming error was suspected. The impact is that if the CCFL model is not used the code will overestimate the water downflow rate by up to 35% for the 1.5 MPa data and up to 43 percent for the 0.3 MPa data.

Author recommendations

None.

Limitations of the study

None identified.

Additional significant study findings

The author stated that a hot leg model with nine control cells between the reactor vessel and the steam generator inlet chamber is adequate for simulating steam-water countercurrent flow in the hot leg during typical reflux condensation conditions if the CCFL model is working properly. However, the evidence for recommending this nodalization over the other three appears weak to the reviewers since one of the other nodalizations produced a closer match to the data (even though the cell length to diameter ratio was less than 1.)

Other comments

None.

2.3.1.8 Direct Contact Condensation.

Report reviewed:

S. Lee and H. J. Kim, "RELAP5 Assessment on Direct-Contact Condensation in Horizontal Cocurrent Stratified Flow," NUREG/IA-0077, April, 1992.

Objectives

The objective was to assess the code's capability to calculate the proper condensation rate on a liquid stratified flow interface.

Summary description of the experiment and the input model

Both RELAP5/MOD2 Cycle 36.04 and RELAP5/MOD3 version 5m5 were assessed using steam condensation rate data generated at Northwestern University. The experimental facility was composed of a rectangular channel that represented the test section, steam and water inlet plena, and a water tank. The water line was a closed loop while the steam line was built to provide steam to the test section. The channel was 1.6 m long, 0.3 m wide, and was 0.06 m deep. Uniform flow was assured by constructing large plena that assured low plenum velocities. The tests were performed at atmospheric pressure with steam flow rates ranging from 0.04 kg/s to 0.16 kg/s, water flow rates ranging from 0.2 kg/s to 1.45 kg/s, and water inlet temperatures ranging from 25 to 50 °C. The injected steam was slightly superheated. The condensation data was obtained by measuring the water flow rate at incremental positions along the channel length.

The test section was nodalized by using a PIPE with 10 cells (each 16 cm long). Four base-case calculations were performed, based on runs 253, 259, 279, and 293, using RELAP5/MOD2/36.04 and RELAP5/MOD3 version 5m5.

A nodalization study was conducted by increasing the number of cells in the test section from 10 to 20. No difference in the calculated condensation rates were observed.

Results significant for code assessment

The code usually undercalculated the liquid fluid depth. The parametric studies focused on the effect of various water flow/steam flow combinations with a constant channel water level. The code calculations of the condensation rates were in reasonable agreement with the data. However, differences were observed between the calculated channel water depth and the local heat transfer coefficient particularly for cases with a wavy interface.

Author recommendations

None.

Limitations of the study

None identified.

Additional significant study findings

None.

Other comments

None.

2.3.1.9 Counter Current Flow Limiting.

Report reviewed

S. Cho, N. Arne, B. D. Chung, and H. J. Kim, "Assessment of CCFL Model of RELAP5/MOD3 Against Simple Vertical Tubes and Rod Bundle Tests," NUREG/IA-0192, June 1993.

Objectives

The objective was to evaluate the code's ability to model counter current flow limiting phenomena (CCFL) in tubes and rod bundles.

Summary description of the experiment and the input model

The study is an assessment of the code's CCFL model performed by comparing its results to experimental data from a simple vertical tube test and rod bundle tests conducted at KAERI. The major CCFL phenomena investigated includes flooding characteristics, the onset of liquid mixing, and two-phase pressure drop when CCFL is present.

The experimental facility is composed of a test section, water and air supply system, and measurement system. The test section consists of a lower plenum, a channel, and an upper plenum. The 3 x 3 tube array in the channel has the same geometrical dimensions of the typical 17 x 17 PWR fuel bundle. The experimental data was taken from the experiments of the simple vertical tubes and 3 x 3 rod bundle test section. Type-1 had no spacer grid, Type-2 had one spacer grid, and Type-3 had two spacer grids.

The nodalization studies showed that coarse nodalization simulated the CCFL phenomena as well as finer nodalization.

Results significant for code assessment

The base case calculations were performed for a simple vertical tube and rod bundle tests. A pair of calculations were performed with and without the CCFL option for each experiment. The calculational results with the CCFL option for the vertical tubes gave reasonable agreement with the data. The code calculated flooding for the rod bundles but did not match the data.

The sensitivity calculations, conducted for different tube diameters without the CCFL model invoked, showed flooding to occur before CCFL was observed in the experiment for small diameter tubes, but showed flooding to occur after CCFL was observed in the experiment for large diameter tubes. When the CCFL model was invoked, the calculation showed a reasonable match to the data. However, when using the RELAP5 CCFL model to simulate a Kutateladze characteristic unphysical results were obtained; liquid downflow was allowed when the upward gas superficial velocity exceeded the flooding point. This deficiency may be due to a coding error. Other deficiencies suggested by the authors are still being investigated.

Author recommendations

None.

Limitations of the study

None identified.

Additional significant study findings

None.

Other comments

None.

2.3.1.10 Critical Flow.

Report reviewed:

K. Kim and H.-J. Kim, "Assessment of RELAP5/MOD2 Critical Flow Model Using Marviken Test Data 15 and 24," NUREG/IA-0086, April, 1992.

Objectives

The objectives were to identify code or model deficiencies and to improve the nodalization for a pipe break or nozzle.

Summary description of the experiment and the input model

The tests were conducted at the Marviken facility by discharging water and steam mixtures from a full-sized reactor vessel through a large diameter discharge pipe (located at the bottom of the vessel) to a nozzle. Tests 15 and 24 were conducted using a constant diameter nozzle (500 mm) with L/D=3.6 in Test 15 and L/D=0.3 in Test 24. The initial fluid temperature was 31 and 33 °C in Test 15 and 24, respectively.

The vessel was modeled as a pipe with 39 cells. The discharge pipe was modeled with three or six cells. The nozzle was modeled as either a pipe or valve (for small L/D). The calculations were run on a CRAY-2S computer.

Although the main objective of the study was to assess RELAP5/MOD2, some calculations were also repeated with RELAP5/MOD3 to evaluate changes in the critical flow model.

Results significant for code assessment

Those results directly pertaining to the RELAP5/MOD3 critical flow model are summarized as follows: (some of the RELAP5/MOD2 results are discussed for comparison purposes only)

- For Test 15, with the nozzle modeled as a pipe with three cells and the discharge piping modeled with 6 cells, both RELAP5/MOD2 and RELAP5/MOD3 calculated the subcooled flow rate accurately. However, in the transition region both codes underpredicted the mass flow rate (RELAP5/MOD2 by about 6% and RELAP5/MOD3 by about 10%). In the two-phase region, RELAP5/MOD2 calculated the flow rate accurately; RELAP5/MOD3 underpredicts the flow rate and indicates flow rate fluctuations.

- For Test 15, with the nozzle modeled as a single volume and the discharge piping modeled with three cells, both RELAP5/MOD2 and RELAP5/MOD3 underpredicted the mass flow rate in the transition region by about 10%. Also, both codes produced fluctuations in mass flow rate in the two-phase region, but the range of time over which the fluctuations occur is reduced in the RELAP5/MOD3 calculation.

- For Test 24, with the nozzle represented by a single junction and the discharge piping modeled with six cells, the results of the two code versions are similar. In the two-phase region the mass flow rate is underpredicted by about 15% for MOD2 and about 30% for MOD3.

The fluctuations in critical flow rate in the two-phase region were attributed to instantaneous fluctuation in the break junction void fraction, which changes the critical velocity. This results in feedback to the oscillations of void fraction, and, subsequently, amplification of the oscillations of the critical mass flow rate.

Author recommendations

The authors offered four recommendations, based on the results of both the RELAP5/MOD2 and RELAP5/MOD3 calculations:

- Choking should be turned off at all junctions except the break.
- For critical flow test (CFT) simulation (larger L/D), the nozzle should be modeled as a pipe or single volume. If the nozzle is modeled as a pipe, uniform cell length may give better mass flow rate results, but with more than 3 cells, the calculation may fail on water property errors.
- For CFT 15 simulation (larger L/D), the pressure at a nozzle inlet is overpredicted for coarse noding of the discharge pipe, thus, a finer noding is recommended. Also, when the L/D of one cell is greater than 1.6, strong fluctuations can occur in the two-phase region.
- For CFT 24 (small L/D), the nozzle should be modeled as a single junction rather than as a pipe. It is suggested that the friction loss pressure drop in a pipe is overpredicted relative to the actual nozzle.

Limitations of the study

None identified.

Additional significant study findings

None.

Other comments

None.

2.3.2 Integral Effects Experiments

The integral effects experiment assessments are reviewed in Section 2.3.2.1 through Section 2.3.2.6 and covered the following transients and conditions:

BETHSY

- Interphase Drag - Section 2.3.2.1, **Reference 4.0-14**.
- SBLOCA - Section 2.3.2.2, **Reference 4.0-15**, Section 2.3.2.5, **Reference 4.0-16**.

- Natural Circulation - Section 2.3.2.4, **Reference 4.0-17**.

Large-Scale Test Facility (LSTF)

- SBLOCA - Section 2.3.2.3, **Reference 4.0-18**.

Semiscale

- SBLOCA - Section 2.3.2.6, .**Reference 4.0-19**

2.3.2.1 BETHSY SBLOCA – Interphase Drag.

Report reviewed:

A. M. Moskalev, V. B. Proklov, and V. L. Roginskaja, "Assessment of RELAP5/MOD3/V5m5 against 0.5% Cold Leg Break in the BETHSY Test 9.1.b," Russian Research Center-Kurchatov Institute, October, 1992.

Objectives

The objective of the study was to assess the ability of RELAP5/MOD2.5 and RELAP5/MOD3 to simulate SBLOCA phenomena and interactions.

Summary description of the experiment and the input model

The experiment was a 0.5% cold leg break (equivalent to 2") without the High Pressure Injection System (HPIS) and with the application of an "ultimate" procedure for mitigation of core heatup and uncovery conducted at the BETHSY scaled test facility. The "ultimate" procedure was activated when the maximum cladding temperature exceeded 450 °C and consisted of the full opening of the three steam generator atmospheric dump valves to cause primary system depressurization leading to accumulator injection and actuation of the Low Pressure Injection System (LPIS).

Results significant for code assessment

Overall, the calculation results agreed fairly well with the experimental data. There was a problem in the simulation of core uncovery which was attributed to the interphase drag model. When the flow regime in the core switched to/from vertically stratified, non-physical oscillations were observed in the void fraction and the water mass distribution in the core. The specific model problem identified was the assignment of a low value of interphase drag to junctions above and below a vertically stratified volume. It was pointed out that in some cases, the interphase drag "jumped" when a mixture level passed through the center of a volume.

Author recommendations

None.

Limitations of the study

Three limitations were identified in the approach. First, the hot and cold leg connections to the reactor vessel were represented by "normal" junctions, not by crossflow junctions, which is the standard practice. No justification was given for this deviation from modeling guidelines. Second, the loop heat structures were not modeled, with the exception of the pump. No justification was given for this omission. If the heat structures are not modeled, it must be demonstrated that the effect of the trace heaters is not significant and can therefore be neglected. Last, the calculated initial power level is slightly low. The reason for this discrepancy was not addressed.

Since interphase drag is computed at junctions in RELAP5/MOD3, as opposed to volume centers, use of the correct junction hydraulic diameter is very important. Since the interphase drag model is cited as the dominant contributor to the core dryout behavior, the authors should provide information about the junction input in the core region. What were the values of junction hydraulic diameter? Do the junctions correspond to grid spacer locations? If so, is the grid spacer hydraulic diameter used at the junctions?

Additional significant study findings

The significant results were all specifically related to code assessment.

Other comments

None.

2.3.2.2 BETHSY SBLOCA.

Report reviewed:

A. S. Devkin and V. L. Kobzar, "Assessment of RELAP5/MOD2.5.V3.f and RELAP5/MOD3.V5m5 against Cold Leg Break Experiment 9.1b (ISP-27)," Russian Research Center-Kurchatov Institute, October, 1992.

Objectives of the study

The objective of the study was to assess the ability of RELAP5/MOD2.5 and RELAP5/MOD3 to simulate SBLOCA phenomena and interactions.

Summary description of the experiment and the input model

The experiment was a 0.5% cold leg break (equivalent to 2 inches) without the High Pressure Injection System (HPIS) and with the application of an "ultimate" procedure for mitigation of core heatup and uncovery conducted at the BETHSY scaled test facility. The "ultimate" procedure was activated when the maximum cladding temperature exceeded 450 °C and consisted of the full opening of the three steam generator atmospheric dump valves to cause primary system depressurization leading to accumulator injection and actuation of the Low Pressure Injection System (LPIS).

Results significant for code assessment

The steady-state results for both codes showed good agreement with the measured values with the exception of the steam generator pressure and mass. This was attributed to an underpredicted heat transfer coefficient on the secondary side of the U-tubes. This is a known deficiency in the code. The problem is caused by the application of heat transfer correlations based on simple flow geometry (i.e., fluid flowing inside a pipe) to the complicated tube bundle/baffle geometry on the secondary side of a steam generator. To obtain the correct primary-to-secondary heat transfer, the steam generator pressure usually cannot be matched. To compensate, a user guideline exists (in volume 5 of the RELAP5 manual) that advises users to adjust the heated equivalent diameter on the secondary side of the U-tubes until the desired secondary pressure is obtained.

The transient calculations showed good agreement in the parameters of primary interest. Some time shift of events (delay) was seen in the RELAP5/MOD3 calculation. Some discrepancies were noted in the break flow in the early phase of the transient (before 3000 seconds). This was attributed to the incorrect calculation of the quality upstream of the break, due in part to the overprediction of the broken leg void fraction when the upper head vapor began to enter the cold legs. The possibility of nodalization/pressure effects on the break flow was investigated in two sensitivity studies using RELAP5/MOD3, but the results showed no major differences from the original calculation. (See the "Limitations of the Study" section below for further discussion of this issue.) There were problems in calculating the rewetting of the upper part of the fuel rods. The authors assert that this was "somewhat predicted with RELAP5/MOD2.5" and that it was underpredicted by RELAP5/MOD3 (no graphs were provided to support either claim). However, the shortcomings were attributed to the multidimensional nature of the rewetting phenomena, which was more obvious in the outer part of the core in the experiment. Thus, the authors claimed, a single channel core model is inadequate.

Author recommendations

It was recommended that the capabilities of RELAP5/MOD3 to calculate the multi-dimensional core rewetting phenomena be investigated further.

Limitations of the study

The only limitation identified was related to the modeling of the break. As noted above, the discrepancies in break flow were not attributed to break modeling because a sensitivity study where the geometry of the nozzle was represented did not significantly affect the results. However, an ISP-27 participant from the INEL found that, by using the separate effects break nozzle data supplied to develop and benchmark the break nozzle in a separate effects calculation, good agreement with break flow data could be obtained.

Additional significant study findings

None.

Other comments

None.

2.3.2.3 Large Scale Test Facility (LSTF) SBLOCA.

Report reviewed:

S. Lee, B. D. Chung, and H. J. Kim, "RELAP5 Assessment Using LSTF Test Data SB-CL-18," NUREG/IA-00095, May 1993.

Objectives

The objective was to evaluate the code's ability to simulate the important phenomena occurring during a SBLOCA such as break critical flow, loop seal clearing and core uncovery, and core heatup.

Summary description of the experiment and the input model

The phenomena investigated included: critical flow, countercurrent flow limiting (CCFL), loop seal clearing and core uncovery, core heatup, stratified two-phase in the horizontal legs, vessel inventory boiloff, and vessel refill due to accumulator injection.

The code was assessed using the experimental data obtained during the SB-CL-18 experiment conducted in the LSTF. The experiment was conducted to investigate the thermal-hydraulic mechanisms responsible for the early core uncovery, including the manometric effect due to an asymmetric coolant holdup in the steam generator upflow and downflow side during the 5% cold leg small break loss-of-coolant accident (SBLOCA).

The base calculation was performed using the nodalization recommended by the INEL.

Results significant for code assessment

The baseline calculations show good agreement with the experimental data in predicting thermal-hydraulic phenomena. The authors, however, point out several differences regarding the evolution of phenomena and affecting the timing order. Specific deficiencies noted by the authors are as follows:

- The calculated break flow rates show some discrepancy with experimental data. Underestimation of the two-phase break flow resulted in an insufficient mass discharge from the primary system prior to the loop seal clearing. Overpredicted vapor phase break flow caused a fast primary mass loss and an earlier accumulator injection following loop seal clearing. The impact is that the timing of the calculated events was shifted from the measured event times.

- The code did not calculate complete loop seal clearing.

Author recommendations

None.

Limitations of the study

None identified.

Additional significant study findings

By doubling the number of loop seal cells from nine to 18 and the number of primary steam generator U-tube cells from eight to 16 the calculation showed better agreement with the data.

Other comments

None.

2.3.2.4 BETHSY Natural Circulation.

Report reviewed:

P. A. Roth and R. R. Schultz, "Analysis of Reduced Primary and Secondary Coolant Level Experiments in the BETHSY Facility Using RELAP5/MOD3," EGG-EAST-9251, July, 1991.

Objectives

The objectives were to: (a) describe the BETHSY facility single-phase natural circulation, two-phase natural circulation, and reflux condensation characteristics and (b) assess the RELAP5/MOD3 code using these data.

Summary description of the experiment and the input model

This report documents the assessment of RELAP5/MOD3 Version 5m5 using the data from BETHSY facility experiments 4.1a-TC and 5.1a. These experiments were designed to study the phenomena that occur during single-phase natural circulation, two-phase natural circulation, and reflux at various secondary conditions. Single-phase natural circulation was studied as a function of the primary mass inventory level, the secondary mass inventory level and the core power. Two-phase natural circulation and reflux condensation were studied as a function of the primary and secondary mass inventory levels.

The base calculations were performed using the nodalization originally specified by the INEL and thereafter modified by considering the output of a number of nodalization studies. Nodalization studies were performed to investigate the best way to nodalize the SG U-tubes, the vessel lower plenum, the vessel upper plenum, the pump (BETHSY has a pump configuration unique to the Framatome PWRs), the SG secondaries, and the core bypass region. Although a number of nodalization studies were performed, only one base calculation was performed for Test 4.1a-TC and Test 5.1a.

Results significant for code assessment

RELAP5/MOD3 was shown to reasonably simulate single-phase natural circulation, two-phase natural circulation, and reflux condensation. The calculated natural circulation primary mass flow rate was consistently greater than the measured values for single-phase natural circulation and two-phase natural circulation at or near the peak mass flow rates in Test 4.1a-TC and Test 5.1 - Part 1. Such a difference can be easily explained by the additional frictional pressure loss sustained in the experiment by the bulk primary mass flow, together with the postulated reverse flow contribution, moving through a reduced number of SG U-tubes.

The minimum calculated two-phase primary natural circulation mass flow rates matched those of the data very closely. The mass inventory level at which reflux condensation began was about 50% both in the code calculation and in the experimental data.

The code was found to be able to calculate the CCFL that occurred during the latter portion of Test 4.1a. Unfortunately the code calculated a considerable oscillation in the vapor velocity which caused CCFL to cease periodically and prevented a buildup of mass in the SG U-tube's upflow sides.

The code's capability to calculate secondary riser mass distribution was found reasonable for both parts of Test 5.1a. In addition, the code gave a reasonable calculation of the secondary inventory degree of superheat for these tests.

Author recommendations

Through a series of nodalization studies, the following user guidelines were identified:

- Doubling the number of nodes representing the steam generator (SG) U-tubes from the base case value of 8 to 16 did not produce any change in the model's ability to predict the onset of reflux at system power levels ranging from 1 to 5% of rated scaled power.

- Core bypass regions should be nodalized to have a complementary nodalization structure to that of the core region.

- If an experiment or plant secondary system condition considering a low secondary liquid level must be simulated, a fine nodalization must be used to accurately capture the primary-to-secondary energy transfer.

Limitations of the study

None identified.

Additional significant study findings

None.

Other comments

None.

2.3.2.5 BETHSY SBLOCA.

Report reviewed

P. A. Roth, C. J. Choi, and R. R. Schultz, "Analysis of Two Small Break Loss-of-Coolant Experiments in the BETHSY Facility Using RELAP5/MOD3," EGG-NE-10353, July, 1992.

Objectives

The objectives were to: (a) gain greater understanding of the phenomena which occur during a small break loss-of-coolant accident, and (b) assess the RELAP5/MOD3 version 7 code using these data.

Summary description of the experiment and the input model

Data from Tests 9.1b and 6.2 TC, conducted in the BETHSY facility describe the phenomena observed during two SBLOCA experiments. Since the two tests were performed from different starting conditions, used different sized break nozzles, and assumed different failures and operator action, they exhibited somewhat different phenomena.

Test 9.1b/ISP27 involved a 0.5% (2-inch) cold leg break without available high pressure safety injection. Reactor scram and a lengthy pump coastdown were used. An operator action was simulated by depressurizing the secondary when core thermocouples detected significant heat up. The experiment continued through accumulator injection and low pressure safety injection (LPSI). This test showed several major phenomena: (a) single- and two-phase flow through a break nozzle, (b) pump operation during two-phase flow, (c) primary and secondary depressurization, (d) natural circulation and reflux cooling, (e) loop seal clearing, (f) core boiloff, (g) accumulator injection, and (h) LPSI injection.

Test 6.2 TC involved a 5.0% (6 inch) cold leg break without available high or low pressure safety injection. Reactor scram was followed by a rapid shutdown of the primary pumps. Accumulator injection began and was terminated before nitrogen entered the system. The transient was terminated when unmitigated core heatup began. No auxiliary feedwater was used but the U-tubes remained covered. This test showed several major phenomena: (a) single- and two-phase flow through a break nozzle, (b) primary system depressurization, (c) natural circulation and reflux cooling, (d) loop seal clearing, (e) core boiloff, and (f) accumulator injection.

The baseline calculations were made using the model developed and tested at INEL.

Results significant for code assessment

The RELAP5/MOD3 simulations of the two tests showed reasonable agreement with experimental data including loop seal clearing and simulation of the vapor pull-through/entrainment phenomena experienced during the 0.5% SBLOCA experiment. A mismatch between the calculated and measured primary inventory distributions at various times during the two transients indicated a likely problem with the interphase drag model.

Three code deficiencies were identified:

- The counter-current flow limiting (CCFL) model was found to contain an error. A code correction will appear in RELAP5/MOD3 Version 8.
- The ECCMIX component was found to calculate excessive condensation compared to the data for the 0.5% SBLOCA experiment. Also use of this model caused the code to fail. However, it is acceptable for use for the 5.0% break experiment.
- Under some conditions, the limits of which have not been rigorously defined, the code will not realistically calculate the process of draining a vertical pipe; voids are calculated to pass into lower cells before the upper cells are fully drained.

Author recommendations

Two user guidelines were identified:

- To more accurately calculate the process of draining a vertical pipe, vertical regions such as the loop seals should be nodalized to 6 to 8 cells in the vertical region upstream of the pump.

- Break nozzles with length-to-diameter ratios greater than 10, used for SBLOCA experiments, can be modeled to produce calculated results that match their calibration data by sizing their volumes to give the same Courant limit as the remainder of the model while maintaining a length-to-diameter (hydraulic) ratio equal to that of the hardware. Using such a technique, the break volume is large enough to allow a reasonable time step for the calculation and the length-to-diameter ratio will allow the nozzle frictional pressure loss to be accurately calculated.

Limitations of the study

None identified.

Additional significant study findings

None.

Other comments

None.

2.3.2.6 Semiscale Small Break LOCA S-NH-1.

Report reviewed:

E. J. Lee, B. D. Chung, and H. J. Kim, "RELAP5 Assessment Using Semiscale SBLOCA Test S-NH-1," Korea Institute of Nuclear Safety, undated.

Objectives

The objective was evaluation of the code capability to simulate thermal-hydraulic behavior during a small break loss-of-coolant accident in a pressurized water reactor, including: primary and secondary side pressure response, break mass flow rate, core thermal-hydraulic response, and the primary mass inventory distribution.

Summary description of the experiment and the input model

The node was assessed using the Semiscale S-NH-1 experimental data. The S-NH-1 experiment was a simulation of a 0.5% small break loss-of-coolant accident in the cold leg. The base calculation was performed using a RELAP5 model of the Semiscale MOD2C facility provided by INEL.

Results significant to code assessment

Although the authors identified the RELAP5/MOD3 base calculation as giving reasonable results, not enough evidence was shown to merit that classification in the reviewers' opinion.

Author recommendations

None.

Limitations of the study

Not enough evidence was presented to support the conclusions.

Additional significant study findings

None.

Other comments

None.

2.3.3 Plant Transients

One study was reviewed which used plant data from an inadvertent safety injection incident for assessment, see Section 2.3.2.1, **Reference 4.0-20**.

2.3.3.1 Inadvertent Safety Injection.

Report reviewed:

K.-T. Kim, B.-D. Chung, I.-G. Kim, and H.-J. Kim, "Assessment of RELAP5/MOD3 Version 5m5 Using Inadvertent Safety Injection Incident Data of Kori Unit 3 Plant," Korea Institute of Nuclear Safety, undated.

Objectives of the study

The objective of this study was to identify the important thermal hydraulic phenomena of an inadvertent safety injection (SI) and to demonstrate the applicability of the code for full-scale plant analysis.

Summary description of the experiment and the input model

On September 6, 1990, an inadvertent safety injection event occurred at the Kori Unit 3 plant in Korea. The plant is a Westinghouse three-loop, 900 MWe design. The transient was initiated by the closure of the main feedwater (MFW) valve of one steam generator (SG) while reactor power was maintained at 83%. Subsequently, a SG low-low level signal tripped the reactor; and although a turbine trip signal was generated by the reactor trip signal, the reactor-turbine inter-trip valve was stuck and thus turbine trip was delayed. SI was actuated on a low steamline pressure signal, as was main steam isolation. The operators then intervened and tripped the turbine manually. Offsite power was lost for three minutes, during which time the reactor coolant pumps did not function due to failure of a diesel generator. SI continued for about 12 minutes. Auxiliary feedwater, controlled by the operators, was supplied to the SGs. One pump was restarted at about 38 minutes after the accident occurred and recovery to hot shutdown conditions was begun.

Each of the three loops was nodalized separately and the downcomer was represented by three stacks of volumes (corresponding to each of the three cold legs) interconnected by crossflow junctions, for simulation of asymmetric effects between loops.

The analysis was performed to assess the performance of the code based on trends rather than on the absolute values because of uncertainty and time shifts in the recorded plant data. Additionally, control of the auxiliary feedwater flow rate was not recorded, but was deduced based on other recorded parameters.

Results significant for code assessment

A minor error correction was made to overcome an input processing failure using the pump controllers for self-initialization. A line of coding in the subroutine rssi.F was corrected.

The following conclusions related to code performance were presented:

- The calculated trends agreed well with the plant data, except in the case of loop temperature. In the case of the cold leg temperature, however, the discrepancy was attributed to errors in the temperature measurements at low flow rates.
- There are some differences between the calculated results and the plant data, but this is attributed to the uncertainty of the instrumentation and the estimation of operation actions.
- Asymmetric effects during this type of transient can be simulated with the three-loop nodalization, assuming the estimations of operator actions are proper.

Author recommendations

To remedy an input processing failure when using the self-initialization controller for pumps, line 139 of subroutine rssi.F must be changed from 13a(7) = 0 to 13a(7) = 2.

Limitations of the study

As the authors acknowledged, the comparison of calculated results to plant data is limited to trends only, due to the lack of reliable recorded data and the estimations of operator actions. Thus, the assessment gives a *qualitative* indication of code applicability.

Additional significant study findings

None.

Other comments

None.

2.3.4 Other

One report was reviewed which used a databank with which to compare results from the Groeneveld CHF lookup table in the code. (Section 2.3.4.1, **Reference 4.0-21**)

2.3.4.1 CHF.

Report reviewed:

L. L. Kobzar and A. I. Suslov, "Assessment of RELAP5/MOD3 CHF Model Against VVER CHF Data," Russian Research Center-Kurchatov Institute, undated.

Objectives of the study

The objective of this study was to assess the CHF model in RELAP5/MOD3 within the larger context of evaluating "the applicability of RELAP5/MOD3 closure relationships to VVER conditions and parameter ranges."

Summary description of the experiment and the input model

Data from the Russian Research Center Kurchatov Institute (RRC KI) VVER CHF data bank were used for comparison with the Groeneveld lookup table model implemented in RELAP5/MOD3. The data used had the following range of parameters: pressure between 21 and 186 bar, mass flux between 219 and 3807 $kg/m^2/s$, equilibrium quality between -0.180 and 0.938. The bundles for which data was compared had rods on a hexagonal pitch, with 7 to 36 heated rods per bundle. The tube diameter ranged from 9.0 to 9.1 mm; the pitch ranged from 12.2 to 12.6 mm; the heated length varied from 1.0 to 3.5 m. All the bundles had a uniform radial and axial heat flux distribution. No RELAP5 input model was used. Results were apparently computed using the Groeneveld model outside the framework of the code.

