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GOTHIC DESIGN REVIEW

FINAL REPORT

Prepared for

the

ELECTRIC POWER RESEARCH INSTITUTE

by the

Design Review Group

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1.0 INTRODUCTION

The Electric Power Research Institute (EPRI) established a peer group to perform a design review of the GOTHIC code package, described below, for containment analysis. This review was conducted to establish a point of reference as GOTHIC is placed under a 10CFR50, Appendix B, QA program for all future work on the code. This effort was necessary because the development effort had been performed with informal QA procedures without independent review. While the review was initiated for version 3.4D, the conclusion of this review applies to Version 4.0. The design review covered the theory, programming, verification, validation and scope of application of the GOTHIC program.

GOTHIC is being developed by Numerical Applications Inc (NAI) under development contracts with EPRI. It is a code package for solving multiphase, multicomponent fluid and heat transfer problems with specific application to nuclear plant containment and confinement analysis. The code package includes three separate computer programs:

1) GOTHIC_P for pre/postprocessing (interactive input preparation and interactive graphical output);

2) GOTHIC_S for reading input, solving the thermal-hydraulic equations, writing output and data files; and,

3) GOTHIC_G for extracting graphics data from the GOTHIC_S results.

The major focus of the review was on GOTHIC_S. GOTHIC_G and GOTHIC_P were not reviewed directly, but, were reviewed implicitly during the process of the design review.

The Design Review Group (DRG) consisted of individuals with considerable knowledge in the design, development and use of large thermal-hydraulic analysis computer codes such as GOTHIC and with large containment test programs. Full names, addresses, phone numbers and resumes of those involved with the design review are presented in Appendix A.

2.0 OBJECTIVES AND SUMMARY

This section presents the objectives and a summary of results from the GOTHIC Design Review.

2.1 DESIGN REVIEW OBJECTIVES

The objective of the GOTHIC Design Review is to:

1. Assure that GOTHIC satisfies the EPRI criteria for code release.

    A. Documentation must exist that:

        1. Describes the theory and assumptions made in developing the models (empirical, first principles, correlations, etc.) within the GOTHIC solver (GOTHIC_S).

        2. Describes the GOTHIC code (GOTHIC_S) logic and solution scheme.

        3. Describes in detail how to prepare the input to the code (GOTHIC_S), both with and without the pre/postprocessor (GOTHIC_P).

        4. Describes the approach and calculations performed in the pre/postprocessor (GOTHIC_P).

        5. Describes how to install the code on a user's computer system.

    B. The code solver (GOTHIC_S) and pre/postprocessor (GOTHIC_P) must be verified to assure:

        1. The coding is consistent with the code documentation (GOTHIC_S).

        2. The solution technique is stable and convergent (GOTHIC_S).

        3. The code is correctly solving the equations of the mathematical model (GOTHIC_S).

        4. The preprocessor (GOTHIC_P) is correctly translating to an input file that an experienced code user would produce.

    C. The code solver (GOTHIC_S) and pre/postprocessor (GOTHIC_P) is validated to perform the analysis required of it by one or more of the following:

        1. Comparison to relevant test data.

        2. Comparison against similar calculation techniques.

        3. Assuring that all results are consistent with physical assumptions made.

2. Determine that GOTHIC is adequate to evaluate the containment and containment sub-compartment response from the full spectrum of high energy line breaks within the design basis envelope as described in FSAR Chapter 6, Section 2. Determine the applicability of GOTHIC for general Thermal-Hydraulic analysis for normal and off-normal conditions in primary containment, secondary containment, supporting fluid systems and other structures. Applications should include pressure/temperature determination, equipment qualification profiles and inadvertent system initiation, degradation or failure of engineered safety features (e.g. loss of one spray train, loss or degradation of fan coolers or HVAC systems) and other thermal-hydraulic phenomena occurring in plant facilities.

   FSAR Chapter 6, Section 2, above is intended to refer to the applicable section of the standard review plan for containment analysis. Some of the older versions of plant FSARs have chapter numbers that are different from the newer FSARs.

2.2 SUMMARY AND CONCLUSIONS

In response to the above objectives and as a result of the review, the DRG makes the following summary and conclusions.

2.2.1 Documentation

The DRG reviewed all GOTHIC documentation. As a result of that review the DRG concludes the following:

1) The GOTHIC Technical Manual provides documentation that describes the theory and assumptions made in developing the models (empirical, first principles, correlations, etc.) and it also describes the code logic and solution scheme.

2) The GOTHIC Programmer Manual provides adequate documentation to describe GOTHIC from a programmer's point of view.

3) The User Manual provides information to describe in detail how to prepare the input both with and without the pre/postprocessor (GOTHIC_P). It also describes the approach and calculations performed in the pre/postprocessor (GOTHIC_P).

4) The documentation is adequate to describe how to install GOTHIC 4.0 on supported computer systems.

2.2.2 Coding, Convergence and Pre/Postprocessor:

The DRG reviewed source code in the areas consistent with the documentation review. Of the approximately 90 code modules of GOTHIC_S, 44 had some level of review. This included the important routines for the mathematical model and numerical solution. Convergence and operation of the pre/postprocessor GOTHIC_P were assessed by test cases of the DRG and by surveys of GOTHIC user experience. As a result of that review the DRG concludes the following:

1) Source code is consistent with the Technical Manual, User Manual and Programmer Manual documentation.

2) Based on the DRG test cases, reports by users, and the technical review, the solution technique of GOTHIC_S is stable and convergent. An iterated Newton method is recommended as a future option in Section 4.3.

3) GOTHIC users have had extensive experience with GOTHIC_P and it is capable of preparing accurate input for GOTHIC_S.

4) The pre/postprocessor (GOTHIC_P) is consistent with the code specification documentation.

5) The pre/postprocessor (GOTHIC_P) correctly generates an input file, consistent with the graphical models and tables, that an experienced user would produce.

6) The pre/postprocessor (GOTHIC_P) is validated to perform the analysis required of it.

2.2.3 Code Qualification

The DRG reviewed code qualification document topics consistent with their areas of technical review and expertise. As a result of that review the DRG concludes the following:

1) The Qualification Manual adequately describes the validation analysis for GOTHIC.

2) The validation analysis demonstrates the capability of GOTHIC to consider a wide range of thermal hydraulic phenomena applicable to containment analysis and general thermal-hydraulic applications. This is supported by successful comparisons to the GOTHIC Standard Problems, DRG demonstration problems and large scale containment experiments. GOTHIC_S is validated to perform the analyses required of it.

3) While the Qualification Manual presents an impressive array of cases and with successful comparisons to data and test cases, the calculations have not had independent review. More extensive review than that provided by the DRG may be necessary for an auditing or licensing body. Such a detailed review was beyond the work scope of the DRG.

4) Users should be aware of the GOTHIC's range of application and the validation analyses that support it.

2.2.4 Adequacy for Containment Analysis

The DRG concludes that the GOTHIC containment analysis package is adequate for containment analysis as defined above in Section 2.1. The mathematical modeling of GOTHIC is best estimate and offers a level of analysis capability consistent with (or of greater capability than) computer programs currently used for containment analysis (such as COMPRESS, CONTEMPT). In that regard GOTHIC has the capability to provide more accurate and mechanistic results than with current containment analysis codes.

The DRG qualifies the above statement as follows:

1) Nodal treatment of the containment and its systems can affect the quality of results. Nodal treatment and junction selections should be carefully reviewed for each application to assure that proper modelling is used.

2) GOTHIC_P can provide user defined input to GOTHIC_S via the *.sin files. The users should retain knowledge of those files since they are the input to GOTHIC_S.

3) While the qualification data base is quite extensive and demonstrates the range of application of GOTHIC, users must be aware of the capability and limitations of GOTHIC to assure its proper use. It should be understood that, while the DRG reviewed the results of the qualification work, it did not review the underlying input file preparation for that work.

4) GOTHIC 4.0 has the capability to perform analysis well beyond the range of the qualification data base presented in the documentation. Its mathematical models and numerical solution have the potential for a wider range of thermal-hydraulic applications. Such applications should be justified by users as appropriate to their analysis.

2.3 FINAL REMARKS

The initial review effort began with GOTHIC 3.4D. During the period from the initial review and this final report, NAI had the opportunity to respond to many original review comments in the form of modification to the mathematical model, coding and documentation. The result is that all DRG findings have been fully resolved and the conclusions of this review apply to GOTHIC 4.0.

3.0 REVIEW ELEMENTS

3.1 MATERIALS REVIEWED

The base documents and materials used to initiate the review included:

GOTHIC Containment Analysis Package, Technical Manual, NAI-8907-06, July, 1991.

GOTHIC Containment Analysis Package, Installation and Operations Manual, NAI-8907-08, April, 1991.

GOTHIC Containment Analysis Package, Programmer's Manual for GOTHIC_S, NAI-8907-10, June, 1991.

GOTHIC Containment Analysis Package, User's Manual, NAI-8907-02, April, 1991.

GOTHIC Containment Analysis Package, Qualification Report for GOTHIC_S, NAI-8907-09, June, 1991.

Quality Assurance Program for Numerical Applications Inc. NAI-QA-1, Rev 4, July 1990.

GOTHIC 3.4D source code.

These are also listed in the References of Section 5.0 together with supplementary materials used for the review. Additional material was reviewed during the conduct of the review as discussed in Section 3.2.

Official correspondence between members of the Design Review Group and the GOTHIC code developers at NAI was coordinated through the Chairman of the Design Review Group. All such correspondence and review forms are part of the Design Review Record inventory as listed in Appendix G.

3.2 CONDUCT OF THE REVIEW

The methods, logic and criteria for the design review were developed by the DRG. Review assignments were made to cover topics presented in the GOTHIC technical reports. The Tables of Contents of the NAI documents were used to identify the specific topics and assignments presented in Table 3.1. Assignments and the conduct of the review were made with the following philosophy:

Technical Manual (TM) review assignments were made consistent with expertise and interest of the reviewers.

Review of the User Guide (UG) and Programmer Manual (PM) follow the Technical Manual assignments so that all members reviewed some aspect of the theory, mathematical modeling, corresponding coding and related input/output.

The Qualification Manual (QM) presents important results that demonstrate GOTHIC's capability to consider containment phenomena. The depth of this review, however, was abbreviated because of time and funding. While NAI has done qualification analysis based on their internal QA procedures, it has not had independent check and review. Because it was not possible to do that independent check as part of the current review, it was necessary to assume the experiments and test cases were properly represented by input and model selections. The approach taken was to assess the nature of the validation analysis in relationship to the modeling features employed. The intent was to make engineering judgement statements regarding:

1) The reasonableness of the validation results in terms of the phenomena being considered.

2) Suitability of GOTHIC to evaluate various features of containment design.

3) The capability of GOTHIC to evaluate FSAR, Chapter 6.2, transient analysis consistent with Objective 2 presented in Section 2.1.

Results were reported on forms filled out during the review process. Reviewers reported both positive findings and exceptions. Exceptions were reviewed with NAI to obtain resolution.

Each review topic and corresponding report was coded by document and section. For example, review of heat exchangers from the Technical Manual was coded from the Tables of Contents of NAI-8907-06 as TM 5.6.

Source code (Version 3.4D, [25]) was also reviewed. All members of the review group executed nondisclosure agreements related to the code and technical reports to protect the proprietary rights of EPRI and NAI.

Each review topic was reported on review forms. Sheets with added information were appended as necessary to support the items listed on the form.

The first meeting of the DRG was November 6-7, 1991, [26] where the above review process was defined. It was followed by a meeting on December 18-19, 1991, [27] where initial review findings were presented and discussed with NAI. Following the December 1991 meeting, approximately 18 months lapsed before the review was resumed [28]. During that period, NAI responded to the initial findings of the DRG in several ways:

1) Prepared revisions to documentation. The Technical Manual was revised [29] and re-issued for review by the DRG.

2) Revised coding leading to Version 4.0

3) Reran and/or revised qualification cases and GOTHIC Standard Problems.

The resumption of the review resulted in the June 8-9, 1993, [30] meeting of the DRG. Prior to that meeting NAI distributed information to each of the DRG members [31, 32, 33, 34] concerning their response to findings from the initial review. That information was also consolidated into a summary document [35] distributed to the DRG. This was used as the DRG "signoff" document for resolution of items at the June 1993 meeting. See Appendix B for a full copy of the summary document that resulted from that meeting.

Following the June 1993 meeting:

1) NAI prepared a summary of all items changed since GOTHIC, Version 3.4D [36]. The changed items pertained to GOTHIC_S and to the corresponding sections of the Technical Manual, where applicable. The summary was sent to all DRG members for their information.

2) NAI prepared responses to open items and distributed them to DRG members [37, 38, 39, 40] for "signoff" to resolve those items.

3) The DRG responded individually [41, 42, 43, 44, 45] to NAI's response to the open items and to the summary of changes.

As a result of this process all review items leading to Version 4.0 were fully resolved.

Table 3.1 Gothic Design Review Group - Review Assignments

TECHNICAL MANUAL (TM)

1.0 Introduction	McFadden
2.0 Containment Analysis	McFadden
3.0 Governing Equations	Rowe
4.0 Junctions	Rowe
5.0 Engineered Safety Equipment	Westinghouse, Slaughterbeck
6.0 Conductors	Rowe
7.0 Interfacial Source Terms	McFadden, Corradini
8.0 Wall Source Terms	McFadden, Corradini
9.0 Stress Tensor and Turbulent Diffusion	Corradini
10.0 Material Properties	McFadden
11.0 Finite Volume Equations	Rowe
12.0 Solution Algorithm	Rowe

USER GUIDE (UG)

1.0 Introduction	All
2.0 Modeling Features	All
3.0 GOTHIC_P Users Guide	Westinghouse
4.0 Common Options and Menus	Westinghouse
5.0 Main	Westinghouse
6.0 Preprocessing	Westinghouse
7.0 Volumes	All (a)
8.0 Flow Paths	All (a)
9.0 Thermal Conductors	All (a)
10.0 Components	All (a)
11.0 Material Properties	All (a)
12.0 Fluid Boundary Conditions	All (a)
13.0 Fluid Initial Conditions	All (a)
14.0 Control Parameters and Restart	All (a)
15.0 Postprocessing	Westinghouse
16.0 Modeling Guidelines	All (a)
17.0 Examples	Westinghouse
18.0 GOTHIC_S User's Guide	All (a)
19.0 GOTHIC_S Input	All (a)
20.0 GOTHIC_G User's Guide	Westinghouse
21.0 Redimensioning GOTHIC	Westinghouse

(a) All members review those sections related to Technical Manual assignment review sections.

