NMC
Committed to Nuclear Excellence

Kewaunee Nuclear Power Plant
N490 Highway 42
Kewaunee, WI 54216-9511
920.388 2560

Point Beach Nuclear Plant
6610 Nuclear Road
Two Rivers, WI 54241
920 755 2321

Kewaunee / Point Beach Nuclear
Operated by Nuclear Management Company, LLC

NRC-02-082

September 30, 2002

10 CFR § 50.90

U.S. Nuclear Regulatory Commission
Attention: Document Control Desk
Washington, D.C. 20555

Ladies/Gentlemen:

Docket 50-305
Operating License DPR-43
Kewaunee Nuclear Power Plant
Kewaunee Nuclear Power Plant Request for Use of GOTHIC 7 in Containment Design Basis Accident Analyses

Reference:

1) NMC letter number NRC-00-082 from K. H. Weinhauer, "Wisconsin Public Service Corporation Reload Safety Evaluation Methods Topical Report, WPSRSEM-NP, Revision 3," to NRC Document Control Desk, dated October 12, 2000

2) NRC letter to Mr. Mark Reddemann, "KEWAUNEE NUCLEAR POWER PLANT – REVIEW FOR KEWAUNEE RELOAD SAFETY EVALUATION METHODS TOPICAL REPORT WPSRSEM-NP, REVISION 3 (TAC NO. MB0306), dated September 10, 2001

Nuclear Management Company, LLC, (NMC) requests Nuclear Regulatory Commission (NRC) permission to change Kewaunee Nuclear Power Plant (KNPP) Facility Operating License DRP-43. NMC is currently licensed to use GOTHIC version 6.0a (GOTHIC 6) in KNPP design basis accident (DBA) containment integrity analyses. We intend to replace GOTHIC 6 with the upgraded version 7.0p2 (GOTHIC 7). Our original request to use GOTHIC was presented to the NRC as part of a larger request to implement a revised Reload Safety Evaluation methodology, described in the topical report WPSRSEM–NP, Revision 3, (Reference 1). The NRC subsequently approved this request (Reference 2). NMC will use GOTHIC 7 for the same purposes for which GOTHIC 6 is now licensed. We will use it to model containment response for loss of coolant accidents (LOCA) and main steam line break (MSLB) accidents.

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The principal difference between GOTHIC 6 and GOTHIC 7 lies in the ability of GOTHIC 7 to model mist diffusion layers. Mist diffusion layers can measurably facilitate heat and mass flow from high moisture content, superheated atmospheres to adjacent heat sinks. Use of the GOTHIC 7 mist diffusion layer model (MDLM) option is expected to predict lower peak containment pressure and temperature.

NMC retained the services of Numerical Applications, Inc., (NAI) of Richland, Washington, to review our proposed application of GOTHIC 7, evaluate it and characterize it with respect to its efficacy and suitability. NAI found our intended use to adequately and conservatively model containment response in the subject DBA with good correlation to the currently licensed methodology. Comments by NAI have been incorporated into NMC's use of GOTHIC 7 and a copy of their report is included herewith. The NAI report was produced in accordance with NAI-QA-1, Revision 13, which conforms to requirements set forth in 10 CFR § 50, Appendix B.

Attachments to this LAR are 1) safety evaluation, significant hazards determination, and statement of environmental considerations, 2) the NAI report, "GOTHIC Containment Analysis Summary Report, Kewaunee Nuclear Power Plant."

NMC has transmitted a copy of this request to the State of Wisconsin, per 10 CFR § 50.91(b)(1).

NMC asks the NRC to approve this request by March 3, 2003, for use in analyses required by our request for power uprate that is currently scheduled for submittal at that time.

If there are questions, please contact either Mr. Thomas J. Webb at (920) 388-8537 or me at (920) 388-8222.

I declare under penalty of perjury that the foregoing is true and correct.
Executed on September 30, 2002.

Sincerely,

Thomas Coutu

Thomas Coutu
Site Vice President
Kewaunee Nuclear Power Plant
Nuclear Management Company, LLC

MTVN

Attachments:
1. Description of Change, Safety Evaluation, Significant Hazards Determination, and Statement of Environmental Considerations
2. NAI-1105-04, Revision 2, "Support for GOTHIC Containment Analysis for the Kewaunee Nuclear Power Plant Summary Report," by T.L. George, Numerical Applications, Inc., dated August 2002

cc - US NRC Region III
US NRC Senior Resident Inspector
Electric Division, PSCW

ATTACHMENT 1

Letter from Thomas Coutu (NMC)

To

Document Control Desk (NRC)

Dated

September 30, 2002

Use of GOTHIC 7 in Containment Design Basis Accident Analyses

Description of Proposed Changes

Safety Evaluation

Significant Hazards Determination

Environmental Consideration

Introduction

Nuclear Management Company, LLC, (NMC) is upgrading its currently licensed code for Generation of Thermal-Hydraulic Information for Containment (GOTHIC) from version 6.0a (GOTHIC 6) to version 7.0p2 (GOTHIC 7). GOTHIC is used for modeling containment response to certain Kewaunee Nuclear Power Plant (KNPP) design basis accidents (DBA).

NMC retained Numerical Applications, Inc., (NAI) of Richland, Washington, to review our intended use, ensure that it produces accurate, conservative predictions of post-accident containment performance, and prepare a report to characterize results of their review for use in this application (Reference 1). The NAI report is provided herewith (Attachment 2).

NMC asks that the NRC provide approval of this request by March 3, 2003, in order to support our planned request for power uprate that is scheduled for that time.

Description of Change

The DBA analyses for which NMC is currently licensed to use GOTHIC are loss of coolant accidents (LOCA) and main steam line break (MSLB) accidents. This request does not change our use of GOTHIC from that which is currently licensed. It merely seeks upgrade to a newer version of GOTHIC. Since NMC is currently licensed for use of GOTHIC, implementing approval will only require minor administrative changes. Thus, there are no document changes requested.

Safety Evaluation

GOTHIC 7 can be used to model a mist diffusion layer (MDL). If MDL is not used, in GOTHIC 7, results for the affected DBA do not differ significantly from results produced by the currently licensed version, GOTHIC 6.[1] Our request and this discussion focuses on MDL.

A MDL is a naturally occurring phenomenon that facilitates heat and mass transfer to heat sinks from adjacent moisture laden, superheated atmospheres. Such a condition is expected during LOCA and MSLB post-accident containment conditions. Modeling MDL more accurately predicts the containment pressure and temperature response. The less refined GOTHIC version 6 does not model MDL, thus it does not directly account for the effect in its predictions. In order to ensure adequate conservatism in the outcome, overall GOTHIC 6 results have been biased conservatively to bound known or expected conditions. By accurately modeling MDL, unnecessary conservatism can be removed and increase margin. Margin is increased when the uncertainty associated with a known, but previously uncalculated, effect is replaced by accurately calculating that effect and, then, adding a conservative bias factor to the calculated result. This has been done with Gothic 7 modeling of MDL.

1 NAI Report, Table 2, "Comparison of 6.0a and 7.0p2 Results for DBAs"

When superheated, humid air is adjacent to a heat sink, water molecules in the atmosphere lose energy to the heat sink. Sub-cooled water molecules condense on the heat sink leaving a boundary layer that tends to be rich in non-condensable gases (air). Without mist, such a layer insulates the heat sink and restricts flow of mass and energy from the general atmosphere to the heat sink. However, formation of a mist layer occurs within the boundary layer space in condensing systems of this type. The mist layer contributes to overall conduction of heat to the heat sink, especially when the general atmosphere is superheated. Although other mass and energy transfer mechanisms also apply according to specific conditions, one of the controlling mass and energy transfer mechanisms in this instance is molecular diffusion.[2] A portion of the mist layer condenses on the heat sink and a portion migrates back to the superheated atmosphere where it absorbs a large amount of energy as it re-vaporizes. This process increases efficiency of mass and energy flow from the superheated atmosphere to the heat sink and has a cooling effect. The conceptual model outlined here is the basis for MDL and is fully described in the NAI report and its supporting documents.

Although the MDL mass and energy transfer can occur near any heat sink, GOTHIC 7 is intentionally restricted to vertical conductors,[3] which adds conservatism to the final outcome. NAI validated the GOTHIC 7 modeling of MDL by extensive comparison to recognized scientific standards and found results to be accurate and conservative.

NMC is currently licensed to use GOTHIC to model aspects of certain KNPP DBA (References 2 through 6). For the purposes of comparison, four bounding design basis accidents (DBA) were selected.[4] These DBA are double ended hot leg break (DEHL) LOCA, double ended pump suction (DEPS) break LOCA, 1.1 ft^2 MSLB (MSLB 1.1) at 0% power with one containment safeguards train failure, and 1.4 ft^2 MSLB (MSLB 1.4) at 100% power with feedwater regulator valve failure. Configuring these DBA scenarios for use with GOTHIC 7 did not significantly affect calculated results. Version to version peak pressure differences obtained using GOTHIC 7 without MDL modeling option activated are within 0.03 psi and peak temperatures are unchanged.[5]

In comparative execution of the two versions, NAI discovered the LOCA DBA modeled in GOTHIC 7 are sensitive to selected time increment size during the early portions of these transients. This is because of the more precise sump modeling ability of GOTHIC 7. Using shorter time increments produced acceptable results consistent with the converged solution for these DBA. NAI now recommends this measure for use with GOTHIC 7.[6]

In addition to reducing the time increment size, NAI concluded that there were several areas of the affected models that would benefit by improvement. Containment spray drop-size is changed to reflect nozzle specification, a linear change in water depth on floor heat sinks is modeled using the SPLIT option, the effect of heat transfer through liquid pools on flooded floors is modeled, and the Uchida option is used from time zero in modeling MSLB cases.

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2 NAI Report, Section 5, "MDLM"
3 NAI Report Table 6, "Containment Conductors"
4 NAI Report Table 1, "DBA Models"
5 NAI Report, Section 3, "Model Upgrade to 7.0p2"
6 NAI Report Section 9, "Conclusion"

The net effect of these improvements is a slight decrease in peak containment temperature and pressure for LOCA cases and a slight increase for MSLB cases. Decreased LOCA peak values are principally the result of using a smaller time increment.

In order to establish the accuracy and relative conservatism of MDL modeling, data recognized to represent an accepted body of scientific work was chosen. NAI applied this data as a suitable standard for gauging performance of Gothic 7's modeling of MDL. Comparing Gothic 7's modeling of MDL with the Carolinas-Virginia Tube Reactor (CVTR) effective heat transfer coefficient, NAI found that when the MDL modeling correlation is applied to a lumped-model similar to that used for KNPP, it under-predicts actual heat transfer by an average of 26% and over-predicts actual peak containment pressure by approximately 3 psia.[7] To ensure that all KNPP results derived by modeling MDL remain conservative, NAI statistically selected a bias factor to be used to reduce effective mass and energy transfer coefficients in the KNPP models. A factor of 0.717 was calculated using the one-sided tolerance limits described by D. B. Owen (Reference 7). Application of this factor to mass and energy transfer coefficients ensures a 95% probability that the predicted effective heat transfer coefficients calculated by MDLM will be less than the measured coefficients in 95% of test cases covered by the validation range. The LOCA and MSLB DBA analyses for KNPP that are affected by the GOTHIC 7 upgrade fall within the validation range.[8]

Even without the bias factor, MDL model already yields CVTR results that predict peak pressures that are greater, thus more conservative, than measured pressures. Adding a bias factor of 0.717 to this initial level of existing MDLM conservatism produces high confidence that predicted results will conservatively bound any rationally postulated DBA of the subject types. The requested upgrade to GOTHIC version 7.0 is conservative, consistent with existing design bases, and conforms to safety analysis acceptance criteria.

Thus, NMC concludes from the results outlined in the NAI report and our own assessment that use of GOTHIC 7 is effective for the proposed purpose, does not alter existing margins to safety, and will not create a circumstance inimical to safe operation.

Significant Hazards Determination

NMC reviewed use of GOTHIC 7 in accordance with provisions set forth in 10 CFR § 50.92 and found that it creates no significant hazard. The proposed changes will not:

1) Involve a significant increase in the probability or consequences of an accident previously evaluated.

   Accident analyses affected by GOTHIC have each been evaluated and found to show good agreement between the GOTHIC 7 analysis and the current analysis of record (AOR). Safety analysis results using GOTHIC 7 are shown to satisfy all applicable design and safety analysis acceptance criteria. Since GOTHIC 7 conforms to design bases and its results are bounded by the existing safety analyses, its use within limits of the bounding accident analyses will not cause an increase in the probability or consequences of an accident previously evaluated. Adherence to safety analysis acceptance criteria prevents use of GOTHIC 7 from creating new challenges to components and systems that could adversely affect their ability to mitigate accident consequence or diminish integrity of any fission product barrier.