Results significant for code assessment

The overall conclusion of the study was that the Groeneveld CHF model requires correction for CHF calculation in VVER type assemblies (hexagonal rod arrangement). The specific findings which supported this were:

- The Groeneveld model significantly overestimates (up to 4 times) CHF at low pressure (20-50 bar); overestimates CHF up to 60% for pressure 70-90 bar; and underestimates CHF up to 50% for pressure > 120 bar.
- At pressure between 80 and 100 bar, the ratio of Groeneveld-calculated CHF to experimental CHF depends upon mass flux. This ratio increases as mass flux decreases.
- The ratio of Groeneveld-calculated CHF to experimental CHF significantly increases at the transition to negative quality.

In addition, comparison of Groeneveld-calculated values to those from a set of test data from the Columbia University CHF data bank (presumably with rods arranged on a square pitch) also showed that Groeneveld overestimated the CHF at pressures between 20 and 50 bar, but less so than for the VVER CHF data.

Author recommendations

Two suggestions were offered for eliminating the deficiency. The first was that the Groeneveld model be corrected by supplying additional multiplication factors. The second was that the method of Groeneveld table development be applied to the VVER data bank to generate a comparable table, and multiplication factors be added if necessary.

One general recommendation was that any CHF table be based on a "subchannel" data bank.

Limitations of the study

The most significant results of the study are not generally applicable for code users, but rather are specific only to those applying RELAP5 for VVER analysis.

Additional significant study findings

None.

Other comments

Included as an appendix was the method of CHF prediction in rod bundles developed in the Russian Research Center, Kurchatov Institute. This correlation is based on databank data for VVER fuel assembly models.

2.4 Summary of the Identified Deficiencies and the Impact on Calculations

In this section, the code deficiencies identified in the studies are summarized and discussed relative to the impact on the performance of the code for the four most common types of calculations--steady-state, LBLOCA, SBLOCA, and operational transients (e.g., loss of feedwater, ATWS). Deficient areas identified in the 18 studies reviewed to date are listed in **Table 2.4-1**. This table is intended as a reference point for code users which can be used in several ways. Using it, deficiencies impacting a particular type of calculation (e.g., SBLOCA) can be quickly identified; further, the conditions under which the deficiency was noted and could be expected to reoccur are listed; finally, a reference is given to the complete study review for a more complete discussion. In the following subsections, related deficiencies are grouped and discussed together when appropriate.

2.4.1 Boiling Instability

Several deficiencies were noted in a separate effects study of the thermal hydraulic instability in slight boiling systems with natural circulation (Leppik, Urusov, and Vladimirov; Section 2.3.1.1). However, these results are applicable only for a particular design of reactor, the Russian-designed AST-500. Since these results are not generally applicable, users are referred to the review of the study, Section 2.3.1.1, for specific information.

2.4.2 Friction Factor and Absolute Form Loss Factors

Both of these deficiencies, identified in a separate effects study (Martin and Taylor; Section 2.3.1.2), stem from the fact that both the friction factor and form loss factors input by users assume fully-turbulent flow. The pressure drop due to these factors is hence underpredicted for flow in the laminar and transition regions. The impact of this deficiency is that under very low flow conditions, which could occur in the natural circulation mode of SBLOCAs, the flow rate could be overpredicted by the code. In such calculations, the Reynolds number should be checked to determine if the flow remains fully-turbulent or not.

Another deficiency related to the friction factor, which has the opposite effect on calculations, is that for a heated surface the decreased viscosity, associated with the radial fluid temperature gradient, is not accounted for. This results in the overprediction of pressure drop across a heated surface (i.e., core). This should considered when running SBLOCA and operational transient calculation

2.4.3 Condensation Model

A separate effects natural circulation code assessment study (Martin and Taylor; Section 2.3.1.2) showed that the mass error increased significantly during condensation as flow transitioned from single-phase to two-phase. This resulted in slowdown of the calculation and often failure. As a workaround, very small time steps were used. Such a method is recommended as a temporary measure for SBLOC calculations.

Table 2.4-1 Deficiencies identified in RELAP5/MOD3.0 by independent code assessment studies.

Code deficiency	Applicable transient(s)	Conditions under which deficiency was noted/phenomena affected	Study (by section number)
Boiling instability	Not for PWRs	Slight boiling system with natural circulation	Section 2.3.1.1
Friction factor	SBLOCA, OT[a]	Low flow natural circulation	Section 2.3.1.2
Absolute form loss factors	SBLOCA	Low flow natural circulation	Section 2.3.1.2
Condensation model	SBLOCA	Transition from single-phase to two-phase natural circulation	Section 2.3.1.2
Accumulator gas temperature	SBLOCA, LBLOCA	Accumulator injection/emptying	Section 2.3.1.3
CHF	SBLOCA, LBLOCA	Rod bundle uncovery	Section 2.3.1.4, Section 2.3.4.1
Interphase drag	SBLOCA, LBLOCA, OT	When flow regime switches to/from vertical stratified (i.e., core); primary mass inventory distribution	Section 2.3.1.5, Section 2.3.2.1, Section 2.3.2.5
CCFL	SBLOCA	SBLOCA hot leg flow, rod bundle flow	Section 2.3.1.7, Section 2.3.1.9, Section 2.3.2.5
Direct contact condensation	SBLOCA	Horizontal stratified flow in the loops	Section 2.3.1.8
Critical flow model	SBLOCA, LBLOCA, OT	Transition and two-phase flow	Section 2.3.1.10, Section 2.3.2.3
Incorrect steady-state heat transfer	Steady-state	SG secondary side heat transfer	Section 2.3.2.2
ECCMIX component condensation	SBLOCA, LBLOCA	ECC injection	Section 2.3.2.5
Vertical pipe draining	SBLOCA	Loop seal clearing	Section 2.3.2.5
Self-initialization pump controller	Steady-state	Code failure in input processing	Section 2.3.3.1

a. Denotes operational transient (e.g., loss of feedwater, ATWS).

2.4.4 Accumulator Gas Temperature

A separate effects study (Howarth and Dimenna; Section 2.3.1.3) pointed out that the lowest accumulator gas temperature is limited to 250 K (-9 °F) by the code. Thus, since the physical limit is less than 250 K, the gas temperature is overpredicted as it enters the system when the accumulators empty. This problem was fixed later; however, in general, accumulator emptying still cannot be calculated by the code without failure.

2.4.5 CHF

A series of comparisons in a separate effects study (Nilsson; Section 2.3.1.4) showed that the calculation of dryout position is non-conservative (i.e., that it is downstream of the actual point). The calculation of the critical heat flux itself, however, was shown to be reasonable. The same study showed that the heater temperature is underpredicted by the code, which is nonconservative, and the axial temperature distribution above the CHF point is unrepresentative. These results were similar to results shown in the developmental assessment calculations. Comparison of the data and the calculations of Bennett's heated tube experiments (see Figure. 2.2-43 of Volume 3, Carlson, et al., 1990) at intermediate mass fluxes showed the same trend. This can impact the core uncovery phase of both SBLOCA and LBLOCA.

2.4.6 Interphase Drag

During a BETHSY facility SBLOCA calculation (Moskalev, Proklov, and Roginskaja; Section 2.3.2.1), some unphysical phenomena were calculated during core uncovery: oscillations were observed in void and water mass distribution. The problem was attributed to a low value of interphase drag at the junctions above and below a vertically stratified volume. However, there are still unanswered questions about the input parameter of junction hydraulic diameter for that particular calculation, since the problem was not reported in other studies which simulated the same experiment. Nevertheless, users should be aware of the potential for oscillations around a vertically stratified volume (e.g., core, loop seals) for SBLOCA and LBLOCA calculations.

A problem thought to be related was encountered in another BETHSY SBLOCA calculation (Roth, Choi, Schultz; Section 2.3.2.5) during the process of draining of a vertical pipe (loop seal). Voids were calculated to pass into lower cells before the upper cells were fully drained. This problem was minimized by a finer nodalization, discussed in Section 2.5.7.

In the same calculation, discrepancies in primary inventory were attributed to the interphase drag model. Although this was a very general remark, it is useful for other users to keep in mind that the inventory distribution can be affected by the interphase drag computation.

2.4.7 CCFL

For a separate effects UPTF calculation (Curca-Tivig; Section 2.3.1.7) good results were obtained when modeling CCFL in the inclined portion of a hot leg for a pressure of 1.5 MPa where the Wallis equation parameters were c(y-intercept)=0.664 and m(slope)=1.0. Results obtained for a pressure of 0.3 MPa were not good: the steam flow rate was underestimated at complete liquid carryover. The same study showed that if CCFL is not used, the water downflow rate is overestimated by up to 35% for 1.5 MPa and 43% for 0.3 MPa. The results appear inconclusive at this time as to the general applicability of the CCFL model for SBLOCA and LBLOCA, since this report indicated a pressure dependency. However, the study did demonstrate the adverse results of not invoking the CCFL model where CCFL is expected to occur.

When used to simulate a Kutateladze characteristic in a tube for another separate effects study (Cho, Arne, Chung, and Kim; Section 2.3.1.9), unphysical results were obtained: liquid downflow occurred when the upward superficial gas velocity exceeded the flooding point. It was suggested that this was due to a coding error, but was not proven.

2.4.8 Direct Contact Condensation (Calculation of Liquid Depth in Channel Flow)

A separate effects study (Lee and Kim; Section 2.3.1.8) showed that the condensation rates at an interface were in good agreement with experimental data, but the liquid fluid depth in the channel was usually underpredicted at a liquid stratified flow interface. An underprediction of the liquid depth in a horizontal channel was also observed by Kukita, et al. (**Reference 4.0-22**). Also in that study, the deficiency cited was the lack of a limit on the liquid velocity below the critical velocity for low mass flux cases; supercritical liquid velocity was calculated by the code. The recommendation in that study was to modify the momentum equations to correctly consider the critical flow phenomenon in gravitation-controlled liquid flow.

Calculating the correct liquid depth under stratified conditions is important in obtaining the correct system mass distribution and in determining the correct upstream conditions for SBLOCAs, particularly when the liquid entrainment/vapor pull-through model is activated.

2.4.9 Critical Flow Model

In calculations of a series of Marviken separate effects tests (Kim and Kim; Section 2.3.1.10), the mass flow rate was underpredicted in the transition and two-phase flow regions by at least 10%. Oscillations were calculated in the two-phase region. An integral effects assessment of an LSTF SBLOCA (Lee, Chung, and Kim; Section 2.3.2.3) also showed that the two-phase break flow rate was underpredicted prior to loop seal clearing and the single-phase vapor break flow rate was overpredicted following loop seal clearing, resulting in a shift in timing of events. The impact is that for both SBLOCA and LBLOCA, the two-phase break flow is expected to be slightly underpredicted. It is recommended that the code-calculated critical flow rate be verified in both the single-phase and two-phase regions by hand calculations (e.g., using the HEM or Henry-Fauske models).

2.4.10 ECCMIX Component - Condensation

The ECCMIX component was found to calculate excessive condensation for one BETHSY 0.5% SBLOCA experiment, but was acceptable for another BETHSY 5% SBLOCA experiment (Roth, Choi, and Schultz; Section 2.3.2.5). Given the mixed results of this study and lacking other independent assessments, no conclusions can be made at this time regarding the general applicability of the ECCMIX component. However, the study did indicate that the ECCMIX component works well for larger breaks with the associated higher velocities; the precise break size where it goes bad is unknown, but from the study results appears to be between 0.5% and 5%. Therefore, particularly in SBLOCA calculations where the ECCMIX component is used, it is recommended that user pay close attention to the behavior in it, particularly the condensation rate, and that a "back-of-the-envelope" calculation be performed to verify the condensation rate.

2.4.11 Incorrect Steady-State Heat Transfer

A deficiency in the heat transfer, noted in an integral calculation (Devkin and Kobzar; Section 2.3.2.2), has been in previous versions of the RELAP5 code and causes a problem during steady-state calculations. The problem is that if the primary system thermal hydraulic conditions are to be calculated accurately, some adjustment is necessary on the secondary side of the steam generators. This deficiency is discussed in Volume 5 of the RELAP5/MOD3 Code Manual, "User's Guidelines," as follows:

"It is often difficult to obtain a satisfactory agreement with steam generator full-power conditions. The difficulty arises because the heat transfer coefficient calculated on the outside surface of the steam generator tubes is based on general vertical-pipe correlations rather than correlations that account for the swirling flows present within the tube bundle region. The effect of this discrepancy is that tube heat transfer is understated by the code, resulting in excessively high calculated primary coolant temperatures. Since the source of the calculated error is understood, it is recommended that the modeler 'adjust' the heat transfer on the outside of the tubes to remedy the discrepancy.

The recommended adjustment is to reduce the input heated equivalent diameter on the heat structure cards for the outer tube surface. It is recommended that instead of using the boiler region hydraulic diameter as the heated diameter that the minimum tube-to-tube spacing be used. If the modeler decides not to follow this recommendation, it will be necessary to compromise an important parameter (such as using a lower secondary pressure, higher primary temperature, or lower feedwater temperature) to simulate full-power steam generator operation."

2.4.12 Self-Initialization Pump Controller

A coding error was found in a plant calculation (Kim, Chung, Kim, and Kim; Section 2.3.3.1) when using the self-initialization pump controller. The correction is simply a change on a line of subroutine coding and is given by the author.

2.5 Nodalization Sensitivities and New or Revised User Guidelines

The results of the RELAP5/MOD3.0 code assessment studies included identification of several nodalization sensitivities and development of new user guidelines and revision of existing guidelines. These are discussed, according to the phenomena affected, in the following subsections.

2.5.1 CHF

In the calculations of the Royal Institute of Technology CHF and dryout tests (Nilsson; Section 2.3.1.4), it was noted that changing the cell length from 0.10 m to 0.5 m did not make a significant difference in the calculation of temperature. It did lead to less resolution of the calculated dryout point and less resolution of steep temperature gradients. However, the implications for plant nodalization are unclear since the experiments used a flat axial power profile.

2.5.2 Hydrodynamic Loads

In a separate effects study (Stubbe and Vanhoenacker; Section 2.3.1.5), RELAP5/MOD3.0 was used to calculate the hydrodynamic loads associated with safety and relief valve discharge piping. Based on the results, several modifications and additions were made to a set of EPRI guidelines for using RELAP5/MOD1 for calculating such loads. Since these results are not generally applicable for any of the four types of calculations under consideration, the user is referred to the review in Section 2.3.1.5 for more specific information.

2.5.3 ECC Downcomer Penetration

Based on the comparison of calculations to data from UPTF (Schneider; Section 2.3.1.6), several nodalization guidelines were recommended. First, the downcomer should be split into two sets of volumes, with crossflow junctions connecting the halves, to account for the non-homogeneous flow distribution. Second, both the forward and reverse loss coefficients at the downcomer azimuthal junction connecting the halves should be set to 500. The authors stated that this damped the oscillations but did not affect ECC bypass and I penetration. Third, the lower plenum should be subdivided into two axial nodes of equal volume for calculation of lower plenum filling. Fourth, the ECC injection ports should be modeled by branches instead of ECCMIX components. However, the study reviewers recommended further nodalization studies to conclusively determine the best nodalization.

2.5.4 Direct Contact Condensation

Based on comparison with separate effects data generated at Northwestern University (Lee and Kim; Section 2.3.1.8), it was observed that further dividing a 1.6 m long channel from 10 to 20 nodes made no difference in the calculated condensation rate.

2.5.5 CCFL

A study comparing calculations to UPTF data (Curca-Tivig; Section 2.3.1.7) indicated that a hot leg with nine nodes between the reactor vessel and the steam generator inlet plenum was adequate for simulating countercurrent flow in the hot leg during typical reflux conditions. However, the evidence for recommending this nodalization was weak.

A separate effects study comparing calculations to rod bundle and tube CCFL experimental data from a KAERI facility (Cho, Arne, Chung, and Kim; Section 2.3.1.9) indicated that coarse noding simulated the phenomena as well as fine noding, but insufficient information was provided on the sensitivity studies to be conclusive.

2.5.6 Critical Flow

Two studies, one using BETHSY SBLOCA data (Roth, Choi, and Schultz; Section 2.3.2.5), the other using Marviken data (Kim and Kim; Section 2.3.1.10), identified nodalization guidelines for break hardware in an experimental facility. However, the implications for modeling breaks in full-scale plants is unclear, since this type of geometry is not present. The one recommendation offered which also applies to plant modeling is that choking should be turned off at all junctions except the break.

In the process of analyzing two SBLOCA experiments in the BETHSY facility, it was noted that break nozzles with L/D greater than 10 can be modeled to match the calibration data by sizing the volumes to give the same Courant limit as the rest of the model while maintaining an L/D equal to that of the hardware. Using this technique, the break volume is large enough to allow a reasonable time step size and the L/D allows the nozzle frictional pressure loss to be accurately calculated.

Comparisons of code calculations to Marviken data yielded several conclusions about modeling break discharge piping and nozzles. First, for nozzles with large L/D a single volume or pipe (with less than 3 volumes) should be used. Second, fine noding is recommended for discharge piping leading to the nozzle, where each node L/D should be less than 1.6. Third, for a nozzle with small L/D use a single junction.

2.5.7 General Primary/Secondary Side Nodalization Effects

Finer SG/Loop Nodalization In an LSTF SBLOCA calculation (Lee, Chung, and Kim; Section 2.3.2.3) a nodalization sensitivity study showed that doubling the number of loop seal nodes from 9 to 18 and the number of steam generator U-tube nodes from 8 to 16 improved the agreement with the experimental data. Calculation comparisons with BETHSY SBLOCA data (Roth, Choi, and Schultz; Section 2.3.2.5) showed that for loop seal clearing the vertical piping upstream of the pump should be nodalized with 6 to 8 cells. This nodalization improved the vertical pipe draining phenomena.

It was shown in BETHSY natural circulation calculations (Roth and Schultz; Section 2.3.2.4) that doubling the number of steam generator nodes from 8 to 16 nodes did *not* affect the calculation of the onset of reflux at power levels from 1-5% of scaled rated power.

Core Bypass. BETHSY natural circulation calculations (Roth and Schultz; Section 2.3.2.4) showed that the core bypass nodalization should correspond to the core nodalization.

Steam Generator Secondary. It was found in the same BETHSY natural circulation calculations (Roth and Schultz; Section 2.3.2.4) that if a low secondary level is expected, such as under secondary boiloff conditions, a fine nodalization in the lower regions is necessary to correctly calculate the liquid level and thus the primary to secondary energy transfer.

2.6 Conclusions and Observations

The major deficiencies identified thus far, those which can have the most impact on calculations are: the dryout position falls downstream of the actual position and the heater temperature is underpredicted by the CHF model, the interphase drag model can cause some oscillations around a volume that is vertically stratified, and the critical flow model underpredicts the flow rate in the two-phase region. Further investigation is necessary to determine conclusively the applicability of the CCFL model and the ECCMIX component, since code assessment studies gave mixed results. One deficiency cited, that of steady-state heat transfer, has been present in previous versions of the code as well and user guidelines exist to minimize the impact.

Several nodalization recommendations were made, the most significant including vessel noding for ECC downcomer penetration during LBLOCA, break nozzle and discharge piping noding for experimental simulations, and finer loop seal noding for SBLOCA loop seal clearing. The nodalization recommendations are not intended to be prescriptive; that is, they are intended only to serve as guidelines. Accumulated user experience with RELAP5 has shown that a nodalization that works well for a given combination or range of conditions for a particular phenomena may still require modification, based on sensitivity studies, for other conditions.

Later, when a larger base of RELAP5/MOD3 user experience exists and more independent assessment is performed, it will be possible to make more conclusions about the applicability of certain models or nodalization techniques. Currently, in the case of many RELAP5/MOD3 models independent assessment has not been extensive, but consists of only one or two studies. And it is accepted that not every assessment is as rigorous as the authors desire, but is constrained by limited resources thus many authors recommended that the identified problems or nodalization suggestions be investigated further.

Based on the code assessment results available so far, the following suggestions are made for the direction of future code assessment studies. It is also recognized that future work should and will include additional assessment as code modifications are made to correct identified deficiencies and as other model improvements are implemented.

- The applicability/limitations of the CCFL model should be investigated further since some inconsistencies have been noted in the studies. In particular, the effects of nodalization on CCFL occurrence must be studied more, since they were unclear from the studies.

- The performance of the ECCMIX component should be investigated further to determine why it performs well in one case and not another and also to determine more precisely the range of break sizes where its use is appropriate.

- More assessment of the interphase drag model in RELAP5/MOD3 should be performed to determine its strengths and limitations and also any effects of nodalization. This assessment is particularly important because interphase drag is one of the fundamental models in the code and can significantly influence many calculations. In particular, the problems of primary system mass distribution and junction oscillations noted in the studies should be investigated in future studies.

- The improvements to the downcomer penetration, ECC bypass, and the upper plenum deentrainment capabilities must be assessed further and the vessel nodalization suggestions presented previously should be validated by additional calculations.

- Other significant model improvements must be assessed, including the vapor pullthrough and liquid entrainment model, the reflood heat transfer model, and the horizontal stratification inception criteria.

- The modifications to the noncondensable model should be assessed to determine if they increase the robustness of the code when noncondensables are present. None of the independent studies reviewed to date have assessed this.

- The effects of more finely nodalizing the loop seal to capture loop seal clearing phenomena accurately should be corroborated by additional calculations before it is accepted as a user guideline.

3 SUMMARY OF RELAP5/MOD3.1 CODE ASSESSMENT THROUGH SEPTEMBER 30, 1995

3.1 Brief Code Description

RELAP5/MOD3.1 was released for general use in March, 1993. The development effort for RELAP5/MOD3.1 was focused on improving the reliability and run-time of the code. A description of the development and developmental assessment of RELAP5/MOD3.1 can be found in **Reference 4.0-23**.

The major changes in the code were revision of the interphase heat transfer model and revision of the wall condensation model. Other models were reinstated to their form in RELAP5/MOD2. A by-product of all the changes was that the run time was significantly improved in the test cases. A chronology of code changes are given in the Appendix. All the most significant changes are listed below.

- Direct heating between phases was added to the interphase heat transfer model.
- The wall condensation model was improved. [The total heat flux uses (T_{wall} -T_{sat}) as the driving force for heat transfer and the heat flux to liquid uses (T_{wall}-T_f) as the driving force. The heat flux to vapor is Q_{total}-Q_{liquid}. This corrected a problem where condensation could occur to liquid colder than the wall.]
- The RELAP5/MOD2 method for calculating (reducing) the interphase heat transfer coefficients when noncondensables are present was reinstated.
- The RELAP5/MOD2 model for calculating the liquid interphase heat transfer coefficient, H_{if}, in bubbly flow was reinstated (to remedy a problem simulating steam injection into subcooled water).
- The RELAP5/MOD2 time smoothing constants were reinstated because the RELAP5/ MOD3 smoothing model gave very little smoothing.
- The umbrella model, which smoothly limits H_{if} based on void fraction, is now implemented at low pressures. Its limits are low at the end values of the void range (0.0 and 1.0), and normal values are used at the mid-range.
- Several corrections/modifications were made to eliminate some water property error occurrences.
- Several corrections/modifications were made to minimize mass error problems.
- Modifications were made in noncondensable appearance coding to eliminate a mass error problem related to the appearance of noncondensables in a two-phase system.
- The accumulator model was modified to allow a lower gas temperature.
- Additional water property failure information was added to the debug printout information.

3.2 Code Assessment Matrix

The RELAP5/MOD3.1 code assessment studies reviewed to date are shown in **Table 3.3-1**. This table indicate the phenomena for SBLOCA and the degree to which each are simulated in each facility. No LBLOCA, using the RELAP5/MOD3.1 code have been reviewed to date. **Table 3.3-1** adheres primarily to the format of the OECD code assessment matrices given in **Table 1.3-1** through **Table 1.3-3**; however, because of the more extensive data set available for SBLOCA-related phenomena, the correlations between test type and phenomena, as well as the test type versus the test facility systems tests, are shown only for SBLOCAs and not for LBLOCAs.

The RELAP5/MOD3.1 code assessment studies reviewed to date include seven recent CAMP/ICAP assessment reports. Three are separate effects experiments and four are integral effects experiments. The code assessments were all completed using version 3.1 unless otherwise noted.

3.3 Summary Reviews of the Code Assessment Reports

3.3.1 Separate Effects Experiments

The separate effects experiment assessments are reviewed in Section 3.3.1.1 through Section 3.3.1.3 and cover the following areas of code capabilities:

- Reflood - Section 3.3.1.1, **Reference 4.0-24**.
- Subcooled Boiling Model - Section 3.3.1.2, **Reference 4.0-25**.
- Inverted-Annular Film-Boiling - Section 3.3.1.3, **Reference 4.0-26**.

3.3.1.1 Reflood Model.

Report reviewed:

B. D. Chung, Y. J. Lee, C. E. Park, S. Y. Lee, Y. S. Bang, K. W. Seul, and H. J. Kim, "Improvements to the RELAP5/MOD3 Reflood Model and Uncertainty Quantification of Reflood Peak Clad Temperature," Korea Atomic Energy Research Institute and Korea Institute of Nuclear Safety, February, 1995.

Objectives

The objective of this study was to assess the ability of RELAP5/MOD3.1-KAERI version to predict phenomena associated with reflood; however, some assessment of the RELAP/MOD3.1 base code was made for comparison purposes.

Summary description of the experiment and the input model

Experimental data (runs 31504, 31805, 31302, 31701, and 33338) from the FLECHT-SEASET facility were used to assess the RELAP5/MOD3.1 code's ability to correctly model reflood phenomena. The FLECHT-SEASET program provides experimental heat transfer and two-phase flow data in simulated PWR geometry for assessment of reflooding, core boil off, and natural circulation phenomena. A series of forced flow and gravity fed bundle reflooding and steam cooling tests were conducted on a heated rod bundle whose dimensions are typical of current PWR fuel rod bundles.

The test section for both the forced and gravity fed experiments were modeled for consistency using a "PIPE" component divided into 20 uniform volumes. Measured fluid conditions were used to define the thermal-hydraulic conditions in the upper and lower time-dependent volumes which represented the upper and lower plena, respectively. The measured flow injection velocity was used to define the flow conditions at the time-dependent junction that connects the lower plena to the test section. The measured power, which decreased during the test period, was used as input data for the heat structures representing the rods. Additional nodes were added to the gravity fed model to represent the downcomer and other associated pipes.

In the experiments used for this assessment the forced flooding rates ranged from 2.4 to 15.5 cm/sec. A flooding rate for the gravity fed experiment (33338) was not given. The injected liquid temperature for all the tests varied from 324 to 326 K. The system pressure was 0.28 MPa and the peak rod power was 2.3 kW/m for all the experiments.

Results significant for code assessment

Based on test run 31504 (reference case) with an injection velocity of 2.46 cm/sec, the RELAP5/MOD3.1 code exhibited several discrepancies associated with the reflood model. These discrepancies are:

- Delayed quenching: The calculated results obtained with the RELAP5/MOD3.1 code show that for a low reflooding rate (< 2.4 cm/sec) there is an unrealistic 200 second quenching tail at the midplane of the core. By quenching tail the authors mean that the modeled cladding temperature continues to decrease gradually over the 200 second period. Over the same period the experimental data shows that the cladding temperature drops abruptly to the coolant temperature at the start of the 200 second period. According to the authors this discrepancy is suspected to be caused by the Chen transition boiling model which yields heat transfer coefficients that are too small.

- High pressure spikes and oscillations during reflood: Unrealistically, large pressure spikes when compared to the experimental data were calculated to occur at the bundle inlet at the time of quenching for each heated structure. The high pressure spikes during the reflood calculations resulted in high steam flow oscillations and liquid carryover.

- Incorrect void profile and vapor-cooling in dispersed flow: Calculated results using the RELAP5/MOD3.1 code show that there is excessive liquid accumulation downstream of the quench front when compared to experimental data.

Author recommendations

Although the authors made no specific recommendations, the new models they put into the RELAP5/MOD3.1-KAERI code show significant improvements in the calculated reflood results; thus, they are listed here as recommendations for improvement to the RELAP5/MOD3.1 code.

- Replace the Chen transition boiling model with a quenching temperature model (modified Henry correlation) and a CHF temperature to determine transition boiling. When incorporated into the RELAP5/MOD3.1-KAERI model, this change resulted in improvements in the prediction of the time of quench and the cladding temperatures.

- Apply a wall vaporization smoothing model and level tracking model to the developing flow. When incorporated into the RELAP5/MOD3.1-KAERI code, these changes rectified the large unrealistic pressure spikes and consequently the pressure trends was well predicted. The wall vaporization smoothing model uses an underrelaxation method to determine the vaporization term in the mass and energy equation as opposed to the explicit method now used in the RELAP5/MOD3.1 code.

- Based on experimental results, set the maximum diameter of a droplet to 2.0 mm. This restriction contributed to increasing the interfacial drag in the dispersed flow regime and improves the axial void profile.

Limitations of the study

None identified.

Additional significant study findings

None.

Other comments

None.

3.3.1.2 Subcooled Boiling Model.

Report reviewed:

A. S. Devkin, A. S. Podosenov, "RELAP5/MOD3 Subcooled Boiling Model Assessment," Nuclear Safety Institute Russian Research Center-Kurchatov Institute, October, 1994.

Objectives

The objective of this study was to assess the RELAP5/MOD3 code capability to model the subcooled boiling process in heated channels.

Summary description of the experiment and the input model

All but one set of experimental data used for this assessment were generated using tubes having internal diameters of approximately 12 mm. The one set of data whose geometry was not a tube corresponded to a narrow flat test section (50 mm by 2 mm). The main parameter of interest was the void fraction distribution along the tube (channel) or, as presented in most of the figures in the reviewed report, the void fraction as a function of the equilibrium quality.