QUALIFICATION MANUAL (QM)

1.0 Introduction	All (a)
2.0 Summary	All (a)
3.0 CSNI Numerical Benchmark Problem	Slaughterbeck
4.0 GOTHIC Standard Problems	Rowe
5.0 Battelle-Frankfurt Test Facility Descr.	Westinghouse
6.0 Battelle-Frankfurt Test D-1	Westinghouse (a), Corradini
7.0 Battelle-Frankfurt Test D-15	Corradini
8.0 Battelle-Frankfurt Test D-16	Westinghouse (a), Corradini
9.0 Battelle-Frankfurt Test 6	Westinghouse (a)
10.0 Battelle-Frankfurt Test 12 and 20	McFadden
11.0 Battelle-Frankfurt Test C-13 and C-15	Corradini
12.0 HEDL Hydrogen Mixing Tests	Corradini
13.0 LACE Tests	Slaughterbeck
14.0 Marviken Full Scale Containment	Slaughterbeck
15.0 CVTR Simulated DBA Tests	Slaughterbeck, Corradini
16.0 HDR Full Scale Containment Experiments	Corradini

(a) Westinghouse to pick at least 2 representative tests for review from Sections 6 through 11.

PROGRAMMER MANUAL (PM)

1.0 Introduction	All
2.0 Flow Chart	All (a)
3.0 Definitions for Common Variables	All (a)
4.0 Subroutine Summaries	All (a)
5.0 Graphics Interface	None (b)

(a) All members review those sections related to Technical Manual assignment review sections.

(b) Review of Section 5.0 is not necessary because it is only related to how changes would be made to the graphics interface.

4.0 RESULTS OF THE REVIEW

The review results are presented as several major parts: 1) Documentation; 2) Source Code; 3) Stability and Convergence; 4) GOTHIC_P; 5) Validation; and, 6) Adequacy for Containment analysis.

4.1 DOCUMENTATION

This review considered the five primary GOTHIC documents.

4.1.1 Technical Manual

All sections of the Technical Manual were reviewed as indicated in Appendix A.1. As a result of the initial review, the original Technical Manual [7] was superseded by a revised Technical Manual [29]. The revision responded to all of the review comments and included added information on the numerical solution.

The DRG concludes that the GOTHIC Technical Manual provides documentation that describes the theory and assumptions made in developing the models (empirical, first principles, correlations, etc.) and it also describes the code logic and solution scheme.

4.1.2 Programmer Manual

All sections of the Programmer Manual were reviewed as indicated in Appendix A.4. Suggestions were made from review findings that will be included in future revisions of the Programmer Manual. All findings of the review are fully resolved. The Programmer Manual provides information that describes the programs organization, variable names, subroutines summary and the graphics interface.

The DRG concludes that the GOTHIC Programmer Manual provides adequate documentation that describes GOTHIC from a programmer's point of view.

4.1.3 User Manual

All sections of the User Manual were reviewed as indicated in Appendix A.2. Suggestions were made from review findings that will be included in future revisions of the User Manual. All findings of the review are fully resolved.

The DRG concludes that the User Manual provides information that describes in detail how to prepare the input both with and without the pre/postprocessor (GOTHIC_P). It also describes the approach and calculations performed in the pre/postprocessor (GOTHIC_P).

4.1.4 Qualification Manual

The material reviewed included the GOTHIC Containment Analysis Package, Qualification Report for GOTHIC_S. Each DRG member evaluated the assigned validation analysis and drew conclusions regarding the code or model features validated by the analysis. Sections of the

Qualification Manual were reviewed as indicated in Section 4.5 and Appendix A.3. Suggestions were made from review findings that will be included in future revisions of the Qualification Manual. All findings of the review are fully resolved.

The DRG concludes that the Qualification Manual adequately describes the validation analysis for GOTHIC.

4.1.5 Installation Manual

The adequacy of the installation documentation was assessed through a survey of installations made by the GOTHIC User Group. A survey letter was prepared with the objective of answering the question: Were you able to install GOTHIC using the information provided in GOTHIC Containment Analysis Package, Installation and Operations Manual and other material supplied by the code distributor, except for site specific requirements? If not, why not?.

Eight responses were obtained. GOTHIC was installed on mainframe, UNIX work station and micro computers (Macintosh, IBM compatible PCs). The responses all were positive relative to the completeness and adequacy of the installation instructions. A summary of the responses is presented in Appendix C.

A comment of interest is:

> "It would be valuable to change dimensions without recompiling."

The DRG concurs with, and suggests, this change for a future version of GOTHIC.

The DRG concludes that documentation is adequate to describe how to install GOTHIC 4.0 on supported computer systems.

4.2 SOURCE CODE

The review of source code was done in a way consistent with the review of the GOTHIC_S code manuals. Each reviewer considered selected code modules and program areas consistent with the technical review and related topics. Of the approximately 90 code modules of GOTHIC_S, 44 had some level of review as indicated in Appendix A.5. All of the important routines related to the numerical solution were reviewed and all review findings were fully resolved.

GOTHIC_P and GOTHIC_G source code was not reviewed. The operation of GOTHIC_P was assessed by the user survey and by example of input prepared with, and without, GOTHIC_P.

Jim McFadden was additionally assigned the task of reviewing a code compilation for undefined variables, undefined externals, and any other errors that may be uncovered for the installed version of GOTHIC at CSA. A summary of the results of his review [43] follow:

The items identified in the review report include:

- Undefined and unused variables,
- Code for models not supported by GOTHIC,
- Use of certain types of DATA statements and intrinsic function,
- An apparent unnecessary subroutine call.

The responses were all satisfactory and are summarized as follows:

- Explanations were provided for the undefined variables (locally specified) and for the DATA statements and the subroutine call,
- The list of unused variables in the Programmer Manual was extended,
- References to unsupported code and models were removed,
- The intrinsic functions were replaced with generic functions (will improve the portability of GOTHIC).

The overall result of this review were changes to documentation and code changes leading to GOTHIC 4.0.

The DRG concludes that source code is consistent with the Technical Manual, User Manual and Programmer Manual documentation.

4.3 STABILITY AND CONVERGENCE

Stability and convergence was assessed from several points of view.

1) Dave Paulsen was assigned the task of investigating convergence and stability by running GOTHIC with selected sample cases. Cases were run to demonstrate stability and convergence by considering null transients. Cases were also considered to demonstrate symmetric results from GOTHIC where symmetry is expected regardless of the nodal order. A summary and results from his review [46] are as follows:

Paulsen #1 (Four node null transient)

Description:

This problem consisted of four identical lumped parameter nodes with one pair stacked directly above the other. The nodes are linked by identical flow paths. All of the nodes are initialized with the same atmospheric conditions. No correction is made to account for the elevation difference. This is a null transient with no transient forcing functions applied.

Solution:

The solution for this problem should be zero flow rates for each of the flow paths once pressures equilibrate. If flows develop after the initial pressure correction, then the solution is not converging or numerical diffusion is driving the result.

In this case, the results are as expected with no flow occurring after the initial pressure transient.

Paulsen #2 (Four node null transient, subdivided volumes)

Description:

This problem is the same as #1 except that each lumped parameter node is horizontally divided into three elevations. The divisions are identical.

Solution:

The same solution as for #1 should be expected for this problem. This case will check the solution to the null transient when volumes are subdivided.

The flow rate is essentially zero. There is a very small flow rate that is much less than 0.001 lbm/sec and it is damping out.

Paulsen #3 (Four node null transient, subdivided volume, switched nodes)

Description:

This problem is the same as #2 except that two nodes have been swapped.

Solution:

This problem should duplicate the solution for #2. If it does, then the node numbering order does not affect the solution. This case did duplicate #2 indicating that the order for numbering nodes does not affect the solution.

While not exhaustive, the above cases demonstrate stable, convergent and symmetric results for simple cases. The results of the cases in the Qualification Manual and those reported by the GOTHIC User Group also support stable and convergent solutions. The DRG has not found any cases of unstable or nonconvergent solutions.

2) In addition to the above stability and convergence tests, GOTHIC also includes time step control. GOTHIC is implicit with regard to sonic propagation and explicit with respect to fluid convection and diffusion. The built-in time step controls are devised to maintain a stable time step for both convection and diffusion. The code also performs tests for nonphysical results and if detected, the solution is backed up one step, the time step halved and step repeated.

3) The code uses a one-step Newton method to advance the solution one time step. The success of this method relies on accurate derivatives to form the linear equations actually solved for the time increment. While the derivatives used in the solution were reviewed and no errors were found, it can not be said there are none.

The one step method is contrasted with a traditional Newton method that is iterated to convergence where residuals approach zero. The one step method is equivalent to one iteration; and, if derivatives are perfect, then the correct answer is obtained as a result of one iteration. Such is the case with a linear system. While nothing has been found to negate the accuracy of the one-step method, it is difficult to assure the accuracy of the solution for all conditions.

It is recommended that consideration be given to including an iterated Newton solution option in a future version of GOTHIC. Such an option would allow assessment of solutions to assure convergence at each time step. An iterated Newton method provides an approach to assure that a converged solution is obtained although it will not identify missing derivatives or errors in derivatives. Convergence is assured if the residuals approach zero. Such an option could be used to confirm the faster one-step method currently being used.

Based on the DRG test cases, reports by users, and the technical review, the DRG concludes that the solution technique of GOTHIC_S is stable and convergent. An iterated Newton method is recommended as a future option.

4.4 GOTHIC_P

GOTHIC_P is an important part of the GOTHIC code package. GOTHIC_P provides an interactive input process that would be the choice of most users. The review of GOTHIC_P consisted of several activities with results as follows:

1) Review of the GOTHIC Programmer Manual and GOTHIC User Manual as it applies to GOTHIC_P. The results of this review are presented in Section 4.1.

2) GOTHIC_P was exercised as part of the review process. Dave Paulsen (Westinghouse) was assigned the task of using GOTHIC_P to prepare input for a representative sample case(s) of their choice. The resulting input file that was prepared was then compared to the input file that would prepared without GOTHIC_P. GOTHIC_S was executed using input from both processes and the results were compared.

   The results showed that GOTHIC_P produced the same input that a user would prepare for GOTHIC_S. Furthermore, GOTHIC_S produced the same results regardless of originating input process.

3) The GOTHIC User Group was surveyed regarding their use of GOTHIC_P. Questions were posed regarding their use, experience, known errors, and usefulness of GOTHIC_P.

   The users provided very positive responses to their use of GOTHIC_P. All users find that GOTHIC_P is very important for input preparation for GOTHIC_S. There has been considerable checking of the two methods of input by the users and with excellent results. There have been a few discrepancies identified and fixed by NAI prior to the design review. The users would conclude that GOTHIC_P is very important to prepare input for GOTHIC_S. A summary of the survey results is presented in Appendix E.

4) GOTHIC_P has also had implicit validation since is was used to prepare all input and presentation of results for all of the cases presented in the Qualification Manual. This is an extensive body of analysis that supports the use of GOTHIC_P.

   The DRG concludes that:

   > **The users have had extensive experience with GOTHIC_P and it is capable of preparing accurate input for GOTHIC_S.**
   >
   > **The pre/postprocessor (GOTHIC_P) is consistent with the code specification documentation.**
   >
   > **The pre/postprocessor (GOTHIC_P) correctly generates an input file, consistent with the graphical models and tables, that an experienced user would produce.**
   >
   > **The pre/postprocessor (GOTHIC_P) is validated to perform the analysis required of it.**

4.5 GOTHIC VALIDATION

The validation of GOTHIC consisted of several activities including: 1) review of GOTHIC Standard Problems; 2) DRG devised test cases; 3) comparisons to test data; and, 4) feature summary.

4.5.1 GOTHIC Standard Problems

These problems provide test cases where known solutions exist. They range from demonstration problems with expected final results to problems with known analytical solutions. These provide an excellent basis to check the code numerical solution and the modeling of physical phenomena. As reported in Section 4.1.4, the documented standard problems were found to be satisfactory for their stated purpose.

The Qualification Manual presents nine of a total of 37 standard problems currently in use by NAI. The DRG has reviewed a summary list of the full set of standard problems but has not reviewed the full set of results. The nine problems that were presented and reviewed were considered valuable to basic code validation and representative of the full set of problems.

The standard problems presented in the Qualification Manual [11] and reviewed include the following:

GOTHIC Standard Problem 1 (Two Volume Recirculation)

The problem considers two side-by-side volumes connected top and bottom by junctions. Heating is applied to one volume and cooling in the other. The steady-state recirculation flow rates and temperatures are defined by an analytical solution that agrees with the GOTHIC calculations.

GOTHIC Standard Problem 3 (Single Volume, Air Compression)

A single volume initially contains air and air is injected at a constant flow rate and enthalpy. The temperature and pressure are defined by analytical solution that agrees with the GOTHIC calculations.

GOTHIC Standard Problem 2 (Single Volume, Air and Hydrogen Compression)

This is the same as Problem 3 above except that hydrogen is injected. The pressure and temperature response calculated by GOTHIC agrees with the analytical solution.

GOTHIC Standard Problem 6 (Two Volume, Nozzle and Pump test)

Two side-by-side volumes are connected top and bottom by horizontal junctions. One volume is filled 60% with water and 40% vapor and the other is full of water. A pump on the bottom junction pumps water from Volume 2 to Volume 1 to test both nozzle and pump components. The results of the GOTHIC calculations agree with the analytical solution for this case.

GOTHIC Standard Problem 7 (Heat Exchanger)

This case tests heat exchanger logic for a parallel-counterflow tube and shell type with shell side mixed and two tube passes. The GOTHIC results agree with an analytical solution for this configuration.