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7 NAI Report, Section 6, "Biasing MDLM"

8 NAI Report Table 5, "MDLM Validation Range and Expected DBA Conditions"

Thus, the requested upgrade to GOTHIC 7 with MDL modeling option will not increase probability or the consequences of an accident previously evaluated.

2) Create the possibility of a new or different kind of accident from any accident previously evaluated.

Upgrade to GOTHIC 7 is a change in analysis methods applied to Kewaunee DBA. Analysis methods are not accident initiators. GOTHIC 7 will be applied in the same manner currently licensed and it is consistent with current plant design bases and licensed accident analysis methodologies. It does not adversely affect any fission product barrier, nor does it alter the safety function of safety related systems, structures, and components depended upon for accident prevention or mitigation. Equipment important to safety will continue to function within design. As demonstrated by the NAI report, GOTHIC 7 yields a representation of expected plant response for affected design basis accidents that is more accurate but remains conservative. GOTHIC 7 predicted results for affected DBA remain bounded by the limiting analyses of record.

Thus, the requested upgrade to GOTHIC 7 does not create the possibility of a new or different kind of accident from any previously evaluated.

3) Involve a significant reduction in the margin of safety.

Upgrade to GOTHIC 7 affects Kewaunee design basis LOCA and MSLB DBA containment analyses. The results predicted by GOTHIC 7 for these DBA analyses remain within limiting design basis accidents of record. GOTHIC 7 accuracy and conservatism in this application has been verified through benchmark analyses against the current analyses of record, validated against recognized standard data, and found to be appropriate for application to Kewaunee DBA. Safety analysis acceptance criteria are satisfied and adherence to safety analysis acceptance criteria using GOTHIC 7 assures that Technical Specification limits will not be exceeded during normal operation.

Thus, upgrade to GOTHIC 7 does not involve a significant reduction in the margin of safety.

Environmental Considerations

NMC has determined that upgrade from GOTHIC 6 to GOTHIC 7 involves no significant hazard consideration. It does not modify any facility component located within the restricted area, as defined in 10 CFR § 20. It makes no significant change in the types of effluents that may be released offsite and it causes no significant increase in individual or cumulative occupational radiation exposure. Accordingly, this revision meets the eligibility criteria for categorical exclusion set forth in 10 CFR § 51.22(c)(9). Pursuant to 10 CFR § 51.22(b), no environmental impact statement or environmental assessment need be prepared in connection with this revision.

References

1. NAI-1105-04, Revision 2, "Support for GOTHIC Containment Analysis for the Kewaunee Nuclear Power Plant Summary Report," by T.L. George, Numerical Applications, Inc., dated August 2002

2. Letter from K. H. Weinhauer (NMC) to Document Control Desk (NRC), "Wisconsin Public Service Corporation Reload safety Evaluation Methods Topical Report, WPSRSEM-NP, Revision 3," dated October 12, 2000, and including subsequent amendatory letters and responses to NRC requests for additional information.

3. Letter from M. E. Reddemann (NMC) to Document Control Desk (NRC), "Nuclear Management Company, LLC. Response to NRC's Request for Additional Information on Wisconsin Public Service Corporation Reload Safety Evaluation Methods Topical Report, WPSRSEM-NP, Revision 3," dated February 7, 2001

4. Letter from M. E. Reddemann (NMC) to Document Control Desk (NRC), "Nuclear Management Company, LLC. Revised Response to NRC's Request for Additional Information on Wisconsin Public Service Corporation Reload Safety Evaluation Methods Topical Report, WPSRSEM-NP, Revision 3," dated March 7, 2001

5. Letter from M. E. Reddemann (NMC) to Document Control Desk (NRC), "Nuclear Management Company, LLC, Response to NRC's Request for Additional Information on Wisconsin Public Service Corporation Reload Safety Evaluation Methods Topical report, WPSRSEM-NP, Revision 3," dated July 26, 2001

6. Letter from John G. Lamb (NRC) to Mark Reddemann (NMC), "Kewaunee Nuclear Power Plant – Review for Kewaunee Reload Safety Evaluation Methods Topical Report WPSRSEM-NP, Revision 3 (TAC NO. MB0306)," dated September 10, 2001

7. D. B. Owen, "Factors for One-Sided Tolerance Limits and for Variables Sampling Plans," XDR-607, Monograph, Sandia Corporation, March 1963

ATTACHMENT 2

Letter from Thomas Coutu (NMC)

To

Document Control Desk (NRC)

Dated

September 30, 2002

Use of GOTHIC 7 in Containment Design Basis Accident Analyses

GOTHIC Containment Analysis Summary Report

Kewaunee Nuclear Power Plant

NAI-1105-04, Revision 2

by T.L. George

Numerical Applications, Inc.

Richland, Washington

August 2002

Support for GOTHIC Containment Analysis for the Kewaunee Nuclear Power Plant

Summary Report

August 2002

TL George

Numerical Applications, Inc.
Richland, WA

Support for GOTHIC Containment Analysis for the Kewaunee Nuclear Power Plant Summary Report

Introduction and Objective

Kewaunee Nuclear Power Plant (KNPP) plans to use GOTHIC to support containment pressure and temperature limits for Design Basis Accidents (DBA) Loss of Coolant Accident (LOCA) and Main Steamline Break (MSLB) in conjunction with their Power Uprate Project. Previously, KNPP used GOTHIC version 6.0a for their DBA analysis [1].

The objective of this project was to develop support for use of GOTHIC's Mist Diffusion Layer Model (MDLM) for heat and mass transfer for the KNPP DBA containment analyses. The MDLM option has been shown to produce lower peak temperatures and pressures, especially for steam line breaks [3]. This objective was accomplished by:

1. Upgrading the existing models to version 7.0p2
2. Making model improvements for the DBA applications
3. Calculating an appropriate factor that can be applied to the MDLM heat transfer option to provide additional conservatism in the DBA results.
4. Implementing the MDLM option with the conservative factor in the DBA models and documenting the results.

Details of the analysis are described in [2].

Four DBA models were used for this analysis, including two LOCA's and two MSLB's as listed in table below.

Table 1 DBA Models

Model	Description
DEHL	Double ended Hot Leg Break LOCA
DEPS	Double ended Pump Suction Break LOCA
MSLB1.1	1.1 ft2 MSLB at 0% Power with failure of one train of containment safeguards
MSLB1.4	1.4 ft2 MSLB at 100% Power with feedwater regulator valve failure

Assumptions

It was assumed that the physical parameters in the existing Kewaunee DBA models are correct and fully qualified. This includes volumes, surfaces areas and relevant dimensions, the number, type and composition of heat sinks, initial conditions, operating characteristics and controlling conditions for spray systems, pumps, fans, valves and heat exchangers, and the mass and energy release data included in the DBA models.

Model Upgrade to 7.0p2

There have been many changes to the code since the release of version 6.0a, including the new wall heat and mass transfer option (MDLM). To provide a basis for the 7.0p2 results, the upgraded 7.0p2 model results were compared with the 6.0a results. The preprocessor automatically upgrades older models but some manual modifications were necessary to make the models compatible with the new features in 7.0p2. None of these modifications had any impact on the calculated results. The 6.0a and 7.0p2 results for pressure, temperature and sump temperature for the four cases are shown in Figures 3 through 22. The peak temperature and pressure values are shown in Table 2.

Table 2 Comparison of 6.0a and 7.0p2 Results for DBAs.

	Peak Pressure		Peak Temperature	
GOTHIC Version	6.0a	7.0p2	6.0a	7.0p2
DEHL	59.48	59.51	265.4	265.4
DEPS	56.92	56.94	261.5	261.5
MSLB1.4	60.93	60.91	267.4	267.4
MSLB1.1	56.96	56.94	261.5	261.5

The version-to-version peak pressures are all within 0.03 psi and the peak temperatures are unchanged. The small differences in peak pressures are attributed to minor code improvements in version 7.0p2.

The graphs for the LOCA cases show some version-to-version differences in the early sump temperature. During this period, there is little water in the sump and the predicted temperature is sensitive to the time step size. The LOCA cases were rerun on both code versions using a smaller time step during the early part of the transient. The results from these runs are shown in Figures 1 through 14. With the reduced time step, the early temperature response predicted by the two codes is very close as shown in Table 3. Further reductions in time step resulted in much smaller changes in the peak conditions indicating that the presented results are substantially at the converged solution.

Table 3 Comparison of 6.0a and 7.0p2 Results for LOCA DBAs with Reduced Time Step Size.

	Peak Pressure		Peak Temperature	
GOTHIC Version	6.0a	7.0p2	6.0a	7.0p2
DEHL	59.35	59.31	265.2	265.1
DEPS	56.73	56.68	261.2	261.1

The long-term sump water temperature predicted by 7.0p2 is lower than that predicted by 6.0a in the DEPS LOCA. The 7.0p2 results are intuitively more correct since the recirculation water entering the containment during the last 50,000 seconds is around 106 F and the temperature should continue to decline towards this value. The 6.0a results show the sump temperature leveling off during the last 50,000 seconds. The difference was shown to be due to the treatment of supersaturated conditions in the two code versions [2]. In versions prior to 7.0, supersaturated conditions (subcooled steam) were dealt with by creating fog. The fog consists of very small drops that are combined with the drops from other sources (blowdown, sprays, etc.). This can cause the average drop size to be much smaller than that produced by the sprays or blowdown resulting in excessive hold up of drops in the atmosphere. In version 7.0 and later, supersaturated conditions result in the creation of a mist.

The mist field is tracked separately from the drops, eliminating the artificial size reduction of the drop field. The small drops created by the fog model in 6.0a during the early part of the DEPS transient effectively reduced the size of the spray drops. These drops are held up in the atmosphere and are gradually deposited on the floor of the containment. With the mist model in 7.0, the drops in the atmosphere are quickly depleted when the sprays are terminated. The prolonged rain out in version 6.0a deposits hot water to the sump that nearly balances (on an energy basis) the cooling provided by the recirculating flow.

Model Improvements

In comparing the 6.0a and 7.0p2 models and results, the need for some model improvements was noted. The first was the need to reduce the time step for the first part of the LOCA transients as noted above. Several additional modifications were made to improve the models.

1) The specified drop size for sprays should be based on nozzle specifications. In the 6.0a models a very small drop size was used to achieve 100% spray efficiency for consistency with earlier CONTEMPT models. The GOTHIC drop heat and mass transfer models can be relied on to give a realistic estimate of the drop heat-up. A typical nozzle drop size of 1 mm was assumed for the improved models. It was noted that these larger drops achieve near 100% efficiency [2] so the impact on results is minor.

2) The LOCA and MSLB models include heat sinks for the floors. Since the floors become flooded with water, their ability to condense steam will be reduced. In the improved models, the floors were allowed contact with the air/steam atmosphere until the water depth reached approximately 1/8 inch. The contact area linearly switches from the vapor to the liquid phase as the water depth rises to the 1/8-inch level. This was accomplished using the SPLIT option on the floor heat transfer models.

3) In the 6.0a models, the liquid vapor interface area was set to zero. This prevents any condensation on the liquid that collects in the sump and on the floors. In the improved models, the liquid vapor interface area was set to the floor area so that once the floors become flooded they can continue to affect condensation via heat transfer though the liquid pool.

4) For the MSLB cases, the Tagami heat transfer option was used with a blowdown energy of 0 and time to peak pressure of 0.01 seconds. This was done to force the heat transfer directly into the Uchida option since the Tagami transitions to the Uchida after the specified time of peak pressure. This approach is overly conservative because the transition to Uchida includes an exponential decay from the peak Tagami value (0 in this case). During this transition period, the effective heat transfer coefficient would be something less than Uchida. In the improved models the Uchida condensation correlation was used from time zero under the DIRECT heat transfer option. It was observed that this change had a very minor effect on peak temperature and pressure [2].

The results from the improved models are shown in Figures 16 through 19. The peak pressures and temperatures from these cases (7.0p2-IM) are shown in Table 4 along with the results from 7.0p2 without the model improvements.

Table 4 Comparison of 7.0p2 Results for Original and Improved Models.

Model	Peak Pressure		Peak Temperature	
	Original	Improved	Original	Improved
DEHL	59.51	59.47	265.4	265.3
DEPS	56.94	56.78	261.5	261.3
MSLB1.4	60.91	61.04	267.4	267.6
MSLB1.1	56.94	57.00	261.5	261.5

Peak values are slightly decreased for the LOCA cases and slightly increased for the MSLB cases. The decrease in the peaks for the LOCA cases is due primarily to the reduced time step during the early part of the transient.

MDLM

The Mist Diffusion Layer Model (MDLM) is fully described in the GOTHIC Technical Manual [4]. A brief overview is provided here.