All the experimental test data (steady-state) used in this assessment were obtained from Russian and English technical journals. The cases selected covered pressures ranging from 0.1 to 14.7 MPa, heat fluxes from 9.73 to 2210 kW/m^2, mass fluxes from 127 to 2960 kg/m^2 s, and subcooling ranging from 3 to 170 K.

Results significant for code assessment

The calculations of void fraction vs. equilibrium quality presented in this report for uniformly heated channels show reasonable agreement with the experimental data sets used for the comparison except for the cases of low pressures where the void fraction is substantially overestimated. Flows with axial power distributions along the tubes show a discrepancy between the calculated vapor generation and condensation rates when compared to corresponding experimental data. Specifically the calculated rate of condensation which is determined by the interphase heat flux on the liquid side is underestimated. Increasing the interphase heat transfer coefficient H_{if} in a number of cases resulted in no changes in the condensation rates. The author attributes this to the limitations placed on the interphase heat transfer rate terms (umbrella model) which decrease the interphase heat transfer coefficients when the void fraction is near zero or one. This artificial decreasing of the interphase heat transfer coefficients appear to contribute to the discrepancy between the experimental and calculated results. The "umbrella" model was implemented into the code due to imperfections of the code numerical scheme.

The calculated void fraction vs. equilibrium quality at lower pressures has a discontinuity in the curve at a quality of 0.05, which appears to be caused by the under estimation of the vapor drift flux at the transition from slug to annular flow.

Most of the cases analyzed for RELAP5/MOD3 were repeated using RELAP5/MOD3[7j] and RELAP5/MOD3.1. The comparison between the RELAP5/MOD3 and the RELAP5/MOD3[7j] and RELAP5/MOD3.1 results are consistent except for the low pressure results. It was found at low pressures using the same time step that the newer versions of the RELAP5 code gave a nonphysical void (oscillatory) distribution along the channel. The nonphysical void distribution was eliminated by reducing the time step. No information was given on the initial time step used and how much it was reduced to solve the problem.

Author recommendations

The authors recommend some modification of the flow regime map, in particular, for the transition between slug and annular-mist regimes at low pressures, however they do not give specific details.

Limitations of the study

This study identified a potential problem with the interphase heat transfer model, however this reviewer believes more information is needed in order to show that the "umbrella model is the cause of the problem.

Additional significant study findings

None.

Other comments

None.

3.3.1.3 Inverted-Annular Film-Boiling.

Report reviewed:

F. de Cachard, "Development, Implementation and Assessment of Specific Closure Laws for Inverted-Annular Film-Boiling in a Two-Fluid Model," Thermal-Hydraulics Laboratory, Paul Scherrer Institute, October, 1994.

Objectives

The objective of this report is to present a new Inverted-Annular Film-Boiling (IAFB) two-fluid model which according to the author is an improvement over the existing models now used in codes such as RELAP5.

Summary description of the experiment and the input model

While no specific comparison of RELAP5/MOD3.1 results with the new model is made in the report, it seems appropriate to include a comparison of the results of the new model with experimental data, since a deficiency was identified in the RELAP5/MOD3.1 reflood model in **Reference 4.0-24**.

The author states that applicability of existing IAFB two-fluid models is limited. In the opinion of the author, the limitations associated with the existing IAFB model can be attributed to shortcomings in the description of heat transfer within the liquid core, to the use of certain correlations outside their validity range, and to limited use of experimental information on IAFB. The usual approach is to develop models employing generally applicable closure laws including adjustable parameters, and to adjust these using global experimental results. The present model has been developed using specific IAFB closure laws (presented in the report) such that they can be adjusted separately using detailed IAFB relevant experimental data.

Results significant for code assessment

The new model has been extensively assessed against forced flow, low quality post-dryout data from four independent sources (54 data sets) which are referenced in the main report. The quench front velocity, the initial flow parameters just downstream from the quench front, and the wall temperature distribution in the dry region were carefully derived from the data and given as inputs to the model. The model then predicted the heat flux and void fraction distributions, which were then compared to the experimental data. The overall predictions are good. The model is shown to apply to steady-state as well as to transient (reflooding) conditions, with very different geometries, i.e. tubes and rod bundles with hydraulic diameters ranging from 4 to 14 mm. Large variations in thermal-hydraulic parameters were investigated, namely, reflooding rates ranging from 3 to 250 cm/s, subcooling ranging from 5 to 80 ^{o}C, pressures between 1 and 4.4 bars, and wall temperature ranging from 400 to 1042 ^{o}C. The power levels associated with the experimental data was not given.

Author recommendations

The author recommends that the new model be used by safety codes such as RELAP5/MOD3.1.

Limitations of the study

No direct comparison is made between the model in RELAP5/MOD3.1 and the proposed new model.

Additional significant study findings

None.

Other comments

None.

3.3.2 Integral Effects Experiments

The integral effects experiment assessments are reviewed in Section 3.3.2.1 through Section 3.3.2.4 and covered the following transients and conditions:

Large-Scale Test Facility (LSTF)

- SGTR - Section 3.3.2.1, **Reference 4.0-27**.

PMK-2

- SBLOCA - Section 3.3.2.2, **Reference 4.0-28**.

BETHSY

- SBLOCA - Section 3.3.2.3, **Reference 4.0-29**.

LOFT

- SBLOCA - Section 3.3.2.4, **Reference 4.0-30**.

3.3.2.1 Large Scale Test Facility (LSTF) Steam Generator Tube Rupture.

Report reviewed:

K. W. Seul, Y. S. Bang, S. Lee, and H. J. Kim, "Assessment of RELAP5/MOD3.1 with the LSTF SB-SG-06 Experiment Simulating a Steam Generator Tube Rupture (SGTR) Transient," Korea Institute of Nuclear Safety, May 17, 1992.

Objectives

The objective of the study was to evaluate the capability of RELAP5/MOD3.1 code to simulate major thermal hydraulic behavior during Steam Generator Tube Rupture (SGTR) accident.

Summary description of the experiment and the input model

To evaluate the RELAP5/MOD3.1 code, data from LSTF SB-SG-06 test simulating the SGTR incident which occurred at Mihama Unit 2 in 1991 are used. The experiment consisted of opening a break valve to a system having approximately the same RCS pressure and temperature as in the Mihama Unit 2. The reactor trip and safety injection signals were set at the same RCS setpoint pressures as in Mihama Unit 2. HPSI flow was directed to the cold legs and vessel upper plenum. The damaged steam generator was isolated 12 minutes after reactor trip. Depressurization of the intact steam generator secondary side was also initiated at the 12 minute mark. Depressurization was terminated according to the Mihama Unit 2 Emergency Operating Procedures.

To stop the break flow, the primary system pressure was reduced by using the pressurizer auxiliary spay, since the PORV in the reactor failed to open. The pressurizer auxiliary spray was actuated 44 minutes after reactor trip. The pressurized auxiliary spray was turned off after the RCS pressure equilibrated with the damaged steam generator secondary side pressure. The HPSI pumps were turned off after the pressurizer water level recovered. Reactor coolant pumps in the intact loop were restarted 65 minutes after reactor trip. The experiment was ended when the RCS conditions were stabilized.

The computer model has 177 volumes connected by 186 junctions and 166 heat structures composed of 947 mesh points for the average U-tube model case. The reactor vessel consists of a downcomer, the lower and upper plenums, the core, the upper head and guide thimble channel. In modeling the upper part of the LSTF downcomer, care was taken to correctly simulate the steady-state mass flow rates in the connection with the hot legs (bypasses), the upper plenum (unintentional leak path) and the upper head (spray nozzles). The core is modeled by one channel of six hydraulic volumes, in which one series of heat structures is used to simulate the fuel assembly. A pipe connection between the upper head and the upper plenum of the pressure vessel is introduced in the scheme to simulate the guide thimble channel path existing in the test facility.

The two loops of the LSTF system are represented by the intact-loop and the broken-loop. Both loops consist of a hot leg, the SG inlet plena, the SG outlet plena, the SG U-tube channel, the loop seal, the reactor coolant pump, and the cold leg. The pressurizer is connected to the intact-loop by means of a surge line. The two SG secondary sides are simulated using identical nodalization. They are both subdivided into the downcomer, the boiling section, the steam separator and the steam dome. The steam and feedwater lines are simulated by using time dependent junctions with imposed flow rates. The relief and safety valves are also connected to the SG steam dome using valve components in which the operational setpoints and conditions are specified to be the same as the experiment.

The U-tube break modes are examined for two cases. Case 1 simulates the double-break as a single-break nozzle based on the LTF SB-SG-06 test configuration. The break nozzle is a straight, cylindrical pipe, 1.8 m in length with an inner diameter of 6.2 mm. Such a nozzle is used to simulate the scaled break area and length as well as the pressure drop along the ruptured tube. Case 2 simulates the single U-tube rupture as a break valves between a single broken U-tube (downflow side) and the SG secondary side. The valve junction diameter is 6.2 mm and the single broken U-tube size has an ID of 19.6 mm. The remaining SG U-tubes are modeled as an averaged single U-tube.

Results significant for code assessment

Overall the RELAP5/MOD3.1 calculation showed good agreement with the SB-SG-06 test data for the SGTR transient. Specifically, the RELAP5/MOD3.1 predicted well the transient behavior of the primary and secondary pressures, the temperatures of the core and hot legs, the break flow rate, HPSI flow rates, the pressurizer and SG water level. The calculated results also indicate that the code predicted well the sequence of events and the major phenomena during the transient such as the asymmetric loop behavior, the RCS cooldown and heat transfer by natural circulation, primary and secondary system depressurization by the pressurizer auxiliary spray and the steam dump using the intact loop SG relief valve (RV). However, there were differences in some items when compared to the applicable test data. Those items are the number of relief valve cycles in the affected SG, the flow regime in the hot leg with the pressurizer, and the break flow rates.

RELAP5/MOD3.1 overestimated the number of relief valve cycles in the isolated SG. In the experiment, the pressurization rate in the affected SG steam dome was determined by condensation and compression of the steam by the ascending SG water level rather than vaporization. However, the code may not properly predict this type of the wall and steam-water interface condensation phenomena. The frequent RV opening caused the overestimated break flow rate. Hence, to obtain the accurate transient behavior including the break flow rate, it may be necessary to improve the models for the wall and steam-water interface condensation for superheated situations, however before one can be certain more studies need to be performed.

The break nozzle model (Case 1) based on the LSTF test configuration provided better agreement with the experiment than the break valve model (Case 2). Also, in the case simulating the SG U-tube rupture using a break valve, the discharge coefficient, C_d, of the break valve had a strong influence on the break flow rate as would be expected.

Author recommendations

It was suggested by the authors that in order to obtain a better representation of the transient behavior including break flow rates, it may be necessary to improve the condensation models representing wall and steam-water interface under superheated situations in the REAP5/MOD3.1 code.

Limitations of the study

In the report it is suggested that the wall steam-water interface condensation model may need to be improved, however no sensitivity studies are presented showing the effects of the condensation model on the results.

The break nozzle used in this study has a large L/D (290). Large L/D nozzle have proven to be difficult to model, thus caution should be used when interpreting the results corresponding to Case 1 as no details are given on the nozzle model.

Additional significant study findings

A comparison between RELAP5/MOD3.1 and RELAP5/MOD3.0 for the above stated transient was also made. The comparison showed that the pressure behavior for both cases after the HPSI were almost identical; the MOD3.1 version of the code better predicted the pressure trend in the early phase of the transient. The improved prediction capability is attributed to the improvement incorporated into the MOD3.1 version; however, no specific improvements were identified as being responsible for the improved results using the MOD3.1 code.

Other comments

None.

3.3.2.2 Cold Leg Break Experiment.

Report reviewed:

V. L. Kobzar, "Assessment of RELAP5/MOD3[7J] Against PMK-2 7.4% Cold Leg Break Experiment (SPE-4)," Nuclear Safety Institute Russian Research Center-Kurchatov Institute, October, 1994.

Objectives

The objective of this study was to assess the ability of RELAP5/MOD3[7J] to simulate important phenomena and interactions due to a cold leg SBLOCA.

Summary description of the experiment and the input model

The experiment was an SBLOCA in the cold leg (7.4% cold leg break) without the High Pressure Injection System (HPIS). The secondary side feed and bleed was used to prevent damage to the core. The test was conducted at the PMK-2 test facility which is a full-pressure 1:2070 scale model of the Paks Nuclear Power Plant. The Paks Nuclear Power Plant is a VVER 440 type reactor which has a horizontal steam generator. The facility is used mainly to investigate processes following small and medium size breaks in the primary circuit and to study the natural circulation behavior of VVER 440 type PWRs.

The experiment with the small break (3 mm diameter) located at the top of the downcomer was initiated from full power. The following sequence of events occurred: (1) The break valve starts to open at 0.0 seconds and is fully open at 0.1 seconds. (2) The SG inlet and outlet valves start to close at 0.0 seconds and are both fully closed at 6 seconds. (3) Scram occurs when the primary pressure drops to 11.15 MPa. (4) Pump coastdown begins when the primary pressure drops to 9.21 MPa. Secondary bleed is initiated at a primary pressure of 9.21 MPa. (5) Secondary emergency feed is initiated at a secondary pressure of 0.93 MPa. (6) Coolant from two safety injection tanks begin flowing into the upper plenum and downcomer when the primary system pressure reaches 5.9 MPa. (7) Low Pressure Injection System (LPIS) is initiated when the primary system pressure drops to 1.04 MPa. (8) Test is ended at 1800 seconds.

The model contained 171 volumes, 175 junctions and 157 heat structures. The heated region of the core was modeled with a "pipe" component with 11 subvolumes. The steam generator tubing is conditionally split into three bundles. Each bundle is represented as a pipe having 4 subvolumes and 4 heat structures providing heat exchange with corresponding volume in the secondary side. The break is modeled as a "motor valve" in which an abrupt area change and choking model were used. The steam generator secondary side has a down-stream part which provides the possibility of coolant circulation inside the steam generator volume. Where cross connections occur, the corresponding volume were split as needed. Cross flow junctions were not used (no explanation was given for not using cross flow junctions).

All external walls of the facility components were modeled as heat structures with a constant heat transfer coefficient on their external surfaces. The bundle interphase friction model was applied in the core. For all other components the interphase friction correlation for a pipe was used.

Results significant for code assessment

The model was adjusted such that steady-state code results were in good agreement with the experimental parameters just before initiation of the transient. One problem was identified in the steady state calculation. The original nodalization of the SG gave too low of a coolant level on the secondary side. The SG was re-nodalized in a somewhat artificial way which resulted in the coolant level on the secondary side matching the steady-state experimental value.

The early stages of the transient (0 to 200 s) showed reasonable agreement with the experimental results: however, the results beyond 200 seconds showed a major discrepancy in the prediction of the primary pressure. The code overpredicted the rate of primary pressure decrease resulting in the early initiation of the LPIS. The problem was first attributed to overprediction of the break flow; however, modification to the break nozzle show no significant change in the resulting primary pressure. The problem was then attributed to over prediction of the heat transfer coefficient (HTC) from the primary to the secondary side of the SG. The author suggested several reasons which might have caused the discrepancy. The suggested reasons are as follows:

- The program overpredicts the heat transfer coefficient for condensation in horizontal SG tubes in the horizontally-stratified flow regime.
- The vapor void fraction in the SG tubes in the experiment was less than in the calculation. This might be true if it were possible for water to remain in the tubes while the collectors were dry.
- The presence of noncondensable gas in the tubes in the experiment.
- The presented experimental primary pressure was higher than real value and the secondary pressure value was lower than the real value because of measurement errors.

The author believes that overprediction of the heat transfer coefficient for condensation in horizontal tubes in the horizontally-stratified flow regime is the most probable reason for the noted discrepancy.

Author recommendations

It is recommended that further investigations, including separate effects experiments, be conducted to further assess the heat transfer coefficient for condensation in horizontal tubes in the horizontal-stratified regime.

Limitations of the study

The use of four subvolumes to model each of the steam generators bundles may not be enough volumes to yield reasonable results, thus care must be exercised when using results from this study.

Additional significant study findings

Care must be taken in modeling the upper plenum. The upper plenum filled with steam soon after the initiation of the transient. The experimental data shows that the upper plenum contains superheated steam during the duration of the transient. The calculation show that this steam condenses because of contact with subcooled water from the accumulator flow.

The modeling of the upper plenum should somehow prevent the direct contact of the cold water from the accumulator with the superheated steam.

3.3.2.3 BETHSY 6-inch Cold Leg Break.

Report reviewed:

Y. J. Chung, J. J. Jeong, W. P. Chang, D. S. Kim, Y. S Bang, H. J. Kim, "Assessment of RELAP5/MOD3 Using BETHSY 6.2TC 6-inch Cold Leg Side Break Comparative Test," Korea Atomic Energy Research Institute and Korea Institute of Nuclear Safety, February 1995.

Objectives

The objective of this study was to assess the ability of the RELAP5/MOD3[7j] code to simulate the phenomena and interactions associated with an SBLOCA

Summary description of the experiment and the input model

This report documents the assessment of RELAP5/MOD3 code version [7j] using data from BETHSY test 6.2TC. This experiment was designed to study the phenomena that occurs during a SBLOCA corresponding to a 6 inch cold leg break (5% break area). The following sequence of events occurred during the test: (1) The break valve was opened at time zero, (2) Primary coolant became saturated, (3) Loop seal clearing occurred, (4) Core heat up occurred, and (5) The emergency core cooling system (accumulators) was activated. The HPSI system was not operated. The test was terminated when the pressurizer pressure fell below 0.7 MPa.

According to the report the nodalization of the BETHSY facility was detailed enough to simulate the important two-phase flow processes such as the core water level depression, loop seal clearing, and transient coolant distribution in the primary cooling system. The input model consisted of 251 volumes, 258 junctions, and 284 heat structures. The three coolant loops are individually modeled.

Results significant for code assessment

Generally, the major thermal-hydraulic phenomena predicted by the RELAP5/MOD3[7j] code and observed in the BETHSY 6.2 TC test were in reasonable agreement; however, some disagreement in the timing of the events were observed. The discrepancies include some deviations in the prediction of loop seal clearing, collapsed core water level after loop seal clearing, and accumulator injection behavior. Specific descriptions of the deviations are as follows:

- In the experiment the loop seal clearing of all loops occurs almost simultaneously at 134 seconds whereas the RELAP5/MOD3[7j] code predicts loop seal clearing beginning at 138 seconds and complete voiding occurring at 200 seconds. This delay in complete voiding of the upflow side of the crossover legs significantly affects the calculation of the collapsed core water level because the remaining liquid water resists the flow of steam toward the break until it is completely cleared.

- Due to faster depressurization in the RELAP5/MOD3[7j] calculations, the accumulator injection begins earlier than in the experiment. The code predicted intermittent injection behavior rather than the continuous behavior as measured, and the depletion of the accumulators is accordingly achieved earlier in the RELAP5 calculation. The time elapsed during 50% injection of the accumulator water in the RELAP5/MOD[7j] calculation is 50 seconds, whereas about 190 seconds was taken in the experiment. This discrepancy has a direct affect on the downcomer and core water level behavior. The authors state that the intermittent injection behavior is caused by code characteristics rather than by inadequate modeling however no detail discussion is given as to why the authors believe this to be the case.

- The calculated collapsed core water level showed substantial deviation from the experimental data especially in the later phase of the transient (RELAP5/MOD3[7j] underpredicted the collapsed core water level by as much as 0.5 meters). This can be attributed to the timing of the loop seal clearing and the early and rapid injection of coolant from the accumulators which is in itself a result of the overprediction of the break flow rate.

Author recommendations

None.

Limitations of the study

None identified.

Additional significant study findings

A sensitivity calculation was performed to determine if changing the two-phase break discharge coefficient from 1.2 to 0.80 would improve the discrepancy between the experimental and calculated results. The results showed that the two-phase break mass flow is reduced in the early phase of the transient but increases in the later period of the transient. Such a behavior was not fully understood by the authors. The overall behavior of the other thermal-hydraulic parameters are almost identical to those of the base case calculation.

A second sensitivity calculation was performed where the interphase drag coefficient was reduced by half. This change resulted in very little difference in the primary system pressure and break flow rate when compared to the base case. However, integrated over time the results show a reduction of 29 kg in the total mass flow from the break. This reduction in the loss of mass is enough to reduce the discrepancy between the experimental and calculated collapsed core water level to 0.2 meters. The authors state that the results generally show that the interphase drag model has large uncertainties associated with it.

3.3.2.4 LOFT TEST L3-6.

Report reviewed:

S. S Pylev, and V. L. Roginskaya, "Application of RELAP5/MOD3.1 Code to the LOFT Test L3-6," Nuclear Safety Institute Russian Research Center-Kurchatov Institute, October, 1994.

Objectives

The objective of this study was to assess the ability of RELAP5/MOD3.1 to simulate the phenomena and interactions associated with an SBLOCA. Specifically, the sensitivity of the calculations to the break nozzle superheated discharge coefficient was investigated.

Summary description of the experiment and the input model

The experiment L3-6 is a small break experiment conducted in the LOFT facility. The small break used in the L3-6 experiment was located in an offtake pipe connected at a right angle to the cold leg of the active loop. The break orifice had a break area corresponding to a break diameter of 4 inches. For this test the accumulators and Low Pressure Injection System (LPIS) were not actuated. The HPIS flow was directed into the reactor downcomer. The primary pumps continued to run during the duration of the transient.

The main objective of the experiment was to determine the primary system mass inventory and distribution as a function of time during the small break depressurization. Three calculations were made to study the sensitivity to break nozzle superheated discharge coefficient. A value of 0.6 was used for the baseline model. Results were also calculated for discharge coefficients of 0.74 and 1.0.

The model used for the assessment was one developed at the Winfrith Center and reported in NUREG/IA-0072. Several minor changes in the model were made to the reactor vessel downcomer and filler gap.

Results significant for code assessment

Overall the transient predictions showed good agreement with the experimental data. The authors, however, noted some discrepancies in the system pressure after the dryout of the cold leg (approximately 860 seconds). It is noted from viewing the figures in the report that at this time the predicted mass flow from the break drop abruptly to a low value (3.8 kg/sec to 1 kg/sec) and the pressure in the intact loop hot leg also starts to deviate for the experimental results (underpredicted). This appears to be a contradiction since one would expect the rate of pressure decrease to be less with less mass flow leaving the system. This discrepancy between the calculated and the experimental date is believed to be due to the mass error in the calculation. The authors believe these discrepancies are due to the RELAP5/MOD3.1 code not simulating the vapor discharge flow correctly during the transition from two-phase flow to superheated flow. The sensitivity calculations using different superheated discharge coefficients showed that reducing the coefficient reduced the rate of pressure decrease; however, at transient times greater than 2000 sec some overprediction of the system pressure was noted. A discharge coefficient of 0.6 results in the best prediction of the hot leg pressure, however all three sensitivity calculations show the same phenomena described above.

It was also observed that the temperature of the coolant in the hot leg and the reactor vessel downcomer were also underpredicted most of the transient. The authors state that this could be due to incorrect initial coolant temperatures.

Author recommendations

None.

Limitations of the study

None identified.

Additional significant study findings

None.

3.3.3 Plant Transients.

None reviewed to date.

3.4 Summary of the Identified Deficiencies and the Impact on Calculations

In this section, the code deficiencies identified in the studies are summarized and discussed relative to the impact on the performance of the code for the four most common types of calculation: steady-state, LBLOCA, SBLOCA, and operational transients (e.g., loss of feedwater, ATWS). In the following subsections, related deficiencies are grouped and discussed together when appropriate.

3.4.1 Reflood

Several deficiencies were noted in a separate effects study (Section 3.3.1.1). The deficiencies were identified as: delayed quenching, high pressure spikes and oscillations during reflood, and incorrect void profile and vapor cooling in dispersed flow. A second independent study (Section 3.3.1.3) identified shortcomings in the description of the heat transfer within the liquid core, the use of certain correlations (no specific correlations are identified) outside the range of there validity, and to limited use of experimental information on IAFB. When new purposed models were used, significant improvements in the calculation of reflood phenomena were noticed (see references for details).

3.4.2 Subcooled Boiling

A separate effects subcooled boiling code assessment study (Section 3.3.1.2) showed that the void fraction for the case of low pressures are overpredicted. The overprediction of the void fraction is attributed to a deficiency in the interphase heat transfer model ("umbrella" model). However more sensitivity studies need to be performed before a recommended solution to this problem can be identified.

A non-physical void profile was identified for cases where relatively large time steps were used. Reducing the time step seem to solve the problem, however no details were give as to the magnitude of the time steps used.

3.4.3 Condensation (Wall and Interfacial)

During the SGTR calculation RELAP5/MOD3.1 code overpredicted the number of relief valve cycles occurring during the transient. The cause of this overprediction of the number of relief valve cycles is though to be due to the inadequacies in the wall and steam-water interface condensation model. However not enough information is available at this time of say definitely that the condensation model is the cause of the above mentioned problem. The results from the PMK cold leg SBLOCA also showed some discrepancy associated with the condensation model in that the model overpredicted the heat transfer coefficients for flow in horizontal SG tubes. No information from the studies is given as to what in the model needs to be improved in order for the model to give a reasonable condensation rate.

3.4.4 Interphase Drag

The BETHSY 6-inch cold leg break study, according to the authors, indicated that the interphase drag model may have some deficiencies associated with the it. Reducing the interphase drag coefficient by one half cause a reduction in the total mass of coolant loss from the system by 29 kg which in turn cause a decrease the discrepancy of the collapsed core water level from 0.5 m to 0.2 m, which is a significant improvement. Problems attributed to the interphase drag model were reported previously (Section 2.4.6). It appears that a more comprehensive sensitivity study of the interphase drag model is warranted.

3.5 Nodalization Sensitivities and New or Revised User Guidelines

3.5.1 Subcooled Boiling

The solution time step of the subcooled boiling study was reduced to eliminate the generation of non-physical void profiles. No details were given.

3.5.2 PMK SBLOCA

The original nodalization of the SG gave too low of a coolant level on the secondary side. The SG was re-nodalized in a somewhat artificial way which resulted in the coolant level on the secondary side matching the steady-state experimental value. No detailed description of the new nodalization scheme was given.

3.5.3 BETHSY 6-inch Cold Leg Break

The two-phase break discharge coefficient was varied from 1.2 to 0.8 to determine its effect on the overall results. Lowering the discharge coefficient from 1.2 to 0.8 reduced the break mass flow rate in the early phase of the transient, however later in the transient the mass flow rate is larger than that associated with a coefficient of 1.2. The overall behavior of the system is approximately the same for the two discharge coefficients.

3.5.4 LOFT SBLOCA

The superheated discharge coefficient was reduced from 1.0 to 0.6. This reduction in the superheated discharge coefficient caused a reduction in the rate of primary pressure decay, however very little effect was seen on the overall behavior of the transient.

3.6 Conclusions and Observations

Two new deficiencies have been identified from the seven studies reviewed above. These new deficiencies are associated with the RELAP5 reflood model and the subcooled boiling model. The other deficiencies noted in the studies have been noted before in the assessment of the RELAP5/MOD3.0 code. These deficiencies are associated with the interphase drag model and the wall and interfacial condensation model.

At this time, assessment studies of the RELAP5/MOD3.1 code are limited. The general conclusions and observations, including the suggestions of future code assessment studies, given in Section 2.6 for the RELAP5/MOD3.0 code are still valid.

Table 3.6-1 RELAP5/MOD3.1 code assessment matrix for PWR SBLOCAs.

MATRIX II
Cross-reference matrix for small and intermediate leaks

Phenomena versus test type
- ● simulated
- – partially simulated
- ○ not simulated

Phenomena versus test facility
- ● suitable for code assessment
- – limited suitability
- ○ not simulated

Test facility versus test type
- ● simulated
- – partially simulated
- ○ not simulated

		Test Type			Test Facility													
					Systems					Sep. effects					Plant Transients		
		Stationary test addressing energy transportation on primary side	Stationary test addressing energy tranp. on sec. side	Small leak w/o HPIS overfeeding, secondary side necessary	BETHSY 1:100[a]	LSTF 1:50	SEMISCALE 1:1600	LOFT 1:50	PKM-2 1:2070	FLECHT-SEASET	KAERI	Marviken	WSRC	UPTF	KRESING (Piping)	ROYAL Inst. of Tech.	KORI Unit 3
Phenomena	Natural circulation 1-phase flow, primary side	●	●	●	●	●		●	●								
	Natural circulation 2-phase flow, primary side	●	●	●	●	●		●	●								
	Reflux condenser mode and CCFL	●	●	●	●	●		○	○								
	Asymmetric loop behavior	–	–	●	–	–		–	–								
	Leak flow	–	–	●	●	●		●	●								
	Phase separation w/o mixture level formation	●	–	●	●	●		○	–								
	Mixture level and entrainment vert. com. s.g[b]	●	●	●	●	–		–	–								
	Mixture level and entrainment in the core	●	–	○	○	–		○	–								
	Stratification in horizontal pipes	●	●	●	●	●		●	●								
	ECC-mixing and condensation	–	–	–	–	–		○	–								
	Loop seal clearance	–	–	●	●	●		●	●								
	Pool formation in UP/CCFL (UCSP)	●	●	○	○	○		○	○								
	Core wide void and flow distribution	●	●	○	○	○		○	○								
	Heat transfer in covered core	●	●	○	●	●		●	●	●							
	Heat transfer partially uncovered core	●	●	○	●	●		●	●	●							
	Heat transfer in SG primary side	●	●	●	●	●		●	●								
	Heat transfer in SG secondary side	○	●	●	●	●		○	●								
	Pressurizer thermohydraulics	–	–	–	–	–		○	–								
	Surgeline hydraulics	–	–	–	–	–		○	–								
	1-and 2-phase pump behavior	–	–	–	–	–		○	–								
	Structure heat and losses[c]	●	●	●	○	○		○	●								
	Noncondensable gas effects	–	–	–	–	–		–	–								
	Phase separ. in T-junc. and effect on leak flow	–	–	●	○	○		○	–								
Test Facility Systems	BETHSY	●	●	●													
	LSTF	–	–	●													
	SEMISCALE	–	–	●													
	LOFT																
	PMK-2																

a. Volumetric

b. Secondary

c. Problem for scaled test facilities

jen1195-006.nod

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APPENDIX A--SUMMARY OF RELAP5/MOD3 CODE VERSIONS, VERSION 3.1 TO 3.2

CODE VERSION BEING CHANGED: selp8k0

CODE VERSION BEING CREATED: rbc3.1

1. TITLE OF CHANGE: Change title and version number and prevent new sparse matrix strategy at restart write.

PROBLEM STATEMENT OR OTHER REASON FOR CHANGE: (1) NRC requested a change in version numbering. (2) Coding that forced a new sparse matrix strategy when restarts were written was found to still be in the code. It should have been removed in a previous update.