GOTHIC Standard Problem 13 (Multinode Volume Compression)

This is the same as Problem 3 but the volume is divided into a 3x3 mesh (3 channels, 3 axial levels) and initially contains air at uniform temperature. Air is injected into the bottom cell of the center channel at constant temperature and flow rate. As the transient progresses, the air temperature increases due to the work of compression. Also, the cool injected air is retarded from rising because of stratification. The results provide the correct mass and energy balance, proper treatment of donor logic and results consistent with expected phenomena.

GOTHIC Standard Problem 26 (Thermal Conduction in a Rod)

This problem considers transient thermal conduction in a rod -- one of several types of conductors considered by GOTHIC. The transient results are in agreement with an analytical solution for the selected conditions.

GOTHIC Standard Problem 28 (Critical Flow)

Critical flow is tested by an upstream boundary condition connected to a volume by junction. Discrete sets of upstream conditions are applied and the most appropriate published model is used to calculate the critical flow. The agreement between the GOTHIC results and the published models is good.

GOTHIC Standard Problem 37 (Condensation Test)

A steam/air mixture is injected into as single volume at various velocities. The GOTHIC computed results compare favorably with experimental data from the University of Wisconsin.

4.5.2 DRG Devised Test Cases.

The DRG devised added test cases to assist with this review. Those cases and the results taken from Dave Paulsen's test cases [46] are as follows:

Paulsen #4 (3 node liquid drain)

Description

This problem consists of three lumped parameter nodes, one above the other two. The two lower nodes are linked to the upper node with identical flow paths. The upper node contains water which should drain down into the lower two nodes.

Solution

The solution to this problem should be that equal amounts of water end up in the two lower nodes with no water remaining in the upper node. This will verify that the code will not holdup liquid in horizontal pipes and shelves.

All of the water except for that below the bottom elevation of the flow paths drained down from the upper node. This indicates that the computational model does not cause liquid holdup.

Paulsen #5 (3 node liquid drain, subdivided volumes)

Description

This problem is identical to #4 except that each node was vertically quartered and divided horizontally into two elevations for a total of eight nodes per volume.

Solution

The solution for this problem should agree with that predicted for #4. The results do not agree exactly with those of #4. This may indicate that some additional liquid is being held up as a result of subdividing the nodes.

NAI Response [47]

Problem 5 ends up with less liquid in the lower volumes because the problem was initialized with less liquid in the upper volume (72 ft in problem 4, 67.5 ft in Problem 5). When this difference is eliminated, the liquid that ends up in the lower volume is the same for the two problems.

Paulsen #6 (2 node manometer)

Description

The problem consists of two lumped parameter nodes linked together with a single flow path. This is a model of a manometer.

Solution

This oscillation should compare with hand calculations and should continue with time.

The results do agree with the hand calculations.

Paulsen #7 (2 node manometer, subdivided volumes)

Description

This problem is identical to #6 except that the lumped parameter nodes have been subdivided into eight elevations.

Solution

The problem should predict the same solution as for #6.

The period is slightly different for this case when compared to #6. This is probably due to a slightly different volume of water being present initially. This oscillation damps with time. The reason for the damping was not investigated.

NAI Response [47]:

The damping is due to the small friction losses in the legs of the manometer and small losses that occur when momentum is transferred from one leg to the other at the junctions. Neither of these losses exist in the lumped volume case.

Paulsen #8 (Ice melting and energy balance)

Description

This problem consists of a single lumped parameter node containing ice. An amount of steam sufficient to melt the ice and result in a pool of water slightly above 32 F is injected.

Solution

The results of this case indicate that all of the ice did not melt and that the water did not end up at the calculated temperature. In addition, the energy imbalance was quite high.

NAI Response #1 [47]:

This model was rerun with the current version (actually Version 4.0 dev, a developmental working version) of GOTHIC. There is an apparent gas mass source for this particular problem that has not been resolved. Other ice tests problems with similar amounts of initial air mass work well (Standard Problem #36). We will continue to work on this problem.

NAI Response #2 after code changes [48]:

This model was rerun using current version (4.0) of GOTHIC. The apparent gas mass source for this particular problem was duplicated. Changes were made to GOTHIC_S to resolve these problems and the model was run again. Improved results were obtained for this problem as well as GOTHIC Standard Problem 36.

4.5.3 Comparison to test data

The validation cases using test data provide a comparison to a range of test data ranging from small scale to rather large simulations of actual containments. The generally good agreement with the test data is a credit to the mathematical models of GOTHIC.

The review coverage from the Qualification Manual is indicated in Appendix A.3. A summary of results follows:

BATTELLE-FRANKFURT TEST D-1, D-15, D-16

Tests D-1, D-15 and D-16 were experiments in the Battelle Frankfurt containment facility designed to model the sub-compartment pressurization resulting from Design Basis Accident (DBA) blowdown transients. These tests were of interest to assess the capability of the GOTHIC's mathematical models to determine the pressure and differential pressure on walls within the structure.

The results of the GOTHIC analysis of Test D-1 followed the trends of the test but over-predicted the volume and wall differential pressures. An extensive investigation into the possible causes of the deviations was performed. The results of the investigation point to uncertainties with the input mass and energy releases noting that the deviations in the mass release rates are on the order of the input mass releases. Since the cause for the mismatch could not be confirmed, the uncertainty remains, as indicated in the code qualification document.

The pressure response predicted by GOTHIC calculations were high compared to the data by some amount for Tests D-1, D-15 and D-16. Several parameters were adjusted in the GOTHIC model to determine possible causes for the discrepancy in the predicted versus measured pressure. Break flow was found to be sensitive and its uncertainty would have a large effect on the pressure response. A ten-fold increase in the heat transfer had a similar effect as a 10% change in break flow. Since these uncertainties offer a reasonable explanation of the differences, the GOTHIC model comparisons to pressure data are judged to be acceptable.

Test D-16 resembles the blowdown transient of a loss-of-coolant-accident. This type of accident is considered in almost every containment integrity analysis. The blowdown consisted of pressurized liquid. The GOTHIC simulation of this test was run out to 50 seconds with comparisons made to both room pressures and temperatures. Room differential pressures was also calculated. The results of the comparisons are all very good. The room pressure, differential pressures, and temperatures agree very well with the data.

BATTELLE-FRANKFURT TEST 6

This test was considered assess GOTHICS capability to model the transport of hydrogen by both convection and diffusion through a containment. This type of analysis is of concern when evaluating severe accident scenarios. The results of the analysis agree reasonably well with the test data; however, there are some deviations. The agreement depends upon the values assumed for the initial temperature distribution within the structure and the mixing lengths assumed for the model. Techniques for determining the appropriate values of mixing length are provided in the discussion of the test comparisons.

BATTELLE-FRANKFURT TEST 12 AND 20

Test 12 in the Battelle-Frankfurt model containment test facility was analyzed as part of the code qualification effort. This test involved the injection of a mixture of hydrogen (67%) and nitrogen (33%) into the test facility. The test conditions, low injection rate and uniform initial temperature distribution provided uniform mixing of the gas. GOTHIC was able to model successfully the experimentally measured gas concentration.

BATTELLE-FRANKFURT TEST C-13 AND C-15

Tests C-15 and C-15 were a series of two steam-water blowdown experiments to model the double-ended break of a main steam-line break in the central region of the containment. GOTHIC modeled theses tests with lumped parameter control volumes, flow paths and thermal conductors. Generally good agreement was found between the predictions and test data.

HEDL HYDROGEN MIXING TESTS

The HEDL tests examined the mixing of hydrogen in a large, simulated, containment volume. The GOTHIC comparisons to data were quite good given the variability in the conditions in the final Tests HM-5 to HM-11. There are no significant differences noted in the comparisons and the GOTHIC results are acceptable.

LACE TESTS

The Lace experiments were performed to simulate the behavior of containment systems during severe accidents. Of particular significance to code verification was the simulation of a failed containment (sudden depressurization) and the subsequent flashing of an internal water pool. GOTHIC calculations of the LACE experiments were performed using a lumped parameter model. The calculated results compared very well with the experimental data. In particular, calculated pressure and temperatures during both the long depressurization and sudden depressurization were in agreement with the data. Comparison to the temperature of the steam-heated tank liquid (internal pool) had some discrepancies during heatup which could have been related to uncertain steam rates, the addition of pump heat or local effects.

MARVIKEN FULL SCALE CONTAINMENT

Data from the Marviken experiments represent an important challenge to computer codes because they represent accident simulations in a large scale, multiple-compartment, pressure-suppression containment system using a range of thermal-hydraulic conditions and varied geometries. These experiments were modeled with GOTHIC using 21 lumped-parameter control volumes, a number of interconnected flow paths, and numerous concrete, steel-lined concrete and steel surfaces. The GOTHIC simulations of the experiments were acceptable with all important trends correctly predicted. Some deviations from test data exist but these are small and consistent with the lumped-parameter model. The GOTHIC comparisons to the Marviken test data are an improvement over all other comparisons known to the review team.

CVTR SIMULATED DBA TESTS

The CVTR experiments were performed in a decommissioned containment building in the late 1960s near Parr, South Carolina, and have been a standard benchmark of containment codes for over two decades. The two-region containment was pressurized by blowdown of a high temperature steam jet into the upper compartment, and then allowed to decay due to heat transfer to the structures, and in some tests due to containment sprays. While the experiments were conceptually simple, concurrent superheated and saturated regions existed in the vapor space, and some heat structures experienced a change from condensing conditions to non-condensing conditions when the structures heated to a temperature above the saturation temperature of the steam in the local vicinity. The varied thermal conditions have made these test historically very difficult for computer codes to simulate.

GOTHIC was used to model the experiments using a lumped-parameter approach, and the code also had difficulty in the calculations of temperature and heat transfer coefficients. GOTHIC was then setup using a distributed parameter model and calculated an improved pressure and temperature history. However, significant temperature differences persisted between measured and calculated temperatures and heat transfer coefficients. When a temporary code modification was made to simulate a fog model (condensation of vapor in the bulk atmospheric regions), the calculated and measured temperatures and heat transfer coefficient trends became much improved. This exercise points to the need for the addition of a fog model for problems of this type where portions of the vapor regions may go from a superheated condition to a saturated region.

HDR FULL SCALE CONTAINMENT EXPERIMENT

The HDR containment in Germany has been used to simulate a wide range of design basis accidents for the international community. The GOTHIC model was used to simulate four particular Tests: V21.1, T31.1, V44 and T31.5. All the steam blowdowns into the air environment showed adequate comparisons between the data and the GOTHIC predictions.

For T31.5 the late time injection of hydrogen showed a stratification that the predictions could not adequately identify. The reason for this stratification, persisting over long times, seems to be unique to HDR. The code calculations could not predict it or its eventual rapid mixing. It is suspected that the number of sensors in the test containment were not sufficient to identify some of the trends. It is also possible that the mathematical models may have had trouble with light gas stratification in a highly compartmentalized containment. Too much numerical mixing (numerical diffusion) at the hydrogen injection point may have also contributed to this problem.

4.5.4 Validation Summary

Based upon the favorable comparisons to GOTHIC Standard Problem, DRG demonstration problems and comparisons to experimental data, the DRG concludes that:

1) **The validation analysis demonstrates the capability of GOTHIC to consider a wide range of thermal hydraulic phenomena applicable to containment analysis and general thermal-hydraulic applications.**

2) **While the Qualification Manual presents an impressive array of cases and with successful comparisons to data and test cases, the calculations have not had independent review. More extensive review than that provided by the DRG may be necessary for an auditing or licensing body. Such a detailed review was beyond the scope of the DRG.**

3) **Users should be aware of the GOTHIC's range of application and the validation analyses that support it.**

4.6 ADEQUACY FOR CONTAINMENT ANALYSIS

A major objective of this review was to determine if GOTHIC is adequate to evaluate the containment and containment sub-compartment response from the full spectrum of high energy line breaks within the design basis envelope as described in FSAR Chapter 6, Section 2. The review was also to determine the applicability of GOTHIC for a wider range of thermal-hydraulic applications in primary containment, secondary containment and related fluid systems. Applications include pressure/temperature determination, equipment qualification profiles and inadvertent system initiation, degradation or failure of engineered safety features (e.g. loss of one spray train, loss or degradation of fan coolers or HVAC systems).

As part of the qualification document review, code model or containment features were identified by each reviewer. The results of all reviewed cases were tabulated to illustrate the range of GOTHIC validation. The results of that compilation are summarized in Table 4.1 for each feature and by Qualification Manual section. The validation cases consider all of the identified model or containment features. The validation cases provide an excellent body of results that demonstrate the range and capability of GOTHIC.