When there is condensation on a cold surface in contact with a mixture of steam and non condensing gases (air in this case), the process typically results in the build up of a liquid film on the surface and an air rich boundary layer between the film and the bulk mixture. If there is a significant amount of air, the condensation rate is usually limited by the rate that the steam can penetrate the boundary layer. A thermal boundary layer also forms at the film surface and sensible heat transfer is limited by the rate that heat can penetrate the thermal layer. The heat and mass transfer through the boundary layer depends on the thermodynamic conditions of the bulk and the liquid film surface and on the bulk and liquid film velocities. The heat transfer through the liquid film depends on the film thickness, conduction and convection within the film, and the film surface and wall temperatures. The MDLM incorporates all of these mechanisms to give their combined effect on the heat and mass transfer rates.

The formation of mist near the wall has been observed in condensing system such as that described above. This mist can contribute significantly to the overall heat transfer rate to the wall, especially when the atmosphere away from the wall is superheated. When the mist formed in the boundary layer migrates to the bulk steam/air mixture, it vaporizes and cools the atmosphere.

This conceptual model for condensation is the basis for the MDLM. The heat transfer coefficients for sensible heat transfer are taken from standard correlations for the relevant convective or diffusion heat transfer. The steam migration rate toward the surface is calculated using mass transfer coefficients derived from the heat transfer coefficients and an assumed heat/mass transfer analogy. The model includes the thermal resistance of the film. Mist formation in the boundary layer is calculated using the temperature and saturation temperature profiles through the boundary layer and the assumption that subcooled steam will not persist in the boundary layer. A fraction (empirically determined) of the mist is assumed to migrate back to the bulk.

The condensation rate is a function of the surface height. Taller structures typically have thicker average film thickness. For pure steam, the condensation rate is controlled by the film thickness and therefore the condensation rate decreases as the wall height increases. However, for steam/gas systems, where the heat and mass transfer rates are controlled by the vapor phase boundary layer, the condensation rate typically increases as the wall height increases. This is attributed to film roughening as the film thickness increases resulting in increased heat and mass transfer rates through the boundary layer. Both of these height effects are included in the MDLM.

The MDLM heat transfer option was previously validated using 8 data sets from 5 different test facilities plus Nusselt's analytic results for pure steam with a total of 118 points. The test set includes the experimental results from Uchida, CVTR, Dehbi and three different configurations at the University of Wisconsin. The validation is fully described in the GOTHIC Qualification Report [3]. The experimental test conditions covered are listed in the table below.

Table 5 MDLM Validation Range and Expected DBA Conditions

Test Parameter	Minimum	Maximum	DBA Range
Height	0.3 m	36 m	~0 – 36 m
Bulk Velocity	0 m/s	3 m/s	~0 – 3 m/s
Total Pressure	1 atm	4.5 atm	~1 - 4 atm
Steam Volume Fraction	0.1	1	~0 – 0.7

The pressure range expected for the DBA is ~1 to ~4 atm and is within the validation basis for the MDLM. Expected containment average steam concentrations range from ~0 to 0.7. Except for the low end, where condensation is minimal, this range is covered by the validation basis. Local concentrations will approach 1.0 but the single volume lumped model uses the containment average conditions. The height refers to the height of the individual conductors with horizontal surfaces having a height of zero. The test set does not specifically address horizontal surfaces but they are not significant contributors in the model because they are removed from the condensing mode as they become flooded. The containment height is similar to the CVTR facility that gives the upper limit on the experimental range. Local, near jet, velocities in a DBA would be significantly outside of the experimental range. However, in the single volume lumped model, these high velocities are conservatively ignored and an approximate bulk average velocity is used that is in the experimental range.

Biasing MDLM

The MDLM heat and mass transfer model in GOTHIC is semi analytic with coefficients adjusted to give a good overall fit to the data set. From the comparison with the CVTR data [3], there is already some conservatism in the correlation when applied to a blowdown in a large dry containment. The correlation under predicts the measured effective heat transfer coefficient in CVTR by an average of 26% and the peak pressure is over predicted by approximately 3 psia when used in a model similar to the lumped model used for the KNPP.

To provide additional conservative margin in this application, the effective heat and mass transfer coefficients are reduced by a statistically based factor. The factor is obtained using the one-sided tolerance limits as describe by Owen [5].

By applying a reduction factor of 0.717 to the MDLM heat and mass transfer coefficients there is a 95% probability that the predicted effective heat transfer coefficient will be less than the measured heat transfer coefficient in 95% of any possible test case within the validation range. Figure 1 and Figure 2 show the predicted versus measured effective heat transfer coefficient for the unbiased and biased MDLM correlation.

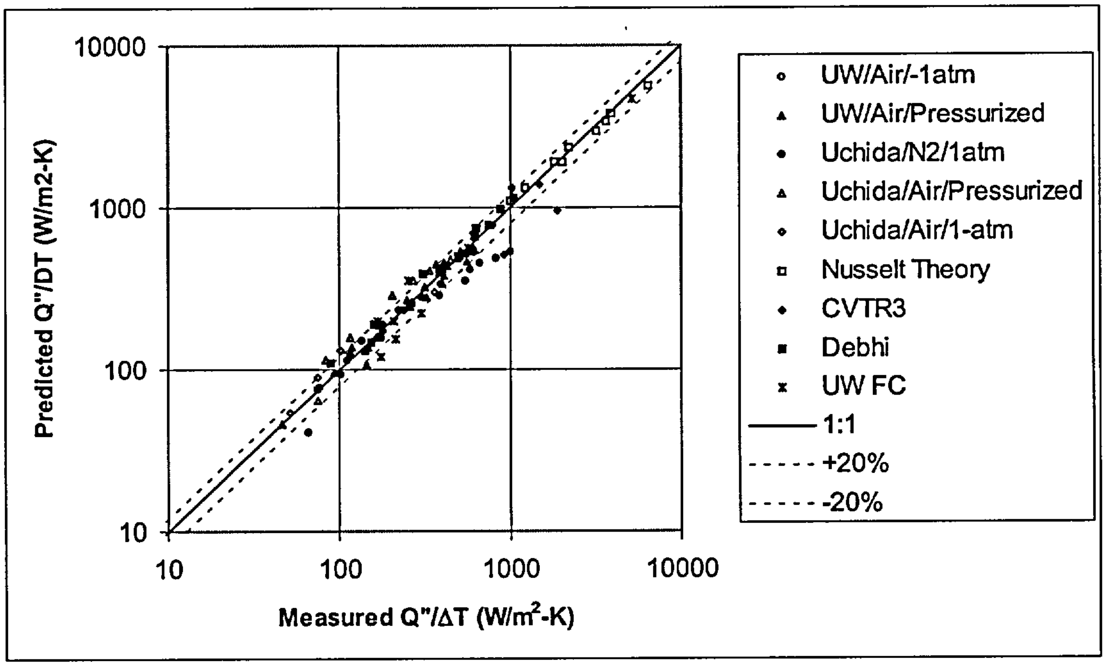

Figure 1 MDLM Heat and Mass Transfer Correlation (unbiased)

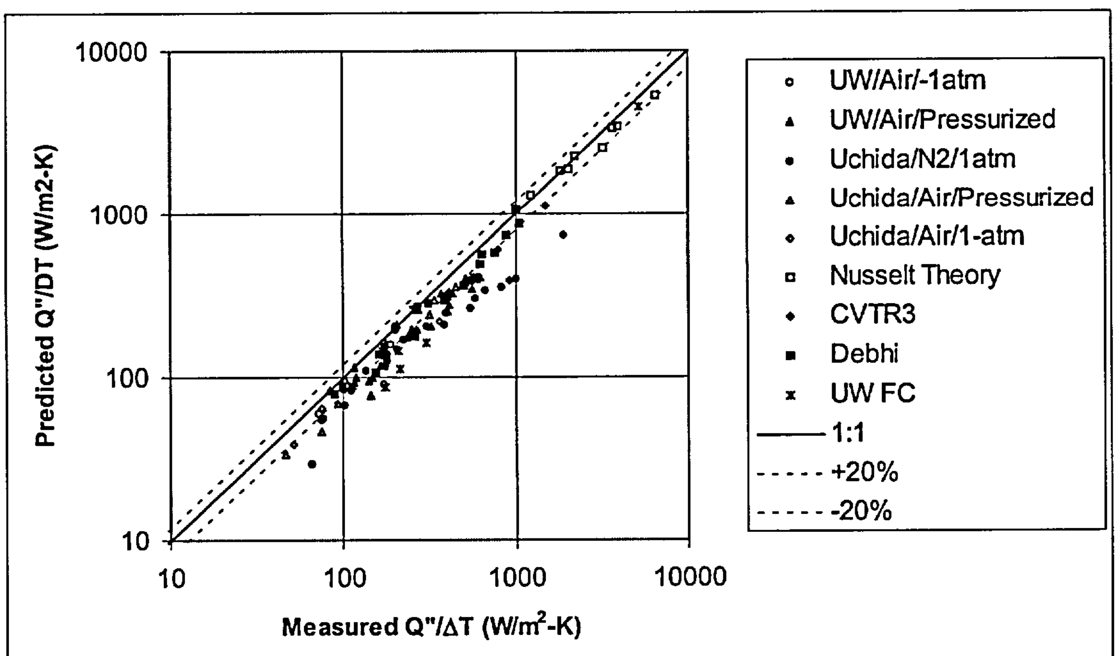

Figure 2 MDLM Heat and Mass Transfer Correlation (biased)

The graph of the biased correlation shows that almost all of the data points fall on or below the diagonal indicating that the predicted value is less than the measured value. The few exceptions are for the comparison with the Nusselt theory and one point from the Debhi test set.

The Nusselt theory is applicable to 100% steam environments only. In this case, the heat and mass transfer rates are determined primarily by the resistance through the liquid film. The reduction multiplier on the MDLM heat transfer option applies only to the heat and mass transfer coefficients calculated for the film/vapor interface. Therefore, the reduction for the pure steam cases is not as great as for the gas/steam mixtures. The pure steam data points are outside of the range of conditions for a DBA in a large dry containment.

Applicability of the MDLM to the KNPP LOCA and MSLB Transients

The validation basis for the MDLM covers the application to the DBA's in the KNPP containment. Furthermore, as discussed in Section 0, when applied to the CVTR tests for a steam blowdown in a full-scale containment, the MDLM option gives peak pressures that are higher than measured. The additional conservatisms taken in this analysis give high confidence that the predicted results conservatively bound the actual outcome of the postulated DBA's.

GOTHIC DBA Models with MDLM

The 7.0p2 GOTHIC models for the LOCA and MSLB were modified to use the MDLM heat and mass transfer option. The heat and mass transfer under the MDLM option is a function of the conductor height as described in Section 0. In version 7.0p2, conductor height is not available from user input and the volume height is used (specified at 100 ft for these models). Since the volume height is greater than the actual conductor height, additional reduction factors were applied to correctly account for the actual conductor height. The MDLM option was conservatively applied only to the vertical conductors. The Uchida condensation option was used for all other conductors. The modeled conductors, the heat transfer option and the applied reduction factor are listed in Table 6.

Table 6 Containment Conductors

Conductor	Description	HT Option	Factor	Area (ft2)
1	Containment Cylinder Wall	MDLM	0.717	41,300
2	Containment Dome	MDLM	0.717	17,300
3	Reactor Vessel Liner and Concrete	MDLM	0.717	1,260
4	Refueling Canal 3/16-in Steel	MDLM	0.717	1,100
5	Refueling Canal 1/4-in Steel	MDLM	0.717	5,500
6	Structural Steel 1	Uchida	1.000	4,055
7	Structural Steel 2	Uchida	1.000	16,925
8	Structural Steel 3	Uchida	1.000	28,500
9	Structural Steel 4	Uchida	1.000	2,000
10	Structural Steel 5	Uchida	1.000	500
11	Handrails	Uchida	1.000	1,695
12	Grating	Uchida	1.000	12,400
13	Conduit + Cable Trays	Uchida	1.000	2,000
14	Ductwork	Uchida	1.000	18,000
15	Walls 1.0-1.9 ft	MDLM	0.388	2,806
16	Floors > 1.0 ft	SPLIT	1.000	12,896
17	Walls 4.0-7.3 ft	MDLM	0.388	18,588
18	Sump Floor	SPLIT	1.000	1,088
19	Walls 2.0-3.2 ft	MDLM	0.388	28,898
20	Floors 4.0-10.0 ft	SPLIT	1.000	6,810

In the MDLM, the enhancement factor on the heat and mass transfer coefficient increases until the conductor height reaches 36 ft and is constant thereafter. The heights of conductors 1 through 5 are assumed to be greater than 36 ft so the reduction factor is due solely to the biasing factor. The reduction factor for conductors 15, 17 and 19 includes the biasing factor and a compensating factor of 0.542 to account for the difference in the assumed conductor height of 15 ft and the specified containment height. All other conductors used the Uchida option with no reduction factor applied.