DESCRIPTION OF CHANGE: (1) A change in numbering in subroutine aatl was made. (2) Coding to force a new sparse matrix strategy in rstrec was removed.

CODE VERSION BEING CHANGED: selp8k

CODE VERSION BEING CREATED: selp8l

CODE VERSION BEING CHANGED: selp8l

CODE VERSION BEING CREATED: selp8m

1. TITLE OF CHANGE: Fix errors in system sorting, point kinetics, and edit in multiple junction processing.

PROBLEM STATEMENT OR OTHER REASON FOR CHANGE: An abort occurred when a user attempted using a time-dependent volume not attached to any other volume. This is not now allowed. Clearing of a dynamic block and a diagnostic dump were removed form reactor kinetics input processing and an error resulted. Edit of initial velocities or flow rates in multiple junction component printed an extra quantity.

DESCRIPTION OF CHANGE: Problem in imlp was fixed so that error diagnostic is issued and problem terminates normally at the end of input processing. Error in rrkin in setting source term was fixed. Branching in rmltpj for editing initial conditions was fixed.

2. TITLE OF CHANGE: Fixes to state routines.

PROBLEM STATEMENT OR OTHER REASON FOR CHANGE: In running an AP600 PRHR separate effects problem, it was found that the liquid density and temperature derivatives were not set when the volume had steam and noncondensable but no liquid.

DESCRIPTION OF CHANGE: In subroutines istate and statep, the liquid density and temperature derivatives are now calculated when the volume has steam and noncondensable but no liquid. In subroutine statep, an extraneous calculation of the saturation derivative was removed when steam and noncondensable are present, and the mixture density variable rhom is now set to a positive number (rho) on a time step repeat so as to not cause a thermodynamic property failure message.

CODE VERSION BEING CHANGED: selp8m

CODE VERSION BEING CREATED: selp8n

1. TITLE OF CHANGE: Boron transport by Godunov method.

PROBLEM STATEMENT OR OTHER REASON FOR CHANGE: A highly diffusive first-order upwind difference method is currently used in RELAP5 for boron transport.

DESCRIPTION OF CHANGE: The second-order accurate Godunov method for boron transport is implemented as an option.

CODE VERSION BEING CHANGED: selp8n

CODE VERSION BEING CREATED: selp8o

1. TITLE OF CHANGE: Fix to wall condensation.

PROBLEM STATEMENT OR OTHER REASON FOR CHANGE: Typpwr ran 40% slower than previous versions (up to 8j) and investigations show phase transition problems at low void fractions caused mass errors and time step reductions.

DESCRIPTION OF CHANGE: Condensation used to be allowed above void fractions of .001. This boundary has been moved to 0.1 and the interpolation between dittus at 0.1 and wall condensation at 0.3 is now done.

CODE VERSION BEING CHANGED: selp8o

CODE VERSION BEING CREATED: selp8p

1. TITLE OF CHANGE: Add debug dumping of common and dynamic blocks, subroutine rpipe corrected to properly read horizontal angles, decknames with seven character names changed, amount of data for general tables increased.

PROBLEM STATEMENT OR OTHER REASON FOR CHANGE: (1) A capability to dump common and dynamic blocks would assist debugging and testing of new coding. (2) Subroutine rpipe was coded to use the wrong card numbers for reading the first (horizontal angle for spherical geometry angles) and the third angle. (3) Some subroutines furnished by ORNL had seven character subroutine names and deck names. The subroutine names were previously changed; the deck names now need changed. (4) Number of sets of data for general tables needed to be increased for a user.

DESCRIPTION OF CHANGE: (1) A subroutine was written to dump common and dynamic blocks to one of two files, the names of which can be specified on the command line. A new run option reads input specifying the dump blocks to be compared on the two files, and read and compares the records. A limited input capability using the 105 card can specify two types of dumps without changing the program. More general usage requires modifying the program to insert calls to the dump subroutine much as the program is sometimes modified to force debug printout. (2) Subroutine rpipe was corrected to use the correct angles for reading in angles. (3) Deck names were changed by removing the seven character decks and replacing them with the identical coding with the six-character deck name. (4) Constants limiting the amount of data allowed in general tables were increased. Program version number was changed.

2. TITLE OF CHANGE: Add DECalpha installation option.

PROBLEM STATEMENT OR OTHER REASON FOR CHANGE: DECalpha installation option needed.

DESCRIPTION OF CHANGE: Added 'decalpha' installation option.

3. TITLE OF CHANGE: Minor error corrections found on alpha compiler.

PROBLEM STATEMENT OR OTHER REASON FOR CHANGE: Minor FORTRAN errors and warnings uncovered on DECalpha chip FORTRAN compiler.

DESCRIPTION OF CHANGE: Undefined index in ibwr.

4. TITLE OF CHANGE: Improvements to noncondensable iteration, fix multiple use of card number in rpipe.

PROBLEM STATEMENT OR OTHER REASON FOR CHANGE: An error in molten metal coding was found in attempting to run sample input. Iteration used in equation of state of a fluid plus noncondensables was not robust. Errors were introduced into subroutine rpipe when new input was added that used the same input as previously entered. The input was documented in completion reports but not in the standard manuals.

DESCRIPTION OF CHANGE: The debug coding in subroutine fwdrag was moved as suggested in previous coding additions in subroutine volvel was fixed. Use of incorrect variable for initial index was fixed in subroutine vfinl. A false convergence was corrected when the reduced changes used to prevent a Newton method advancement from increasing the previous error were not used to test convergence. Card numbers of previously entered but undocumented input was changed. Manual was modified to include the input changes. Program version number was changed.

CODE VERSION BEING CHANGED: selp8p

CODE VERSION BEING CREATED: selp8q

1. TITLE OF CHANGE: Option 14 for turning off constitutive relations.

PROBLEM STATEMENT OR OTHER REASON FOR CHANGE: During the course of development, it is sometimes necessary to turn off all the constitutive relations. This is often the case when running the water faucet problem.

DESCRIPTION OF CHANGE: Subroutine vexplt is modified to turn off the constitutive relations using change option 14. The change to subroutine rchng to add change option 14 is being submitted with update edh8pa.

2. TITLE OF CHANGE: Option 13 for vertical stratification changes

PROBLEM STATEMENT OR OTHER REASON FOR CHANGE: Analyses of the transient response of the AP600 with RELAP5 have identified anomalous behavior of the calculated flow and heat and mass transfer in the CMT as it drains. Some of the characteristics observed in the response of the CMT that have indicated problems include: (1) spikes in the pressure as each control volume in turn empties as the liquid drains from the CMT, (2) very large, physically unrealistic, rapid increases and decreases in the condensation rate for the vapor at the vapor-liquid interface, and (3) physically unrealistic transport of the vapor into the liquid-filled control volumes below the volume containing the interface.

DESCRIPTION OF CHANGE: A minimum size of bubbles and droplets is used in the bubbly and mist flow regimes. Changes to the smoothing of the interfacial heat transfer coefficient correlations at the vapor void fraction limits of 0.0 and 1.0. Implementation of the donor-acceptor finite-difference approximation for the void fraction for control volumes under vertically-stratified conditions. Elimination of the flow-regime transition regions near the vapor void fraction limits of 0.0 and 1.0. These changes are activated with change option 13.

CODE VERSION BEING CHANGED: selp8q

CODE VERSION BEING CREATED: selp8r

1. TITLE OF CHANGE: Correct incorrect dynamic block definitions involving some option.

PROBLEM STATEMENT OR OTHER REASON FOR CHANGE: Dynamic block definitions in jundat for some options was modified incorrectly in last update such that removing them led to compilation errors.

DESCRIPTION OF CHANGE: Jundat was corrected. Program version number was changed.

CODE VERSION BEING CHANGED: selp8r

CODE VERSION BEING CREATED: rbc3.1.8s

1. TITLE OF CHANGE: Change version numbering, fix sparse matrix strategy effect on restart, and reformat coding for maintainability.

PROBLEM STATEMENT OR OTHER REASON FOR CHANGE: (1) NRC requested that the version numbering be changed. (2) The coding in rstrec that writes restart records and set flags forcing a new matrix strategy should have had the coding forcing the new matrix strategy removed in a previous update. The new matrix strategy caused different answers in a run with a restart and an identical run without restarts. (3) Subroutines prednb and pstdnb were not indented for ease of reading code and future coding changes are planned.

DESCRIPTION OF CHANGE: (1) Version numbering was changed. (2) The coding forcing a new matrix strategy was removed. (3) Subroutines prednb and pstdnb were reformatted to simplify possible future coding changes.

2. TITLE OF CHANGE: Standardize volume input new style.

PROBLEM STATEMENT OR OTHER REASON FOR CHANGE: phase 2.

CODE VERSION BEING CHANGED: rbc3.1.8s

CODE VERSION BEING CREATED: rbc3.1.8t

1. TITLE OF CHANGE: Fix miscellaneous reported errors, fix title problems introduced last update, change heat transfer common blocks as part of future work.

PROBLEM STATEMENT OR OTHER REASON FOR CHANGE: (1) The second period in the version number was treated as a floating point number by cnv32.f. The printout of defined variables incorrectly printed table was out of date. An abort occurred in invhts due to a user error in heat structures. Some RELAP5 decks had not been converted to use implicit none. (2) Common blocks htrcm and htscr need changing for future changes to increase implicitness between heat conduction and hydrodynamics. Change option 26 added to protect the added implicitness until changes are proven. Deck tpawht is no longer used as of last update.

DESCRIPTION OF CHANGE: (1) A # sign is used for the internal version number separator instead of a period to avoid the problem with cnv32 interpreting the period as part of a floating point number. The printout of defined variables was fixed. Subroutine aatl was fixed to recognize the new format of the names during restart processing the rstplt file. A test was entered in invhts to prevent processing of heat structures with input errors in the inverted list heat structures attached to volumes. RELAP5 subroutines that did not use implicit none were modified to do so. (2) Additional variables were added to common blocks htrcom and htscm to allow addition of added implicitness. Change option 26 was added to mark the coding for added implicitness.

CODE VERSION BEING CHANGED: rbc3.1.8t

CODE VERSION BEING CREATED: rbc3.1.8u

CODE VERSION BEING CHANGED: rbc3.1.8u

CODE VERSION BEING CREATED: rbc3.1.8v

1. TITLE OF CHANGE: Add changes from DECalpha testing, increase number of components allowed on shaft component.

PROBLEM STATEMENT OR OTHER REASON FOR CHANGE: DECalpha version failed during a problem execution. User reported problem where limit of ten components attached to a shaft component is not enough.

DESCRIPTION OF CHANGE: DECalpha had fatal error with write list mismatched to format. Lower floating point limit for DECalpha had to be changed. Number of components that can be attached to a shaft component has been increased to 20. Program version number was changed.

CODE VERSION BEING CHANGED: rbc3.1.8v

CODE VERSION BEING CREATED: rbc3.1.8w

1. TITLE OF CHANGE: Double dynamic space, add variables to voldat block, provide more detail in heat transfer correlations.

PROBLEM STATEMENT OR OTHER REASON FOR CHANGE: (1) Users are now running large enough problems that exceed the dynamic space allocated. (2) Voldat space needed to be increased to provide variables for increased implicitness between heat conduction and hydrodynamics and to store void fraction times density and void fraction times density times energy to decrease run times. The variable qwf was added to the voldat block. (3) As part of adding the dependence of wall heat transfer coefficient on surface and water temperatures, the coefficient for the liquid temperature, the coefficient for the saturation temperature that transfers heat to the liquid, the coefficient for the vapor temperature, and the coefficient for the saturation temperature that transfers heat to the vapor were individually returned, and certain sums of those coefficients. Some logic simplification was made to the heat transfer correlation routines. (4) A temporary common block was added as part of the oxidation fix in a previous update with the intent to move the variable to voldat if the fix was successful.

DESCRIPTION OF CHANGE: (1) Dynamic space was doubled from one-half million words to one million words. (2) Voldat space increased. Coding using new space not yet added. (3) The changes were made so as not to change results, at least assuming perfect arithmetic. Small differences were noted in the typpwr problem due to changes in prednbv and conden. (4) Oxidation variable was added to voldat and affected coding changed. Program version number was changed.

2. TITLE OF CHANGE: Radiation time step control corrections.

PROBLEM STATEMENT OR OTHER REASON FOR CHANGE: Need to add change options to exercise time smoothing with different time smoothing constant; the same for exercising radiation time step control. divide by zero encountered in that time step control.

DESCRIPTION OF CHANGE: Add change options to exercise time smoothing with different time smoothing constants, add option to exercise radiation time step control. Put in divide by zero protection.

CODE VERSION BEING CHANGED: rbc3.1.8w

CODE VERSION BEING CREATED: rbc3.1.8x

1. TITLE OF CHANGE: Add coding to allow more implicit coupling of heat conduction and hydrodynamics and protect divide by zero in eqfinl.

PROBLEM STATEMENT OR OTHER REASON FOR CHANGE: (1) NRC has funded a task to add more implicit numerics to portions of the code. (2) A divide by zero occurred in eqfinl turing testing. (3) Deck wfricj is not used.

DESCRIPTION OF CHANGE: (1) The heat transfer coefficient subroutines have been modified to return more components of the total coefficient and now include the coefficients to vapor and liquid due to the difference between the wall temperature and saturation temperature. The partial coupling between the heat conduction and hydrodynamics (option 4 on time step control card) has been extended to include the dependence on saturation temperature. (2) The divide by zero was protected by testing the divisor and not dividing if the divisor is zero. The result of the divide would have been the internal energy but that will be set to the saturation value in this case. Program version number was changed.

2. TITLE OF CHANGE: Corrections to time step repetition and introduction of the globally convergent Newton's method for noncondensable state equations.

PROBLEM STATEMENT OR OTHER REASON FOR CHANGE: Surry fails due to nonconvergence of Newton's method. Suspect may be due to either the not very fast convergence rate of the line search Newton's method or because of the ill-conditions of the Jacobian matrix.

DESCRIPTION OF CHANGE: Put in a globally convergent Newton's method that has protection against ill-conditions of the Jacobian matrix.

CODE VERSION BEING CHANGED: rbc3.1.8x

CODE VERSION BEING CREATED: rbc3.1.8y

1. TITLE OF CHANGE: Add coding to advance heat conduction simultaneously with hydrodynamics.

PROBLEM STATEMENT OR OTHER REASON FOR CHANGE: Advancing heat conduction simultaneously with hydrodynamics is expected to make the code more robust and to decrease run times by allowing larger time steps.

DESCRIPTION OF CHANGE: Heat conduction advancement routine modified to assume fluid temperatures are unknown.

2. TITLE OF CHANGE: Add border banded matrix solver as possible replacement for sparse matrix solver.

PROBLEM STATEMENT OR OTHER REASON FOR CHANGE: New matrix solver is expected to be faster than currently used sparse matrix solver, especially on machines allowing vector processing and parallel processing.

DESCRIPTION OF CHANGE: Subroutines are being added to ease future testing. Coding is not being added in this update to connect to the new routines.

3. TITLE OF CHANGE: Direct heating and water packer modifications.

PROBLEM STATEMENT OR OTHER REASON FOR CHANGE: In running an AP600 PRHR separate effects problem, it was found that the direct heating term was too large when the gas was subcooled. Also, it was found that the water packing modifier (1.0e6) was too large at low pressures.

DESCRIPTION OF CHANGE: In comdecks voldat and voldatc, add the variable hgf (direct heating heat transfer coefficient), and in subroutines phantv, vexplt, and vimplt, set and use hgf = 1.0e4 for the direct heating heat transfer coefficient. In subroutine packer, begin ramping down the water packer modifier (1.0e6) at 1,500 psia (10.3421356e6 Pa) to a lowest value of 1.0e4 at 1,250 psia (8.6184463e6 Pa).

4. TITLE OF CHANGE: Heat transfer smoothing.

PROBLEM STATEMENT OR OTHER REASON FOR CHANGE: (1) The Chen F factor in prednb has a discontinuity in it as shown in the Gist b07 input deck. It can go from 1.0 at zero liquid flux to a giant number with a little liquid flux. (2) The same input deck showed that htrc1 did not let a surface go into dryout cooling when $t_w < t_{sat} + 1.0$. (3) In dittus the code used a vertical natural convection correlation even in horizontal flow. (4) For vertical bodies three natural convection correlations were used and they had discontinuities at junctions. (5) For thin channels ORNL wanted the Petukhov correlation in place of Dittus-Boelter for liquid forced convection but this made a discontinuity when boiling began because Chen boiling uses Dittus-Boelter. (6) Dittus did not allow natural convection below a Reynolds number of 1.e6 which could cause discontinuities. (7) The natural convection correlations use hydraulic diameter instead of length. (8) During a transition from some liquid to no liquid in a cell the correlation used is changed and a glitch occurs. (9) There was no natural convection correlation for flow between parallel plates. (10) In an almost all-air Gist run, the gas was heating up even though it was hotter than the wall and no compression was occurring. (11) The equilibrium quality was not one when the void fraction was one in a Gist cell.

DESCRIPTION OF CHANGE: (1) Make the minimum flux be 0.1 in htcond. (2) In htrc1 take out the t_w requirement for DNB. (3) Use Incropera & DeWitt p. 506 equation 932 for horizontal. (4) Use Churchill-Chu from Incropera & DeWitt p. 501 equation 926. (5) Use Petukhov in prednb for thin channels. (6) Remove the restriction. (7) Use the length from the 801 and 901 cards. These cards will be updated later to add a new length for natural convection. (8) Have the gas and liquid natural convection correlation be the same. (9) The Elenbaas correlation was added. See Incropera & DeWitt p. 514 equation 939. (10) Change dittus and htrc1 so they work together in this case. The htc partitioning is done in htrc1 and the driving potential is t_w - t_g. (11) Change the definition of quale in ivlvel and vlvela to only consider the steam in the gas enthalpy. That is do not include the air.

CODE VERSION BEING CHANGED: rbc3.1.8y

CODE VERSION BEING CREATED: rbc3.1.8z

1. TITLE OF CHANGE: Correct gap conductance error, get storage for new matrix solver, continue changes for advancing heat conduction with hydrodynamics

PROBLEM STATEMENT OR OTHER REASON FOR CHANGE: (1) Problem failed in gap conductance subroutine. (2) Tsetsl needed to be modified to obtain storage and pointers for new matrix solver. (3) Work has been in progress in improving partial-implicit coupling between heat conduction and hydrodynamics, and changes are continuing.

DESCRIPTION OF CHANGE: (1) Temporary storage used in madata was not the same storage used in gapcon to retrieve the data. Fixed by using mnemonic names which are more secure against other programming changes. (2) Tsetsl was modified to allocate storage and to set up pointers for new matrix routine. (3) Changes for implicit coupling of heat conduction and hydrodynamics continued, but coding should be protected by chngno(33) tests. Program version number changed.

2. TITLE OF CHANGE: Take qffo calculation out of htrc1 for mode 0, 1, 2.

PROBLEM STATEMENT OR OTHER REASON FOR CHANGE: When the fully-implicit calculation is operational it needs qffo, qfgo, htcg, and htcf to be in dittus all the time.

DESCRIPTION OF CHANGE: These four variables were moved from htrc1 to dittus. Htrcom was changed to add ratio and ratio1 to it so they would be in both dittus and htrc1.

3. TITLE OF CHANGE: Have htrc1 save CPU time based on $t_w > t_{sat} (P_{tot})$.

PROBLEM STATEMENT OR OTHER REASON FOR CHANGE: Htrc1 skips to prednb in two places based on t_w relative to t_{sat} based on partial pressure. For boiling it should be based on total pressure.

DESCRIPTION OF CHANGE: Change the wall superheat criteria to include saturation temperature based on total pressure.

4. TITLE OF CHANGE: Add htcg to conden.

PROBLEM STATEMENT OR OTHER REASON FOR CHANGE: Conden was not calculating htcg in one path. In another path it should have been calculating it from qfgo.

DESCRIPTION OF CHANGE: Replace one line and add one line.

5. TITLE OF CHANGE: Water packer and eccmixer fixes.

PROBLEM STATEMENT OR OTHER REASON FOR CHANGE: (1) In running an AP600 PRHR separate effects problem, it was found that the water packer logic was not working properly during the check for bad donoring after a water pack. (2) A RELAP5 Newsletter member found that the eccmixer volume flow regime was not printed or plotted correctly in MOD3.1. It was correct in earlier versions.

DESCRIPTION OF CHANGE: (1) In comdecks jundatc and voldatc, add comments for water packer junction flag (jcex, bit 17), water packer volume flag (imap, bit 31), and update missing comments for other bits in jcex and imap. In subroutines packer and vfinl, set water packer flags and use the donors from the packed volume for the case that bad donoring occurs after water packing. (2) In subroutine phantv, fix the logic so that the eccmix flow regime is properly printed and plotted.

6. TITLE OF CHANGE: Remove discontinuity in Unal's correlation.

PROBLEM STATEMENT OR OTHER REASON FOR CHANGE: A Newsletter member reported a discontinuity in Unal's subcooled flow boiling correlation at a pressure of 1 MPa.

DESCRIPTION OF CHANGE: A journal article was submitted and published (Nuclear Technology, June 1993) that modified Unal's correlation (with the approval of Unal) to use a pressure of 1.1272 MPa for the switch between the two parts of the correlation. In subroutine hifbub, use 1.1272 MPa rather than 1 MPa for the switch between the two parts of the correlation, and change the appropriate comment cards. In subroutine eccmxv, change the appropriate comment cards. In subroutine eccmxj, remove an unneeded external statement.

7. TITLE OF CHANGE: Correct various code errors as defined below.

PROBLEM STATEMENT OR OTHER REASON FOR CHANGE: Correct errors uncovered in running accelerated Surry problem.

DESCRIPTION OF CHANGE: Delete debug printout. Put in patch to bypass floating exception that occurs in majout when running accelerated Surry problem on first time step of restart from steady-state run in which only one time step is done in steady-state run. The patch bypasses calculation of wall friction factors, which are calculated only for purpose of printout. One of the variables is undefined in calculating wall friction, possibly due to a bad index.

CODE VERSION BEING CHANGED: rbc3.1.8z

CODE VERSION BEING CREATED: rbc3.1.8aa

1. TITLE OF CHANGE: Fix of restart when adding nearly-implicit option, continued coding for simultaneous advancement of heat conduction and hydrodynamics, change of coding to bypass calculation of heat conduction quantities during a repeat of a time step, fix of abort during debug printout, and continued addition of new matrix solvers.

PROBLEM STATEMENT OR OTHER REASON FOR CHANGE: (1) Problem failed when restarting with a nearly-implicit option and original problem did not specify nearly-implicit advancement. (2) Continued addition of simultaneous advancement of heat conduction and hydrodynamics. Additions include part of coding to include saturation temperature as a function of total pressure to implicit terms. (3) Changes in RELAP5 gap conductance and rupture models should allow calls to heat conduction thermal properties subroutines not to be repeated during a repeat of a time step. Changes in htcond can allow calls to heat transfer correlations to be skipped during a repeat of a time step. (4) Debug printout in vexplt caused abort on some machines. (5) Continued coding to test new sparse matrix routines.

DESCRIPTION OF CHANGE: (1) Fixed detection logic in tsetsl that determines that storage layout must be redone due to nearly-implicit option being added. (2) Added two new variables of voldat for new saturation temperature. Coding completed for the effects of the liquid temperature, vapor temperature, and saturation temperature corresponding to partial pressure except for final heat transfer rates used for editing only. (3) Changes to ht1tdp, ht1sst, cplexp, and htcond were made to allow skipping of calls to material property and heat transfer correlation subroutines during a repeat of a time step. The elimination of the repeat has not been done in these changes. (4) Added coding to zero out unused noncondensable variables in debug print logic. Error was caused in a previous update where only variables needed are zeroed out in regular advancement coding. (5) Coding was modified in tsetsl to handle new matrix routines. New routines are still being tested. Program version number changed.

2. TITLE OF CHANGE: Correct problem with dittus smoothing.

PROBLEM STATEMENT OR OTHER REASON FOR CHANGE: Ratiox was initialized when dittus was called from other than htrc1.

DESCRIPTION OF CHANGE: The variables ratiox and ratiol were changed to alpf10 and alpg10 and alpf10 was set to -1.0 in htrc1 as a flag. Then in dittus alpf10 is tested before use.

CODE VERSION BEING CHANGED: rbc3.1.8aa

CODE VERSION BEING CREATED: rbc3.1.8ab

1. TITLE OF CHANGE: Increase fast common size for very large problems, coding additions for simultaneous advancement of heat conduction and hydrodynamics continued, coding for iterative solver added, and restart error when switching to nearly-implicit option fixed.

PROBLEM STATEMENT OR OTHER REASON FOR CHANGE: (1) Very large AP600 problems needed more storage. (2) Existing coding for simultaneous advancement of heat conduction and hydrodynamics had to be changed on account of new use of saturation temperature corresponding to total pressure. (3) The benefits of using iterative solver for hydrodynamics needs testing for AP600 work and future funded work. (4) Restart failed when restarting from deck without nearly-implicit advancement to a run with it.

DESCRIPTION OF CHANGE: (1) Common fast was increased to 2,000,000 words. (2) Coding nearing completion. Changes still needed in heat transfer correlation subroutines for use of saturation pressure corresponding to total pressure. Derivatives of heat transfer correlations with respect to surface and sink temperatures still needed. (3) Generalized minimum residual iterative solver added as option to code. Semi-implicit advancement ran with typpwr; nearly-implicit still needs work. (4) Test determining when to redo storage allocation for sparse matrix was fixed. Program version number was changed.

2. TITLE OF CHANGE: Add border banded matrix solver.

PROBLEM STATEMENT OR OTHER REASON FOR CHANGE: Larger problems require better matrix solvers.

DESCRIPTION OF CHANGE: Border banded matrix solver added as possible replacement for current sparse matrix routines.

3. TITLE OF CHANGE: Diagnostic edit fixes and remove unused variables.

PROBLEM STATEMENT OR OTHER REASON FOR CHANGE: In debugging problems, it was noticed that labels for the diagnostic edits were out of place and that there were some unused junction block variables.

DESCRIPTION OF CHANGE: In subroutines jchoke, phantv, preseq, statep, vimplt, vlvela, and volvel, fix labels for diagnostic edits. In comdecks jundat and jundatc as well as subroutines ijprop, jchoke, and mover, remove the unused junction block variables ftgj, ftgjo, ftfj. ftfjo, qualj, and qualjo.

CODE VERSION BEING CHANGED: rbc3.1.8ab

CODE VERSION BEING CREATED: rbc3.1.8ac

1. TITLE OF CHANGE: Add additional matrix solvers, reduce run time by removing some inp9 calls, and fix majout abort.

PROBLEM STATEMENT OR OTHER REASON FOR CHANGE: Add to and correct coding so that developers can test three matrix solvers to perhaps replace current sparse matrix routines. Large input processing times were observed for the large AP600 deck. Users reported aborts in majout.

DESCRIPTION OF CHANGE: $if def protection was placed at usage of new variables in RELAP5 coding. Code now contains coding for a border banded matrix solver, a generalized maximum residual iterative solver, and a alternating direction relaxation solver. Chngno input is needed to access the new solvers. Several calls to inp9 which removes used input data from the list were eliminated saving 100 seconds from run. Use of fwalf and fwalg as scratch variables in ielvtn was eliminated and these variables are now initialized to 0.0 during input processing. This should eliminate the abort in majout. Program version number was changed.

2. TITLE OF CHANGE: Add properties before call dittus.

PROBLEM STATEMENT OR OTHER REASON FOR CHANGE: rho was not being set prior to the dittus call in prednb and beta and cps were not being set in pstdnb. It is not certain that problems were being caused by this oversight so this change is strictly preventive.