As seen in the table, all items have had one or more validation analyses. The validation analyses cover some aspects of both BWR and PWR containments including the PWR ice condenser containment. The qualification calculations provide an adequate base for code qualification. The DRG concludes the following:

> **The validation of GOTHIC as presented and reviewed by the DRG demonstrates that GOTHIC is adequate to evaluate the containment and containment sub-compartment response from the full spectrum of high energy line breaks within the design basis envelope as described in FSAR Chapter 6, Section 2. GOTHIC 4.0 has the capability to perform analysis well beyond the range of the qualification data base presented in the documentation. Its mathematical models and numerical solution has the potential for a wider range of thermal-hydraulic applications. Such applications should be justified by users as appropriate to their analysis.**

Table 4.1. Summary of Validation Items

Item	Qualification Manual Report Sections										
	3.0	4.1	4.2	4.3	4.4	4.5	4.6	4.7	4.8	6.0	7.0
Fluid Momentum	-	x	-	-	x	-	x	-	x	-	-
Energy Transport	x	x	x	x	-	x	x	x	x	-	-
Non Condensible Gases	x	-	x	x	-	-	-	-	-	x	x
Equation of State	x	x	x	x	-	x	x	-	x	x	x
Pressure Response	x	-	x	x	-	-	x	-	x	x	x
Temperature Response	x	x	x	x	-	x	x	x	-	x	x
Humidity Response	x	-	-	-	-	-	-	-	-	x	x
Hydrogen Transport	-	-	-	x	-	-	-	-	-	-	-
Energy Sources	x	x	-	-	-	-	-	-	-	x	x
Pumps/Fans	-	-	-	-	x	-	-	-	-	-	-
Valves	-	-	-	-	-	-	-	-	-	-	-
Nozzles	-	-	-	-	x	-	-	-	-	-	-
Heaters/Coolers	-	x	-	-	-	-	-	-	-	-	-
Heat Exchangers	-	-	-	-	-	x	-	-	-	-	-
Subcompartment Analysis	-	-	-	-	-	-	-	-	-	x	-
High Energy Line Breaks	-	-	-	-	-	-	-	-	-	x	-
PWR Standard Containment	-	-	-	-	-	-	-	-	-	-	-
PWR Ice Containment	(a)	-	-	-	-	-	-	-	-	-	-
BWR Containment	-	-	-	-	-	-	-	-	-	-	-
BWR Pressure Suppression	-	-	-	-	-	-	-	-	x	-	-
Fluid/Structure Inter.	-	-	-	-	-	-	-	-	-	-	-
Other: Conductors	-	-	-	-	-	-	-	x	-	x	
Subdivided Vol.	-	-	-	-	-	-	x	-	-	-	-
Critical Flow	-	-	-	-	-	-	-	-	x	-	-
Turbulence	-	-	-	-	-	-	-	-	-	-	-
3-D Calculation	-	-	-	-	-	-	-	-	-	-	-

(a) See Section 4.5.2 for DRG Ice Test Case

Table 4.1 (Cont.). Summary of Validation Items

Item	Qualification Manual Report Sections								
	8.0	9.0	10.0	11.0	12.0	13.0	14.0	15.0	16.0
Fluid Momentum	-	x	x	-	-	x	x	-	-
Energy Transport	x	x	-	-	-	x	x	-	-
Non Condensible Gases	x	x	x	x	x	x	x	x	x
Equation of State	x	x	-	-	-	x	x	-	-
Pressure Response	x	x	x	x	x	x	x	x	x
Temperature Response	x	-	-	x	x	x	x	x	x
Humidity Response	x	-	-	x	x	x	x	x	x
Hydrogen Transport	-	x	x	-	-	-	-	-	-
Energy Sources	x	-	-	x	x	x	-	x	x
Pumps/Fans	-	-	-	-	-	-	-	-	-
Valves	-	-	-	-	-	x	-	-	-
Nozzles	-	-	-	-	-	-	-	-	-
Heaters/Coolers	-	-	-	-	-	x	-	-	-
Heat Exchangers	-	-	-	-	-	-	-	-	-
Subcompartment Analysis	x	-	x	-	-	-	x	-	
High Energy Line Breaks	x	-	-	-	-	-	-	-	-
PWR Standard Cont.	-	-	-	-	-	x	-	-	-
PWR Ice Containment	-	-	-	-	-	-	-	-	-
BWR Containment	-	-	-	-	-	-	x	-	-
BWR Pressure Suppression	-	-	-	-	-	-	x	-	-
Fluid/Structure Inter.	-	x	-	-	-	-	-	-	-
Other: Conductors	x	-	-	-	-	-	-	-	-
Subdivided Vol.	-	x	-	-	-	-	-	-	-
Critical Flow	-	-	-	-	-	x	-	-	-
Turbulence	-	x	-	-	-	-	-	-	-
3-D Calculation	-	x	x	-	x	-	-	x	-

5.0 UNRESOLVED ISSUES AND RECOMMENDATIONS

All items from the review have been fully resolved. The following recommendations are offered:

1) The DRG is aware of the possibility of providing dynamic memory allocation for GOTHIC. The DRG recommends that this be done to eliminate the need to recompile the code for different problems sizes. This would help assure consistent code control.

2) It is recommended that consideration be given to including an iterated Newton solution option in a future version of GOTHIC. Such an option would allow assessment of solutions to assure convergence at each time step. Convergence is assured if the residuals approach zero in an iterated solution. Such an option could be used to confirm the faster one-step method currently being used.

3) GOTHIC would benefit from a "fog model" to correctly simulate condensation of vapor in bulk atmospheric regions when all, or portions, of the vapor region go from superheated conditions to saturated regions.

6.0 DOCUMENTATION

The following documentation represents the record of the GOTHIC Design Review Group:

1) An inventory of all items in the record. See Appendix G for the final inventory and location of records.

2) All materials handed out during the design review meetings or transmitted to the DRG members for their use in the review.

3) Floppy diskettes containing the source code -- GOTHIC 3.4D and 4.0.

4) Pertinent computer runs including input files (floppy disk format).

6) Meeting minutes.

7) All task review and summary review forms used to record the work.

8) Review Findings and Responses, Master Signoff Copy, June 8, 1993.

9) Response signoff by DRG to open items from June 1993 meeting.

10) Design Review Final Report.

The records of this design review represent a quality assurance record and are to be stored and protected by NAI according to their QA procedures. The chairman of the DRG has inventoried the records to verify that all documents identified have been placed in the record. Copies of the design review material are also being retained by EPRI and by D.S. Rowe (DRG Chairman).

7.0 REFERENCE MATERIAL

The following material was distributed to the DRG at its meeting on November 5-6, 1991.

1. Memorandum from Mati Merilo: Design Review of GOTHIC, October 29, 1991.

2. VIPRE-01 Design Review Plan

3. VIPRE-01 Design Review Executive Summary

4. RETRAN-02 MOD002 Design Review Executive Summary Report, August 12, 1983.

5. Tom George, Presentation Vugraphs, GOTHIC.

6. Tom George, Presentation Vugraphs, GOTHIC Qualification Simulations.

7. GOTHIC Containment Analysis Package, Technical Manual, NAI-8907-06, July, 1991.

8. GOTHIC Containment Analysis Package, Installation and Operations Manual, NAI-8907-08, April, 1991.

9. GOTHIC Containment Analysis Package, Programmer's Manual for GOTHIC_S, NAI-8907-10, June, 1991.

10. GOTHIC Containment Analysis Package, User's Manual, NAI-8907-02, April, 1991.

11. GOTHIC Containment Analysis Package, Qualification Report for GOTHIC_S, NAI-8907-09, June, 1991.

12. Quality Assurance Program for Numerical Applications Inc. NAI-QA-1, Rev 4, July 1990.

13. NRC, Part 50, Appendix B - Quality Assurance Criteria for Nuclear Power Plants and Fuel Reprocessing Plants.

14. NUREG-0800, Standard Review Plan, Section 6.2.1 Containment Functional Design, Rev. 2, July 1981, Pages 1-7.

15. NUREG-0800, Standard Review Plan, Section 6.2.1.1.A PWR Dry Containments, Including Subatmospheric Containments, Rev. 2, July 1981.

16. NUREG-0800, Standard Review Plan, Section 6.2.1.1.B Ice Condenser Containments, Rev. 2, July 1981.

17. NUREG-0800, Standard Review Plan, Section 6.2.1.1.C Pressure-Suppression Type BWR Containments, Rev. 6, August 1984.

18. NUREG-0800, Standard Review Plan, Section 6.2.1.2 Subcompartment Analysis, Rev. 2, July 1981.

19. NUREG-0800, Standard review Plan, Section 6.2.1.3 Mass and Energy Release Analysis for Postulated Loss-of-Coolant Accidents, Rev. 1, July 1981.

20. NUREG-0800, Standard Review Plan, Section 6.2.1.4 Mass and Energy Release Analysis for

Postulated Secondary System Pipe Ruptures, Rev. 1, July 1981.

21. NUREG-0800, Standard Review Plan, Section 6.2.1.5 Minimum Containment Pressure Analysis for Emergency Cooling System Performance Capability Studies, Rev. 2, July 1981.

22. NUREG-0800, Standard Review Plan, Section 6.2.3 Secondary Containment Functional Design, Rev. 2, July 1981.

23. Pages 6.2-8 through 6.2-39 from LSCS-FSAR.

24. Pages 6.2-1 through 6.2-46 from Arkansas Nuclear One, Unit 2, FSAR.

Added material distributed to the DRG following the first meeting included:

25. 3.5" Computer Disks (2), GOTHIC.386, V3.4d, November 13, 1991.

26. Minutes of November 6-7, 1991 Meeting (Revised 12/19/91 to reflect corrections from original draft.

27. Minutes of December 18-19, 1991 Meeting.

28. Letter: A. Singh to D. Rowe, Design Review of GOTHIC, June 16, 1993.

29. GOTHIC Containment Analysis Package, Technical Manual for GOTHIC_S, NAI-8907-06, July, Rev 2, (DRAFT).

30. Minutes of June 8-9, 1993 Meeting (Revised 6/23/93 to reflect corrections from original draft.

31. Letter: L. Wiles to D. Rowe, NAI Responses to findings for the Technical Manual, May 11, 1993.

32. Letter: L. Wiles to D. Rowe, NAI Responses to findings for the Programmer Manual and Installation Manual, May 24, 1993.

33. Letter: L. Wiles to D. Rowe, NAI Response to findings for the Qualification Manual and Source Code, May 27, 1993.

34. Letter: L. Wiles to D. Rowe, NAI Responses to findings for the User Manual, May 27, 1993.

35. Review Findings and Responses (Prepared by Larry Wiles (NAI), Master Signoff Copy from DRG Meeting, June 8, 1993).

36. Letter: L. Wiles to D. Rowe, Items: 1) Update of GOTHIC Standard Problem List; 2) Code change summary since Version 3.4D, June 15, 1993.

37. Letter: L. Wiles to D. Rowe, Responses to Open Items (by D. Rowe) from June, 8-9, 1993 Meeting, June 23, 1993.

38. Letter: L. Wiles to D. Slaughterbeck, Responses to Open Items (by D. Slaughterbeck) from June, 8-9, 1993 Meeting, June 23, 1993.

39. Letter: L. Wiles to M. Corradini, Responses to Open Items (by M. Corradini) from June, 8-9, 1993 Meeting, June 23, 1993.

40. Letter: L. Wiles to J. McFadden, Responses to Open Items (by J. McFadden) from June, 8-9, 1993 Meeting, June 23, 1993.

41. Letter: D. Slaughterbeck (SAIC) to D. Rowe, Resolution of Comments on GOTHIC Review, June 27, 1993.

42. Letter: J. McFadden (CSA) to D. Rowe, Resolution of Comments on GOTHIC Review, Ref: CSA-262-93, June 30, 1993.

43. FAX: J. McFadden, Additional Text for Design Review Report, July 2, 1993.

44. Letter: M. Corradini to D. Rowe, (Signoff on NAI responses), July 6, 1993.

45. Letter: D. Paulsen to D. Rowe, GOTHIC review signoff and comment on Qualification Manual, ET-RMOI-CRA-93-238, July 21, 1993.

46. Letter: D. Paulsen to D. Rowe, Items: 1) GOTHIC review materials; 2) Test cases; 3) Disk with input files, ET-SOAR-CDBT-92-025, January 15, 1992.

47. FAX: L. Wiles (NAI) to D. S. Rowe, Responses to Some comments in the Draft Final Report, June, 24, 1993.

48. Letter: L. Wiles to D. Rowe, NAI Response and Code Changes for Ice Problem, July 21, 1993.

49. Letter: J. Harrell to D. Rowe, GOTHIC Comparison to COMPRESS for HEL/EQ Work, FILE: NF-2191.009, December 1991.

APPENDIX A -- SUMMARY OF REVIEW COVERAGE

The original findings reports from the review are contained in the findings notebook identified in Appendix G.

A.1 TECHNICAL MANUAL (TM)

- Not reviewed
x Review completed, report form completed.

Topic	Reviewer DCS	DLP	DSR	JHM	MLC
1.0 INTRODUCTION	x	-	-	x	-
2.0 CONTAINMENT ANALYSIS	x	-	-	-	-
2.1 Containment Phenomena	x	-	-	x	-
2.2 Modeling Approach	x	-	-	x	-
2.3 Computational Grid	x	-	-	x	-
2.4 Major Assumptions	x	-	-	x	-
2.5 Variables and Equations	x	-	-	x	-
3.0 GOVERNING EQUATIONS	-	-	-	-	-
3.1 Mass Conservation	-	-	x	-	-
3.2 Energy Conservation	-	-	x	-	-
3.3 Momentum Conservation	-	-	x	-	-
3.4 Equation of State	-	-	x	-	-
3.5 Boundary Source Terms	-	-	x	-	-
3.6 Interfacial Source Terms	-	-	x	-	-
3.7 Reduced Equations for Lum...	-	-	x	-	-
4.0 JUNCTIONS	-	-	x	-	-
4.1 pool Height and Vapor Fr...	-	-	x	x	-
4.2 Junction Volume Fractions	-	-	x	-	-
4.3 Junction Gravity Heads	-	-	x	-	-
4.4 Momentum Transport	-	-	x	-	-
4.5 Critical Flow Model	-	-	x	-	x
5.0 ENGINEERED SAFETY EQUIPMENT	-	-	-	-	-
5.1 Pumps and Fans	x	x	-	-	-
5.2 Valves, Doors and Vacuum Br..	x	-	-	-	-
5.3 Nozzles	x	x	-	-	-
5.4 Heater/Coolers	x	-	-	-	-
5.5 Volumetric Fans	x	x	-	-	-
5.6 Heat Exchangers	x	-	-	-	-
6.0 CONDUCTORS	-	-	x	-	-

Topic	DCS	DLP	DSR	JHM	MLC
7.0 INTERFACIAL SOURCE TERMS	-	-	-	-	-
7.1 Flow Regimes	-	-	-	x	x
7.2 Interfacial Area	-	-	-	x	x
7.3 Interfacial Drag	-	-	-	x	x
7.4 Vaporization and Condensa..	-	-	-	x	x
7.5 Drop Entrainment and Depo..	-	-	-	x	x
7.6 Combined Interface Source ..	-	-	-	x	x
8.0 WALL SOURCE TERMS	-	-	-	-	-
8.1 Energy source Terms	x	-	-	x	x
8.2 Momentum Source Terms	-	-	-	x	x
9.0 STRESS TENSOR AND TURB...	-	-	-	-	x
9.1 Viscous and Turbulent St..	-	-	-	-	x
9.2 Turbulent Energy Diffusion	-	-	-	-	x
9.3 Turbulent Mass Diffusion	-	-	-	-	x
10.0 MATERIAL PROPERTIES	-	-	-	-	-
10.1 Water Properties	-	-	-	x	-
10.2 Steam Properties	-	-	-	x	-
10.3 Gas Properties	-	-	-	x	-
10.4 Gas Mixture Properties	-	-	-	x	-
11.0 FINITE VOLUME EQUATIONS	-	-	-	-	-
11.1 Conservation Equations	-	-	x	-	-
11.2 Computational Mesh and Var..	-	-	x	-	-
11.3 Finite Volume Equations	-	-	x	-	-
11.4 Junction Equation	-	-	x	-	-
11.5 Conductor Equation	-	-	x	-	-
11.6 Boundary Condition	-	-	x	-	-
11.7 Viscous and Turbulent Str..	-	-	-	-	x
12.0 SOLUTION ALGORITHM	-	-	x	-	-
12.1 Solution of Momentum Eq..	-	-	x	-	-
12.2 Linearization of Mass and ..	-	-	x	-	-
12.3 Solution of the System Pres..	-	-	x	-	-
12.4 Unfolding of Independent ..	-	-	x	-	-
12.5 Time Step Control	-	-	x	-	-

A.2 USER GUIDE (UG)

- Not reviewed
x Review completed, report form completed.