Results for the revised DBA models are listed in the table below and compared with the improved 7.0p2 model results from Table 4.

Table 7 Comparison of 7.0p2 Results for Improved Models and Improved Models with MDLM.

	Peak Pressure		**Peak Temperature**	
Model	**Improved**	**Improved/ MDLM**	**Improved**	**Improved/ MDLM**
DEHL	59.47	59.45	265.3	265.3
DEPS	56.78	57.52	261.3	261.5
MSLB1.4	61.04	58.73	267.6	264.2
MSLB1.1	57.00	54.80	261.5	258.0

The results from the DEHL break are essentially unchanged. The DEPS LOCA shows an increase in peak pressure of 0.74 psia. This case has a double pressure peak. In the model without MDLM the maximum pressure occurs at the first peak. With the MDLM option, the maximum occurs at the second peak. The extra conservatism in the reduction factors appears to have a more significant impact in the longer term. For the two MSLB cases, the MDLM gives a significant reduction in peak pressure and temperature.

Conclusion

Migration of the 6.0a DBA models to 7.0 showed small differences in peak pressures and temperatures. Differences in the sump temperature transients were explained. Some model improvements were implemented and it is recommended that these improvements be used in any subsequent analysis. There is some sensitivity to time step size, especially early in the LOCA transients. The time step should be small enough to ensure a converged solution. Activating the MDLM heat and mass transfer option for the large vertical conductors in the improved 7.0p2 models resulted in slightly lower peak pressure for the DEHL case and a higher peak pressure for the DEPS. The higher peak pressure in the DEPS case is attributed to the reduction factors applied to the heat and mass transfer correlations and not the MDLM itself. For the MSLB cases, the MDLM option provided significant benefit, reducing the peak pressure by more than 2 psi for both cases.

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1. WPSRSEM-NP-A Revision 3, Kewaunee Nuclear Power Plant Reload Safety Evaluation Methods for Application to Kewaunee Volumes 1,2, October 2001.
2. NAI-1105-03 Rev 1, "Support for GOTHIC Containment Analysis for the Kewaunee Nuclear Power Plant Calculations Notes", July 2002.
3. "GOTHIC Containment Analysis Package Qualification Report, Version 7.0", NAI 8907-09 Rev 6, Numerical Applications, Inc, Richland, WA, July 2001.
4. "GOTHIC Containment Analysis Package Technical Manual, Version 7.0", NAI 8907-06 Rev 12, Numerical Applications, Inc, Richland, WA, July 2001.
5. DB Owen, "Factors for One-Sided Tolerance Limits and for Variables Sampling Plans", XDR-607, Monograph, Sandia Corporation, March 1963.