DESCRIPTION OF CHANGE: Set these variables.

CODE VERSION BEING CHANGED: rbc3.1.8ac

CODE VERSION BEING CREATED: rbc3.1.8ad

1. TITLE OF CHANGE: Change simultaneous advancement of heat conduction and hydrodynamics to use four fluid temperatures, allow nearly-implicit advancement to use general minimum residual iterative scheme, fix accumulator to avoid abort during debug printout, and fix tabular feedback in kinetics.

PROBLEM STATEMENT OR OTHER REASON FOR CHANGE: (1) Heat transfer correlations were changed to use the saturation temperature corresponding to total pressure in addition to the previously used liquid temperature, vapor temperature, and saturation temperature corresponding to partial pressure. This change required changes in the coding for the partially-implicit and completely-implicit advancement of the heat conduction and hydrodynamics. (2) The generalized minimum residual iterative scheme seems to work with large problems using semi-implicit advancement and is faster than the original sparse matrix routines. This techniques needs to be tested on the nearly-implicit advancement technique. (3) Code aborted during debug printout due to attempted printout of uninitialized spherical accumulator variables.

DESCRIPTION OF CHANGE: (1) Changes were made to the heat transfer correlation subroutines, heat conduction advancement, heat conduction interface coding, and some hydrodynamic routines to use four fluid temperatures instead of the previous three temperatures. This should complete the coding for the partial- and complete-implicit advancement of the heat conduction and hydrodynamics. (2) The subroutines vimplt and simplt were modified to use the iterative scheme as well as the original sparse matrix routines. The iterative solver seems to work for problems such as edhtrk and typpwr, but fails on AP600. Several problems were fixed in handling crossflow. (3) The accumulator debug printout was fixed by initializing the quantities in the input routine. Program version number was changed.

CODE VERSION BEING CHANGED: rbc3.1.8ad

CODE VERSION BEING CREATED: rbc3.1.8ae

1. TITLE OF CHANGE: Add experimental coding to limit state property extrapolation, correct error in statep, bring change comment to current code.

PROBLEM STATEMENT OR OTHER REASON FOR CHANGE: Code fails too frequently with extrapolation error when computing metastable conditions. Statep error was encountered when water property error was encountered and quality value was then not a valid number.

DESCRIPTION OF CHANGE: Code has a 50 K limit on the amount that the state routines can extrapolate into the metastable region from saturation conditions. Using Option 36, the code will only extrapolate temperature and specific volume conditions to 50 K but will not set extrapolation error flag. Valid quantity was set prior to state property call so valid quantity was available even if state call did not complete properly. Listing of change options was not up to date. Subroutine rchng was updated to list current active change options. Program version number was changed.

2. TITLE OF CHANGE: Correct one point in CHF table.

PROBLEM STATEMENT OR OTHER REASON FOR CHANGE: A CAMP user found a typo in chfcal which made the value high by a factor of 10. This was a point at P = .2 MPa, G = 10, x = .3. Because of the low pressure and low flow it should not have been a problem for most RELAP5 users.

DESCRIPTION OF CHANGE: Move the decimal point.

3. TITLE OF CHANGE: Option 14 (no constitutive relations) for two-step.

PROBLEM STATEMENT OR OTHER REASON FOR CHANGE: A user was running the water faucet problem on both the semi-implicit and nearly-implicit (two-step) schemes and noticed that the semi-implicit scheme gave the correct results whereas the nearly-implicit scheme did not.

DESCRIPTION OF CHANGE: In subroutine vimplt, add coding to turn off the constitutive relations if change option 14 is invoked on Card 1.

4. TITLE OF CHANGE: RELAP5 code coupling model.

PROBLEM STATEMENT OR OTHER REASON FOR CHANGE: This feature was designed in support of the NRC's ALWR program. Specifically, it allows another code to be linked with RELAP5/MOD3. The primary mission for this task was to link the containment analysis code CONTAIN.

DESCRIPTION OF CHANGE: Changes to main body of the RELAP5 code are minimal. That is, calls to new functions provide the bulk of the new coding. Additionally, to use this feature, new object libraries need to be linked with the existing code. These new libraries are the PVM functions needed for any code coupling.

5. TITLE OF CHANGE: Volume storage for level tracking model.

PROBLEM STATEMENT OR OTHER REASON FOR CHANGE: Implementation of level tracking model in RELAP5.

DESCRIPTION OF CHANGE: Set up volume-variable storage for level tracking model.

CODE VERSION BEING CHANGED: rbc3.1.8ae

CODE VERSION BEING CREATED: rbc3.1.8af

1. TITLE OF CHANGE: Wall flashing and condensing made more implicit, repeated computations in hydrodynamics eliminated, correction to spherical accumulator, failure to recover from input error corrected.

PROBLEM STATEMENT OR OTHER REASON FOR CHANGE: Semi-implicit advancement scheme under certain circumstances modifies wall flashing or condensing values as void fraction approaches limit of 0.0 or 1.0. Improved running may be obtained by making the wall flashing and condensing more implicit. Terms involving void fractions and densities were repeatedly being computed. Accumulator failed when trip was used. User reported code abort following user input error.

DESCRIPTION OF CHANGE: The recent changes to improve the partial-implicit coupling of heat conduction with hydrodynamics and the addition of fully-implicit coupling of heat conduction and hydrodynamics was extended to include wall flashing and condensing. When activated, the previous modification of the wall flashing and condensing is bypassed. A previously entered modification to the matrix factoring had to be removed because the matrix element a23 has more terms and the change is no longer valid. This change has been completed only for semi-implicit. Changes for nearly-implicit will be entered in next update. Void fraction-density and void fraction-density-internal energy products were computed and stored in statep. Other routines were modified to use these stored products rather than recompute them. Recent accumulator changes that modified accumulator storage block overwrote trip pointer. Storage equivalencing was corrected. Coding in ivelst was changed to properly handle incorrect user input. Program version number was changed.

2. TITLE OF CHANGE: RELAP5 code coupling model updates.

PROBLEM STATEMENT OR OTHER REASON FOR CHANGE: These modifications redefine the strategy for communication between two codes.

DESCRIPTION OF CHANGE: Information is now exchanged on the first time step and a separate communication frequency for how often the child process communicates with RELAP5/MOD3 has been removed. Other minor fixes are included.

3. TITLE OF CHANGE: GE separator and dryer models.

PROBLEM STATEMENT OR OTHER REASON FOR CHANGE: A mechanistic GE separator model, a GE dryer model, and combination separator-dryer models are being added as options with the current RELAP5 separator model retained as the default.

DESCRIPTION OF CHANGE: (1) separ.H modified to add additional parameters necessary to describe new models. (2) rbrnch.F modified to add space to fa and ia to hold the new parameters. (3) rbrnch.F temporarily modified to set values for the new variables. This will be changed once cards are found and checking routines written for user-defined parameters. (4) jprop.F now calls a separator subroutine. (5) Appropriate subroutines added which contain separator and/or dryer models. (6) mlist has an additional entry isepst for workstations.

4. TITLE OF CHANGE: Mixture level tracking model.

PROBLEM STATEMENT OR OTHER REASON FOR CHANGE: Implementation of mixture level tracking model in RELAP5.

DESCRIPTION OF CHANGE: Mixture level tracking model is implemented as an option.

5. TITLE OF CHANGE: BPLU modification.

PROBLEM STATEMENT OR OTHER REASON FOR CHANGE: The BPLU solver does not run on any platform because incompatible versions of some routines were installed simultaneously.

DESCRIPTION OF CHANGE: This set of changes allows the BPLU solver to run, both on the Cray and on DECstation5000. There is no claim of optimal performance on any platform; some previous optimization work has been left out to get this to run.

CODE VERSION BEING CHANGED: rbc3.1.8af

CODE VERSION BEING CREATED: rbc3.1.8ag

1. TITLE OF CHANGE: Complete simultaneous advancement of heat conduction and hydrodynamics, modified matrix subroutine for faster execution, eliminated most goto's in phantv.

PROBLEM STATEMENT OR OTHER REASON FOR CHANGE: (1) Installation of simultaneous advancement of heat conduction and hydrodynamics has been ongoing for the last several updates. Change should allow larger time steps, especially in the later stages of long term transients, and more robust execution. (2) Subroutine lusol0 was observed to require 11% of the run time of a large problem when the generalized residual iterative method was used to solve the hydrodynamics equations. (3) Phantv requires a large fraction of compute time and also needs to have derivative information added to the coding.

DESCRIPTION OF CHANGE: (1) Corrections consist of hopefully the final changes as determined by testing. Some coding changes for increased efficiency can probably be made in preseq and vimplt. Change option controlling the option was removed and specifying bit 4 on the time step control now selects the fully implicit coupling between heat conduction and hydrodynamics. This bit used to specify partial-implicit coupling. The bit also causes an implicit computation of the mass transferred between phases due to wall heat transfer in place of the explicit computation and also separates wall flashing from wall condensation. The separation is needed to eliminate an error when some wall surfaces attached to a volume were flashing and others were condensing. (2) Subroutine lusol0 which obtains a solution from a factored matrix and a right-hand side was modified by unrolling the innermost do loops. (3) This change eliminates most of the goto's so that reading and modifying the code is easier.

2. TITLE OF CHANGE: Base rey on diamv, add hlam parallel plates.

PROBLEM STATEMENT OR OTHER REASON FOR CHANGE: A laminar correlation for rectangular channels is not in the code. The diameter in Reynolds numbers used in heat transfer correlations is heated diameter. Petukov correlation uses heated diameter in the Nusselt number. The viscosity in the Petukov correlation uses T_{wall} as a reference temperature. The heated diameter was being used in the horizontal natural convection correlation.

DESCRIPTION OF CHANGE: A laminar correlation for rectangular channels is added. This is active when users set htopa to 2. At ORNL's request the hydraulic diameter is also used in the Petukov correlation. The viscosity in the Petukov correlation is set to use a reference temperature of the minimum t_{wall} and t_{sat} instead of t_{wall}. In the horizontal natural convection correlation the length term was changed to be the forward or reverse length.

3. TITLE OF CHANGE: Condensation model based on the Colburn and Hougen stagnant film theory.

PROBLEM STATEMENT OR OTHER REASON FOR CHANGE: Implementation of a set of correlations for wall condensation with noncondensable gases as an option for users to improve RELAP5's capability in condensation calculation.

DESCRIPTION OF CHANGE: The correlations are: (1) laminar-Nusselt. (2) turbulent-Shah, (3) noncondensable-Colburn-Hougen

4. TITLE OF CHANGE: Fix output, fix grid spacer input.

PROBLEM STATEMENT OR OTHER REASON FOR CHANGE: Erroneous output.

DESCRIPTION OF CHANGE:

5. TITLE OF CHANGE: Correct undefined variables.

PROBLEM STATEMENT OR OTHER REASON FOR CHANGE: Compiler detects variable use before definition. In some cases this is just poor flow control.

DESCRIPTION OF CHANGE: Corrected undefined variables.

CODE VERSION BEING CHANGED: rbc3.1.8ag

CODE VERSION BEING CREATED: rbc3.1.8ah

1. TITLE OF CHANGE: Add/correct inverse donoring for special components for nearly-implicit advancement, add first coding for void dependence of h_{if} and h_{ig}, fix new separator model, correct compile errors when compile options are removed, and fix argument mismatch between userp and zuint.

PROBLEM STATEMENT OR OTHER REASON FOR CHANGE: (1) The nearly-implicit advancement uses an inverse donoring step during the second phase of the advancement. Many of the special components that do not use standard donoring did not provide for the proper inverse donoring. (2) The h_{if} and h_{ig} quantities are being made more implicit in void fraction in an attempt to achieve more robust execution. (3) The new separator models had compile warning messages. (4) Compile errors occurred when some compile time options were removed.

DESCRIPTION OF CHANGE: (1) For all components the inverse donoring is done by defining the ratio of the junction void fraction to the donored volume void fraction. This ratio is used in simplt to handle the inverse donoring. This assumes that only the void fraction is changed when standard donoring is not used. Instances of qualaj and qualnj not being the standard donored quantities were removed. (2) The h_{if} and h_{ig} quantities are being made implicit in void fraction by using the two term Taylor series in void fraction. The void fraction derivatives of h_{if} and h_{ig} are approximated from the change in h_{if} and h_{ig} during the last time step divided by the change is void fraction. All underrelaxation and the modification of h_{if} and h_{ig} to avoid overrunning quality limits are disabled when this option is used. This option is controlled by chngno(26). (3) Unneeded coding in the separator model was removed. (4) Small errors in protecting compile time coding were fixed.

2. TITLE OF CHANGE: Modification of time step control.

PROBLEM STATEMENT OR OTHER REASON FOR CHANGE: Improvement of RELAP5 run time.

DESCRIPTION OF CHANGE: A new algorithm for time step control is implemented as an option in RELAP5/MOD3 to make the program run faster. This new algorithm removes the restriction that the program will not double the time step if the doubled time step is greater than the Courant limit. The new algorithm will run at the Courant limit if the increasing time step exceeds the Courant limit. An option is also added to change the multiplication from 2 to 4 and reduction factor from 0.5 to 0.25 used in mass error check for time step control.

CODE VERSION BEING CHANGED: rbc3.1.8ah

CODE VERSION BEING CREATED: rbc3.1.8ai

1. TITLE OF CHANGE: Add natural circulation lengths and fouling factors for heat structures, fix unaligned word, remove several NRC compile protection options.

PROBLEM STATEMENT OR OTHER REASON FOR CHANGE: (1) Natural circulation channel length and fouling factor data are additional data needed for heat structures. (2) Last update had an unaligned floating point word in a common block. (3) Several NRC related compilation define variables can now be removed.

DESCRIPTION OF CHANGE: (1) Add channel length and fouling factor variables to htsrcm dynamic block and associated comments block. Add coding to read the additional data. Coding to include friction factor has been added to steady-state and transient coding. Coding for using additional channel length data will be added later. (2) Added dummy integer to make number of integers preceding unaligned word an even number of integer words. (3) NRC-related define variables including boront, frifac, level, sphacc, and ondimk were removed. (4) Protection was placed on new the direct solver, the GMRES iterative solver, and the associated coding that sets up and call the routines. Change program version number.

2. TITLE OF CHANGE: BPLU improvements.

PROBLEM STATEMENT OR OTHER REASON FOR CHANGE: Improvement RELAP5 solver run-speed on workstations and Cray.

DESCRIPTION OF CHANGE: Modifications to the factorization and back substitution routines for performance enhancement on both scalar and vector platforms. Supporting modifications made to the RELAP5 calling routines tsetsl and vfinl.

3. TITLE OF CHANGE: Make SRL wall friction model default model.

PROBLEM STATEMENT OR OTHER REASON FOR CHANGE: The USNRC has decided that the improved wall friction model added to RELAP5 as part of the code improvement work funded by SRL should be the default wall friction model.

DESCRIPTION OF CHANGE: This update modifies the coding for change option 22 so that the new model is the default model and the old model can be activated by change option 22 rather than the other way around as in previous versions of the code. It also removes compile time define "frifac" making the new model a permanent part of the code source. It also fixes an error in setting the power for the conduction solution in routine ht2tdp.

4. TITLE OF CHANGE: Add input processing for new separator models.

PROBLEM STATEMENT OR OTHER REASON FOR CHANGE: The implementation of the GE separator and dryer model from the TRAC-BWR code did not provide any way for the user to activate the new models through user input.

DESCRIPTION OF CHANGE: This update modifies the input processor for the separator component to read a new card which specifies the separator option. It also makes some login changes to help prevent removal of too much of the minor phase through the junctions whose void fraction has been modified by the separator and dryer models.

5. TITLE OF CHANGE: Remove common variable tsat.

PROBLEM STATEMENT OR OTHER REASON FOR CHANGE: The variable tsat, stored in common htrcom had been removed in most places, but was still in the common htrcom and used in several routines. It was not initialized and caused a fatal run error when using ORNL ANS model.

DESCRIPTION OF CHANGE: Replaced tsat with tsatt(iv) in several subroutines and removed tsat from common

6. TITLE OF CHANGE: (1) Correct modeling of release of gases from fuel rods to fluid. (2) Correct error in gap conductance model for RELAP5 heat structure. (3) Correct new style input processing error for view factor calculations. (4) Correct output errors. (5) Correct resistance in electrical heater rod model.

PROBLEM STATEMENT ORREASON FOR CHANGE: The simultaneous release of all the fill gas and fission gases in thousands of fuel rods at the same split second leads to water property failures in RELAP5.

DESCRIPTION OF CHANGE: An error was corrected in the gap conductance model for RELAP5 heat structures. The error caused a discontinuity in the calculated gap conductance with respect to increase in temperature of the fuel in the rod.

CODE VERSION BEING CHANGED: rbc3.1.8ai

CODE VERSION BEING CREATED: rbc3.1.8aj

1. TITLE OF CHANGE: Fix miscellaneous small changes found in testing for production version and removing many compile options.

PROBLEM STATEMENT OR OTHER REASON FOR CHANGE: (1) Error was introduced in changes to enter natural circulation channel lengths and fouling factors. (2) Errors were found in reactor kinetics input routines when removing some compile options.

DESCRIPTION OF CHANGE: (1) Dimensioning error in rhtcmp was fixed. (2) Proper ranges for compile time directives were entered. Program version number was changed.

CODE VERSION BEING CHANGED: rbc3.1.8aj

CODE VERSION BEING CREATED: rbc3.1.1

1. TITLE OF CHANGE: Clean up miscellaneous errors found in testing for production version.

PROBLEM STATEMENT OR OTHER REASON FOR CHANGE: Default friction model used heated wall effect; desired default model to require input to obtain heated wall effect. Border banded matrix solver needed added to nearly-implicit advancement.

DESCRIPTION OF CHANGE: Default input for friction now specifies improved model for Colbrook relation but does not specify heated wall effect. Corrections made to friction and heated wall calculation. Additions made to allow border banded matrix solver to be used with nearly-implicit advancement. Program version number was changed.

CODE VERSION BEING CHANGED: rbc3.1.1

CODE VERSION BEING CREATED: rbc3.1.8ba

1. TITLE OF CHANGE: Fix border banded solver.

PROBLEM STATEMENT OR OTHER REASON FOR CHANGE: Corrections to border banded matrix solver to allow application to nearly-implicit advancement involved changes which were not added to semi-implicit advancement, leading to failures in semi-implicit advancement.

2. TITLE OF CHANGE: Make separator more robust.

PROBLEM STATEMENT OR OTHER REASON FOR CHANGE: The separator subroutine as written by GE did not always converge to a solution because the search interval for the root was too coarse. The routine also failed to recognize that one of the two functions could change sign and become negative causing the error to increase after initially decreasing.

DESCRIPTION OF CHANGE: This update modifies the GE routine to recognize that the error may increase after initially increasing and refine the search interval to find the initial guess for the root. The carryover and carryunder qualities are added as minor edit variables so that the user can see what the separator model is doing.

CODE VERSION BEING CHANGED: rbc3.1.8ba

CODE VERSION BEING CREATED: rbc3.1.8bb

1. TITLE OF CHANGE: Remove redundant coding in vimplt-pimplt, continue elimination of goto's in phantj, fix logic in positioning thermodynamic tables, and add vollev variable to scnreq.

PROBLEM STATEMENT OR OTHER REASON FOR CHANGE: (1) Redundant coding exists in vimplt and pimplt. (2) Elimination of goto logic in phantj will ease maintenance and is the first step towards possible vectorization. (3) Error was encountered during restart. Error involved moving thermodynamic tables and not resetting flag that kept track of to which fluid pointer was set. (4) Volume variable for level position within volume needed added to scnreq.

DESCRIPTION OF CHANGE: (1) Redundant coding removed by using scratch space to store quantities the first time they are needed and using the saved variables in other routines as needed. This step also aids vectorization. (2) Goto's are being replaced with if-then-else logic and sometimes new logical variables are introduced. (3) Fluid pointer was set to null any time storage that was moved. (4) Volume variable vollev was added to scnreq. Program version number was changed.

2. TITLE OF CHANGE: Resubmit vfinl water packer fix.

PROBLEM STATEMENT OR OTHER REASON FOR CHANGE: Updates selp8y to make selp8z contained updates to subroutines packer and vfinl, which set water packer flags and use the donors from the packed volume for the case that bad donoring occurs after water packing. This was submitted for inclusion in selp8z, but only the updates to subroutine packer are in selp8ba; the updates to subroutine vfinl are not in selp8ba.

DESCRIPTION OF CHANGE: In subroutine vfinl, use the donors from the packed volume for the case that bad donoring occurs after water packing.

CODE VERSION BEING CHANGED: rbc3.1.8bb

CODE VERSION BEING CREATED: rbc3.1.8bc

1. TITLE OF CHANGE: Add vectorization to some loops in vimplt.

PROBLEM STATEMENT OR OTHER REASON FOR CHANGE: Volume loops in vimplt were modified to enhance vectorization.

DESCRIPTION OF CHANGE: Errors were corrected in r3dcmp, volvel, and vimplt.

2. TITLE OF CHANGE: Noncondensable reduction of h_{if} from literature.

PROBLEM STATEMENT OR OTHER REASON FOR CHANGE: The reduction of the liquid interphase heat transfer coefficient (h_{if}) is currently based on a non-literature-based factor.

DESCRIPTION OF CHANGE: In subroutine phantv, use the Vierow-Schrock (UCB) reduction factor on the liquid interphase heat transfer coefficient as is done on the wall condensation heat transfer.

CODE VERSION BEING CHANGED: rbc3.1.8bc

CODE VERSION BEING CREATED: rbc3.1.8bd

1. TITLE OF CHANGE: Start vectorization of momentum equation coding in vimplt, clean up some majout coding, bypass viscosity subroutine calls in fwdrag when not needed.

PROBLEM STATEMENT OR OTHER REASON FOR CHANGE: Momentum equations can be vectorized. Goto logic that could be easily converted to if-then-endif logic was noticed when reading majout code looking for reflood error. Code ran more slowly when new friction model was made the standard option.

DESCRIPTION OF CHANGE: First pass at vectorizing momentum equations in vimplt was completed. If-then-else coding replaced goto logic in some printout associated with heat structure and reflood printout. New friction model includes a heated wall model which requires two additional calls to the viscosity routines. These quantities are essentially ignored when an input quantity is zero. Since this input quantity is usually zero, coding was entered to bypass the viscosity calls in this case. This is probably one of the reasons a user reported the most recently released version of the code is slower than previously released versions. Program version number was updated.

2. TITLE OF CHANGE: Fixes divides by zero in ijprop and jprop.

PROBLEM STATEMENT OR OTHER REASON FOR CHANGE: An NRC user reported that a ROSA deck that had run on Versions 80 and 3.1 now fails in input processing in subroutine ijprop in Version 3.1.1. Also, in running an AP600 CMT tank problem, the code now fails in subroutine jprop.

DESCRIPTION OF CHANGE: In subroutines ijprop and jprop, fix divides by zero by skipping around sections of coding when the volume fraction is single-phase as is currently done for the separator model in subroutine jprop.

CODE VERSION BEING CHANGED: rbc3.1.8bd

CODE VERSION BEING CREATED: rbc3.1.8be

1. TITLE OF CHANGE: Extend vectorization of nearly-implicit subroutines, move calls to new matrix solution subroutines to be more modular.

PROBLEM STATEMENT OR OTHER REASON FOR CHANGE: (1) Vectorization of heavily used subroutines are needed as part of task of increased run time performance. (2) Call to the subroutines for the sparse matrix routines, the border banded routines, and the generalized minimum residual iterative scheme were not implemented in a similar fashion, leading to more difficult maintenance of the code.

DESCRIPTION OF CHANGE: (1) Vectorization should be nearly complete for pimplt, vimplt, and simplt. This makes the extent of vectorization for the nearly-implicit the same as for the semi-implicit advancement. (2) Calls to all the various matrix solution routines were moved to subroutine syssol and the calls for matrix solution in subroutines pimplt, simplt, vfinl, and vimplt were changed to simply call subroutine syssol.

2. TITLE OF CHANGE: Fixes more divides by zero in jprop and stdsp.

PROBLEM STATEMENT OR OTHER REASON FOR CHANGE: In running a problem where steam bubbles up through water using the level model, a failure occurred in subroutine jprop. A divide by zero has also been reported in stdsp.

DESCRIPTION OF CHANGE: In subroutine jprop, fix divides by zero by skipping around sections of coding when the volume fraction is single-phase for the case of the level model. Also fixed stdsp in the same manner.

CODE VERSION BEING CHANGED: rbc3.1.8be

CODE VERSION BEING CREATED: rbc3.1.8bf

CODE VERSION BEING CHANGED: rbc3.1.8bf

CODE VERSION BEING CREATED: rbc3.1.8bg

1. TITLE OF CHANGE: Preliminary vectorization of phantv, level tracking secret option removed, improper call to htfinl, and errors in tsetsl corrected.

PROBLEM STATEMENT OR OTHER REASON FOR CHANGE: (1) An attempt at vectorizing phantv is being made for increased run time performance. (2) Level tracking model used 'secret' option to allow its use. (3) Subroutine htfinl (used in implicit coupling of heat conduction and hydrodynamics) was called incorrectly when no heat structures were present.

DESCRIPTION OF CHANGE: (1) Changes were made to phantv, fidis, and hifbub to add vectorization. Only the first initializing loop and the smoothing coding at the end of the routine were vectorized. (2) "Secret' option control and any compile time control on the level tracking model was removed. (3) Additional test for the presence of heat structures was added to test for calling htfinl. Program version number was changed.

CODE VERSION BEING CHANGED: rbc3.1.8bg

CODE VERSION BEING CREATED: rbc3.1.8bh

1. TITLE OF CHANGE: Add alternate set of variables to reactor kinetics tabular feedback, add more vector directives to phantv.

PROBLEM STATEMENT OR OTHER REASON FOR CHANGE: (1) The tabular feedback used in point reactor kinetics used moderator density, moderator temperature, fuel temperature, and boron density as input variables. A more user-convenient set, especially considering how the input data is obtained from vendors and utilities, is void fraction, liquid moderator density, fuel temperature, and boron concentration. This set has been added as a user-selectable set of variables. (2) Examination of Cray compilation listing showed some loops that were modified/added to vectorize did not vectorize. (3) Restart problems have been reported.

DESCRIPTION OF CHANGE: (1) The new set of variables has been added as a user-selectable set of variables. (2) Compiler directives were added to enable vectorization. (3) One restart problem has been fixed. When restarting a problem when using the BPLU solver. Program version number changed.

2. TITLE OF CHANGE: Limit continuation cards to 19.

PROBLEM STATEMENT OR OTHER REASON FOR CHANGE: SUN detects more than 19 continuation cards.

DESCRIPTION OF CHANGE: Limits cards

3. TITLE OF CHANGE: Correct common block alignment errors.

PROBLEM STATEMENT OR OTHER REASON FOR CHANGE: Code installation detects alignment errors.

DESCRIPTION OF CHANGE: Realigned common blocks.

CODE VERSION BEING CHANGED: rbc3.1.8bh

CODE VERSION BEING CREATED: rbc3.1.8bi

1. TITLE OF CHANGE: Correct friction subroutine abort when heat transfer correlation package is not used, add missing initialization to reord routine to prevent failure, subroutine hloss modified to use list vectors, use of pointers to allow stride of one started, indexing error in subroutine pimplt fixed, add underflow protection to exp call, fix print loop when sparse matrix needed new strategy, and remove unused variable tsat.

PROBLEM STATEMENT OR OTHER REASON FOR CHANGE: (1) Friction subroutine (fwdrag) aborted due to an attempted divide by zero when the heat transfer correlation package was not being used. (2) Border banded solver failed on some problems with an error message issued by subroutine reord. (3) List vectors had been provided to drive the abrupt area model subroutine (hloss), but the subroutine had not been modified to use them. (4) Volume, junction, and a hydrodynamic scratch block use dynamic storage and assign storage such that a non-unit stride is needed. (5) A user reported a failure in pimplt. (6) Code aborted in CORA-9 simulation in identical coding that appears both phantv and phantj. (7) A user and a developer reported a print loop stating sparse matrix was singular. (8) The variable tsat in common block htrcom was no longer being used but was still being set in some subroutines.

DESCRIPTION OF CHANGE: (1) Setting of default heated hydraulic diameter was not being done when user-supplied heat transfer correlation was not being used, yet heated wall friction effect (new model) requires the data. Problem was fixed by always setting defaults. (2) Integer variable that was not initialized caused the random failure; variable was properly initialized. (3) Subroutine hloss was modified to use existing list vectors. (4) Coding is being added to use the pointer statement with the result being that a unit stride can be used. This should increase performance on both vector machines and those using caches. (5) An indexing error associated with adding vectorizing code to pimplt was fixed. (6) Error is caused by calling the exponential subroutine with a large negative number. Expected result is a return of zero. This may be a problem only on the DECrisc with the new DEC compiler, but protection was added that the result is zero when the argument to the exponential function is smaller than -200. (7) Error was found in recent change merging all matrix solution techniques into subroutine syssol. Error was corrected. Program version number was changed. (8) The variable tsat was removed from the htrcom block and the statements setting it in some subroutines were removed.