Topic	Reviewers DCS	DLP	DSR	JHM	MLC
1.0 INTRODUCTION	-	x	x	x	-
1.1 General Description	-	x	x	x	-
1.2 About this manual	-	x	x	x	-
1.3 Recommendations for New GOTH..	-	x	x	x	-
2.0 MODELING FEATURES	-	x	x	-	-
2.1 The Basics	-	x	x	-	-
2.2 Constructing a Model	-	x	x	-	-
3.0 GOTHIC-P USERS GUIDE	-	x	x	-	-
3.1 Running GOTHIC-P	-	x	x	-	-
3.2 Menus	-	x	x	-	-
3.3 Input Methods	-	x	x	-	-
3.4 Internal Variables	-	x	x	-	-
3.5 Mouse Directed Graphics Edit..	-	x	x	-	-
3.6 Table Editing	-	x	x	-	-
3.7 Menu Editing	-	x	x	-	-
3.8 Units	-	x	x	-	-
3.9 Files	-	x	x	-	-
3.10 GOTHIC-P Failure and File ..	-	x	x	-	-
4.0 COMMON OPTIONS AND MENUS	-	x	-	-	-
4.1 Common Menu Options	-	x	-	-	-
4.2 Functions	-	x	-	-	-
4.3 Function Menus	-	x	-	-	-
4.4 Libraries	-	x	-	-	-
4.5 Menus Menu	-	x	-	-	-
5.0 MAIN	-	x	-	-	-
5.1 Main Menu	-	x	-	-	-
5.2 Redimensioning GOTHIC-S	-	x	-	-	-
5.3 GOTHIC-P Configuration	-	x	-	-	-
6.0 PREPROCESSING	-	x	-	-	-
6.1 Preprocessing Menu	-	x	-	-	-
7.0 VOLUMES	-	x	x	x	x
7.1 Control volume Menus	-	x	x	x	x
7.2 Subvolume Menus	-	x	x	x	x
8.0 FLOW PATHS	-	x	x	x	x
8.1 Flow Path Menus	-	x	x	x	x

Topic	DCS	DLP	DSR	JHM	MLC
9.0 THERMAL CONDUCTORS	x	x	x	x	x
9.1 Conductor Menus	x	x	x	x	x
9.2 Surface Temperature and Heat ..	x	x	x	x	x
9.3 Conductor Type Menus	-	x	x	x	x
10.0 COMPONENTS	x	x	-	-	-
10.1 Components Menu	x	x	-	-	-
10.2 Pumps	x	x	-	-	-
10.3 Pumps and Fan Menus	x	x	-	-	-
10.4 Pump/Fan Type Menus	x	x	-	-	-
10.5 Valves and Doors	x	x	-	-	-
10.6 Valve and Door Menus	x	x	-	-	-
10.7 Valve and Door Types Menu	x	x	-	-	-
10.8 Heat Exchangers	x	x	-	-	-
10.9 Heat Exchanger Menus	x	x	-	-	-
10.10 Heat Exchanger Type Menus	x	x	-	-	-
10.11 Vacuum Breakers	x	x	-	-	-
10.12 Vacuum Breaker Menus	x	x	-	-	-
10.13 Vacuum Breaker Type Menus	x	x	-	-	-
10.14 Spray Nozzles	x	x	-	-	-
10.15 Spray Nozzle Menus	x	x	-	-	-
10.16 Coolers and Heaters	x	x	-	-	-
10.17 Cooler/Heater Menus	x	x	-	-	-
10.18 Volumetric Fans	x	x	-	-	-
10.19 Volumetric Fan Menus	x	x	-	-	-
10.20 Trips	x	x	-	-	-
10.21 Component Trips Menu	x	x	-	-	-
11.0 MATERIAL PROPERTIES	-	x	-	x	x
11.1 Material Types Menu	-	x	-	x	x
12.0 FLUID BOUNDARY CONDITIONS	-	x	x	-	x
12.1 Boundary Conditions Menu	-	x	x	-	x
12.2 Gas Pressure Ratios	-	x	x	-	x
12.3 Assumptions and Limitations	-	x	x	-	x
13.0 FLUID INITIAL CONDITIONS	-	x	x	-	-
13.1 Initial Conditions Menu	-	x	x	-	-
13.2 Assumptions and Limitations	-	x	x	-	-
14.0 CONTROL PARAMETERS AND REST..	-	x	x	-	-
14.1 Control Parameters Menu	-	x	x	-	-
14.2 Restart Instructions	-	x	x	-	-

Topic	DCS	DLP	DSR	JHM	MLC
15.0 POSTPROCESSING	-	x	-	-	-
15.1 Postprocessing Menus	-	x	-	-	-
15.2 Line Graphs	-	x	-	-	-
15.3 Vector/Contour Graphs	-	x	-	-	-
15.4 Graph Configurations and Annot..	-	x	-	-	-
16.0 MODELING GUIDELINES	-	x	-	-	
16.1 General Considerations	-	x	x	-	-
16.2 Volumes	-	x	x	-	-
16.3 Junctions	-	x	x	-	-
16.4 Subvolume Connections	-	x	x	-	-
16.5 Boundary conditions	-	x	x	-	-
16.6 Initial Conditions	-	x	x	-	-
16.7 Components	x	x	x	-	-
16.8 Conductors	-	x	x	-	-
16.9 Lumped Parameter Versus Distr..	-	x	x	-	-
16.10 Lumped Parameter Modeling	-	x	x	-	-
16.11 Distributed Parameter Modeling	-	x	x	-	-
16.12 Modeling Situations	-	x	-	-	-
16.13 Run Control	-	x	-	-	-
16.14 Errors and Debug	-	x	-	-	-
16.15 Double Precision	-	x	-	-	-
17.0 EXAMPLES	-	x	-	-	-
17.1 Large Dry PWR Containment	x	x	-	-	-
17.2 Mark I BWR Containment	x	x	-	-	-
18.0 GOTHIC-S USER GUIDE	x	x	x	-	-
18.1 GOTHIC-S Geometry Model	-	x	x	-	-
18.2 Group 2: Channel Input Data	-	x	x	-	-
18.3 Group 3: Transverse Channel ..	-	x	x	-	-
18.4 Group 4: Section Data	-	x	x	-	-
18.5 Variations in Channels and Gaps	-	x	x	-	-
18.6 Thermal Conductors	x	x	x	-	-
18.7 Thermal Conductor Types	x	x	x	-	-
18.8 Axial Power Profiles and Forc..	x	x	x	-	-
18.9 Fluid Initial Conditions	-	x	x	-	-
18.10 Boundary Conditions	-	x	x	-	-
18.11 Recommended Usage of GOTHIC..	-	x	x	-	-
18.12 Printer Output for GOTHIC-S	-	x	x	-	-

Topic	DCS	DLP	DSR	JHM	MLC
19.0 GOTHIC-S INPUT	x	x	x	x	-
19.1 Problem Identification and ..	-	x	x	x	-
19.2 Calculation Variables and Init..	-	x	x	x	-
19.3 Channel Description	-	x	x	x	-
19.4 Transverse Channel Connection ..	-	x	x	x	-
19.5 Channel, Section, and Vertical ..	-	x	x	x	-
19.6 Variation Data	-	x	x	x	-
19.7 Regular and Simple Conductor Data	-	x	x	x	-
19.8 Conductor Type Description	-	x	x	x	-
19.9 Material Property Tables	-	x	x	x	-
19.10 Power Tables	-	x	x	x	-
19.11 Heat Exchanger Data	x	x	x	x	-
19.12 Pump and Fan Data	x	x	x	x	-
19.13 Valve and Door Data	x	x	x	x	-
19.14 Nozzle Data	x	x	x	x	-
19.15 Heater/Cooler Data	x	x	x	x	-
19.16 Volumetric Fan Data	x	x	x	x	-
19.17 Trip Data	x	x	x	x	-
19.18 Turbulent Diffusion and Visc..	-	x	x	x	-
19.19 Boundary Conditions	-	x	x	x	-
19.20 Output Options	-	x	x	x	-
19.21 Time Domain Data	-	x	x	x	-
20.0 GOTHIC-G USER GUIDE	-	x	-	-	-
20.1 Interactive Operation	-	x	-	-	-
20.2 Batch Operation	-	x	-	-	-
20.3 Mainframe Usage	-	x	-	-	-
21.0 REDIMENSIONING GOTHIC	-	x	-	-	-
21.1 Double Precision	-	x	-	-	-

A.3 QUALIFICATION MANUAL (QM)

- Not Reviewed
x Review completed, report form completed.

Topic	Reviewers DCS	DLP	DSR	JHM	MLC
1.0 INTRODUCTION	-	-	-	x	-
2.0 SUMMARY	-	-	-	x	-
3.0 CSNI NUMERICAL BENCHMARK	x	-	-	-	-
4.0 GOTHIC STANDARD PROBLEMS	-	-	-	-	x
4.1 GOTHIC Standard Problem 1	-	-	x	-	-
4.2 GOTHIC Standard Problem 3	-	-	x	-	-
4.3 GOTHIC Standard Problem 2	-	-	x	-	-
4.4 GOTHIC Standard Problem 6	-	-	x	-	-
4.5 GOTHIC Standard Problem 7	-	-	x	-	-
4.6 GOTHIC Standard Problem 13	-	-	x	-	-
4.7 GOTHIC Standard Problem 26	-	-	x	-	-
4.8 GOTHIC Standard Problem 28	-	-	x	-	-
5.0 BATTELLE-FRANKFURT TEST FAC..	-	-	-	-	x
6.0 BATTELLE-FRANKFURT TEST D-1	-	x	-	-	x
6.1 Test Description	-	x	-	-	x
6.2 GOTHIC Model Description	-	x	-	-	x
6.3 GOTHIC Data Comparison	-	x	-	-	x
7.0 BATTELLE-FRANKFURT TEST D-15	-	-	-	-	x
7.1 Test Description	-	-	-	-	x
7.2 GOTHIC Model Description	-	-	-	-	x
7.3 GOTHIC Data Comparison	-	-	-	-	x
8.0 BATTELLE-FRANKFURT TEST D-16	-	x	-	-	x
8.1 Test Description	-	x	-	-	x
8.2 GOTHIC Model Description	-	x	-	-	x
8.3 GOTHIC Data Comparison	-	x	-	-	x
9.0 BATTELLE-FRANKFURT TEST 6	-	x	-	-	-
9.1 Test Description	-	x	-	-	-
9.2 GOTHIC Model Description	-	x	-	-	-
9.3 GOTHIC Data Comparison	-	x	-	-	-
10.0 BATTELLE-FRANKFURT TEST 12, 20	-	-	-	x	-
10.1 Test Description	-	-	-	x	-
10.2 GOTHIC Model Description	-	-	-	x	-
10.3 GOTHIC Data Comparison	-	-	-	x	-

Topic	DCS	DLP	DSR	JHM	MLC
11.0 BATTELLE-FRANKFURT TEST C-13 ..	-	-	-	-	x
11.1 Test Description	-	-	-	-	x
11.2 GOTHIC Model Description	-	-	-	-	x
11.3 GOTHIC Data Comparison	-	-	-	-	x
12.0 HEDL HYDROGEN MIXING TESTS	-	-	-	-	x
12.1 Test Description	-	-	-	-	x
12.2 GOTHIC Model Description	-	-	-	-	x
12.3 GOTHIC Data Comparison	-	-	-	-	x
13.0 LACE TESTS	x	-	-	-	-
13.1 Test Description	x	-	-	-	-
13.2 GOTHIC Model Description	x	-	-	-	-
13.3 GOTHIC Data Comparison	x	-	-	-	-
14.0 MARVIKEN FULL SCALE CONT.	x	-	-	-	-
14.1 Test Description	x	-	-	-	-
14.2 GOTHIC Model Description	x	-	-	-	-
14.3 GOTHIC Data Comparison	x	-	-	-	-
15.0 CVTR SIMULATED DBA TESTS	x	-	-	-	x
15.1 Test Description	x	-	-	-	x
15.2 GOTHIC Model Description	x	-	-	-	x
15.3 GOTHIC Data Comparison	x	-	-	-	x
16.0 HDR FULL SCALE CONT. EXP.	-	-	-	-	x
16.1 Test Description	-	-	-	-	x
16.2 GOTHIC Model Description	-	-	-	-	x
16.3 GOTHIC Data Comparison	-	-	-	-	x

A.4 PROGRAMMER MANUAL (PM)

- Not Reviewed
x Review completed, report form completed.

Topic	Reviewers DCS	DLP	DSR	JHM	MLC
1.0 INTRODUCTION	-	x	x	x	-
2.0 FLOW CHART	-	x	x	x	-
2.1 Startup Sequence	-	x	x	x	-
2.2 Code Initialization	-	x	x	x	-
2.3 Group Input	-	x	x	x	-
2.4 Transient Control	-	x	x	x	-
2.5 Boundary Conditions	-	x	x	x	-
2.6 Conductor Solution	-	x	x	x	-
2.7 Ice Condenser	-	x	x	x	-
2.8 Explicit Flow Solution	-	x	x	x	-
2.9 Mass and Energy Residuals	-	x	x	x	-
2.10 Time Step Completion	-	x	x	x	-
2.11 Output Processing	-	x	x	x	-
2.12 Evaluation of Trip Status	-	x	x	x	-
3.0 DEFINITIONS FOR COMMON VAR..	-	x	x	x	-
4.0 SUBROUTINE SUMMARIES	-	x	x	x	-
5.0 GRAPHICS INTERFACE	-	x	-	-	-

A.5 SOURCE CODE MODULES

- Not Reviewed
x Review completed, report form completed.