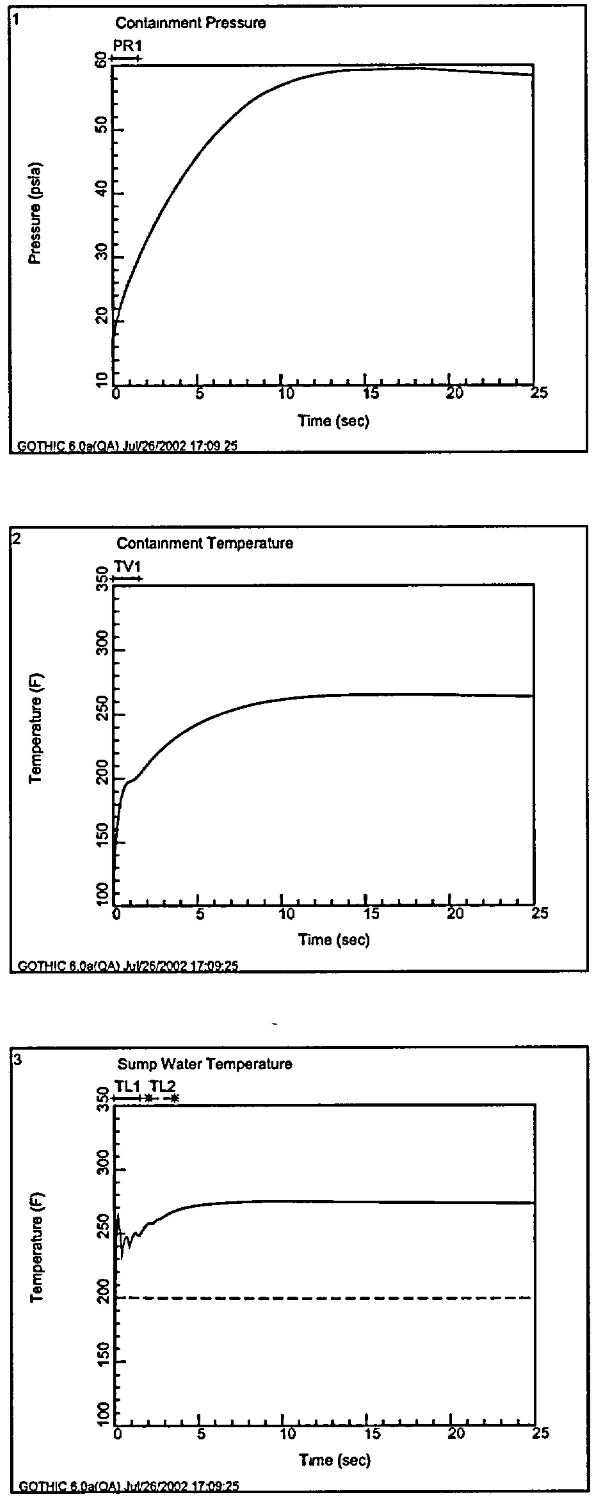


Figure 3 DEHL LOCA GOTHIC 6.0a

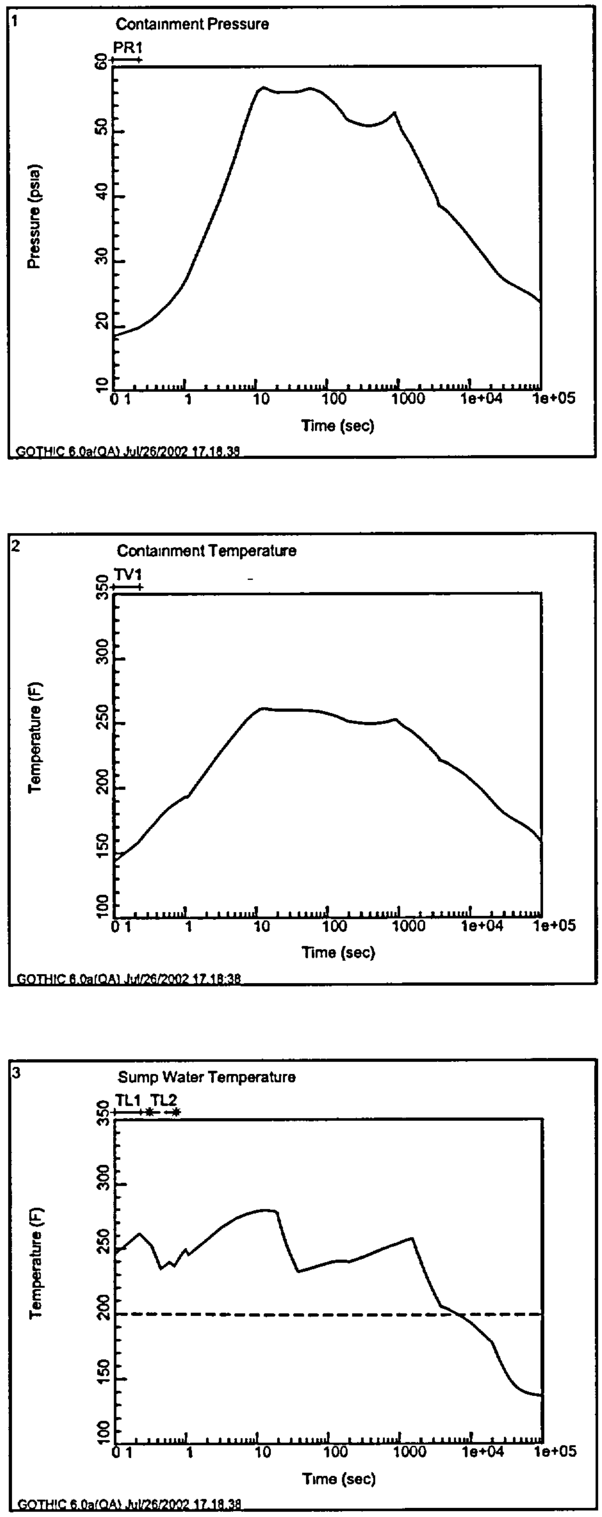


Figure 4 DEPS LOCA GOTHIC 6.0a

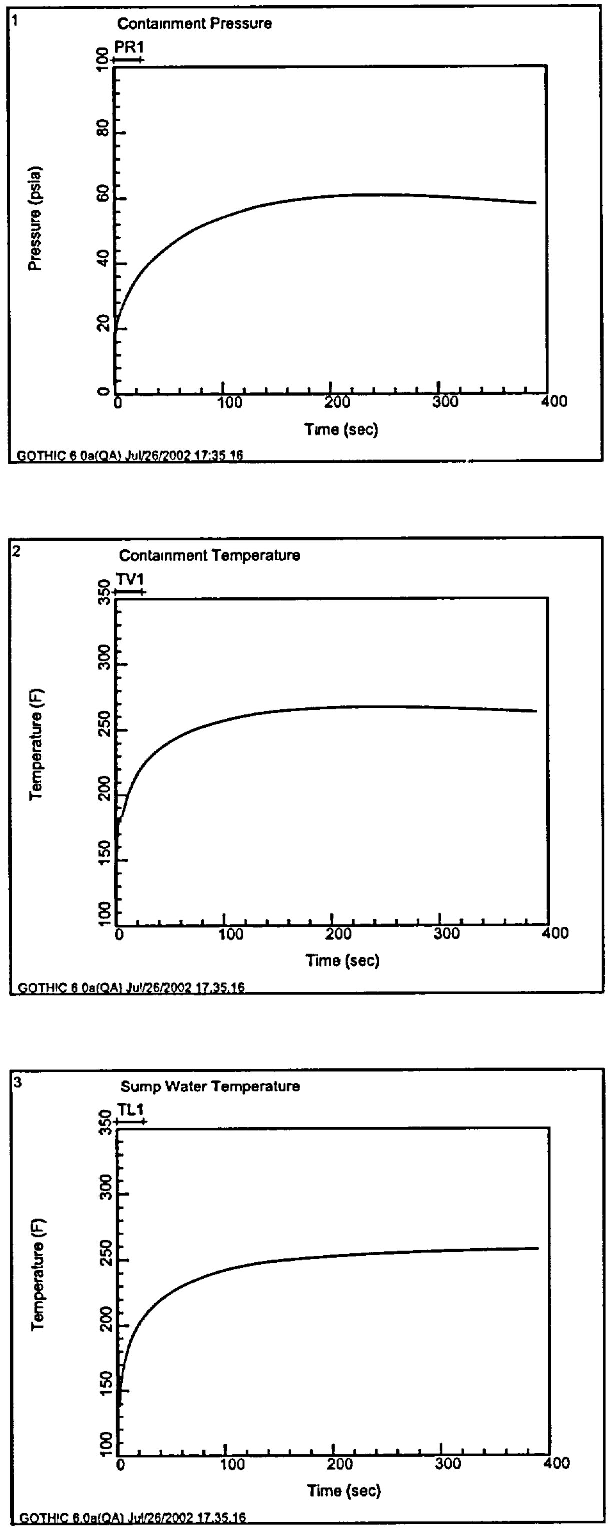


Figure 5 1.4 ft² MSLB GOTHIC 6.0a

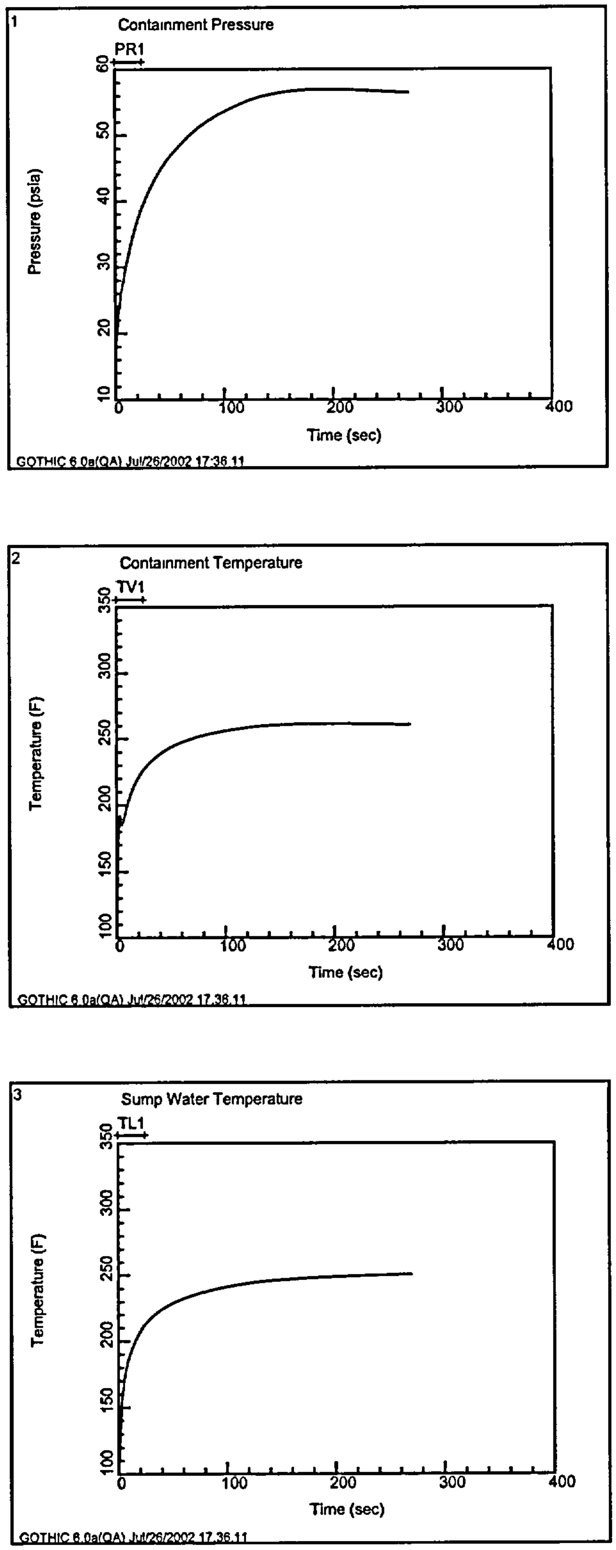
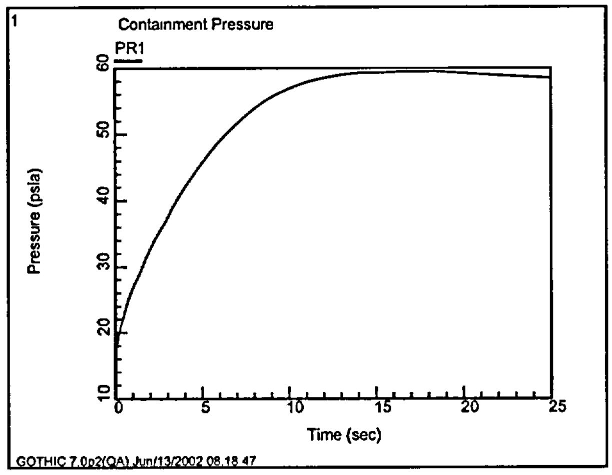
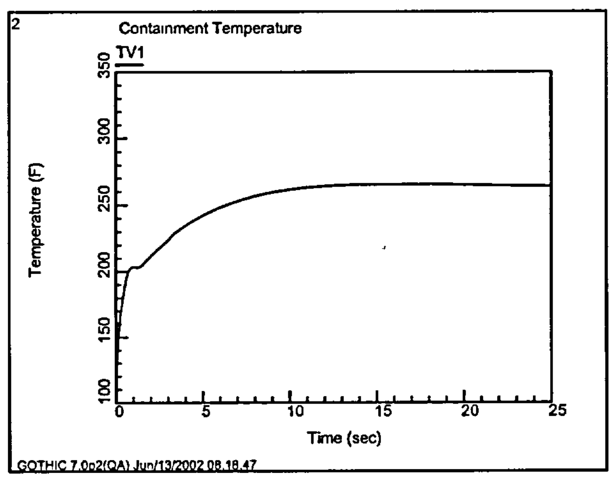