2. TITLE OF CHANGE: Fixes to eccmxj, eccmxv, and phantv. Add change Option 37 to turn off the umbrella model.

PROBLEM STATEMENT OR OTHER REASON FOR CHANGE: (1) A Newsletter member reported errors in the eccmixer routines eccmxj and eccmxv. He also had questions regarding the post-CHF logic in subroutine phantv. (2) An INEL user was running as OSU calculation, and there were small amounts of void in the system that should not be there. These small amounts of void go away when the umbrella model is not used.

DESCRIPTION OF CHANGE: (1) In subroutine eccmxj, correct the calculation of the vapor Reynolds number in wavy flow and plug flow. Also, remove unused calculations in plug flow. In subroutine eccmxv, correct the calculation of the lower limit interfacial area in wavy flow and plug flow. In subroutine phantv, there was no error in the post-CHF logic in the code version A Newsletter member was examining (MOD3.1). In reading the logic in version 8bh, there was an error introduced in version 8ag. The interpolation between inverted annular- and inverted-slug was fixed for the calculation of h_{if} and h_{ig}. (2) In subroutines phantv and rchng, use change option 37 to turn off the umbrella model.

CODE VERSION BEING CHANGED: rbc3.1.8bi

CODE VERSION BEING CREATED: rbc3.1.8bj

1. TITLE OF CHANGE: Add coding protection to new models, add user-defined time step control via control system.

PROBLEM STATEMENT OR OTHER REASON FOR CHANGE: (1) Compile time protections were left off of some new NRC models, preventing release of RELAP5 corrections. (2) User-selected time steps are often needed in anticipation of some events such as valve opening/closing.

DESCRIPTION OF CHANGE: (1) Compile time protections were added (or in some cases restored) for cylindrical accumulator, level, added separators, and boron transport models. (2) Card 200 was modified to accept an optional control system number which if entered, would use the specified control variable as the maximum time step. Program version number was changed.

2. TITLE OF CHANGE: Fix default and low pressure subcooled boiling model.

PROBLEM STATEMENT OR OTHER REASON FOR CHANGE: The default and low pressure subcooled boiling model activated in a discontinuous manner in the presence of noncondensable gas causing code failures. The low pressure subcooled boiling model was also left out of subroutine pstdnb.

DESCRIPTION OF CHANGE: The liquid saturation enthalpy used in the subcooled boiling model was changed to use the total pressure rather than the partial pressure of steam. They are the same when no air is present but using the partial pressure causes the subcooled boiling model to activate discontinuously when air first appears in a volume. The low pressure subcooled boiling model changes were added to subroutine pstdnb.

3. TITLE OF CHANGE: Eccmixer and noncondensable fixes.

PROBLEM STATEMENT OR OTHER REASON FOR CHANGE: (1) In reading Volume 1 of the code manual, it was found that the Jacob number was taken to the 2/3 power twice in the interfacial heat transfer correlation for the film in annular-mist. (2) A CAMP user reported that the code did not treat the noncondensable quality consistently with the phase specific internal energies for which conservation and nonconservation derived values are sometimes mixed. He also reported that the final adjustment to the mass transfer term for noncondensable can result in a sudden large flow on the next time step as the mass transfer term is a source to the momentum equations.

DESCRIPTION OF CHANGE: (1) In subroutine eccmxv, the Jacob number is taken to the 2/3 power once. (2) In subroutine eqfinl, the treatment of the noncondensable quality is made consistent with the phase specific internal energies. In subroutines eqfinl and simplt, the final adjustment to the mass transfer term for noncondensable was removed, and both subroutines were made consistent with respect to mass transfer.

CODE VERSION BEING CHANGED: rbc3.1.8bj

CODE VERSION BEING CREATED: rbc3.1.1.1

1. TITLE OF CHANGE: Noncondensable fix to tstate and change separator coding back to earlier coding in stdsp.

PROBLEM STATEMENT OR OTHER REASON FOR CHANGE: (1) A Newsletter member reported that time-dependent volume boundary condition option 4 was correct for the time zero major edit, but that it gave the wrong state for times after time zero. (2) An INEL user reported that vapor is donored through separator fallback junction when it is not expected.

DESCRIPTION OF CHANGE: (1) In subroutine tstate, make the coding the same as subroutine istate for option 4 by removing an if test. (2) In subroutine stdsp, calculate other junction void fraction before 90% limit.

2. TITLE OF CHANGE: Fix compile time protection and fix restart.

PROBLEM STATEMENT OR OTHER REASON FOR CHANGE: (1) Compile time protection must be entered so that the code can be removed as needed for various transmittals of RELAP5. Code failed in test of transmittal to NRC after removing code. (2) Failure was reported during an attempted restart.

DESCRIPTION OF CHANGE: (1) Fixes to compile time protection are added. (2) Restart failure was traced to recent change in moving storage for scratch and memory of matrix strategy and setting list vectors. Errors fixed and some savings in dynamic space were made. Program version number was changed.

3. TITLE OF CHANGE: Fix in PVM coupling routine.

PROBLEM STATEMENT OR OTHER REASON FOR CHANGE: Currently the method of coupling Contain to RELAP through the use of PVM uses time-dependent volume(s) in RELAP and is limited to storing the contain(ment) state just as type 3 conditions (temperature and pressure). Subroutine pvmset checks on other variables, quala and quals, that are not available for type 3 condition time-dependent volumes thus causing code failures.

DESCRIPTION OF CHANGE: In subroutine pvmset, lines testing on quala or quals, were protected to see that they were not used for type 3 conditions.

4. TITLE OF CHANGE: Correct definition of pr in shah correlation.

PROBLEM STATEMENT OR OTHER REASON FOR CHANGE: Shah has two pr variables. One is Prandtl Number the other is reduced pressure. Originally reduced pressure was not used.

DESCRIPTION OF CHANGE: Change pr in the z term to be reduced pressure in conden and pintfc. In conden ptot is used and in pintfc the interfacial pressure is used.

CODE VERSION BEING CHANGED: rbc3.1.8bj

CODE VERSION BEING CREATED: rbc3.1.8bk

1. TITLE OF CHANGE: Add first phase of new type of water property subroutines, fix divide by zero in conden.

PROBLEM STATEMENT OR OTHER REASON FOR CHANGE: (1) Current water property subroutines have very complex logic and represent a sizeable portion of the run time. The complexity is due to the use of pressure and temperature as the independent variables when the most common entry is with pressure and internal energy. Use of pressure and temperature tables also leads to very complex procedures to handle the two-dimensional interpolations when the saturation line passes through the rectangle of table values. Complex logic requires computer time and cannot be effectively vectorized. (2) A user reported divide by zero failure in conden.

DESCRIPTION OF CHANGE: (1) New tables have been generated using pressure and internal energy as the independent variables. No if test logic for the saturation line is needed and subroutines can be vectorized. Viscosity, thermal-conductivity, and surface tension are now computed along with thermodynamic quantities. This is only the first phase; the capability is not operational; the coding is protected by $if def, newwatrp. (2) Possible divide by zero in conden is now better protected. Program version number was changed.

2. TITLE OF CHANGE: Noncondensable fix to tstate.

PROBLEM STATEMENT OR OTHER REASON FOR CHANGE: A Newsletter member reported that time-dependent volume boundary condition option 4 was correct for the time zero major edit, but that it gave the wrong state for times after time zero.

DESCRIPTION OF CHANGE: In subroutine tstate, make the coding the same as subroutine istate for option 4 by removing an if test.

3. TITLE OF CHANGE: PHANTJ clean-up.

PROBLEM STATEMENT OR OTHER REASON FOR CHANGE: On many machines including Crays, goto's cause inefficient compilation resulting in slower run time.

DESCRIPTION OF CHANGE: Removal of all but 2 goto's. Some algebraic transformations. Code produces same answers on Cray and DECalpha on test problems typpwr, edhtrk, AP600.

CODE VERSION BEING CHANGED: rbc3.1.8bk

CODE VERSION BEING CREATED: rbc3.1.8bl

1. TITLE OF CHANGE: Add first coding for stride 1 data base, add new water property table subroutines, add setting of imap for improved crossflow model, tab characters removed.

PROBLEM STATEMENT OR OTHER REASON FOR CHANGE: (1) Faster execution is expected if a stride of one is used when possible. (2) Current water property table lookup and interpolation cannot vectorize well, yet require considerable computer time. (3) Tab characters were found in program source and some compilers do not allow them.

DESCRIPTION OF CHANGE: (1) Scratch dynamic block was modified and volvel subroutine was modified to use stride of one. This coding is protected by compile time variable pointer and coding cannot be activated until all required subroutines have been modified. This activation is at compile time only. (2) Fluid h2on (number 12) has been added to code and the three branches normally used to call the appropriate thermodynamic property subroutines has been extended to four branches. In addition the new routines return transport properties and appropriate changes were made. Problems using the existing fluids should execute with no change in answers. Some routines that did not have tests for the proper subroutine call or did not use proper fluid dependent values for triple- and critical-points were modified to do so. (3) Tab characters were removed. Program version number was changed.

2. TITLE OF CHANGE: Change separator coding back to earlier coding in stdsp.

PROBLEM STATEMENT OR OTHER REASON FOR CHANGE: An INEL user reported that vapor is donored through separator fallback junction when it is not expected.

DESCRIPTION OF CHANGE: In subroutine stdsp, calculate other junction void fraction before 90% limit.

3. TITLE OF CHANGE: Correct errors in late phase modeling and initialization.

PROBLEM STATEMENT OR REASON FOR CHANGE: Correct errors identified and resolved while performing full plant analyses and correct initialization errors for new style input.

CODE VERSION BEING CHANGED: rbc3.1.8bl

CODE VERSION BEING CREATED: rbc3.1.8bm

1. TITLE OF CHANGE: Statement on default friction values corrected, correction of units conversion for shaft component and clean up of control system coding, equation of state error corrected, more changes to new water property routines, diagnostic message removed, error in variable use corrected, compile time option errors fixed.

PROBLEM STATEMENT OR OTHER REASON FOR CHANGE: (1) Statement of default friction values were incorrect although only the message was incorrect; intended values were used. (2) A user reported that the friction multiplier for shaft and generator components was incorrect. (3) Error was introduced in last updates in changing viscosity and thermal-conductivity for mixed gasses in istate to be the same as in statep. (4) Further coding was added to new water thermodynamic and transport property subroutines and calling routines. (5) Diagnostic message was being issued from simultaneous equation solver for hydrodynamic equations. (6) A user reported use of wrong variable in trnset initialization subroutine. (7) Errors were found when stripping code of certain compile time options in preparation for a transmittal.

DESCRIPTION OF CHANGE: (1) Format statement was corrected to state the correct value of the default viscosity ratio. (2) Coding, which may have been changed from the original coding, used English units of (ft-lbf)/(rev/min) while input manual stated (ft-lbf-s). Coding was changed to conform to input manual. While examining coding, unnecessary statement numbers were removed and many if-goto's were changed to if-then-else logic. (3) Coding in statep was copied correctly to istate. (4) New thermodynamic and transport properties can run some simple problems but much work remains. (5) Unwanted diagnostic message was removed. (6) Variable was indeed incorrect but error was benign in that both variables were equivalenced to the proper point. Correction makes reading of the code much easier. (7) Fix recently introduced errors with additions to coding protected by mmfld option. Program version number was changed.

2. TITLE OF CHANGE: Several fixes for accumulator.

PROBLEM STATEMENT OR OTHER REASON FOR CHANGE: There were several errors in the accumulator. First, the wall friction coefficient uses the fully turbulent Colebrook value which is no longer available because of the new wall friction model. The backup logic for the accumulator erroneously advanced the accumulator state in subroutine stacc even when the routine was called to reset the accumulator state to the beginning of advancement conditions. The logic for the check valve had been changed, which caused it to chatter. Finally, divide by zero was encountered in the junction property logic for the accumulator.

DESCRIPTION OF CHANGE: The fully turbulent wall friction factor is computed if the new wall friction factor option is used and obtained from the surface roughness variable if the old friction factor model is used. The logic is changed in subroutine stacc to advance the accumulator state only when the routine is called at the end of a successful advancement. The logic is complicated by the fact that the advancement may fail after subroutine stacc has been called due to excessive mass error. The backup logic for a spherical accumulator is removed from subroutine accum and moved to subroutine stacc so that the backup is preformed in a single subroutine. It should be noted that subroutine stacc performs three functions; (1) advances the accumulator mass and energy equations, (2) computes the accumulator state from the pressure and internal energy, and (3) backs up the accumulator gas and liquid masses for a failed advancement. This routine (stacc) should be broken into three routines, each with a single task. The check valve logic is returned to its former methodology in which the reverse pressure gradient keeps the valve closed only if the flow is zero at the beginning of the advancement. Once the accumulator is emptying, only reverse flow or activation of a trip can close the check valve. Finally, protections are inserted in the junction property logic for the accumulator to protect against a divide by zero.

3. TITLE OF CHANGE: Correct definition of pr in Shah correlation.

PROBLEM STATEMENT OR OTHER REASON FOR CHANGE: Shah has two pr variables. One is Prandtl number the other is reduced pressure. Originally reduced pressure was not used.

DESCRIPTION OF CHANGE: Change pr in the z term to be reduced pressure in conden and pintfc. In conden, ptot is used and in pintfc the interfacial pressure is used.

4. TITLE OF CHANGE: Use local film thickness in Nusselt.

PROBLEM STATEMENT OR OTHER REASON FOR CHANGE: The Nusselt number in conden is based on cell length and is an average value for vertical flow. With this update it will now be based on local film thickness.

DESCRIPTION OF CHANGE: The vertical Nusselt HTC will now be based on conductivity/thickness. The liquid mass flux will be used to calculate a film Reynolds number which is related to the laminar film thickness.

CODE VERSION BEING CHANGED: rbc3.1.8bm

CODE VERSION BEING CREATED: rbc3.1.8bn

1. TITLE OF CHANGE: Move subcooled boiling model to more efficient locations, modify delay control component when time changed at restart, coding cleanup in iconvr and convr, and define and adechk decks corrected.

PROBLEM STATEMENT OR OTHER REASON FOR CHANGE: (1) Subcooled boiling is calculated in prednb and pstdnb. Therefore sometimes we get two steam table calls and two subcooled boiling calculations that give the answer twice per cell per time step. Also when noncondensables are present the equilibrium quality and vaporization enthalpy are based on partial pressure instead of total pressure. (2) Delay component has incorrect table for interpolating delayed values when time is changed at restart either by switching between steady-state and transient or vice versa or when time is reset by a Card 200 entry. (3) Control system subroutines had many redundant statement numbers and extensive goto logic. (4) Define decks and adechk decks were not consistent due to recent additions.

DESCRIPTION OF CHANGE: (1) A new subroutine has been added called suboil. It is called from htrc1. The vaporization enthalpy and quality are based on total pressure. (2) When advancement time is changed by either a switch from steady-state to transient or vice versa or through a 200 card, the table of past results saved as a function of time is changed to agree with the new advancement time. Input manual was changed to give more warnings on the effect of change to the advancement time. (3) Redundant statement numbers in subroutines iconvr and convar were removed and if-then-else logic replaced many goto statements. (4) Define and adechk decks were made consistent. Program version number was changed.

2. TITLE OF CHANGE: Crossflow modification.

PROBLEM STATEMENT OR OTHER REASON FOR CHANGE: The length scale of the crossflow model needs to be a user-specified one. Also, the friction term is suggested to be added in the crossflow junctions. The change allows more generalized input processing for the length scale and the friction calculations for the crossflow.

DESCRIPTION OF CHANGE: R-level subroutines (rsngv, rbrnch) are modified to incorporate the user input for the crossflow. Transient coding has been modified for the friction term.

3. TITLE OF CHANGE: Energy dissipation due to form loss.

PROBLEM STATEMENT OR OTHER REASON FOR CHANGE: In some cases RELAP5 calculations show an energy imbalance when form loss is present in the system. This occurs because the energy dissipation due to form loss is not included in the energy equation.

DESCRIPTION OF CHANGE: Use change option 41 to include in the energy equation the energy dissipation due to form loss.

CODE VERSION BEING CHANGED: rbc3.1.8bn

CODE VERSION BEING CREATED: rbc3.1.8bo

1. TITLE OF CHANGE: Fix errors introduced in last update and other errors found and changed in common block jundat.

PROBLEM STATEMENT OR OTHER REASON FOR CHANGE: (1) Errors introduced in last update include: inconsistent format statements in suboil caused termination; incorrect protection of crossflow coding caused long run time. (2) Error in accum execution coding was traced to improper setting of lsuces variable in input processing. (3) The common block jundat needs to be changed to add improved irreversible loss model.

DESCRIPTION OF CHANGE: (1) Write and format statements changed in suboil, and crossflow coding fixed in vexplt and vimplt. (2) The lsuces variable was set to zero after being used in tests in subroutine imlp. (3) Four variables were added to jundat common block. Program version number was changed.

CODE VERSION BEING CHANGED: rbc3.1.8bo

CODE VERSION BEING CREATED: rbc3.1.8bp

1. TITLE OF CHANGE: Add G factor to reactor kinetics decay heat calculation.

PROBLEM STATEMENT OR OTHER REASON FOR CHANGE: Users requested addition of G-factor to decay heat part of reactor kinetics calculation.

DESCRIPTION OF CHANGE: Additional input was added to reactor kinetics to allow users to specify adding G-factor to the decay heat calculation. Four subroutines that advance the decay heat equations were modified: a subroutine for power history for point kinetics, a subroutine for power history for space kinetics, the overall reactor kinetics transient advancement subroutine for point kinetics, and the subroutine for decay heat for space kinetics advancement. Program version number was changed.

2. TITLE OF CHANGE: Same statep and eqfinl limits for noncondensables.

PROBLEM STATEMENT OR OTHER REASON FOR CHANGE: In running an AP600 4-inch SBLOCA, it was found that the code used different statep noncondensable limits than eqfinl noncondensable limits.

DESCRIPTION OF CHANGE: In subroutine statep, use the same noncondensable limits as is done in subroutine eqfinl.

3. TITLE OF CHANGE: Change the band within the iterative solver.

PROBLEM STATEMENT OR OTHER REASON FOR CHANGE: The bandwidth is not flexible enough to allow the iterative solver to both converge rapidly and yet be small enough to minimize the run time

DESCRIPTION OF CHANGE: Change the half bandwidth from 75 to a value to be determined during the run. The minimum for a 1-D problem is 35. The bandwidth is adjusted upwards during the run if nonconvergence is detected. On the other hand, there is no provision to reduce the bandwidth during the run.

4. TITLE OF CHANGE: Implement natural convection length + htc options.

PROBLEM STATEMENT OR OTHER REASON FOR CHANGE: The length for CHF was being used for natural convection. An NRC user saw large HTC caused by this. In addition we needed more ability for the users to specify the type of hydraulic cell a heat slab is connected to, i.e., flow in an annulus outside of rods, parallel plates, etc.

DESCRIPTION OF CHANGE: This update makes use of the input added a few months ago. It allowed users to input a natural convection length for forward and reverse flow plus a fouling factor on cards 801 and 901. This change now makes these variables: the natural convection length, the rod pitch to diameter ratio, and the fouling factor. In addition we needed more ability for the users to specify the type of hydraulic cell a heat slab is connected to, i.e. flow in an annulus outside of rods parallel plates, etc.

CODE VERSION BEING CHANGED: rbc3.1.8bp

CODE VERSION BEING CREATED: rbc3.1.8bq

1. TITLE OF CHANGE: Add new variables to scnreq for level tracking model, correct G-factor for infinite operating time, fix istate error.

CODE VERSION BEING CREATED: rbc3.1.8bq, this line was wrong in the installation and had rbc3.1.8bo instead. Also the program version number was rbc3.1.1.2 instead of rbc3.1.8bq.

PROBLEM STATEMENT OR OTHER REASON FOR CHANGE: (1) Two variables in level tracking model needed to be added to scnreq capability for interpretation of results. (2) G-factor did not yield correct results at initialization for infinite operating times. Protection was incorrect for new water property capability.

DESCRIPTION OF CHANGE: (1) Two new level tracking variables were added to scnreq. (2) G-factor calculation in reactor kinetics was corrected. (3) Protection was corrected in istate. Program version number was changed.

2. TITLE OF CHANGE: Eliminate n5fprs parameter.

PROBLEM STATEMENT OR OTHER REASON FOR CHANGE: A parameter in the farays block must be set equal to the parameter ndcomp.

DESCRIPTION OF CHANGE: Change all references from n5fprs to ndcomp

3. TITLE OF CHANGE: Change fission product cards to match code documentation.

PROBLEM STATEMENT OR OTHER REASON FOR CHANGE: Fission product input card numbers did not match code documentation.

DESCRIPTION OF CHANGE: Changed code to match manual.

4. TITLE OF CHANGE: Form loss modification.

PROBLEM STATEMENT OR OTHER REASON FOR CHANGE: The user-specified form loss is modified. The changes include Reynolds number dependence of the form loss for both forward and reverse flow cases. The change allows more generalized input processing for the form loss coefficients.

DESCRIPTION OF CHANGE: R-level subroutines are modified to incorporate the user input for the form loss coefficients. Transient coding has been added to calculate the Reynolds number dependence of the K loss.

CODE VERSION BEING CHANGED: rbc3.1.8bq

CODE VERSION BEING CREATED: rbc3.1.8br, rbc3.1.1.2

1. TITLE OF CHANGE: Modify reactor kinetics G factor to use table for all time periods under user control, fix errors in form loss coefficients input.

PROBLEM STATEMENT OR OTHER REASON FOR CHANGE: (1) G-factor has a discontinuity at 1.0e4 s when using equation. (2) Errors were found in recent updates for additional form loss data.

DESCRIPTION OF CHANGE: (1) Through user option, table can be used to obtain G-factor over entire range. (2) Errors in isngj, rbrnch, rpipe, rpmvnj, and rsngv were corrected. Program version number was not changed since it was changed to rbc3.1.1.2 in last update.

2. TITLE OF CHANGE: Direct heating from fluid to noncondensable for nearly-implicit advancement.

PROBLEM STATEMENT OR OTHER REASON FOR CHANGE: Establish consistency between models in semi- and nearly-implicit advancement schemes.

DESCRIPTION OF CHANGE: Eliminated secret option 38, which became the default model. Model implemented in vimplt and simplt.

CODE VERSION BEING CHANGED: rbc3.1.8br

CODE VERSION BEING CREATED: rbc3.1.8bs

1. TITLE OF CHANGE: Fix interactive commands (readnonb) capability, fix errors recently introduced in vexplt and vimplt.

PROBLEM STATEMENT OR OTHER REASON FOR CHANGE: (1) Interactive command capability, especially the &stop command, are needed to debug code. When the code is taking small advancements the &stop command can terminate the run with complete minor and major edits. (2) Errors were introduced as part of form loss changes.

DESCRIPTION OF CHANGE: (1) Changes were made to interi to get code to work with readnonb subroutine from envrl library. Scripts were changed for DECrisc, DECrisc2, and DECalpha machines to turn on the readnonb compile time option. (2) Error of using a volume velocity in place of a junction velocity in vexplt and vimplt was fixed. Program version number was changed.

2. TITLE OF CHANGE: Make SRL CHF option 51.

PROBLEM STATEMENT OR OTHER REASON FOR CHANGE: An earlier update had made the default option 1 instead of zero. 1 had been for SRL.

DESCRIPTION OF CHANGE: Make the SRL option number 51.

3. TITLE OF CHANGE: Improvements to the critical flow model.

PROBLEM STATEMENT OR OTHER REASON FOR CHANGE: (1) A transition from choked flow to subsonic flow is accompanied by a discontinuous mass flow rate; (2) At the onset of critical flow of vapor, the mass flow rate is overestimated.

DESCRIPTION OF CHANGE: (1) A stronger unchoking test is used to remove the discontinuous prediction of mass flow rate and ensure that the pressure drop is always large enough to maintain choked flow; (2) Iteration is used to determine hydrodynamic conditions at the throat, so that the sonic velocity is not overestimated at the onset of critical flow. (1) The first change is activated by change option 42, only in the case of an abrupt area change; (2) The second change is activated by change option 43, only in the case of single-phase vapor.

4. TITLE OF CHANGE: Fix in PVM coupling routine.

PROBLEM STATEMENT OR OTHER REASON FOR CHANGE: Currently the method of coupling Contain to RELAP through the use of PVM uses time-dependent volume(s) in RELAP and is limited to storing the contain(ment) state just as type 3 conditions (temperature and pressure). Subroutine pvmset checks on other variables, quala and quals, that are not available for type 3 condition time-dependent volumes thus causing code failures.

DESCRIPTION OF CHANGE: In subroutine pvmset, lines testing on quala or quals, were protected to see that they were not used for type 3 conditions.

5. TITLE OF CHANGE: Correct error message on temperature initialization.

PROBLEM STATEMENT OR OTHER REASON FOR CHANGE: Error message on initialization of initial temperatures for some components was misleading.

DESCRIPTION OF CHANGE: Corrected.

CODE VERSION BEING CHANGED: rbc3.1.8bs

CODE VERSION BEING CREATED: rbc3.1.8bt

1. TITLE OF CHANGE: Correct implicit connection of heat conduction/transfer and hydrodynamics, fix zero raised to zero power in new transient form loss coding.

PROBLEM STATEMENT OR OTHER REASON FOR CHANGE: (1) A user reported an error in implicit connection of heat conduction/transfer. (2) Execution terminated due to floating point number being raised to floating point power.

DESCRIPTION OF CHANGE: (1) Corrected indexing error in ht1tdp. (2) Protection using a max function was applied to Reynolds number in transient form loss coding.

2. TITLE OF CHANGE: Bug fix for incorrect reload of solution variables in time-dependent volumes for failed advancements.

PROBLEM STATEMENT OR OTHER REASON FOR CHANGE: Solution variables (voidg, ug, etc.) in time-dependent volumes were improperly reloaded from old time variables in the event of a failed time advancement.

DESCRIPTION OF CHANGE: Changed tstate to prevent premature overwrite of old time variables. Changed statep to compute voidf from voidg for time-dependent volumes.

3. TITLE OF CHANGE: Implicit interface heat transfer coefficient.

PROBLEM STATEMENT OR OTHER REASON FOR CHANGE: The implicit interface heat transfer model was implemented for both the nearly- and semi-implicit advancement schemes. The model was left as secret option number 26 since it was shown that the approximation to the derivative using old information was inadequate.

DESCRIPTION OF CHANGE: New terms from linearization were introduced to the local 5 x 5 matrix and source terms for solution of new time variables.

4. TITLE OF CHANGE: Fix for initial noncondensable appearance.

PROBLEM STATEMENT OR OTHER REASON FOR CHANGE: The code sometimes failed with a very high vapor temperature on the time step after noncondensable gas first appeared in a cell. The code didn't let subcooled noncondensable gas appear in a cell.

DESCRIPTION OF CHANGE: The changes make the code repeat an advancement whenever noncondensable gas is detected to appear in a cell. The matrix coefficients for the cell in which noncondensable gas is to appear are computed using an estimated noncondensable gas quality computed from the noncondensable source term found during the initial attempted advancement. All changes are related to the repeated advancement except for those in fwdrag where the Reynolds numbers for the laminar and turbulent regimes are contained in variables initialed by data statements instead of being hard coded. This change is cosmetic but will facilitate changing the regime boundaries if needed. The changes for the air appearance only apply to the semi-implicit numerical scheme without molten metal. For air appearance with molten metal or for the nearly-implicit scheme, the same kind of changes need to be made.

5. TITLE OF CHANGE: Fix for mechanistic separator model.

PROBLEM STATEMENT OR OTHER REASON FOR CHANGE: The coding for the mechanistic separator had several errors in the specification for the variables introduced when the subroutine was converted for 32-bit integers. The root finding algorithm had an error and needed to have taken at least two steps before the binary chopping coding could be activated.

DESCRIPTION OF CHANGE: The variable definitions were changed to be consistent for 32-bit integers and the control logic for the binary chopping was changed to take at least two steps before being activated. The combined separator/dryer option was also reactivated having been erroneously commented out by a previous update.

6. TITLE OF CHANGE: Fix for kinetics.

PROBLEM STATEMENT OR OTHER REASON FOR CHANGE: There were several errors in the kinetics. The first error caused incorrect power distributions whenever there was a non-fueled region (i.e. a reflector) on the top of the reactor. The second error was in a printout in the kinetics.

DESCRIPTION OF CHANGE: The change to the power distribution was made by moving the initialization of a variable to another loop and the fix to the printout was to ensure that the number of blanks written to pad a line was always greater than or equal to one.

7. TITLE OF CHANGE: CCFL modification.

PROBLEM STATEMENT OR OTHER REASON FOR CHANGE: The CCFL model is modified to include the limits of both liquid and vapor zero velocities. This modification will be activated by using the change option number 42.

DESCRIPTION OF CHANGE: rchng subroutine is modified to incorporate the user selection of the use of modified CCFL model. The limitation is implemented in the ccfl subroutine.

8. TITLE OF CHANGE: Crossflow modification update

PROBLEM STATEMENT OR OTHER REASON FOR CHANGE: The use of crossflow model invokes the use of undefined area information. Those undefined variables are defined to make the code run for all the possible input combinations.

DESCRIPTION OF CHANGE: Several subroutines (flostv, icompn, vlvela, ivlvel) are identified for using the undefined variables. Those variables are set to the default values in this update.

9. TITLE OF CHANGE: Main coding for the thermal stratification model.

PROBLEM STATEMENT OR OTHER REASON FOR CHANGE: Numerical diffusion messes up CMT calculations.