Topic	Reviewers DCS	DLP	DSR	JHM	MLC
GOTHIC-S					
afromh.f	-	-	-	x	-
bacout.f	-	-	x	-	-
bc2.f	-	-	x	-	-
blkdat.f	-	-	-	x	-
boiling.f	-	-	-	x	-
clear.f	-	-	-	-	-
clearc.f	-	-	-	-	-
compin.f	-	-	-	-	-
condin.f	-	-	x	x	-
conten.f	-	x	-	-	-
cpropi.f	-	-	x	-	-
ctheat.f	-	-	-	-	-
curve.f	-	-	-	-	-
curve1.f	-	-	-	-	-
curvem.f	-	-	-	-	-
datm.f	-	-	-	-	-
debug.f	-	-	-	-	-
deform.f	-	-	-	-	-
dmpit.f	-	-	-	-	-
dmpmvy.f	-	-	-	-	-
dumpit.f	-	-	-	-	-
dvdhl.f	-	-	-	-	-
dvdhv.f	-	-	-	-	-
dvdpv.f	-	-	-	-	-
edit.f	-	-	-	-	-
error.f	-	-	-	-	-
fillro.f	-	-	x	-	-
gamsrc.f	-	-	x	x	-
gaphtc.f	-	-	-	-	-
gasmix.f	-	-	-	x	-
gasp.f	-	-	-	x	-
gauss.f	-	-	-	-	-
gcrit.f	-	-	-	-	-
graph.f	-	-	-	-	-
gssolv.f	-	-	x	-	-
gthcon.f	-	-	-	-	-
hcool.f	-	-	-	x	-
heat.f	-	-	-	x	x
heatx.f	-	-	-	-	-
hgas.f	-	-	-	x	-
hgasm.f	-	-	-	x	-

Topic	DCS	DLP	DSR	JHM	MLC
icon.f	-	-	-	x	-
ifacejn.f	-	-	x	x	-
igraf.f	-	-	-	-	-
init.f	-	-	x	x	-
input.f	-	-	x	-	-
intfr.f	-	-	x	x	-
jcritf.f	-	-	-	-	x
juncmom.f	-	-	-	-	-
load.f	-	-	-	-	-
main.f	-	-	x	-	-
mdepend.f	-	-	-	-	-
moment.f	-	x	x	-	-
move.f	-	-	-	-	-
newdlt.f	-	-	-	-	-
nozcur.f	-	x	-	x	-
outer.f	-	-	x	-	-
pool.f	-	-	-	x	-
post3d.f	-	-	x	-	-
prep3d.f	-	x	x	-	-
prop.f	-	-	-	x	-
propgrn.f	-	-	-	x	-
pump.f	-	x	-	-	-
qfront.f	-	-	-	-	-
qoxide.f	-	-	-	-	-
reduce.f	-	-	x	-	-
restrt.f	-	-	-	-	-
result.f	-	-	x	x	-
sat.f	-	-	-	x	-
sedit.f	-	-	-	-	-
setin.f	-	-	x	-	-
setout.f	-	-	-	-	-
setup.f	-	-	-	-	-
solids.f	-	-	-	-	-
splitit.f	-	-	-	-	-
stress.f	-	-	-	-	-
temp.f	-	-	-	-	-
tgas.f	-	-	-	x	-
timchk.f	-	-	-	-	-
timstp.f	-	-	x	-	-
tpress.f	-	-	-	-	-
trans.f	-	-	x	x	-
transp.f	-	-	-	x	-
trip.f	-	-	-	-	-
valve.f	-	-	-	-	-
veloc.f	-	-	x	-	-
velocit.f	-	-	x	-	-
volliq.f	-	-	-	x	-
volvap.f	-	-	-	x	-
xtra1.f	-	-	-	-	-

GOTHIC-G

Topic	DCS	DLP	DSR	JHM	MLC
avgvsl.f	-	-	-	-	-
axplt.f	-	-	-	-	-
bypass.f	-	-	-	-	-
contur.f	-	-	-	-	-
getlab.f	-	-	-	-	-
getvsl.f	-	-	-	-	-
grafix.f	-	-	-	-	-
levels.f	-	-	-	-	-
quevb.f	-	-	-	-	-
radplt.f	-	-	-	-	-
restb.f	-	-	-	-	-
talk.f	-	-	-	-	-
timplt.f	-	-	-	-	-
velvct.f	-	-	-	-	-
vessl1.f	-	-	-	-	-

A.6 INSTALLATION MANUAL (IM)

- Not Reviewed
x Review completed, report form completed.

Topic	Reviewers DCS	DLP	DSR	JHM	MLC
1.0 INTRODUCTION	-	-	-	-	-
2.0 HP WORKSTATIONS RUNNING STAR..	-	-	-	-	-
3.0 386 BASED PERSONAL COMPUTER	a	-	-	x	-
4.0 IBM MAINFRAMES	-	-	-	-	-
5.0 CDC MAINFRAMES	-	-	-	-	-
6.0 UNPACKING FILES	x	-	-	-	-
7.0 SAMPLE PROBLEM DESCRIPTION	-	-	-	-	-

(a) Macintosh IIci (Unsupported Computer)

General comments provided by DCS, DLP and JHM.

APPENDIX C – SUMMARY OF INSTALLATION SURVEY

The original installation survey responses are contained in the findings notebook identified in Appendix G.

RESPONSES FROM:

Karsten Fischer	Battelle-Europe
Jim Harrell	CP & L
Dave Paulsen	Westinghouse
Tom Yadon	Duke Power
Paul Sicard	Entergy (Waterford-3)
Vijay Chandra	PSE&G
Liang-Ruey Chang	PG&E
Pete Studer	TVA

INSTALLATIONS REPORTED:

Mainframes		
	IBM (MVS)	?
	CDC CYBER (NOS VE)	?
UNIX Workstations		
	Apollo 1000	FTN 10.8
	Apollo 3000	FTN 10.8
	Sun	F-77
	HP	HP-UX F77
	IBM/RS-6000	XL Fortran
Microcomputers		
	386	NDP 2.0.8
	Compaq, 486/33L	NDP Fortran 486
	Compaq, 386/33	NDP Fortran 386
	IBM PS/2 (386)	NDP Fortran
	Compaq, 386	As compiled by NAI
	IBM, 386	As compiled by NAI
	Compaq, 386	

QUESTIONS SUMMARY:

Have you installed the double precision version?	2 Yes	6 No (a)
Have you changed dimensions in the code?	4 Yes	4 No (a)
Have you installed GOTHIC_P?	6 Yes	2 No
Have you installed GOTHIC_G?	7 Yes	1 No
Have you executed the code sample problem correctly?	4 yes	(a) (b)
Are the installation instructions complete and adequate?	10 Yes	

(a) 1 no response due to no man hours spent on topic.

(b) 4 no responses indicate the sample problem has not been run; can not assess "run correctly".

SUMMARY OF COMMENTS:

Yadon: "GOTHIC_P not currently running on RS-6000, currently under investigation, believed to be due to differences in A/X Windows versions."

Fischer: "GOTHIC_P installed on Apollo under X Windows."

Paulsen: "It would be useful to have a listing of what files should be contained in each of the subdirectories. When the code is moved for configuration control it seems that some number of files are missed."

Studer: "The installation instructions seem complete for the UNIX X-Windows version. We are also considering putting the code on our NOS/VE CDC CYBER 2000. The instructions for this machine are general in nature only."

Sicard: "It would be valuable to change dimensions without recompiling."

APPENDIX D – SUMMARY OF APPLICATION SURVEY

The original application survey responses are contained in the findings notebook identified in Appendix G.

RESPONSES FROM:

Karsten Fischer	Battelle-Europe
Jim Harrell	CP&L
Dave Paulsen	Westinghouse
Tom Yadon	Duke Power
Paul Sicard	Entergy (Waterford-3)
Vijay Chandra	PSE&G
Pete Studer	TVA (Minimal response, work is just starting)
Ray Wong	Ontario Hydro

ANALYSES PERFORMED:

Fischer

- Natural Convection in Waste Storage Facility
- Hydrogen Distribution (HDR Test 11.2)
- Hydrogen Distribution and Catalytic Reaction (BMC Tests)
- Aerosol Distribution (BMC VANAM Tests)
- H2/Aerosol Distribution in Severe Accident (German Risk Study)

Harrell

- Comparison of GOTHIC and COMPRESS
- High Energy Line Break / EQ Compartment Analysis
- HVAC Failure, Room Heatup Calculations
- PWR Containment Analysis

Paulsen

- Code Comparison to Test Results

Yadon

- Dry Containment analysis
  - Peak building pressure
  - Long term temperature response
  - LB and SB LOCA
- Ice Condenser Containment Analysis
  - Compare to Battelle Test Program Facility Data

Chandra

- Air Bubble Force on Pressurizer Drain Tank
- Room Heatup due to Steam Pipe Break
- Steel Heatup due to Fire

Sicard

Large Break LOCA (Verified Calc EC-S90-011)
Small Break LOCA
Inadvertent Spray (Draft Calc EC-S91-019)
Steam Line Break (Verified Calc EC-S91-007)

Studer

(None performed yet)

Wong

Powerhouse Environment study
Atmospheric Toxic Gas Dispersion
Hydrogen Mixing in Containment
Jet Loading on spray Header in Vacuum Building

QUESTIONS SUMMARY (for those who have used the code, 7 of 8):

Have you used GOTHIC_P?	7 Yes	0 No
Have you used GOTHIC_G?	7 Yes	0 No
Have you compared GOTHIC results with other analyses?	5 Yes	2 No

INTENDED FUTURE APPLICATIONS:

Fischer

Analysis of BMC VANAM Tests
- H2 & Aerosol
- H2 Deflagration

Harrell

BWR Containment Analysis -- Incl. Local Suppression Pool Temperature

Paulsen

Ice Condenser Containment Licensing Analysis
Dry Containment Licensing Analysis
Best Estimate Licensing Containment Analysis
H2 Analysis
Auxiliary Building Analysis

Yadon

Ice Condenser Containment Response
(peak pressure, long term temperature)
Dry Containment (SB LOCA)

Chandra

BWR Containment Temperature Analysis -- Small Break in Steam Line

Sicard

FSAR Sect 6.2 Analysis
EQ Analysis

Studer

EQ Analysis -- Localized Heatup (3D analysis)
Ice Condenser Containment Analysis -- Plant Life Extensions
Mark I Containment Analysis -- Plant Life Extensions

Coulter

Optimize fans in containment for hydrogen dispersion

ANALYSIS SUMMARY

Fischer

H2 Distribution and Catalytic Reactions in BMC.

Model: 13 volumes, 26 junctions, 1 fan, 46 heat slabs, steam injection by pressure boundary condition, hydrogen recombiner model coupled with volumetric fan leakage and heat transfer to environment.

Compared results to data; documented in BF-V 67709-04 (in German)

Good comparison between blind pretest predictions and experimental data for distribution of H2 concentration and temperature.

Chandra

Room heatup due to Steamline Break.

Model: 3 volumes, 6 junctions, 2 valves, 1 fan, G-K condensation.

Analysis not compared to data or other analysis. Documented (no ref)

Results described as reasonable.

Paulsen

Model tests for HWRF and AP600, H2 mixing Tests.

model: various nodal treatments, 1-2 fans.

Analysis being compared to data and other calculations, not documented.

No results.

Harrell (#1)

Comparison of GOTHIC to COMPRESS

Numerous high energy line breaks including #2 and #3 that follow. See Letter: Jim Harrell to Don Rowe, GOTHIC Comparison to COMPRESS for HEL/EQ Work, FILE: NF-2191.009, December 1991.

Once an appropriate set of GOTHIC input was prepared and code difference identified, the comparisons became quite good. When minor differences were noted they were attributed to minor conservatism in COMPRESS. The overall conclusion is that GOTHIC can replace COMPRESS for future analysis.

The GOTHIC_P processor was used to prepare input and found to be very useful. The initial *.sin files were checked and few minor errors were found and fixed by NAI.

Harrell (#2)

10" HPCI Steam line Break in Mini Steam Tunnel -- EQ Temperature Profiles.

Model: 12 volumes, 19 junctions, 4 valves (and doors), 11 conductors, 3 boundary conditions. Checked compressible flow and revaporization fraction effects.

Compared to other calculations, results documented in handout to GOTHIC User Group meeting December 11-12, 1991. See Letter [49]: Jim Harrell to Don Rowe, GOTHIC Comparison to COMPRESS for HEL/EQ Work, FILE: NF-2191.009, December 1991.

Plots of temperature and pressure and their peak values were compared with the original ALE code (COMPRESS, similar to COMPARE). Excellent agreement was obtained in peak values and curve shapes for temperature and pressure in the break area.

Harrell (#3)

4" Reactor Water Cleanup Line Break -- EQ Temp. and Pressure profiles.

Model: 12 volumes, 17 junctions, 1 valve, 9 conductors, 3 boundary conditions. Checked several variation of BC parameters, particularly drop size effects).

Compared to other calculations, results documented in handout to GOTHIC User Group meeting December 11-12, 1991. See Letter [49]: Jim Harrell to Don Rowe, GOTHIC Comparison to COMPRESS for HEL/EQ Work, FILE: NF-2191.009, December 1991.

Very good results. Temperature and pressure in all the critical compartments matched well throughout the time periods of interest.

Harrell (#4)

Model Diesel Generator Rooms at Brunswick (BWR) -- Numerous HVAC Operating conditions.

Model: 1 volumes, 45 subvolumes, 7 junctions, 10 heaters/coolers, 1 valve, 6 conductors, 7 boundary conditions. Automatic subdivision of conductors and vertical variation tables were used.

Compared to data gathered during fuel oil burn test of the diesels. Documentation is planned.

A very good match between the measured temperatures in various ares of the diesel room was obtained over a three hour time period.

Harrell (#5)

Room Heatup after Failure of HVAC.