Figure 6 1.1 ft^2 MSLB GOTHIC 6.0a





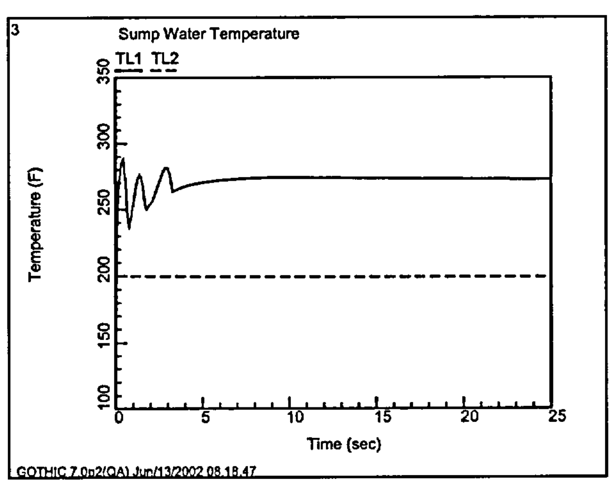


Figure 7 DEHL LOCA GOTHIC 7.0p2

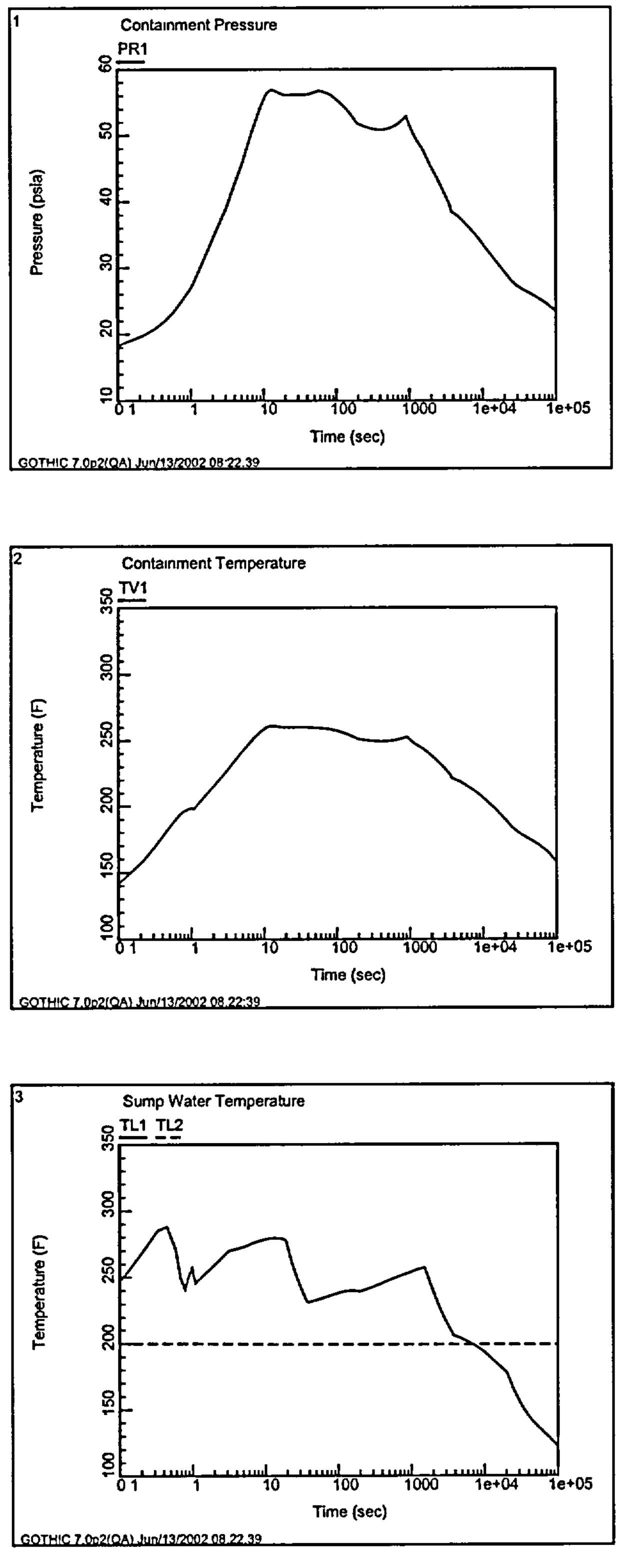


Figure 8 DEPS LOCA GOTHIC 7.0p2

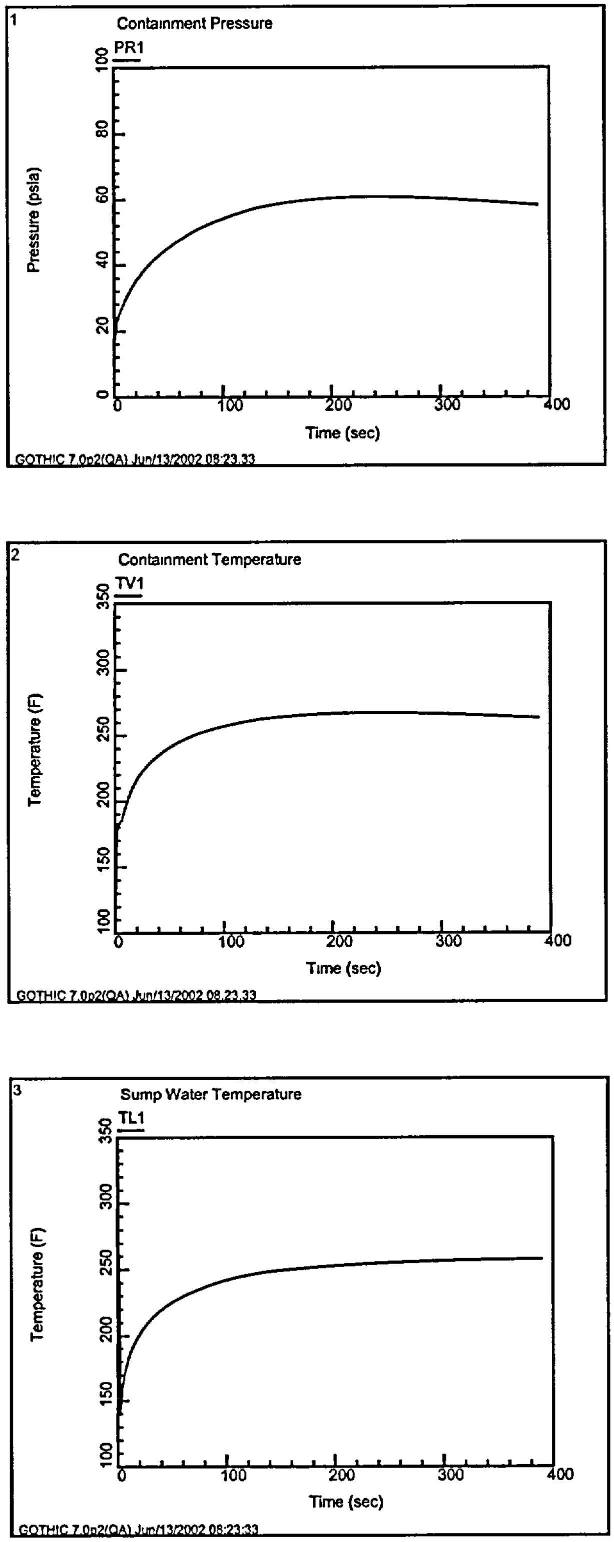


Figure 9 1.4 ft^2 MSLB GOTHIC 7.0p2

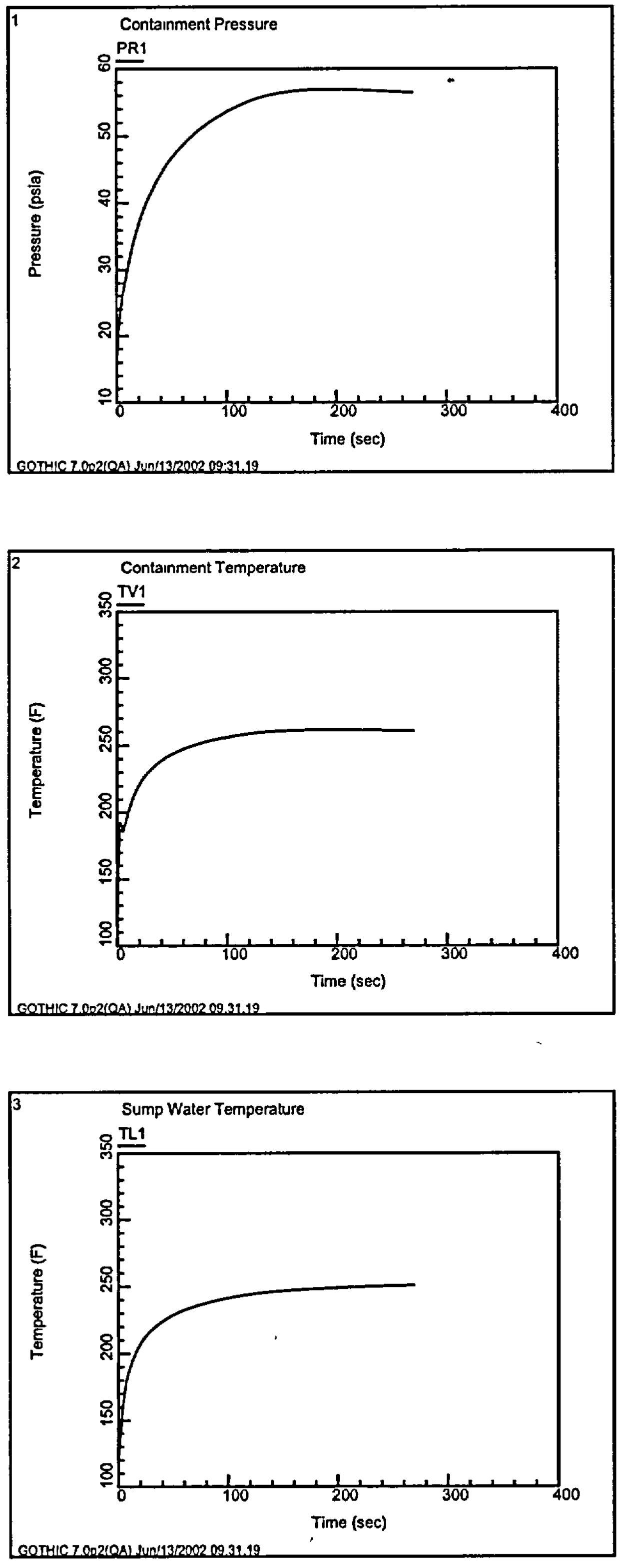


Figure 10 1.1 ft^2 MSLB GOTHIC 7.0p2

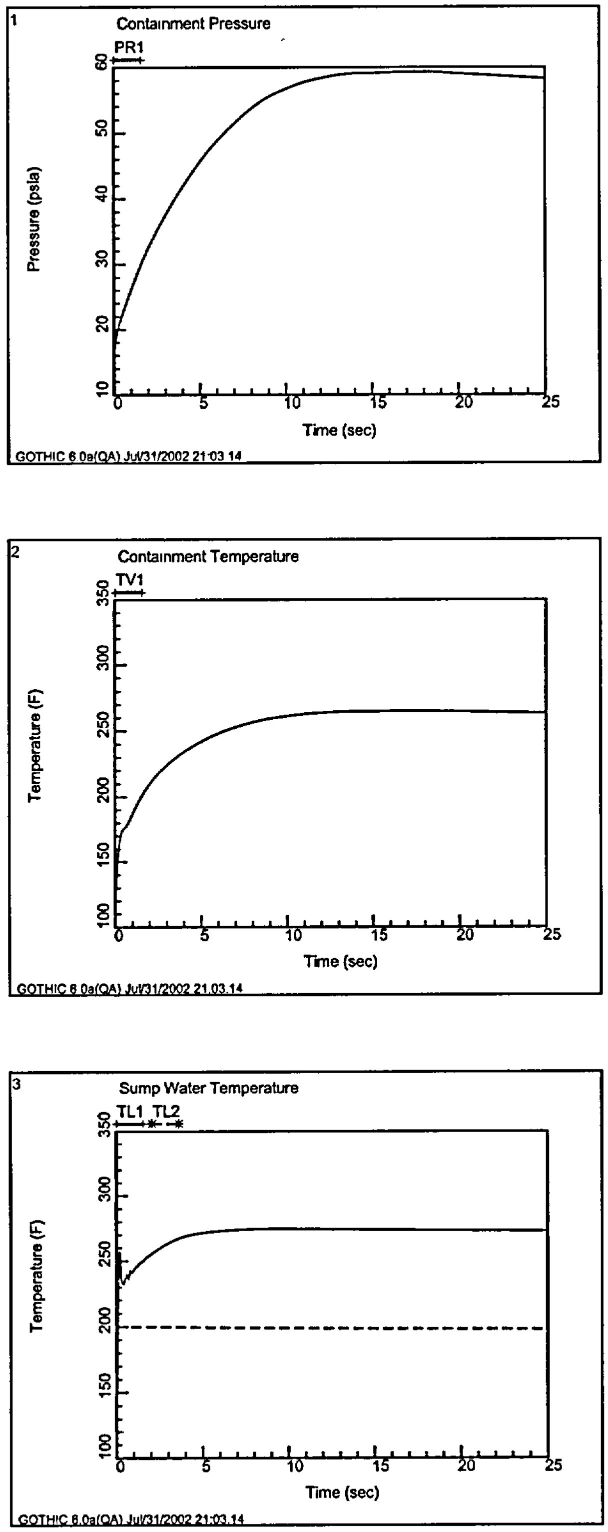


Figure 11 DEHL LOCA GOTHIC 6.0a – Reduced Time Step

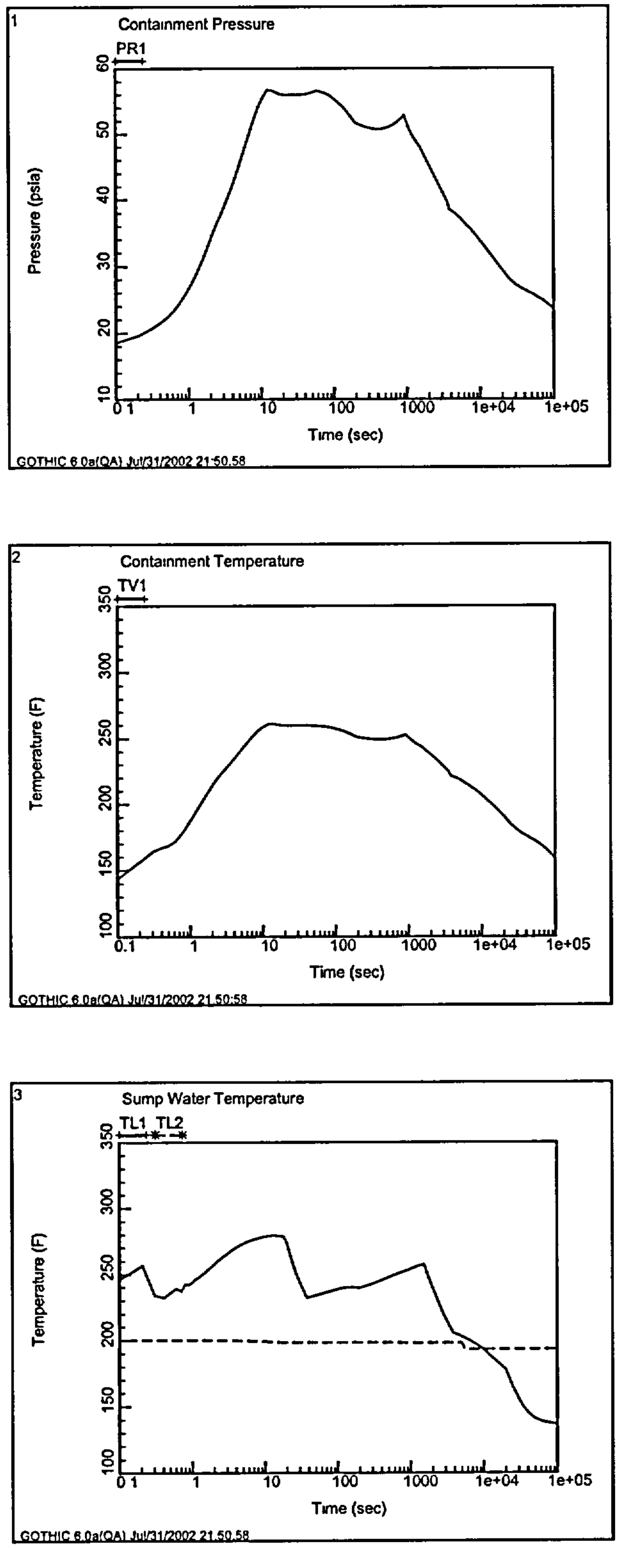


Figure 12 DEPS LOCA GOTHIC 6.0a – Reduced Time Step