DESCRIPTION OF CHANGE: Put in a front tracking model which is very similar to the level tracking model. In particular, the new subroutine added, tfront, is almost identical to subroutine level in terms of the main logic but with void replaced by internal energy of liq. Warning: tfront has to be in define and tfront flag has to be turned on in the input deck.

10. TITLE OF CHANGE: Mixture level tracking model update.

PROBLEM STATEMENT OR OTHER REASON FOR CHANGE: Improvement of the mixture level tracking model.

DESCRIPTION OF CHANGE: Major changes are: (1) Include the vertically stratified model when the level model is activated. (2) Add the stretch logic in subroutine packer to take care of negative pressure spikes. (3) Modify junction void calculation for interfacial friction. (4) Correct subroutine phantj.

CODE VERSION BEING CHANGED: rbc3.1.8bt

CODE VERSION BEING CREATED: rbc3.1.8bu

1. TITLE OF CHANGE: Fix if-test in ht1tdp and fix problems reported in extension of RELAP5 to PC's.

PROBLEM STATEMENT OR OTHER REASON FOR CHANGE: (1) 8bt version failed in edrst (restart of edwards pipe problem) on DECalpha machine. (2) An INEL user reported FORTRAN compilation difficulties when installing code on PC machines.

DESCRIPTION OF CHANGE: (1) If test modified from goto to if-then-else logic in last update was corrected. (2) A bad goto into a if-then-else construction was fixed in cmpcom. A bad protection using newwtrp was fixed in tstate. Program version number was changed.

2. TITLE OF CHANGE: Improvement to the calculation of sonic velocity for critical flow of subcooled liquid.

PROBLEM STATEMENT OR OTHER REASON FOR CHANGE: During critical flow of subcooled liquid, the mass flow rate may be unaffected by a change of upstream pressure. This problem occurs because the equilibrium sound speed at the junction is calculated assuming the junction contains saturated liquid at the upstream temperature.

DESCRIPTION OF CHANGE: Use momentum and mechanical energy balances to calculate the pressure and internal energy at the junction and use the water property tables to obtain the thermodynamic properties of a saturated liquid-vapor mixture at this pressure and internal energy.

3. TITLE OF CHANGE: Allow the code to cut the time step if the iterative solver does not converge.

DESCRIPTION OF CHANGE: Set lsuces = 5 if the iterative solver does not converge when the half-bandwidth for the ilut fill is equal to 75, the max allowable value. Hydro then immediately returns to dtstep if this is the case.

4. TITLE OF CHANGE: CCFL modification update.

PROBLEM STATEMENT OR OTHER REASON FOR CHANGE: The use of CCFL model invoke the use of limiting liquid velocity. This update prevents the limiting liquid velocity going to zero.

DESCRIPTION OF CHANGE: A line of ccfl subroutine has been modified with a max function of FORTRAN coding.

CODE VERSION BEING CHANGED: rbc3.1.8bu

CODE VERSION BEING CREATED: rbc3.1.8bv

1. TITLE OF CHANGE: Modify comdecks and add option number 45 in anticipation of changes in interphase condensation model and clear equation of state error flags on noncondensable appearance logic.

PROBLEM STATEMENT OR OTHER REASON FOR CHANGE: (1) New model for interphase condensation needs additional variables added to voldat and statec and a secret option number. (2) Equation of state errors were terminating runs and it appeared to be present during noncondensable appearance logic.

DESCRIPTION OF CHANGE: (1) Variables added to comdecks voldat and statec. Option number 45 added. This change should have no effects on results until other coding is added that use these variables and option number. (2) Coding to clear bits marking equation of state errors was added after call to mover (and statep) in noncondensable appearance logic. This coding may not be needed and may be removed as part of further testing of noncondensable appearance logic. Change program version number.

2. TITLE OF CHANGE: Stop divide by zero in prednb.

PROBLEM STATEMENT OR OTHER REASON FOR CHANGE: MIT in-out surge problem failed on version 8bu in prednb with refl = 0.0.

DESCRIPTION OF CHANGE: The minimum liquid velocity of the Chen data base is 0.06 m/s. Set refl to the max of gliqa, 1.0 and voidf*ρ_f*0.06.

3. TITLE OF CHANGE: Input processing for GE separator/dryer.

PROBLEM STATEMENT OR OTHER REASON FOR CHANGE: The geometric and performance data for the GE separator and dryer were hard coded in the input processing routine and couldn't be changed by the user.

DESCRIPTION OF CHANGE: The change was to add new input cards for the separator component which contain the data for the GE separator and dryer models.

4. TITLE OF CHANGE: Removal of undefined variable in reord, bppram.

PROBLEM STATEMENT OR OTHER REASON FOR CHANGE: Setting core to an illegal number results in a run time error in reord because an unneeded variable in not initialized.

DESCRIPTION OF CHANGE: Remove all references to the unneeded variable, ndxsys.

5. TITLE OF CHANGE: Modification of tempf in vexplt so that only hot fluid in the cell that contains the front is allowed to flash in the thermal stratification model.

PROBLEM STATEMENT OR OTHER REASON FOR CHANGE: Only the hot fluid in the cell that contains the front should be allowed to flash

DESCRIPTION OF CHANGE: Make sure the temperature of the hot fluid is used in the computation of mass and energy transfer

6. TITLE OF CHANGE: Bug fix for vectorized unchoking logic in the nearly-implicit time advancement scheme.

PROBLEM STATEMENT OR OTHER REASON FOR CHANGE: Variable "scvjck" was loaded incorrectly when unchoking occurred.

DESCRIPTION OF CHANGE: Modified vimplt to include correct pointers.

7. TITLE OF CHANGE: CCFL modification update.

PROBLEM STATEMENT OR OTHER REASON FOR CHANGE: There has been errors on calculating the CCFL bit in ccfl subroutine. This update corrects the error.

DESCRIPTION OF CHANGE: Several lines of the ccfl subroutine have been modified with a max function of FORTRAN coding.

CODE VERSION BEING CHANGED: rbc3.1.8bv

CODE VERSION BEING CREATED: rbc3.1.8bw

1. TITLE OF CHANGE: Condensation model (option 45).

PROBLEM STATEMENT OR OTHER REASON FOR CHANGE: The condensation model is not technically defensible.

DESCRIPTION OF CHANGE: Add new subroutines condn2, htfilm, ncfilm, and ncprop. Modify subroutines htrc1 and phantv to call these new subroutines.

2. TITLE OF CHANGE: Use phantj from version 8bc.

PROBLEM STATEMENT OR OTHER REASON FOR CHANGE: In running an AP600 4-inch SBLOCA, the calculation failed after 10 seconds on versions with the new if-then-else logic.

DESCRIPTION OF CHANGE: In subroutine phantj, use the logic of version 8bc.

3. TITLE OF CHANGE: Rearrange input data for mechanistic separator.

PROBLEM STATEMENT OR OTHER REASON FOR CHANGE: The input data for the mechanistic separator asked for several data items which were required to be zero.

DESCRIPTION OF CHANGE: The input processing for the mechanistic separator was changed so that only nonzero data items were needed.

4. TITLE OF CHANGE: Improvement to the unchoking test used in the critical flow model.

PROBLEM STATEMENT OR OTHER REASON FOR CHANGE: The current unchoking test checks that the throat pressure is larger than the downstream pressure. Although this test is not plausible, it was left in the code because no problems were observed until recently. We have seen that this test may cause oscillations in the flow rate.

DESCRIPTION OF CHANGE: An improved unchoking test was implemented.

DECKS CHANGED: jchoke

5. TITLE OF CHANGE: Stretch logic modification.

PROBLEM STATEMENT OR OTHER REASON FOR CHANGE: Make stretch logic as an option in subroutine packer.

DESCRIPTION OF CHANGE: A user can use option 32 to turn on stretch logic in subroutine packer.

CODE VERSION BEING CHANGED: rbc3.1.8bw

CODE VERSION BEING CREATED: rbc3.1.2

1. TITLE OF CHANGE: Further corrections for air appearance.

PROBLEM STATEMENT OR OTHER REASON FOR CHANGE: A one line addition was left out of the minimum air source update, the minimum air source term had the time step size erroneously included, and a logic error caused an infinite loop when air tries to appear in two different volumes during the same time step.

DESCRIPTION OF CHANGE: Add the line left out of the previous update for the minimum air source, remove the time step size dependence of the minimum air source term, and modify the air appearance logic to detect appearance in more than one cell during a time step. Add option 46 for air appearance.

2. TITLE OF CHANGE: Interfacial heat transfer modification.

PROBLEM STATEMENT OR OTHER REASON FOR CHANGE: Improve interfacial heat transfer calculation when level exists in the volume.

DESCRIPTION OF CHANGE: Using only the interfacial heat transfer correlation for stratified flow when level presents in the volume.

3. TITLE OF CHANGE: Corrections for separator input processing.

PROBLEM STATEMENT OR OTHER REASON FOR CHANGE: One of the default values for the GE separator model was reversed between the two-stage and three-stage separator options

DESCRIPTION OF CHANGE: Correct the reversed numbers.

CODE VERSION BEING CHANGED: rbc3.1.2.1

CODE VERSION BEING CREATED: rbc3.1.2.2

1. TITLE OF CHANGE: Version 3.1.2.1 fixes.

PROBLEM STATEMENT OR OTHER REASON FOR CHANGE: The heated length for natural convection was not being used in the Nusselt number the way it was in the Grashoff number for horizontal surfaces in natural convection mode. It uses the McAdams correlation. The default natural convection length is set to the heated hydraulic diameter if it is less than this diameter. Subroutine pintfc was modified to avoid compiler warning message. Affected coding was in an error message. Program version number was updated.

2. TITLE OF CHANGE: Error corrections and fine tuning of model.

REASON FOR CHANGE AND DESCRIPTION OF CHANGE: The if def, tfront not used in jprop. This is corrected. In addition, the tfront coding for the velocity flip flop case in jprop that was missing is now added. Fine tuning: the front crossing cell boundary criterion is now changed to 0.98 and 0.02 for more robust running because the previous choices, 0.995 and 0.005 cause the code to fail for a ROSA problem.

3. TITLE OF CHANGE: Add volume and junction variables to assist interpretation of simulation results.

REASON FOR CHANGE AND DESCRIPTION OF CHANGE: NRC requested two volume and one junction variables be added to the code to assist interpretation of simulation results. Variables, tmassv, tiengv, and flenth were added to voldat, voldatc, jundat, and jundatc dynamic blocks. Variables were also added to scnreq.

CODE VERSION BEING CHANGED: rbc3.1.2

CODE VERSION BEING CREATED: rbc3.1.8ca

1. TITLE OF CHANGE: Corrections made to implicit coupling between heat conduction and hydrodynamics, coding (and error correction) changes to flostv, local variable problem in ht1tdp, correct indexing error in interi, fixed card number problem in pipe component input, space-dependent kinetics problem fixed, tstate problem reported by outside user, and DECalpha compiler problem avoided.

PROBLEM STATEMENT OR OTHER REASON FOR CHANGE: (1) Errors were observed in hydrodynamic conditions during testing of new condensation model. (2) Changes for crossflow model involved calling subroutine flostv found in this subroutine. (3) As part of searching for an error on a Stardent computer, an improperly set local variable was found in htrc1. (4) Indexing initialization error was found in interi. (5) Two different types of input in pipe component were assigned the same card number. (6) Recent G-factor change to reactor kinetics led to space dependent kinetics error. (7) Error in coding in tstate was reported by outside user. (8) An iand(ior(fortran construction) was shown to compile di incorrectly in one location in code.

DESCRIPTION OF CHANGE: (1) Coding errors in the stage where some of the results from the expanded form of the hydrodynamic equations are used in the unexpanded form were found and corrected. (2) Subroutine flostv was modified for ease of maintenance and better performance. Improved version will continue to be checked to verify problems have been fixed. (3) Local variable was properly defined. (4) Index was changed to use correct index. (5) Card number of molten metal input changed to new card number to avoid conflict in card numbers. (6) Indexing problem fixed so that both point- and space-dependent kinetics problems now execute. (7) A reciprocal operation was done to avoid later divides but divides were not changed to multiplies. Problem fixed. (8) All instances of that iand(ior(construction) were changed for DECalphas. Program version number has been changed.

2. TITLE OF CHANGE: Nearly-implicit velocity flip/flop.

PROBLEM STATEMENT OR OTHER REASON FOR CHANGE: Implement the velocity flip/flop redonoring scheme used in the semi-implicit scheme in the nearly-implicit in an attempt to reduce mass error accumulation.

DESCRIPTION OF CHANGE: Using the explicit estimate of the new time junction velocities in vimplt, junction properties are redonored with a call to jprop(1) and a bad donoring check is performed. If bad donoring occurs, code flow returns to the top of vimplt and the velocity matrix is reconstructed. This model is implemented as change option 16 since the coding and physics has not been fully verified.

3. TITLE OF CHANGE: Semi-implicit velocity flip/flop restructuring.

PROBLEM STATEMENT OR OTHER REASON FOR CHANGE: The logic flow of vfinl contained several deficiencies: (1) jprop(1) was called twice in succession, the results of the second call being ignored. (2) A second bad donoring check was always performed. (3) Redundant save/restore operations could be performed

DESCRIPTION OF CHANGE: The flow of vfinl was restructured, eliminating the above logic problems and replacing all goto logic with if-then-else logic.

4. TITLE OF CHANGE: Jetmixer/eccmix model enhancements.

PROBLEM STATEMENT OR OTHER REASON FOR CHANGE: (1) Jetmix/eccmix models in the nearly-implicit time advancement scheme used explicit velocities, resulting in a model that was Courant limited. To run BWR simulations above the Courant limit, an implicit model is required. (2) Jetmix/eccmix models did not obtain the correct single-phase limits.

DESCRIPTION OF CHANGE: (1) Model was re-derived to incorporate implicit velocities. Convective terms for the jetmix/eccmix components are precomputed in vimplt. Diagonal matrix coefficient and source terms are pre-loaded, new coefficients and off-diagonal terms were incorporated into the throw loop. (2) The single-phase limit was applied by incorporating ratios of the appropriate void fractions.

5. TITLE OF CHANGE: Implement gravcn in 26 subroutines.

PROBLEM STATEMENT OR OTHER REASON FOR CHANGE: The gravitational constant was hard wired in many subroutines and the constant varied slightly in some of them.

DESCRIPTION OF CHANGE: Use the constant gravcn from the contrl common block.

6. TITLE OF CHANGE: HT mode 3-4 number error.

PROBLEM STATEMENT OR OTHER REASON FOR CHANGE: The nucleate boiling logic for deciding on whether to be in mode 3 or 4 was checking tempf against satt which is the saturation temperature based on partial pressure.

DESCRIPTION OF CHANGE: Use tsatt in place of satt to get tsat based on total pressure.

7. TITLE OF CHANGE: Make SRL CHF option 51.

PROBLEM STATEMENT OR OTHER REASON FOR CHANGE: The comment in htrc1 had the mode 10 and 11 description backwards.

DESCRIPTION OF CHANGE: Make the comment compatible with the coding.

8. TITLE OF CHANGE: Correct dimensioning bug.

PROBLEM STATEMENT OR OTHER REASON FOR CHANGE: Encountered bug when incorrectly dimensioned arrays in balon2 overwrote variables in common

DESCRIPTION OF CHANGE: Changed dimension of arrays in common block farays from (81,5) to (81,ndcomp)

9. TITLE OF CHANGE: User-control of debug printout.

PROBLEM STATEMENT OR OTHER REASON FOR CHANGE: The debug printout for a large problem contains too much information to be useful.

DESCRIPTION OF CHANGE: Add the capability for the user to specify the volumes, junctions and subroutines from which he wishes to get debug output. Input card 2 names the volumes, card 3 names the junctions and card 4 names the subroutines giving debug output. A missing card implies "all". Input card 5 names subroutines for which the debug print is disabled. An input deck cannot have both card 4 and card 5.

10. TITLE OF CHANGE: Add air appearance repeats to statistics printout.

PROBLEM STATEMENT OR OTHER REASON FOR CHANGE: The statistics printout did not include the number of repeats due to air appearance in the volumes.

DESCRIPTION OF CHANGE: Add the capability to print out the number of time step repeats caused by air appearance in the volumes.

CODE VERSION BEING CHANGED: rbc3.1.8ca

CODE VERSION BEING CREATED: rbc3.1.8cb

1. TITLE OF CHANGE: Add changes to new condensation model, correct implicit coupling of heat conduction-transfer and hydrodynamics, limits on frequencies for minor edits, major edits, and restarts eliminated, use of local variable before its being set corrected, divide by zero during input processing fixed.

PROBLEM STATEMENT OR OTHER REASON FOR CHANGE: (1) Changes to the new condensation model need to be entered into code as part of debugging of implicit coupling of heat conduction and hydrodynamics. (2) Errors in the implicit coupling of heat conduction-transfer were demonstrated by a condensation problem with a very thin heat structure and high thermal-conductivity. (3) A user requested that limits on the frequencies for minor edits, major edits, and restarts be raised. (4) Local variable in h1tdp was being used before being set. (5) Divide by zero during input processing was reported by a user.

DESCRIPTION OF CHANGE: (1) New condensation changes were added to code. Subroutine changed are condn2, htfilm, htrc1, ncfilm, phantv, prednb. (2) Errors were corrected and condensation problem now executes. (3) Limits on frequencies for edits and restart were removed. (4) Local variable was moved so that it was being set properly. (5) Relocation of a test to protect against a divide by zero was moved to the proper position in invhts subroutine.

2. TITLE OF CHANGE: User control of printout and final air changes.

PROBLEM STATEMENT OR OTHER REASON FOR CHANGE: The printout for a large problem contains too much information to be useful. Some changes in the air appearance logic were needed.

DESCRIPTION OF CHANGE: This update adds to following capabilities: (1) Add the capability for the user to specify the volumes and junctions from which he wishes to get output as well as specify which sections in the major output he wishes to have printed. Input card 2 names the volumes, card 3 names the junctions and card 4 names the sections apparent in the output. A missing card implies "all". Input card 5 names sections for which the print is disabled. An input deck cannot have both card 4 and card 5. (2) Make final changes to the air appearance logic. The new air appearance logic is activated unconditionally instead of needing change option 46. (3) Changes the logic for water packing messages so that they only appear on the printed output if "debug" option is active. A count of the number of times that water packing is activated was added to the volume statistics portion of the major edit. (4) Add the capability to stop the code gracefully on HP workstations by sending signal 2 to the executing job. Exit gracefully means printing a major edit and writing a final plot/restart record.

3. TITLE OF CHANGE: Fixes to debug in subroutines ccfl and fwdrag. Fixes to if/then/else logic in subroutines phantj and phantv.

PROBLEM STATEMENT OR OTHER REASON FOR CHANGE: Subroutine ccfl debug wrote out the junction index with too small of a format, and subroutine fwdrag had the wrong label. The if/then/else logic in subroutine phantj had errors and unnecessary logical variables, and it was removed in rbc3.1.8bw. Subroutine phantv had unnecessary logical variables and the logic was inconsistent with subroutine phantj.

DESCRIPTION OF CHANGE: Remove the writing of the junction index in subroutine ccfl as is currently done in other routines. Fix the debug label in subroutine fwdrag. The if/then/else logic was fixed and the unnecessary logical variables were removed in subroutine phantj. The unnecessary logical variables were removed and the coding was made similar in subroutine phantv to subroutine phantj as was the case when the 2 routines were split from subroutine phaint.

4. TITLE OF CHANGE: Correct installation bug.

PROBLEM STATEMENT OR OTHER REASON FOR CHANGE: Alignment error in oxstat from oxdcon. Use of asterisk to separate output.

DESCRIPTION OF CHANGE: Corrected oxstat alignment and removed use of asterisk in output.t

CODE VERSION BEING CHANGED: rbc3.1.8cb

CODE VERSION BEING CREATED: rbc3.1.8cc

1. TITLE OF CHANGE: Fix error in clearing statistics flag, fixed errors in and activated new crossflow model and made the old model accessible by option 25.

PROBLEM STATEMENT OR OTHER REASON FOR CHANGE: (1) Program aborted in random fashion on some problems. (2) The new crossflow model was left inactivated by forcing option 25 to always be set. When activated, the code failed on some problems.

DESCRIPTION OF CHANGE: (1) Error in clearing statistics gathering flag was corrected. (2) Crossflow model was activated by removing statement setting the option 25 flag. Also corrected some errors found in testing. Program version number was changed.

2. TITLE OF CHANGE: User control of printout and final air changes.

PROBLEM STATEMENT OR OTHER REASON FOR CHANGE: The underflow error handler for the HP needs to be in the environmental library since it is needed by the routine which generate the steam tables. The program termination capability for the HP needs to be in the RELAP library since it uses a RELAP common block.

DESCRIPTION OF CHANGE: This update separates the underflow and program termination routines into separated decks so that they can reside on the proper library.

3. TITLE OF CHANGE: AP600 changes.

PROBLEM STATEMENT OR OTHER REASON FOR CHANGE:

DESCRIPTION OF CHANGE: (1) Adds AP600 embedded flow channels. (2) Eliminates component iteration. (3) Eliminates 1-D heat transfer.

4. TITLE OF CHANGE: Linearly-implicit interphase drag for semi-implicit scheme (change option 47) and removes time step repeat logic if noncondensable appears (change option 46).

PROBLEM STATEMENT OR OTHER REASON FOR CHANGE: An external user showed that void oscillations occurred for a bubble rise problem using the current zip-implicit interphase drag for the semi-implicit scheme. Multiple users suggest allowing the ability to turn off the time step repeat logic if noncondensable appears. The ability to turn off a new option is consistent with other major changes to the code (i.e., new crossflow model).

DESCRIPTION OF CHANGE: In subroutines rchng and vexplt, use change option 47 to use linearly-implicit interphase drag for the semi-implicit scheme. In subroutines rchng, eqfinl, and statep, use change option 46 to turn off the noncondensable appearance time step repeat logic.

CODE VERSION BEING CHANGED: rbc3.1.8cc

CODE VERSION BEING CREATED: rbc3.1.8cd

1. TITLE OF CHANGE:

REASON FOR CHANGE AND DESCRIPTION OF CHANGE: (1) The quantities, htcoff and htcofg, were in voldat and were defined in scnreq. They are no longer used and similar variables have been put in scrtch space. They have been removed from scnreq and will be removed from voldat at the next change to that dynamic block. (2) The variable dz is obsolete in RELAP5 coding. Use of this variable in RELAP5 has been changed to hydzc. (3) The subroutine flostv which sets the sinb variable and imap flags has been fixed to prevent storing the wrong imap values. Setting if sinb in r-level hydrodynamic volume input processing subroutines has been removed. (4) A character variable defined as one character was changed to the proper number of characters. This was reported in diagnostics during an IBM installation. (5) Unused variables were removed from the statep subroutine. (6) A user reported overflows in fields of screen message written during RELAP5 execution and inability to see time step size when very small time steps are being used. Format of message was changed to resolve problems. (7) Program version number was changed.

CODE VERSION BEING CHANGED: rbc3.1.8cd

CODE VERSION BEING CREATED: rbc3.1.8ce

1. TITLE OF CHANGE: Correct error in flostv, add changes for PC version, remove unneeded variables from voldat.

REASON FOR CHANGE AND DESCRIPTION OF CHANGE: (1) Subroutine flostv failed due to a divide by zero. Protection was added to protect against the divide by zero. (2) Changes to allow compilation and execution on personal computers was added. (3) Due to recent changes in the implicit coupling of heat conduction-transfer and hydrodynamics, seven variables were no longer needed in voldat since scratch variables were now being used. These have now been removed. Program version number was changed.

2. TITLE OF CHANGE: Fix error in HTRC1.

PROBLEM STATEMENT OR OTHER REASON FOR CHANGE: An INEL user was getting a divide by zero in prednb because dtsat was 0.0. Fix this by sending the code to dittus when dtsat is 0.0.

3. TITLE OF CHANGE: Fix keyboard interrupt for HP.

PROBLEM STATEMENT OR OTHER REASON FOR CHANGE: The name of the keyboard interrupt handling routine for HP systems was changed from "terminate" to "controlc" but the call to the routine in SR gninit was not changed accordingly.

DESCRIPTION OF CHANGE: This update changes the call to the interrupt handling routine for HP systems.

4. TITLE OF CHANGE: General bug corrections.

5. TITLE OF CHANGE: AP600 grey rods.

PROBLEM STATEMENT OR OTHER REASON FOR CHANGE: AP600

DESCRIPTION OF CHANGE: Modified cylin to track ss-304. Modified thermal properties routines to use single-entry point shielded 1-D heat conduction and component iterative capability in cylin.

6. TITLE OF CHANGE: Fix a sign in bmtm.F.

REASON FOR CHANGE AND DESCRIPTION OF CHANGE: Fix the a sign in the code so that the Godunov method is applied to reverse flow correctly.

CODE VERSION BEING CHANGED: rbc3.1.8ce

CODE VERSION BEING CREATED: rbc3.1.8cf

1. TITLE OF CHANGE: Remove unneeded save statements, fix diagnostic statement in heat structure input, fix indexing error introduced in noncondensable equation of state, fix bad units on elevation checker diagnostic, fix crossflow related errors in r-level subroutines.

REASON FOR CHANGE AND DESCRIPTION OF CHANGE: (1) Fortran 90 compilation complained about unneeded save statements. Save statements in most common blocks that are referenced in main program were deleted. (2) A user reported an abort due to bad input to heat structures that was not detected. Recently introduced error was corrected. (3) Indexing error was recently introduced into statep. Error was fixed. (4) Elevation diagnostic message printed bad elevation in metric only. Code was changed to print value in output units. (5) Crossflow errors that failed to process default input was corrected. Program version number was updated.

2. TITLE OF CHANGE: Fix errors in rhtcmp, htrc1, dittus, and condn2.

PROBLEM STATEMENT OR DESCRIPTION OF CHANGE: Rrhtcmp talked about natural convection length reverse when it should have been pitch to diameter ratio. Also the natural convection lengths are set to the heated hydraulic diameter if the first is less than the later. The MIT condensation problems where oscillations in and out of the conden mode when quala reaches .95. This change moves the cut-off to 0.999. Condensation will be much less at 0.999 so oscillations will be much less severe. In dittus, the htdiam was used in the Nusselt part of McAdams natural convection and htlenc was used in the Grashof part. Put htlenc in the Nusselt number part. There were two errors in coefficients in condn2. Correcting them only effects cases with option card 1 with a 45 on it.

3. TITLE OF CHANGE: Error corrections and fine tuning of model.

REASON FOR CHANGE AND DESCRIPTION OF CHANGE: Fine tuning: the front crossing cell boundary criterion is now changed to 0.98 and 0.02 for more robust running because the previous choices, 0.995 and 0.005 cause the code to fail for a ROSA problem.

4. TITLE OF CHANGE: Improvements to the critical flow model.

PROBLEM STATEMENT AND DESCRIPTION OF CHANGE: Change options 42 and 43, which are improvements to the critical flow model, have undergone testing to become a permanent part of the code.

CODE VERSION BEING CHANGED: rbc3.1.8cf

CODE VERSION BEING CREATED: rbc3.1.8cg

1. TITLE OF CHANGE: Remove some secret options, add NRC requested output quantities, fix Fortran-90 complaints, fix new energy coefficient computation.

REASON FOR CHANGE AND DESCRIPTION OF CHANGE: (1) Remove several of the 'secret' options. Options being removed have been tested sufficiently to make decision. (2) Two volume quantities and one junction quantities were computed and made available for plotting at NRC request. (3) A compilation using Fortran-90 had complaints about save statements. Save statements were not needed and thus removed. (4) Errors were found in new options for energy loss coefficients. An else statement was added to properly handle loss coefficient when new input was not used. Program version number was advanced.

2. TITLE OF CHANGE: Option 45 fixes.

PROBLEM STATEMENT AND DESCRIPTION OF CHANGE: A number in PHANTV was changed from 1.6 to 2.6. The diffusion coefficients for eight gases was activated. By placing the constants in moncn. The initial value of the interface temperature was placed in istate. ncfilm now loads the initial guess of interface temp from voldat and puts the final value back before exiting. mcfilm and ncwall also uses Dittus-Boelter instead of Gilliand.

3. TITLE OF CHANGE: Error correction to tfront model.

REASON FOR CHANGE AND DESCRIPTION OF CHANGE: The tfront coding for the velocity flip flop case in jprop that was missing and was added to 8cf. A mistake was made in that a perturbation of the model rather than the model itself was added. This is now corrected.

CODE VERSION BEING CHANGED: rbc3.1.8cg

CODE VERSION BEING CREATED: rbc3.1.8ch

1. TITLE OF CHANGE: Incorporate ORNL changes.

PROBLEM STATEMENT OR OTHER REASON FOR CHANGE: Bugs encountered during ORNL analysis.

DESCRIPTION OF CHANGE: Correct channel box bugs.

2. TITLE OF CHANGE: Fix error in conden.

PROBLEM STATEMENT OR OTHER REASON FOR CHANGE: The condensation coding does not match the manual. The Nusselt calculation should not be skipped when geometry 153 is set on word 3 of the 501 heat structure card. This update greatly improves the UCB-Kuhn assessment.