Model: Various number of volumes and subdivided volumes were used; a representative model had 10 volumes, 2 of 10 subdivided, 8 junctions, 23 heaters/coolers, 51 conductors. Reference pressure was used to correct buoyancy forces.

Compared to lumped parameter hand calculations for transient and steady behavior prior to subdividing. No reported documentation.

Lumped parameter results matched very well prior to subdividing. Subdivided results appeared qualitatively reasonable based on equipment locations.

Harrell (#6)

Various Lumped Parameter analysis for H.B. Robinson.

Typical Model: 2 volumes, 3 junctions, 1 heater/cooler, 1 fan, 20 conductors, 2 boundary conditions. Checked operation of revaporization fraction, nozzles (not used in final runs).

Compared to results from CONTEMPT. Peak pressure and their times of occurrence matched well. Times of occurrence of peak temperatures matched well but the GOTHIC peak temperatures values were generally lower. The results are not documented.

Yadon

Battelle Ice Condenser Test Facility simulation (ongoing).

Model: 8 volumes, 5 subdivided volumes, 28 junctions, turbulence model.

Compared to data, not documented.

Results are mixed -- depends on mixing length parameter in turbulence model.

NAI Response [47]:

It is true that mixing length can have a significant influence on the results for a specific problem. Recommended mixing lengths are given in the User Manual and experience with this parameter are noted in the Qualification manual. Following these guidelines should provide a good starting point for a new model.

Sicard (#1)

LB LOCA at Waterford-3.

Model: Setup to match modeling used for CONTEMPT.

Compared to CONTEMPT results, documented in Waterford-3 Calculation EC-S90-011 (Selected pages attached to survey response).

The pressure and vapor temperature response of GOTHIC is consistent with (very good) with CONTEMPT. The GOTHIC calculated liquid sump temperature is higher than

CONTEMPT. There is opinion of the GOTHIC User Group that "CONTEMPT tended to underpredict the sump temperatures during blowdown".

Sicard (#2)

Main Steam Line Break at Waterford-3.

Model: Setup to match modeling used for CONTEMPT.

Compared to CONTEMPT results, documented in Waterford-3 Calculation EC-S91-007 (Selected pages attached to survey response).

The pressure response of GOTHIC compares well with CONTEMPT. The GOTHIC calculated vapor temperature (superheated) is significantly lower and the liquid sump temperature is higher than CONTEMPT. There is excellent agreement for the surface temperatures of the various conductors exposed to the containment vapor. The differences noted are claimed to be due the over conservatism in CONTEMPT.

Sicard (#3)

Containment Vacuum Breaker Analysis for Inadvertent Spray at Waterford-3.

Model: Setup to match modeling used for CONTEMPT.

Compared to CONTEMPT results, documented in Waterford-3 Calculation EC-S91-019 (draft) (Selected pages attached to survey response).

The comparisons for the cases considered show that the depressurization calculated by GOTHIC is faster than that of CONTEMPT by 13 to 19%. The final pressures are nearly identical. Valve models were included in these cases and the GOTHIC model produced more valve cycles than CONTEMPT.

Wong (#1)

Powerhouse Environment Study following Secondary Side Pipe Break

Model: 2 volumes, 1 subdivided volumes (560 cells), 18 junctions, 8 valves, 538 heat exchangers.

Results were compared to other analysis. Documented in Ontario Hydro report #90003.

Generally reasonable results were obtained. Difficult to model the steam jet in larger cells. Had to adjust break areas to get right amount of air entrainment.

Wong (#2)

Toxic Gas Dispersion Outside Powerhouse

Model: 1 volume, 1 subdivided volume (819 cells), 22 junctions.

Results not compared to other data or analysis. Ontario Hydro report to be issued.

Generally reasonable predictions. Difficult to assign correct turbulent mixing length to establish steady state velocity profile. Certain degree of error due to numerical diffusion.

APPENDIX E – SUMMARY OF GOTHIC_P SURVEY

The original GOTHIC_P survey responses are contained in the findings notebook identified in Appendix G.

Responses from

Paul Hansen	GPU Nuclear
Jim Harrell	CP & L
Paul Sicard	Entergy (Waterford-3)
John Link	GPU Nuclear
Dave Paulsen	Westinghouse
Raymond Wong	Ontario Hydro
Randall Richardson	Baltimore Gas & Electric
Tom Yadon	Duke Power
Pete Studer	TVA
James McLeod	Southern Services
Vijay Chandra	PSE&G

1. Have you prepared GOTHIC_S input with GOTHIC_P? 9 Yes 2 No

2. Have you prepared GOTHIC_S input without GOTHIC_P? 5 Yes 6 No

3. Have you ever compared the results of both methods of input? 3 Yes 8 No

4. Do you know of any discrepancies between the two input methods? 1 Yes 10 No

   The Yes response was from Dave Paulsen. He reported as part of the design review.

5. Provide comments regarding the usefulness of GOTHIC_P.

   Summary of typical responses:

   Harrell: "GOTHIC_P is very useful for geometry input. Much quicker to use the code. No problems have been encountered with GOTHIC_P prepared input."

   Chandra: "Very easy to use. Direct table editing is tedious." (See NAI response, Page 1.)

   NAI Response [47]:

   "The original editor in GOTHIC_P was an abbreviated version of "vi". Many users indicated some frustration using "vi", probably because use of "vi" requires being familiar with a variety of commands, while the only place they encountered "vi" was during their GOTHIC sessions. Such limited use would make it difficult to become an adept "vi" user. In response to this user feedback, a new editor has been added to GOTHIC_P as the default editor. The new editor is easy to use, and operates much like editors found in most word processors. For now, "vi" is still available for those who have endured the learning curve and mastered its great power."

Studer: "GOTHIC_P should have full QA Review consistent with GOTHIC_S. It should be able to produce all input consistent with the capability of GOTHIC_S."

McLeod: "GOTHIC_P is extremely important. Without GOTHIC_P, the validation of GOTHIC_S is just one more code. Benchmarks should be based on validation using GOTHIC_P to prepare input. GOTHIC_S input/output should be transparent to the user."

Hansen: "There is a user responsibility when using GOTHIC_P. Need complete echo of input as interpreted by GOTHIC_S to assure input confidence."

NAI Response [47]:

> Output for a GOTHIC_S simulation that is not a restart begins with a complete echo and summary of the input. If the input was written from GOTHIC_P, the user can review the echo of the input to note that the actual GOTHIC_S input is clearly what is intended, since some table values in GOTHIC_P are processed to arrive at the GOTHIC_S input. The input summary is intended to be a complete description of all GOTHIC_S input. It is printed in table format with descriptive headings. Some processed GOTHIC input is also in these tables.

Sicard: "Very useful. Input description is much easier. GOTHIC_P prepared input runs faster with GOTHIC_S."

Yadon: "GOTHIC_P models run faster. Creating large input files without it can be very tedious. Users need to maintain some familiarity with the *.sin files for checking purposes. Management would never consider the GOTHIC_P tables to be a substitute for the *.sin file in QA documentation." (See NAI response, Page 2.)

NAI Response [47]:

> NAI contends that use of GOTHIC_P reduces the time required to prepare an input file for GOTHIC_S, compared to creating the input file with an editor. More importantly, use of GOTHIC_P makes it possible to avoid errors that are common, especially in large problems. However, the appropriateness of a model, which includes its run time are dependent on the care and experience of the user. It is easier to build an input file with GOTHIC_P than with an editor, but the quality of the model remains the responsibility of the user in either case.

Wong: "FATHOMS model input (over 3000 lines) have been regenerated by GOTHIC_P without error. Compared model input for: sub-volumes, valves, trips, heat conductors, initial conditions, boundary conditions and control parameters." (Note: FATHOMS was a predecessor to GOTHIC.)

Paulsen: "GOTHIC_P simplifies the input process, reduces the model construction, debug and modification time significantly."

APPENDIX F – RESUMES OF DESIGN REVIEW MEMBERS

The DRG consisted of the following members:

Donald S. Rowe	Rowe & Associates 10202 217th Ct. NE Redmond, WA 98053 (206) 868-2448	 (206) 868-2458 (FAX)
Michael L. Corradini	University of Wisconsin 1500 Johnson Drive Madison, WI 53706 (608) 263-2196	 (608) 262-6707 (FAX)
David L. Paulsen	Westinghouse Energy Center PO Box 355 Pittsburgh, PA 15230 (412) 374-5572	 (412) 374-5744 (FAX)
	Westinghouse Energy Center 4350 Northern Pike Monroeville, PA 15146	
Donald C. Slaughterbeck	Science Applications International Corp. PO Box 50697 545 Shoup Avenue Idaho Falls, ID 83403-0697 (208) 528-2118	 (208) 528-2185 (FAX)
James H. McFadden	Computer Simulation & Analysis PO Box 51596 450 D Street Idaho Falls, ID 83405 (208) 529-1700	 (208) 529-1723 (FAX)

RESUME

DONALD S. ROWE, Ph.D., PE

Education

BS, Mechanical Engineering, University of Washington, 1960
MS, Nuclear Engineering, University of Washington, 1963
PhD, Mechanical Engineering, Oregon State University, 1973

Experience

Dr. Rowe has thirty years experience in energy related technology. His experience background includes contributions as an individual contributor and management. Areas of special technical expertise include: reactor safety analysis and licensing, heat transfer aspects of nuclear fuels, computational methods development, engineering analysis, engineering design, and large scale laboratory experiments. Managerial skills include both personnel and program management. He has published many technical papers and has presented numerous invited lectures and seminars. He is a registered professional engineer in the State of Washington.

Dr. Rowe began his career with General Electric, Schenectady, New York in 1960 as a thermal and fluid flow analyst for naval nuclear reactor systems. He transferred to the General Electric site at Richland, Washington in 1963 and stayed with Battelle-Northwest Laboratory when the AEC contracts were transferred in 1965.

With Battelle, he provided major contribution and technical lead on research topics including: two-phase flow, critical heat flux, computer code development (COBRA), flow mixing, heat transfer, flow blockage, and emergency core cooling systems (ECCS) evaluation. From 1973 to 1976, he managed thermal-hydraulic analysis methods development and experiments.

From 1976 to 1977, Dr. Rowe was Manager, Fuel Technology, in the Research and Technology Department at Exxon Nuclear Company in Richland, Washington. He had management responsibilities for Exxon Nuclear fuels research and development programs.

Rowe & Associates was established in 1977. This engineering consulting firm provides expert capability in heat transfer and fluid flow with emphasis on two-phase numerical methods and applications. While expertise continues in matters related to the thermal-hydraulics of nuclear reactor technology, that expertise has been applied to other areas including general two-phase systems, energy storage, fusion energy and space systems.

In 1983 Dr. Rowe also became involved with the University of Washington through the position of Affiliate Professor of Nuclear Engineering. He has been responsible for teaching courses in Reactor Engineering and Design for both fission and fusion reactor systems. He has also advised students on graduate research topics.

DONALD S. ROWE

PROFESSIONAL AFFILIATIONS

American Society of Mechanical Engineers
- K-13 Nucleonics Heat Transfer Committee
- Session Co-Chairman 1975 Natl. Heat Transfer Conference
- Session Co-Chairman 1977 Winter Annual Meeting
- Heat Transfer Division Professional Dev, Chair 1983-1985
- Heat Transfer Div. Membership Development Committee, 1985-1989

American Nuclear Society
- Paper Review Committee
- Computational Benchmark Committee
- Session Chairman, Numerous Annual Meetings
- Math & Comp Division, Treasurer 1976-77
- Math & Comp Division, Executive Committee 1977-79
- Thermal-Hydraulics Division, Treasurer 1979-80
- Thermal-Hydraulics Division, V-Chair 1980-81
- Thermal-Hydraulics Division, Chair 1981-82
- Thermal-Hydraulics Division, Executive Committee 1982-83
- Puget Sound Section, Chair 1980-81, 1988-present
- Short Course Committee, Founding Chair, 1982-85
- National Program Committee, 1982-85
- Professional Development Committee, 1983-1985
- National Board of Directors, 1987-1989

University of Washington
- Affiliate Professor of Nuclear Engineering, 1983
- Acting Professor of Nuclear Engineering, 1984-85
- Affiliate Professor of Nuclear Engineering, 1986-present

Journal Paper Reviewer
- Journal of Heat Transfer
- Journal of Fluid Mechanics
- Nuclear Technology
- Nuclear Technology Fusion
- Nuclear Science and Engineering
- Nuclear Engineering and Design (Editorial Adv. Board)
- International Journal of Heat and Mass Transfer

Bellevue Chamber of Commerce
- Energy and Environmental Needs Committee, Chair 1982-84

Honors and Awards
- Fellow, American Nuclear Society, 1984

Registered Professional Engineer (Washington 9957)

MICHAEL L. CORRADINI

Professor of Nuclear Engineering and Engineering Physics
University of Wisconsin-Madison

EDUCATION

MASSACHUSETTS INSTITUTE OF TECHNOLOGY

- January 1977 - Master of Science in Nuclear Engineering
  September 1978 - PhD in Nuclear Engineering

- Studied under Professors N.E. Todreas, W.M. Rohsenew, A.A. Sonin.
  Thesis topic: Heat Transfer and Fluid Flow Aspect of Fuel-Coolant Interaction

- Rockwell International Fellowship 1975-1977. Sigma Xi, ANS, ASME

MARQUETTE UNIVERSITY

- May 1975 - BS in Mechanical Engineering. Broad Mechanical Engineering curriculum with emphasis in fluid flow, thermodynamics and heat transfer.