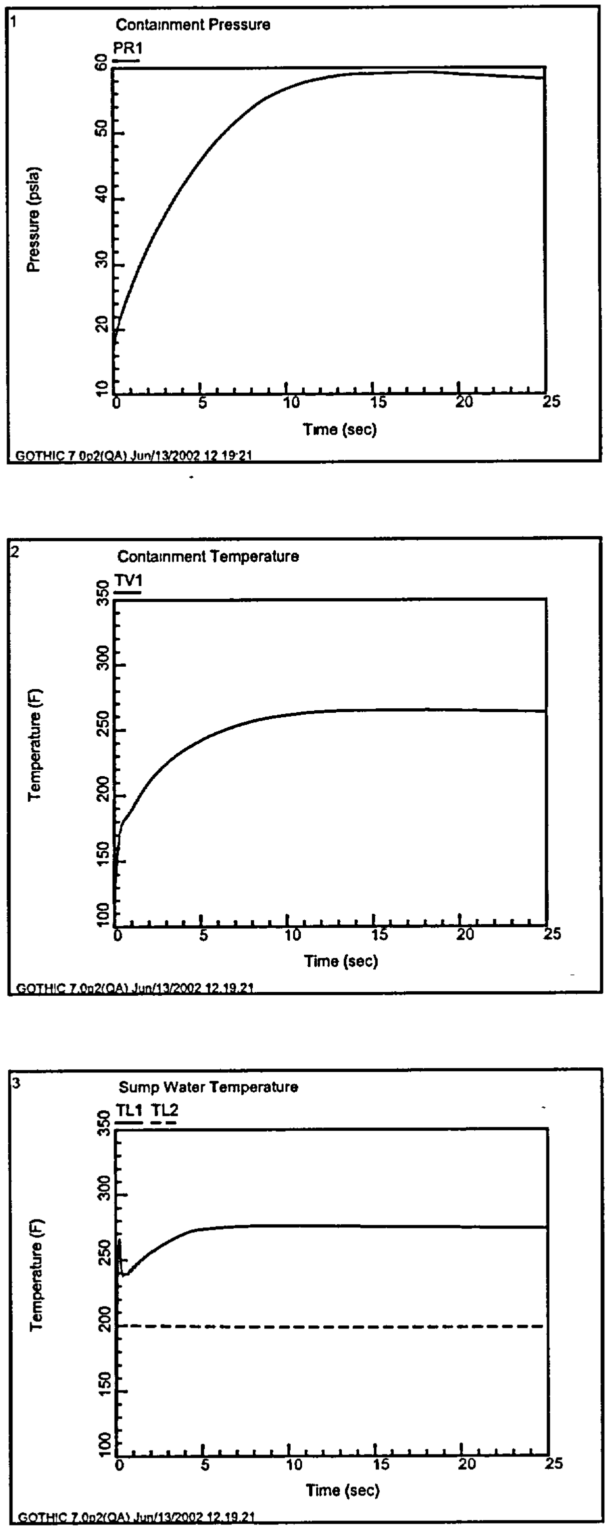


Figure 13 DEHL LOCA GOTHIC 7.0p2 – Reduced Time Step

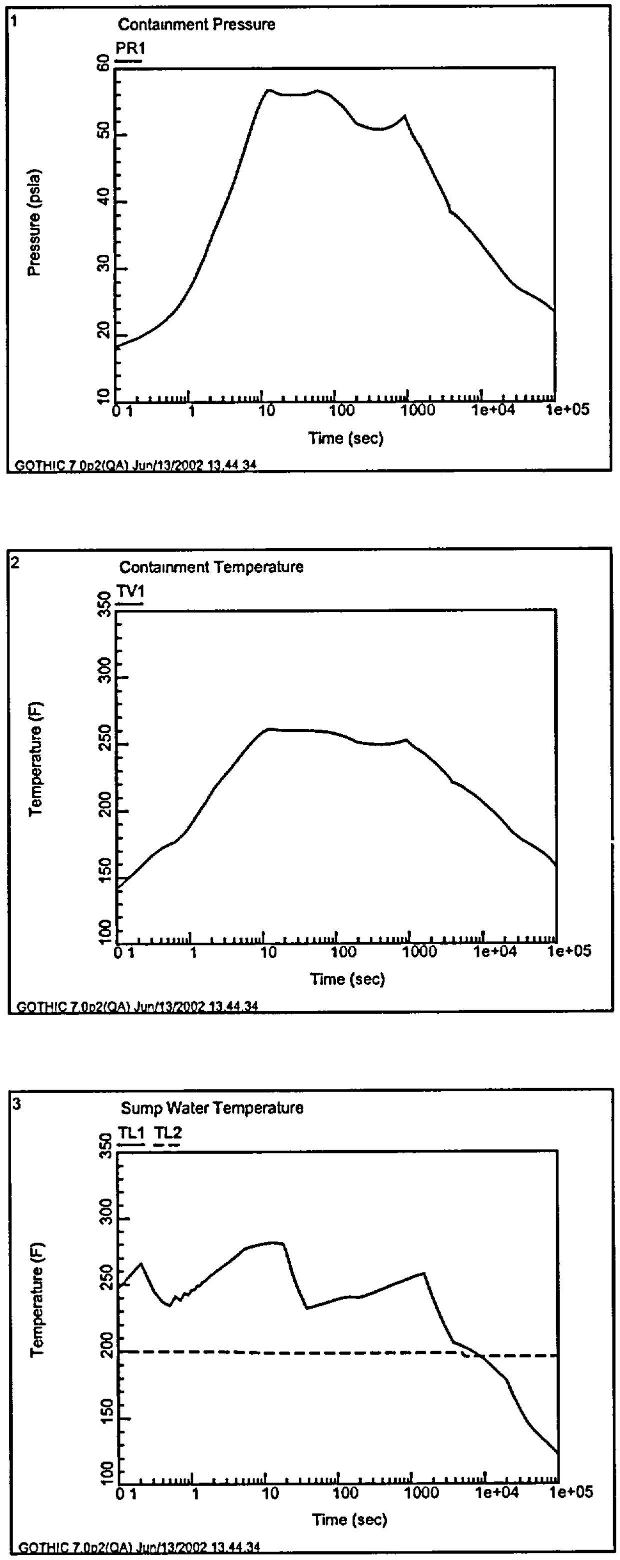


Figure 14 DEPS LOCA GOTHIC 7.0p2 – Reduced Time Step

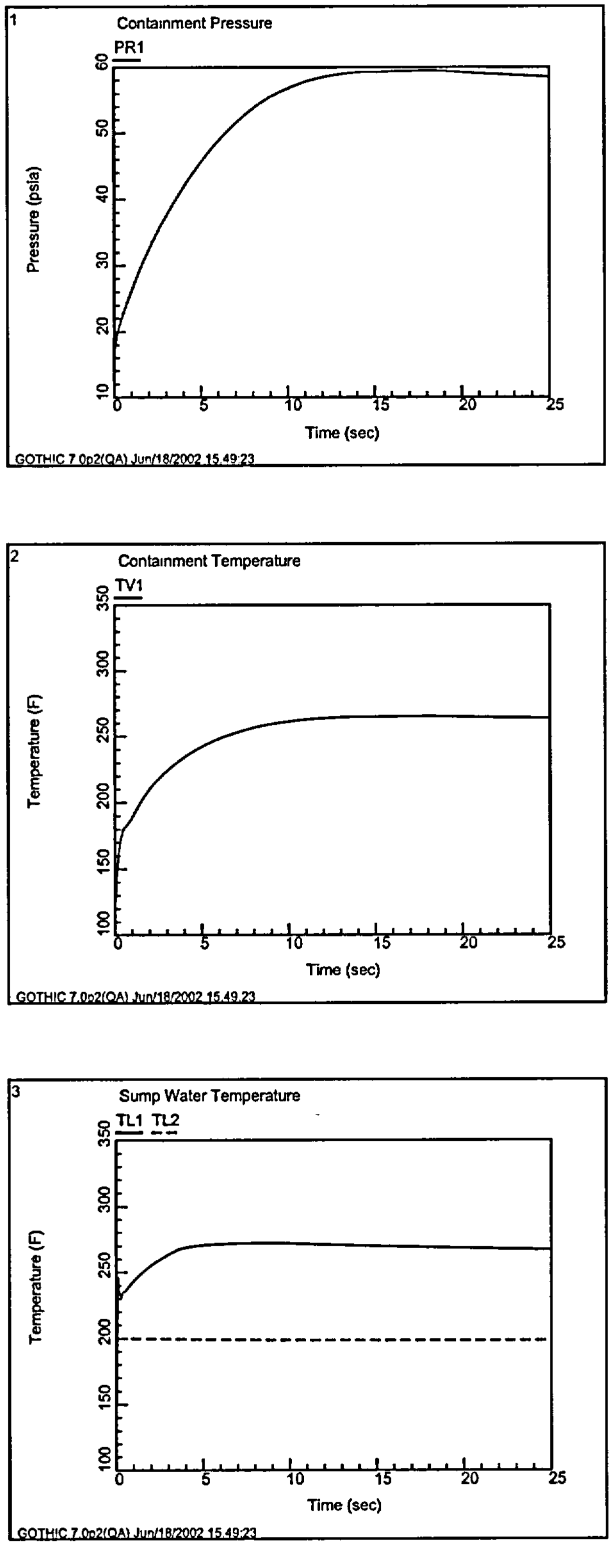


Figure 15 DEHL LOCA GOTHIC 7.0p2 – Improved Model

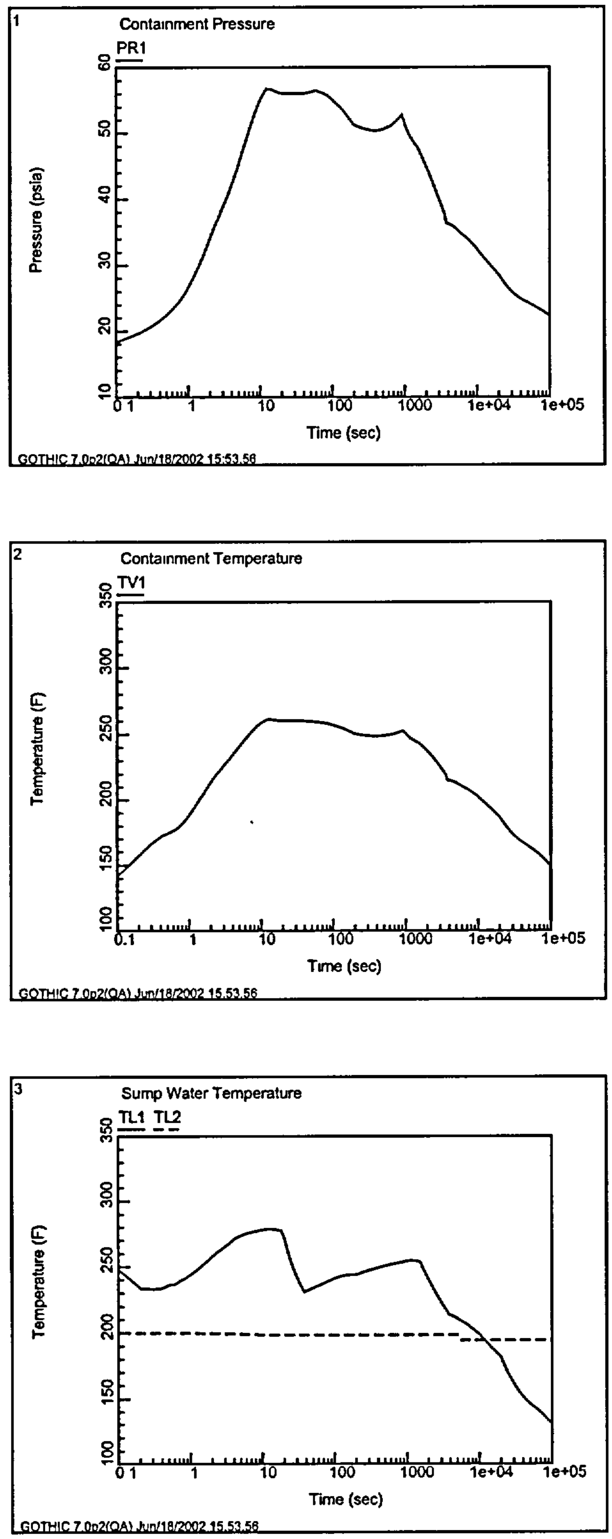


Figure 16 DEPS LOCA GOTHIC 7.0p2 – Improved Model

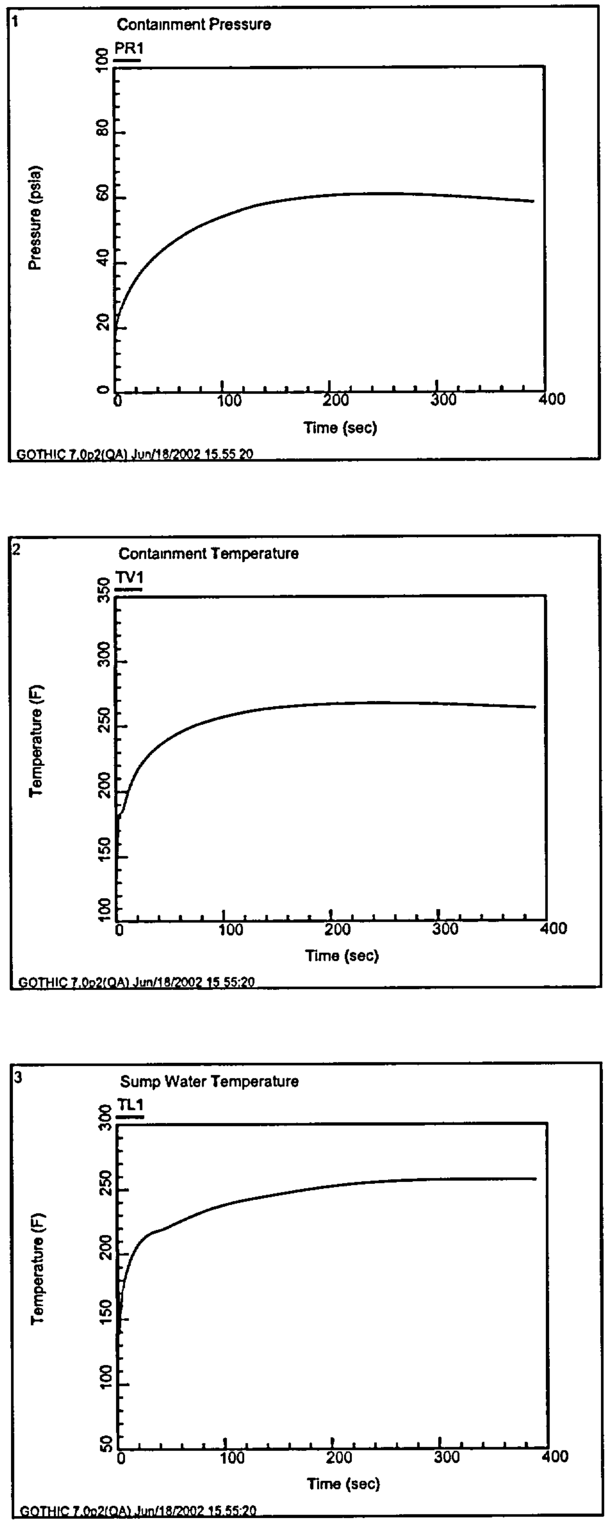


Figure 17 1.4 ft^2 MSLB GOTHIC 7.0p2 – Improved Model

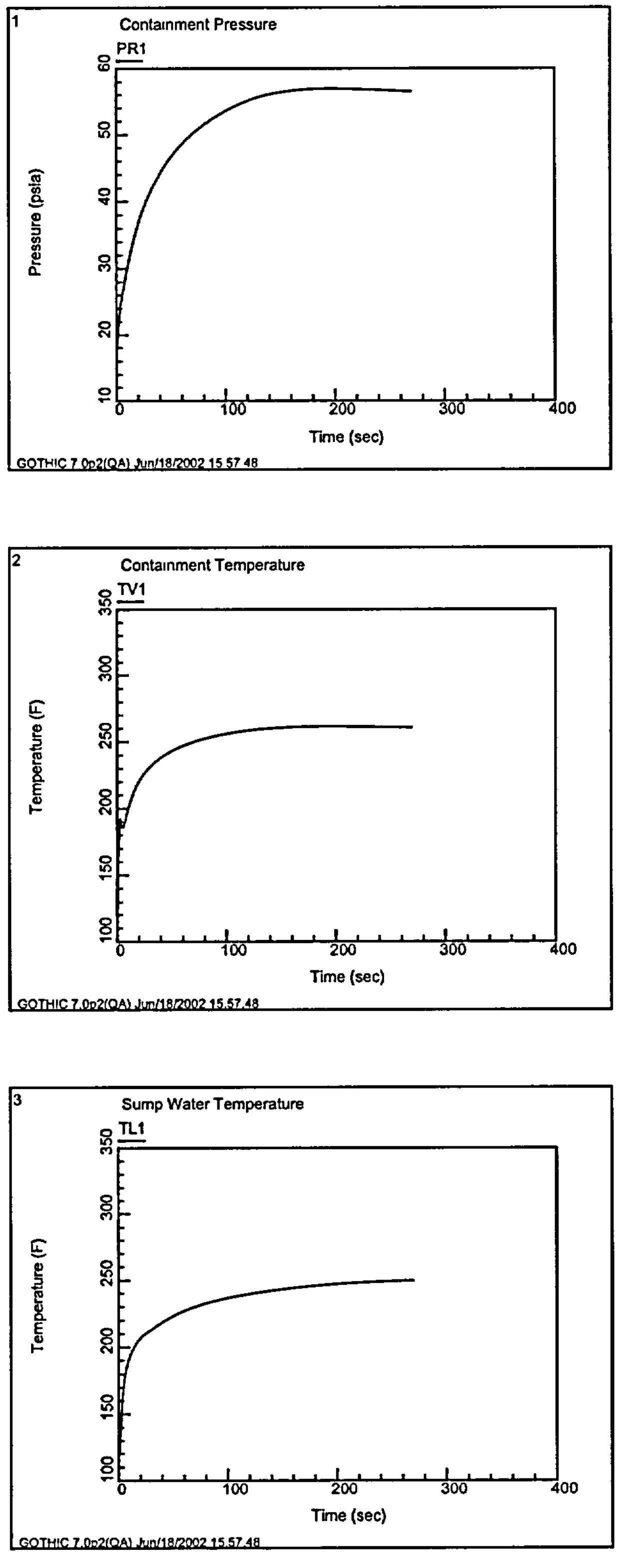
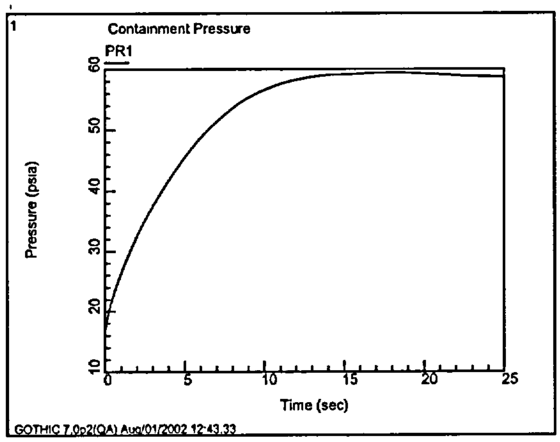