CODE VERSION BEING CHANGED: rbc3.1.8ch

CODE VERSION BEING CREATED: rbc3.1.8ci

1. TITLE OF CHANGE: Restore metastable extrapolation option, add option for direct heating, fix form loss calculation, add comments for invhtb dynamic block, fix problem in computing saturation temperature when total pressure is over critical pressure, correct radiation input to match manual.

REASON FOR CHANGE AND DESCRIPTION OF CHANGE: (1) Standard testing and developmental assessment have shown problems with the option of changing the extrapolation limits and time step halving. The extrapolation model and option used in 8cf was restored. (2) Some time ago, the direct heating model between vapor and liquid was changed. This has caused surprising differences in some simulations. To allow testing, an option has been added to switch back to the older model to facilitate testing. (3) A typing error in the form loss computation in vimplt has been fixed and coding was rearranged there and in vexplt for more efficient execution. (4) A comments comdeck was added for the invhtb dynamic block. (5) A divide by zero in statep due to attempting to evaluate the saturation temperature from a pressure above the critical point was fixed. Problems still remain and the noncondensable coding may not operate over the critical pressure. A do loop testing for time-dependent variables in statep was changed to loop using the list vector for time-dependent variables.

CODE VERSION BEING CHANGED: rbc3.1.8ci

CODE VERSION BEING CREATED: rbc3.1.8cj

1. TITLE OF CHANGE: Use a common definition of pi in all routines, fix write statement, fix too small dimension in rrestf, put label after stop statements, switch back dissipation energy term to older version, fix secret options comments, change choking back to previous model.

REASON FOR CHANGE AND DESCRIPTION OF CHANGE: (1) A user pointed out that some subroutines use a value of pi defined in an initializing routine, others use local definition of pi. Many of the local definitions use differing numbers of significant digits, round differently, and some have reversed digits. Coding was modified so that all references to pi now use the common definition. (2) A write statement in a subroutine used for debugging had the unit field missing. This was in a diagnostic message. It has been fixed. (3) A dimension statement was too small in rrestf. This was corrected to the proper size. (4) Several stop commands did not use a character label following the command. This allowed the problem to terminate with no information on what caused the stop. Now labels giving the subroutine name have been added to each stop command other than the one in the main program. (5) The energy dissipation term was switched in a recent version to be in effect. The logic has been reversed and the default is that the dissipation energy in not included unless the option is on. (6) Some of the secret option comments were not up to date with the recent removals, switching of options, and reversals of the past few updates. They were modified to be up to date. (7) The choking model changes led to differences in results from previous results. Changes were moved back to previous versions but newer model can be accessed through options 42 and 43.

2. TITLE OF CHANGE: Four error fixes to 8ci.

REASON FOR CHANGE AND DESCRIPTION OF CHANGE: (1) Manual said it is an error not to specify the local boiling factor on heat slabs. The code printed asterisks but did not fail. Now it does. (2) The code was stopping with no explanation on the KWU9 test case. This was traced to being in the Colburn-Hougen iteration to find the interface temperature with the wall temperature 1 millionth of a degree less than t_{sat}. No root could be found so it went to a 'stop' statement. The 'stop' was replaced with a 'return' and a flag is set so that when it returns to htrc1 it jumps to dittus with mode = 2. Also htrc1 was changed so that t_{wall} must be at least 0.001 less than t_{sat} or it will not go to conden. Removed the call to stcset since it is in htrc1. (3) When an input deck was in British units the pitch-to-diameter ratio was being multiplied times 0.3048 m/ft in rhtcmp. This was a hold-over from when word 10 on the 801/901 card was a natural convection length. (4) A CAMP member pointed out that the droplet drag was taking the minimum of Chawla-Ishii Stokes curve and 0.45 instead of the maximum. This was fixed in fidis2

CODE VERSION BEING CHANGED: rbc3.1.8cj

CODE VERSION BEING CREATED: rbc3.1.3

1. TITLE OF CHANGE: Change version number to production name, fix error in define variable, fix diagnostic message on elevation change input, make secret option for selecting matrix routines illegal.

REASON FOR CHANGE AND DESCRIPTION OF CHANGE: (1) An error in checking the consistency between vertical angle and elevation data when the input elevation was zero has been fixed in several components reading single-volumes. (3) Secret options for controlling matrix solver were made illegal. This will be corrected in the next update. (4) Change version number to a production version number.

CODE VERSION BEING CHANGED: rbc3.1.3

CODE VERSION BEING CREATED: rbc3.1.4

1. TITLE OF CHANGE: Several errors and a few improvements were added to make a temporary production version.

REASON FOR CHANGE AND DESCRIPTION OF CHANGE: (1) Remove Option 44 with the option activated. This makes permanent a fix to the CCFL model. (2) Subroutine chfkut had an incorrect span for a $if def line. Count field was changed. (3) Boron transport option 23 was reversed so that the normal donoring option is standard and the new reduced diffusion method is requested by activating the option. (4) The variable quale, (used to calculate CHF) is calculated in subroutine vlvela and ivlvel. For tmdpvol's it was getting overridden with quals in subroutine tstate. Change tstate to not calculate quale. The value of quale calculated in vlvela and ivlvel was based on the cell center mass flux but for predicting CHF in a cell it is more accurate to base it on the cell exit mass flux. These two routines were changed to use exit steam and liquid flow in the first direction. (5) Change option 49 was added to prevent all water packing when activated. (6) Change option 50 was added to prevent all choking when activated. (7) A printout that was affected when option 25 was used to switch between the new or prior crossflow model was corrected. (8) A data statement was corrected to eliminate a compiler warning. (9) The coding to process volume flags in the crossflow direction was not entered in the input processing subroutine for pipes. The coding has now been added. (10) The problem time was added to the message stating that a restart record has been written. (11) The output quantities, tmassv, tiengv, and flenth, recently were added for assistance in interpreting results. These were missing for accumulator volumes and all junctions when nearly-implicit advancement was used. This has been fixed. (12) A fix was added to statep to allow recovery from a water property error when an extremely small amount of liquid was present. (13) An error in processing wall friction when magneto-hydrodynamic effects were included was fixed. (14) An absolute operation was omitted from the energy loss effects computation. This has been fixed. (15) A NaN appearing in debug printout was fixed. (16) Program version number was advanced.

CODE VERSION BEING CHANGED: rbc3.1.3

CODE VERSION BEING CREATED: rbc3.1.3da

1. TITLE OF CHANGE: Fix quale for tmdpvol, make quale a cell exit quantity.

REASON FOR CHANGE AND DESCRIPTION OF CHANGE: (1) The variable quale, (used to calculate CHF) is calculated in subroutines vlvela and ivlvel. For tmdpvol's it was getting overridden with quals in subroutine tstate. Change tstate to not calculate quale. (2) The value of quale calculated in vlvela and ivlvel was based on the cell center mass flux but for predicting CHF in a cell it is more accurate to base it on the cell exit mass flux. These two routines were changed to use exit steam and liquid flow in the first direction.

2. TITLE OF CHANGE: Correction to friction printout, trivial coding changes to reduce warning messages, fix units conversion in new crossflow input, fix processing of trip stop card due to ftb checking, move statement numbers to eliminate warning messages, addition of new output variables to accumulators and implicit advancement, and valve coding was modernized.

REASON FOR CHANGE AND DESCRIPTION OF CHANGE: (1) Corrections were made to coding using the new water property package that uses pressure and internal energy as the independent variables. Changes were made to istate, statep, and the interpolation subroutines. Development is not complete with this capability. Some checkout coding was removed from istate. (2) Users reported incorrect results in major edits concerning friction values. Output corrected. (3) Warning messages were being issued by the cnv32 routine. This was traced to a line containing subroutine name but the arguments following on the next line. Putting at least one argument on the subroutine line eliminated the warning messages. Note that the original Fortran coding was legal; cnv32 just didn't like it. (4) Processing of stop trip data failed when new capability of loading ftb areas with NaN's. The coding worked before but is more correct now. (5) Some subroutines had statement numbers starting in column 1. This triggers warning messages when the define variable is off. Statement numbers were moved to be right justified. (6) New output quantities were recently added to the computations and added to scan request capability so that they could be edited in minor edits and be plotted. These were not included in accumulators or for nearly-implicit advancement. (7) Valve coding was converted to if-then-else-endif and indented. (8) Program version number was advanced.

CODE VERSION BEING CHANGED: rbc3.1.3da

CODE VERSION BEING CREATED: rbc3.1.3db

1. TITLE OF CHANGE: Change scdinp compile option to avoid Fortran-90 problem, clean up coding based on diagnostic messages from compilers, fixes to inertial valve, and comment out use of testda in sysitr and syssol.

REASON FOR CHANGE AND DESCRIPTION OF CHANGE: (1) The compile time option scdinp completely eliminated some subroutines, causing some compilers to complain when given a null deck. Option was repositioned to leave a subroutine return end shell that can be compiled. (2) Various compilers give error messages concerning the coding. Changes were made in response to messages from a Fortran-90 compilation. (3) Some changes to the inertial valve coding needed further changes. (4) Debug quantities were set in testda in sysitr and syssol. These have been commented out. (5) Program version number was advanced.

2. TITLE OF CHANGE: Fix recovery of equation of state error in statep.

REASON FOR CHANGE AND DESCRIPTION OF CHANGE: Tests with coding that NaN's scratch areas after use discovered unset quantities as part of the noncondensable coding that recovers from a liquid equation of state error when almost no liquid is present. The recovery was fixed.

CODE VERSION BEING CHANGED: rbc3.1.3db

CODE VERSION BEING CREATED: rbc3.1.3dc

1. TITLE OF CHANGE: Eliminate unneeded save statements, blank statements removed, if-goto logic replaced in hydrodynamic component input routines, further refinements to new water property subroutines, error in tstate affecting mass error fixed, and error in servo valve fixed.

REASON FOR CHANGE AND DESCRIPTION OF CHANGE: (1) Save statements were added to most common blocks at some point in the past. Fortran-90 (at least the Dec Fortran-90 compiler) complains about multiple save statements. Thus they have been removed. Commons that must have their information preserved should be invoked in the main (RELAP5) program. This has been done also. Some variables had to be renamed to avoid conflicts with other variables in common. (2) Blank lines were removed since they cause a diagnostic in the precompilers. (3) If-goto logic was replaced with if-then-endif logic in hydrodynamic component input routines. This was done as part of work modifying rbrnch. (4) Further fixes and refinements were put into the new water subroutine package. The typical problem now runs to 1,200 seconds using the new properties and using either semi- or nearly-implicit advancement. (5) An error in tstate in not setting rhom for one of the noncondensable type entries led to incorrect mass error, leading to slow run times. This has been fixed. (6) An error in the servo valve introduced with recent valve changes to eliminate if-goto logic has been fixed. (7) The version number has been advanced.

2. TITLE OF CHANGE: More inertial valve changes.

REASON FOR CHANGE AND DESCRIPTION OF CHANGE: Added variable aflapr to cmpdtv.H. It is the inertial valve disk area. Added aflapr definition to Ccmpdtv.H. Use 2pi from the cons.H common in icompn.F. Use aflapr in valve.F. Change inertial valve θ to average ω. Also change the Cc table argument from fraction theta to fraction area. rvalve.F uses π and changes what limits are placed on the inertial valve input. rstrec has a line that now prints the time with the restart number.

CODE VERSION BEING CHANGED: rbc3.1.3dc

CODE VERSION BEING CREATED: rbc3.1.3dd

1. TITLE OF CHANGE: Local scrtch to global scrtch.H.

REASON FOR CHANGE AND DESCRIPTION OF CHANGE: Variable additions to scrtch.H. The scratch area in the /fast/ common block was accessed using both local and global variables. The global variables were in the scrtch.H comdeck. The local variables were declared and equivalenced inside each subroutine. Some of the variables were local to a subroutine, i.e., they did not have to survive beyond the end of the subroutine. Others were set in one subroutine and had to survive to a later subroutine. It was difficult for the programmers to know which variables were available for use. As a side benefit, it was hoped that this would turn up places where scrtch variables were used before being defined.

NaN coding: As part of this process, coding was also added to put NaNs in the scrtch variable locations after they were done being used. This served as a check to make sure that garbage was not being picked up from a previous use of a scratch slot and used as a new scrtch variable before the new variable was initialized. NaNs are useful because when the code tries to use a NaN in a calculation, it generates a IEEE exception and the code stops. This coding is under the control of $if def,nanscr. There were conflicts between the local scrtch and global scrtch variables and between just local variables in some routines. Thus, some variable name changes were necessary. There were also conflicts within the scrtch.H comdeck as well and the name changes that were made there are documented in the beginning of the comdeck. In order to make it easy for those who are familiar with the old name, a comment was added to all the routines in which name changes were necessary that gives the old name as well as the new name. These comments were placed immediately after the comments on the purpose of the routine. They follow a comment line that reads: c These local variables had their names changed. These comments will be pulled out at a later date, after the programmers become familiar with the new names.

Debug routines for: lpdat.H, contrl.H, voldat.H, jundat.H, scrtch.H blocks. Added some other routines to help with the debugging and analysis of the scrtch variable usage. These are presently called by a new routine named snapit. A sample call is at the beginning of hydro but is commented out. The snapit routine should be called under a if (ncount .eq. number) control. The routines that do the actual printing are in the environmental library and have names like snp*.F or s2p*.F. By using $if def,name / $endif pairs inside the printout routines, plpdat, pcontrl, pvoldat, pjundat, pscrtch, it is also possible to further restrict the printout to only variables of interest. An example from the edhtrk.i test problem for each of four types of variables (double precision, integer, packed integer, character*8) is shown below. At the top of each block, the name of the block and other information about the block are also printed, like number of volumes, skip factor, and ncount.

Printout of /fast/ area: A new routine, fildmp, was added to printout the /fast/ storage area in a sorted order. It is sorted by increasing storage location and includes the name of the comdeck that is used to access that storage area. It could prove useful to a programmer if he/she suspects that they are picking up a value from outside your storage area. Fildmp is called from trnset.

Dinstls changes. Changes made to the dinstls script to allow use on the gcc compiler instead of the cc compiler. The cc compiler on the hp does not have the ANSI options, but the gcc compiler does. A fourth parameter was added that is 'gcc' if the gcc compiler is to be used on the 'hp' computer. If it is omitted, nothing changes and cc is used. The changes are in the call to denvrl.

New scrtch.H comdeck: This set of comments on the scrtch variables consists of four lists: (1) The variables are listed by increasing slot number. This list indicates the type of variable: vol or jun. It also indicates where the variable was finished being used and set to a NaN. (2) The variables are listed in alphabetic order. (4) The variables used in each subroutine are listed by increasing slot number. (4) The variables are listed by increasing slot number. This list has > s between the subroutine names to indicate that the variable has to survive from the previous subroutine to the following subroutine. This list is useful for determining if a slot or variable is free to be used elsewhere.

Define additions: define was changed to add $define nanscr. This slows the code down, but it may catch some problems with use of scrtch.H, so if a programmer suspects problems with scrtch, then turn this define on, rebuild the code, and rerun the code. It may show where the problem is. The variable nanscr turns on the writing of NaNs into the scrtch variable locations. This is done by calling the subroutines nanscv and nanscj. The one with the v suffix is used for volume variables, and the one with the j suffix is used for the junction variables, i.e., they run over all the volumes or over all the junctions in the scrtch area. The NaN is generated by setting all the exponent bits to 1s and setting the high order fractional bit to a 1. The lower order fractional bits are set to the location of the word with respect to the start of scrtch.H in the /fast/ common block. In addition, the second highest bit of the second half of the word, i.e., the part that is used when an integer is equivalenced to the ia(2,*) array, is also set of a 1, so if it is used for an index into the fa array, it goes off into left field and generates a range error on most cpus. (The highest bit is the sign bit). A spelling error was found in jundatc.H and corrected: jacto should be jcato. The correspondence between the component type number and name of the component was added to the cmpdatc.H common deck.

References: A CAMP members' work was used to get some idea of what variables were involved and where they were defined and how long they had to survive. Two files, store-s and store-n, can be replaced by (4) from scrtchc.H. A directory was inserted separately for that purpose, but it is still included as part of scrtchc.H so that it goes along with the code.

CODE VERSION BEING CHANGED: rbc3.1.3dd

CODE VERSION BEING CREATED: rbc3.1.3de

1. TITLE OF CHANGE: Use cos(ang) instead of sin(90-ang) in inertial valve and change the default condensation to Shah-Colburn-Hougen.

REASON FOR CHANGE AND DESCRIPTION OF CHANGE: Speed up CPU by using cos(angle) instead of sin(90-angle). Change the default condensation to Shah-Colburn-Hougen.

2. TITLE OF CHANGE: Fix error in ht1inp.

REASON FOR CHANGE AND DESCRIPTION OF CHANGE: Failure of code in qmwr when only a MW reaction input card is included in the input deck. There was no gap conductance model cards in the deck. These two models should be independent of each other. With this change in ht1inp.F, they are independent of each other, i.e., you can have one without the other.

3. TITLE OF CHANGE: Save matrix needed for moving problems, a scrtch block was fixed, RCS version numbers were added, processing of volume flags in crossflow directions for pipes was added, coding of volume flags was reviewed and coding changed to be consistent, coding to print compile defines was simplified, option 44 (ccfl) was removed with the option active, options 51 and 52 added to eliminate water packing and choking, define variable corrected, local variable initialized in suboil for debug convenience, and some pointer option coding removed.

REASON FOR CHANGE AND DESCRIPTION OF CHANGE: (1) Recent scrtch space changes did now allow successful compilation when the mmfld compile variable was undefined. This has been corrected. (2) A comment card with $Id: history.l,v has been added to come comdecks and decks. The RCS program changes the $Id: history.l,v Exp $ field to add version information. Eventually, this will be done for all comdecks and decks. (3) Coding to process volume flags in the crossflow directions was not entered into the pipe component input routine. This has now been done. (4) A review of the coding for volume flags was done. Coding was modified to be more consistent over the hydrodynamic input routines, and consistent with transient coding. The input manual will be updated. (5) Subroutine adechk which lists the compile time option was modified to be more easily maintained. Define variables can be simply added or deleted without having to maintain a consistent data statement. (6) Chngno(44) (ccfl change) option was removed with the change active. (7) Compile time options, hconden and gesep, were removed with the options activated. (8) Chngno(51) was added to eliminate water packing for all volumes. This same option is 49 in rbc3.1.4. (9) Chngno(52) was added to eliminate choking for all junctions. This same option is 50 in rbc3.1.4. (10) Compile variable dgbkin was changed to dbgkin in nontwoh. (11) In suboil, gammul was initialized to zero for debug printout. (12) Pointer option was removed in volvel. Coding used 'Cray' pointers which are not standard. This was done in the hope of decreased run times which were not realized. Similar work can be done using Fortran 90 techniques. Remaining pointer coding will be removed in upcoming updates. (13) Program version number was updated.

CODE VERSION BEING CHANGED: rbc3.1.3de

CODE VERSION BEING CREATED: rbc3.1.3df

1. TITLE OF CHANGE: Add RCS identifiers to several decks, scrtch comdeck changed, correct/ improve interphase mass transfer terms, remove unneeded scrtch variables from separator subroutines, corrections to recent modification to volume flag handling, complete coding change in pimplt, part of coding using Cray pointers removed, cnv32.f modified so that protection of '[' not required, common usage corrected.

REASON FOR CHANGE AND DESCRIPTION OF CHANGE: (1) RCS identifiers added to several decks. Decks with only this modification are not included in the lists below. (2) The scrtch comdeck had two scratch variables added and the parameter statement defining the skip factor was moved from the tmhlp comdeck to the scrtch comdeck. (3) The usage of the variables involved in interphase mass transfer was not correct with some of the recent changes. With the addition of scrtch variables (2 above) and the change of dotmo to vapgno, the use of the following variables are defined. gammaw is the new time value (including extrapolation) of wall heat flashing; gammac is the new time value of wall condensation; dotm is the new time value of bulk mass transfer, vapgen is the sum of wall heat flashing, wall condensation, and bulk mass transfer, and vapgno is the old time value of vapgen. Vapgen, dotm (as gammai), gammaw, and gammac are defined in scnreq and are thus available for minor edit, plotting, etc. (4) Scratch variables were locally defined in some separator decks. A recent change moved scrtch variable definitions to the scrtch comdeck and in addition these quantities were not used. Thus they were removed. (5) Some of the recent changes in handling of volume flags needed correction. The same error of using the wrong subscript was entered into several r-level and print subroutines. These have been corrected. A separate error in storing flags in r3dcmp was corrected. (6) Coding changes to vectorize parts of pimplt were not complete with old and new coding marked by temporary $if def's. The old coding which was being used was now incomplete in the handling of noncondensables and boron. This has been fixed with the vector coding now being used. (7) Experimental coding using Cray pointers was removed (eventually all of it will be removed.) The same effect will be implemented with Fortran 90 constructs and will thus be standard coding. (8) The preprocessor, cnv32, was modified so that it can process decks for full 64-bit machines (such as Cray) but only process the '['symbol. The [symbol is used to indicate that 1, instead of 2, was to be inserted for 32-bit machine conversions. This line of coding had to be protected by $if def,in32 and another line had to be entered for 64-bit machines. Now only the single line of coding need be entered. Some decks are modified to eliminate the extra line. The source code is still correct if the extra lines are still present. (9) Program version number was advanced.

CODE VERSION BEING CHANGED: rbc3.1.3df

CODE VERSION BEING CREATED: rbc3.2dg

1. TITLE OF CHANGE: Reverse boron advancement option, fix dynamic file print, fix volume flag settings and printout, make size of fast variable, version numbers set, unused variables removed, volume flag corrections, input restrictions added, output for friction fixed, and horizontal void fraction gradient model fixed.

REASON FOR CHANGE AND DESCRIPTION OF CHANGE: (1) Reverse the change option for boron transport such that the option when off uses the original boron transport and when on used the less diffusive boron transport method. (2) A recently added section of the listing of dynamic file usage had incorrect names of comdecks. These were corrected. (3) Friction flag was left out of some printouts of volume flags. Also pump component set thermal stratification (mistake from when the same bit was scaler wall friction option). These have been fixed. (4) The size of fast common was made dependent on compile variable titlbet. When titlbet is defined, fast is increased to 5M words instead of the standard 2.2M words. (5) Program version number was incremented. Also, compile variables were set so that the NRC production version, and the ongoing development version all have different titles. (6) Unused variables were removed from subroutine htrcn2. (7) Printout for volume flags was corrected. (8) Connection restrictions for level tracking and thermal stratification model were added to input processing. The diagnostic message concerning thermal stratification was moved. (9) Major edit printout for wall friction was fixed. (10) An error in the horizontal void fraction gradient model was fixed.

2. TITLE OF CHANGE: Comment in conden, format in recrst, Shah in dittus.

REASON FOR CHANGE AND DESCRIPTION OF CHANGE: The comment about the alternate condensation model was incorrect. The format for printing time of restart is slightly changed. The Reynolds number exponent on the Shah correlation in Dittus was 0.61, it is now 0.62 which is the correct value.

3. TITLE OF CHANGE: Correction of boron transport model for pipe with crossflow junction.

REASON FOR CHANGE AND DESCRIPTION OF CHANGE: The Godunov method implemented for boron transport calculation of one-dimensional flow has a faulty logic for pipe with crossflow. The code is updated such that the Godunov method is used only for a volume connected with one junction to the inlet and one junction to the outlet.

CODE VERSION BEING CHANGED: rbc3.2dg

CODE VERSION BEING CREATED: rbc3.2dh

2. TITLE OF CHANGE: Correct divide by zero in level, correct divide by zero in eqfinl.

REASON FOR CHANGE AND DESCRIPTION OF CHANGE: (1) A user had a divide by zero in level subroutine. Unprotected divide by zero was fixed. (2) A user discovered divide by zero in eqfinl. Protection was added to avoid the divide by zero. (3) Program version number was advanced.

CODE VERSION BEING CHANGED: rbc3.2dh

CODE VERSION BEING CREATED: rbc3.2di

1. TITLE OF CHANGE: Correct offtake model for top and bottom junctions.

REASON FOR CHANGE AND DESCRIPTION OF CHANGE: (1) In running the AP600 DVI break, it was noticed that the offtake model was not coming on for a top junction. The indices used in imap to determine the flow map were using the vertical direction rather than the horizontal direction, which is needed for the model. This modification needs to be made more general in the future to allow vertical direction. (2) Program version number was advanced.

CODE VERSION BEING CHANGED: rbc3.2di

CODE VERSION BEING CREATED: rbc3.2dj

1. TITLE OF CHANGE: Add option 53 to remove 50 K limit for steam/noncondensables.

REASON FOR CHANGE AND DESCRIPTION OF CHANGE: In running the AP600 DVI break, an INEL user found that the calculation failed in the DVI line after the accumulator emptied of water and noncondensables had entered. The failure was a failure to converge the steam/noncondensable iteration after 20 attempts at the minimum requested time step. The change is to install option 53 which removes the 50 K limit for steam/noncondensables in subroutine statep. The option also removes the time step control based on 50 K for steam/noncondensables. Program version number was advanced. NRC number was set to 3.2x0.

2. TITLE OF CHANGE: Correct offtake model for new crossflow model.

REASON FOR CHANGE AND DESCRIPTION OF CHANGE: In running the SPES DVI break, an INEL user found that calculation ran very slow due to problems in a volume where a connected junction invoked the off-take model.

CODE VERSION BEING CHANGED: rbc3.2dj

CODE VERSION BEING CREATED: rbc3.2dj1

1. TITLE OF CHANGE: Add athrot test in zeroing out volume velocities.

REASON FOR CHANGE AND DESCRIPTION OF CHANGE: In running a long term OSU SBLOCA calculation, an INEL user found many code failures in the DVI line due to bad junction velocities. The change is to add a throat ratio (athrot) test in addition to the velocity test when deciding which terms in the summations should be zeroed out in the volume velocity subroutines ivlvel, vlvela, and volvel.

2. TITLE OF CHANGE: Use of new connection codes allowed in separator, jetmixer, turbine, and eccmix components, setting of no abrupt area flag when momentum flux omitted now removed, crossflow and horizontal entrainment/pullthrough now allowed in valves, boron initialization in pipe component fixed, default hydraulic diameters for crossflow directions improved, diagnostic message in rbrnch fixed, excessive lines in scrtch common fixed.

REASON FOR CHANGE AND DESCRIPTION OF CHANGE: (1) Separator, jetmixer, turbine, and eccmix hydrodynamic components have extra checking of connections to volumes as required by the respective models. The checks used the old volume connections codes (which are still allowed) but did not allow the new codes. The input coding has been modified to allow the new connection codes. (2) Code previously set the abrupt area model off if the crossflow model was requested. With the changes in the crossflow model, this is no longer needed. When the momentum flags, which used to be called crossflow flags) are on, the abrupt area flag is no longer set to off. (3) Valves are now allowed to be connected in crossflow mode, to remove momentum flux terms, and to use the horizontal stratification entrainment/ pullthrough model. (4) The processing of initial conditions for pipe components did not recognize the need for additional boron data as stated in the manual. The need would be recognized only if the last volume specified boron, rather than as intended if any volume specified boron. This has been fixed. (5) The default hydraulic diameter for the optional crossflow directions was not computed consistently in all components and was not appropriate for the stated assumption of a circular pipe. This computation is now consistent and is considered a better approximation. (The user should enter the hydraulic diameter in most cases.) (6) A diagnostic message in rbrnch giving the number of words in the input line rather than card number was corrected. (7) The problem with too many continuation lines in the sctch common block (effected the SUN-OS compiler only) was fixed in two ways. The number of lines was reduced to meet the Fortran 77 standards. The scripts for the SUN-OS compiler were modified to accept a large number of lines in a statement. (8) Program version number was advanced

CODE VERSION BEING CHANGED: rbc3.2dj1

CODE VERSION BEING CREATED: rbc3.2dj2

1. TITLE OF CHANGE: Fixes in eqfinl, rlevel, statep, and viscos.

PROBLEM STATEMENT OR OTHER REASON FOR CHANGE: (1) An INEL user found that the total mass transfer rate (vapgen) was incorrect when plotting CMT test calculations. (2) During testing and manual changes for MOD3.2, errors were found in R-level subroutines. (3) During testing for MOD3.2, a divide by zero was found in subroutine statep. (4) An INEL user obtained a floating point exception error in viscos.

DESCRIPTION OF CHANGE: (1) Subroutine eqfinl was fixed to correctly calculate the variable vapgen. (2) Subroutine raccum, rbrnch, rpipe, rpmvnj, and rturb were fixed to correct errors in junction flags a, h, and s, as well as for connection codes. Subroutine rpipe was fixed to correct volume flag f. Subroutines rpipe, rsngv, and rbrnch were fixed to correct default hydraulic diameters. (3) Subroutine statep was fixed to protect a divide by zero in the noncondensable appearance logic. (4) Subroutine viscos was fixed by using triple-point temperature when liquid temperature is less than triple-point temperature.

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S. Smith, NRC Project Manager

11. ABSTRACT *(200 words or less)*

Summaries of RELAP5/MOD3 code assessments, a listing of the assessment matrix, and a chronology of the various versions of the code are given. Results from these code assessments have been used to formulate a compilation of some of the strengths and weaknesses of the code. These results are documented in the report. Volume 7 was designed to be updated periodically and to include the results of the latest code assessments as they become available. Consequently, users of Volume 7 should ensure that they have the latest revision available.

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