PROFESSIONAL EXPERIENCE

- Member of the Technical staff at Sandia National Laboratories, 1978-81
  - Principal Investigator for the LWR Steam Explosion Research Program for the USNRC
  - Analyst for the Transition Phase Research Program in LMFBR for USNRC
  - Analysis and experiments in conjunction with the Hydrogen Research Program for USNRC
  - Analyst for the LWR Molten-Core-Concrete Research Program for USNRC
  - Analyst for the DOE Nevada Test Site Yucca Mountain Radioactive Waste Characterization Study
- Presently Professor at the University of Wisconsin-Madison in Nuclear Engineering and Engineering Physics and Mechanical Engineering

PROFESSIONAL AWARDS AND DISTINCTION

- Advisor/Consultant to the Presidential Commission on Three Mile Island, 1979
- Member of NRC Review Group on the PRA Guidebook 1981
- Awarded the NSF Presidential Young Investigator's Award in 1984
- Member of the Radioactive Waste Review Board Technical Advisory Council for the State of Wisconsin
- Consultant to the NRC Advisory Committee on Reactor Safeguards for Severe Accidents and Waste Management
- Vice-Chairman of NRC Steam Explosion Expert Review Group
- Chairman of NRC NUREG-1150 Containment Event Tree Review Group, 1985
- Representative of Core-Concrete Interaction Experiment Review Committee (BETA, ACE)
- Director of UW Nuclear Safety Research Center
- Member of Expert Group on Source Term for NUREG-1150 (MCCI and FCI), 1988
- Member of DOE New Production Reactor Safety Board (1988-1990)
- Member of EPRI Advanced Containment Experiment Technical Advisory Committee
- Fellow of the American Nuclear Society 1990
- ANS Young Members Engineering Achievement Award

RESUME

James H. McFadden   Principal Analyst, Computer Simulation & Analysis

Education: BS Physics, Loras College - 1962
MS Nuclear Science, University of Iowa - 1965
PhD Nuclear Engineering, Iowa State University - 1968

Experience:

Mr. McFadden has 23 years of experience working in the electric utility and nuclear power fields. The primary area of interest has involved the development and application of computer codes for nuclear reactor safety analysis. This work has included project management responsibilities, participation in the development activities, and implementation of the verification and validation program for the RETRAN series of computer programs. Specific technical items pertinent to the GOTHIC review include the development of constitutive models for heat transfer and mass and momentum exchange in multi-phase flows.

From 1968 to 1975, Mr. McFadden was an associate scientist at the Idaho National Engineering Laboratory. At the INEL, the primary work involved the development, testing, and validation of constitutive equations to model wall-to-phase and interphase momentum exchange and energy exchange for steam-water systems, and the implementation of these models in steady-state and transient computer codes. He also worked in the areas of radiological safety analysis, atmospheric dispersion of fission products, and modeling of fission product behavior in operating reactor fuel pins.

Mr. McFadden was affiliated with Energy Incorporated from 1975 to 1988. At EI, he was involved in energy systems analysis, two-phase flow modeling, was the project manager of the RETRAN code development team, and provided overall support for software development and thermal-hydraulic analysis activities. He was a contributing author to the Software Procedures and the Software Standards manuals that were used for safety related software projects at EI, and he participated in software design reviews, both as chairman of a design review committee and as technical member of a code development project.

Mr. McFadden left EI in 1988 and is a co-founder of CSA. At CSA, he has continued to work in modeling of two-phase flow, on the development of models for use in analyzing nuclear reactor plant transients, and as a participant in independent software design reviews. The COBRA-SFS computer code was the subject of one of the software reviews.

Professional Affiliations:

American Nuclear Society (National and Idaho Section)
American Physical Society
American Society of Mechanical Engineers

Publications:

Mr. McFadden has contributed to approximately 30 professional reports, technical papers and presentations. The publications pertinent to the GOTHIC Design Review are listed below.

"Unequal Phase Velocity Models of Annular-Dispersed Flow", Transactions of the American Nuclear Society, Washington, October 1974, (with R. F. Farman)

"Heat Transfer and Friction Correlations Required to Describe Steam-Water Behavior in Nuclear Safety Studies", 15th National Heat Transfer Conference, San Francisco, August 1975 (with C. W. Solbrig, R. W. Lyczkowski and E. D. Hughes)

"An Evaluation of State-of-the-Art Two-Velocity Two-phase Flow Models and Their Applicability to Nuclear Reactor Transients Analysis", EPRI NP-143, February 1976 (with E. D. Hughes, R. W. Lyczkowski and G. F. Niederauer)

"Numerical Methods for Solving the Governing Equations for a Seriated Continuum", ANCR-NUREG-1340, September 1976 (with R. E. Narum, C. E. Noble and G. A. Mortenson)

"RETRAN - A Program for One-Dimensional Transient Thermal-Hydraulic Analysis of Complex Fluid Flow Systems", 4 Volumes, EPRI CCM-5, December 1978 (with K. V. Moore, et al.)

"Ver cation and Qualification of the RETRAN Computer Code", 1980 ANS/ENS Topic Meeting on Thermal Reactor Safety, Knoxville, April 1980 (with L. J. Agee)

"Numerical Aspects of the RETRAN Code System", ANS/ENS International Topical Meeting on Advances in Mathematical Methods for the Solution of Nuclear Engineering Problems, Munich, April 1981 (with L. J. Agee)

"RETRAN-02 - A Program for Transient Thermal-Hydraulic Analysis of Complex Fluid Flow Systems: Volume 1 - Equations and Numerics", EPRI CCM-1850, April 1981, revised June 1987 (with M. P. Paulsen, et al.)

"RETRAN-02 - A Program for Transient Thermal-Hydraulic Analysis of Complex Fluid Flow Systems: Volume 4 - Applications", EPRI CCM-1850, January 1983 (with C. E. Peterson and G. C. Gose)

"RETRAN-03 - A Program for Transient Thermal-Hydraulic Analysis of Complex Fluid Flow Systems", EPRI NP-7450-CCML, July 1991, (with M. P. Paulsen, et al.)

DONALD C. SLAUGHTERBECK

Position with Company:
Senior Engineer

EDUCATION::

University of Wyoming: M. S., Mechanical Engineering, 1965
University of Wyoming: B. S., Mechanical Engineering, 1964
Continuing education in evening courses (24 semester hours beyond M.S.), and at short courses and seminars.

EXPERIENCE SUMMARY:

Mr. Slaughterbeck is a containment analysis specialist with over 24 years experience in containment and severe accident safety analysis for the government, private, and foreign sectors. He has demonstrated capabilities in thermal-hydraulic analyses using computer simulations, and has provided on-site test support to several large scale experimental containment facilities in this country and abroad. Recent containment tasks have included an in-depth review of condensation and convective heat transfer correlations with application to equipment qualification in advanced containment codes, analytical support to a nuclear utility related to the influence of discharge parameters on containment behavior, and calculations related to the containment transients for a proposed power upgrade. For the ATR at the INEL, Mr. Slaughterbeck has performed safety analyses of ATR capsule and loop experiments, and contributed to an analysis of safety-related equipment.

PROFESSIONAL EXPERIENCE:

Since Mr. Slaughterbeck joined the Intermountain Technologies Division of SAIC in 1988, he analyzed a number of nuclear safety issues and participated in programs for DOE, EPRI, and the nuclear utilities. He is currently completing efforts directed toward establishment of the containment pressure and temperature envelope for a nuclear utility undergoing a power upgrade and a DOE reactor to establish equipment qualification criteria. He recently completed an analysis of the influence of discharge parameters on the containment transient for a commercial nuclear plant. He performed an analysis of condensing-steam heat transfer correlations suitable for an advanced containment analysis code under development by EPRI, and established a set of containment problems for use in verification and validation of the advanced code. For the ATR at INEL, he performed safety analyses of ATR capsule experiments, and contributed to an analysis of safety-related equipment. The particular areas where Mr. Slaughterbeck contributed to specification of safety-related equipment in ATR included evaluating and interpreting the ATR PRA analysis and accident scenarios. He was a safety analyst on a proposed high level waste vitrification facility at the Hanford site, and contributed to the SAR for that facility. Safety assessments on natural and operational hazards were performed by Mr. Slaughterbeck for hazardous, radioactive, and reactive waste storage facilities at the INEL. He led a team that developed a mini-risk assessment technique for facilities with low inventories of hazardous or radioactive materials and applied the method to three waste management facilities. He reviewed, as part of a peer group, aspects of a probabilistic risk assessment on the N reactor at the Hanford site, and resolved several safety issues for restart of the Savannah River production reactors. A formulation of operational safety requirements including safety limits, limiting control settings, and limiting conditions for operation was completed for a high level liquid waste storage facility at Hanford.

As an employee of Intermountain Technologies, Inc., Mr Slaughterbeck completed a number of tasks for NRC, EPRI, DOE, nuclear fuel vendors, and the nuclear utilities. These include support to and participation in three international testing programs related to containment transients and severe accidents: Marviken Jet Impingement Tests in Sweden, Marviken Aerosol Transport Tests in Sweden, and the LWR Aerosol Containment Experiments (LACE) experiments at Hanford. He performed in-depth analysis of specific issues such as containment siting, jet impingement, severe accident evaluations, PRA lessons-learned for advance reactor design, emergency response, condensing-steam heat transfer, containment and DNBR licensing calculations for industry, Safety Analysis Report (SAR) analyst and author, PRA of safety systems, aerosol transport in piping and containment systems, computer code uncertainty analysis, PRA reviews, and small-break analysis models. He helped to develop and was the first to demonstrate a turbine meter with hydrostatic bearings for the measurement of very low velocity compressible flow. He frequently presented results of tests and analyses to peer-review groups and to international technical advisory groups.

While employed at the Idaho National Engineering Laboratory, Mr. Slaughterbeck provided key assistance to the NRC in the formulation of Regulatory Guides and Standard Review Plans governing containment licensing topics and fuel-coolant heat transfer correlations. He published various parametric studies related to containment behavior in response to a LOCA. As a full-time safety analyst on NRC's first probabilistic risk assessment, the Reactor Safety Study, he was instrumental in the development of the event tree methodology and classification of system interactions and interdependencies. In 1976, Mr. Slaughterbeck was selected to represent the NRC as their on-site representative to the Marviken Containment Response Tests in Sweden. Following his return, he supervised an engineering group involved in providing technical assistance to the NRC.

As an analyst in the propulsion research staff at the Boeing Company, Mr. Slaughterbeck performed studies involving the statistical variations of engine thrust variations, jet wake noise reductions, and flow resistance to fiber-metal acoustic linings.

PROFESSIONAL SOCIETY AFFILIATIONS AND ACTIVITIES:

Member, American Society of Mechanical Engineers, current Director and past chairman. Member, American Nuclear Society. Mr. Slaughterbeck has presented technical papers at several national meetings of both the ASME and ANS.

SECURITY CLEARANCES:

Active DOE "L" Clearance

PUBLICATIONS

"Measurement of Natural and Forced Convection Gas Velocities with Aerosols Using a Hydrostatic Fluid Bearing Turbine Flow Meter", paper presented at 4th Miami International Symposium on Multiphase Transport and Particulate Phenomena, D. C. Slaughterbeck, December 1986.

"Auxiliary Building Thermal-Hydraulic Conditions Relevant to Radionuclide Retention for the Interfacing Systems LOCA", paper presented at ANS Meeting on Source Terms, Snowbird, Utah, D. C. Slaughterbeck, P. R. Davis, and F. A. Rahn, July 1984.

"Large-Scale, Two-Phase Jet Impingement Experiments at Marviken", Paper presented at ANS Meeting, Chicago, Illinois. Co-authors, D. Slaughterbeck, D. Mecham, O. Sandervag, J. Collen, August 1982.

"California Underground Siting Study: Selection and Analysis of Accident Sequences", Paper presented at ANS Meeting, Atlanta, Georgia, co-authors, P. R. Davis, C. S. Miller, D. C. Slaughterbeck, August 1979.

"Nuclear Safety Experiments in the Marviken Power Station", Nuclear Safety Magazine, D. C. Slaughterbeck and L. Ericson, August 1977.

"Flow Film Boiling Heat Transfer Correlations - Parametric Study with Data Comparisons", ASME 73-HT-50, D. C. Slaughterbeck, August 1973.

Statistical Regression Analysis of Experimental Data for Flow Film Boiling Heat Transfer", ASME 73-HT-20, D. C. Slaughterbeck, August 1973.

"Correlations to Predict Maximum PWR Containment Pressures Following a Loss-of-Coolant Accident", Proceedings of the New Developments in Reactor Mathematics and Applications Meeting of the American Nuclear Society, Idaho Falls, ID, D. C. Slaughterbeck, May 1971.

Review of Heat Transfer Coefficients for Condensing Steam in a Containment Building Following a Loss-of-Coolant Accident, IN-1388, D. C. Slaughterbeck, 1970.

Pressure Responses of PWR Containments - A Parametric Analysis, IDO-17300, D. C. Slaughterbeck, June 1969.

"Pressure-Temperature Response of PWR Containments - A Parametric Analysis", Proceedings of the 15th Annual Meeting of the American Nuclear Society, Seattle, Washington, D. C. Slaughterbeck, June 1969.

DAVID L. PAULSEN

FIELD: Nuclear Safety

Total Experience: 7 years
Westinghouse: 5 years

RELATED PROFESSIONAL EXPERIENCE

(1990-PRESENT) ENGINEER, CONTAINMENT DESIGN AND BWR TECHNOLOGY, WESTINGHOUSE NUCLEAR TECHNOLOGY DIVISION

Responsible for performing containment integrity analyses including FSAR analyses and addressing licensing issues and BWR non-LOCA transient analyses. Responsible engineer for the GOTHIC code.

(1985-1990) ENGINEER, SAFEGUARDS ANALYSIS II, WESTINGHOUSE NUCLEAR TECHNOLOGY DIVISION

Responsible for performing small and large break LOCA accident analyses and LOCA hydraulic forces analyses and for performing safety evaluations on the analyses. Responsible for the LOCA related portion of the fuel reload scope and evaluation for various nuclear units. Performed various non-LOCA transient analyses on an as needed basis.

EDUCATION

Bachelors of Science Nuclear Engineering, Kansas State University, 1982
Masters of Engineering Nuclear Engineering, Penn State University, in progress

APPENDIX G – DESIGN REVIEW FINAL INVENTORY

The following constitutes the DRG record:

1) Copies of all reference material as presented in Section 7.0.

2) A three-ring binder notebook with:
   - Original DRG findings (filled out review forms)
   - Original survey responses

3) Computer disks with GOTHIC 3.4D and GOTHIC 4.0 code (source code for all modules).

4) Computer disks with GOTHIC input files for all:
   - Standard problems
   - Demonstration cases
   - Validation analyses

   This includes files for all reported analysis in the documentation whether reviewed by the DRG or not.