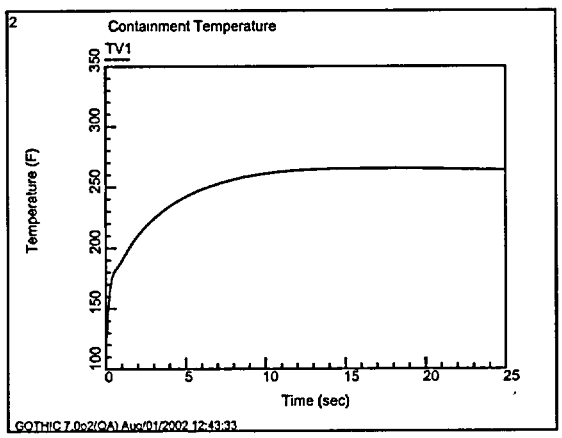


Figure 18 1.1 ft^2 MSLB GOTHIC 7.0p2 – Improved Model





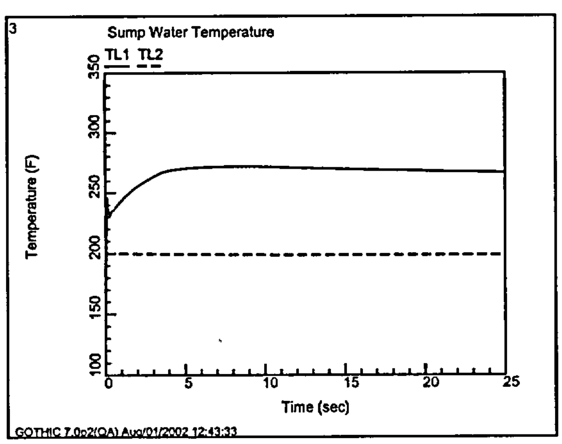


Figure 19 DEHL LOCA GOTHIC 7.0p2 - MDLM

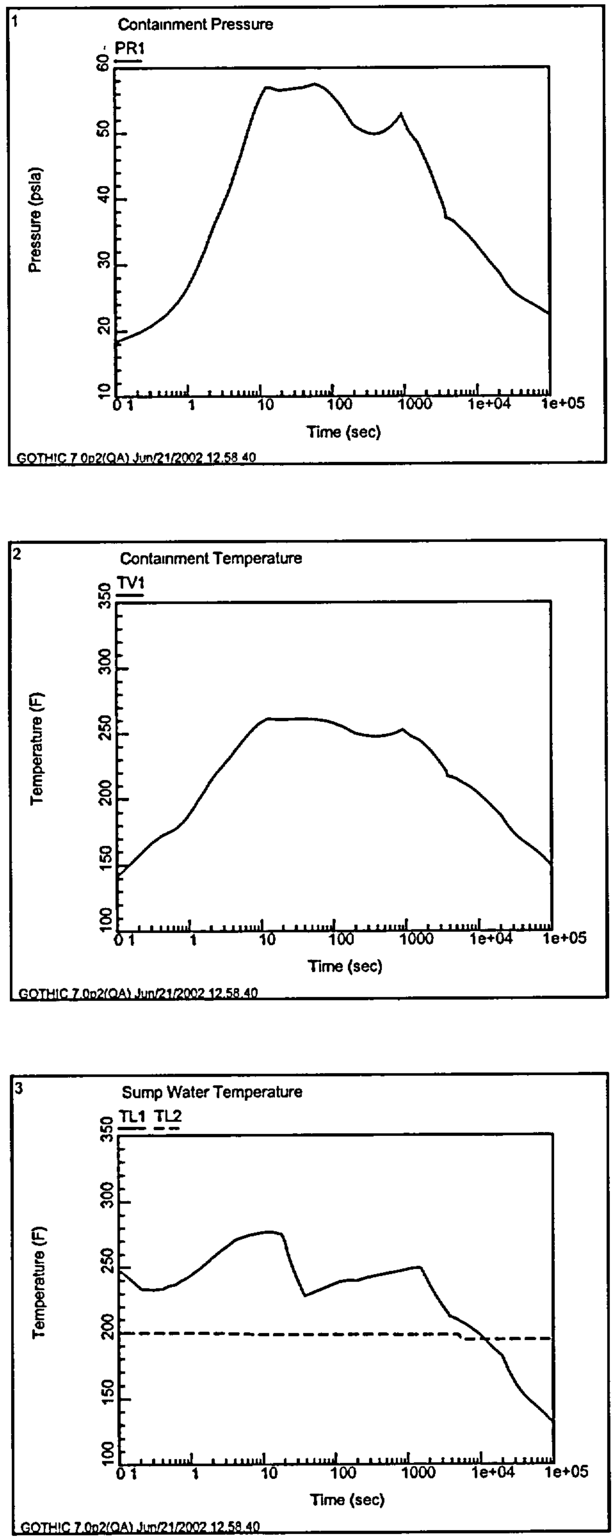


Figure 20 DEPS LOCA GOTHIC 7.0p2 - MDLM

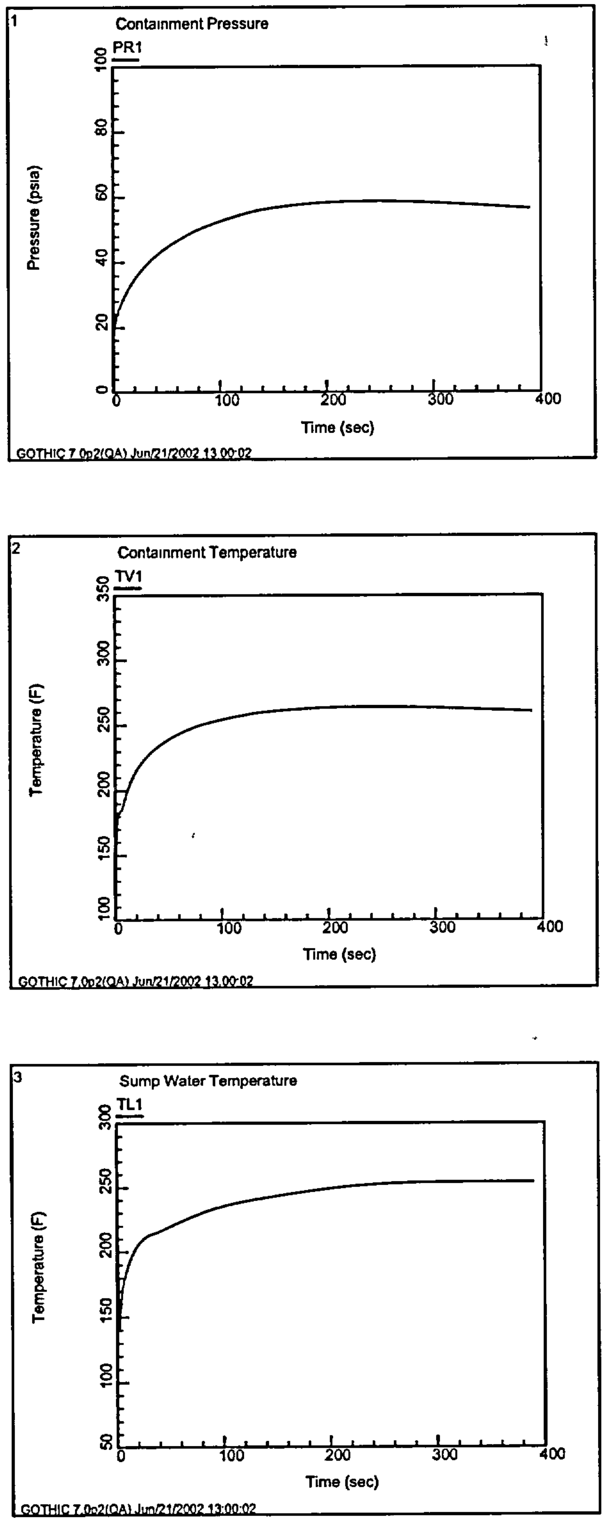
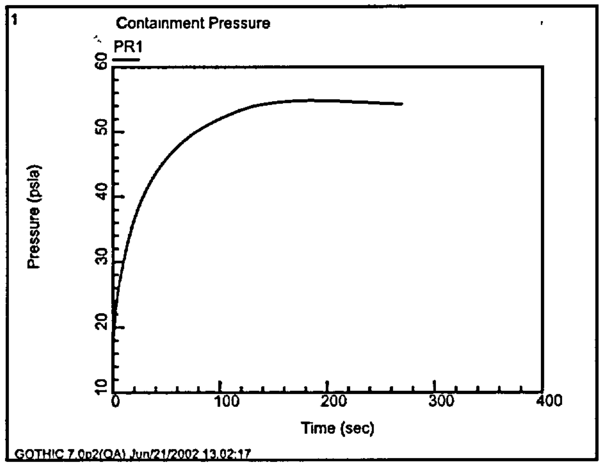
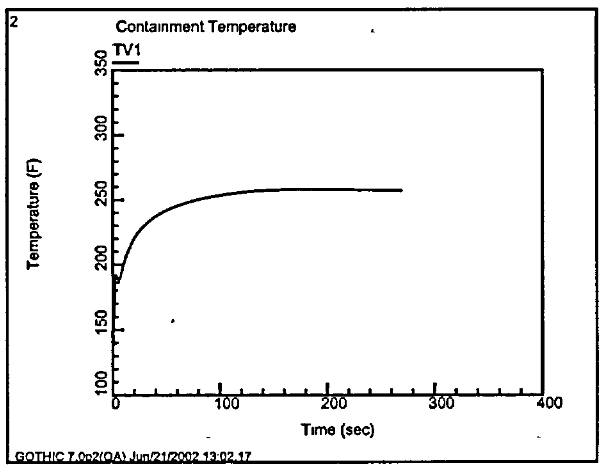


Figure 21 1.4 ft^2 MSLB GOTHIC 7.0p2 - MDLM





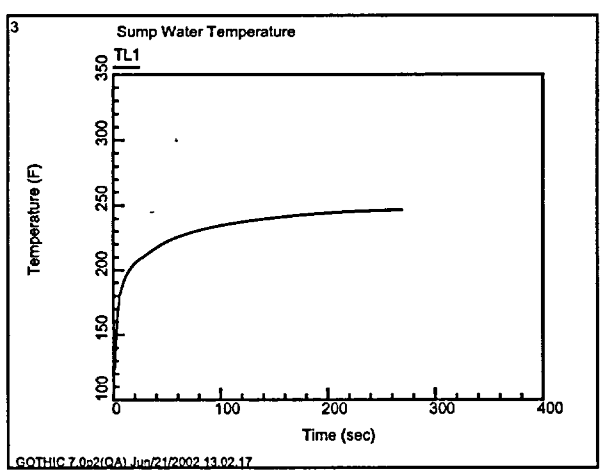


Figure 22 1.1 ft^2 MSLB GOTHIC 7.0p2 – MDLM