WCAP-15872-NP-A, Rev. 0

Project Number 694

March 9, 2005

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U.S. Nuclear Regulatory Commission
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Subject: Westinghouse Owners Group
Transmittal of NRC-Approved Topical Report WCAP-15872-NP-A, Rev 0, (Non-Proprietary) "Use of Alternate Decay Heat Removal in Mode 6 Refueling," (TAC MB9020) (Task 2075)

Reference: 1. Letter, H. Berkow (NRC) to G. Bischoff (WOG), "Final Safety Evaluation for Topical Report WCAP-15872-NP, Rev 00, "Use of Alternate Decay Heat Removal in Mode 6 Refueling (TAC No. MB9020)" dated November 30, 2004.

The purpose of this letter is to transmit four (4) non-proprietary copies of WCAP-15872-NP-A for NRC files. This transmittal completes action on topical report WCAP-15872; thus, the WOG requests that TAC No. MB9020 be closed.

WCAP-15872-NP-A contains the staff's Safety Evaluation, resolution of comments on the draft Safety Evaluation, and historical review information as requested by Reference 1. Consistent with standard Westinghouse practice, replaced topical report pages are not compiled separately since they are typically integrated into the final report or into responses to the staff's questions.

WCAP-15872-NP-A does not contain information proprietary to Westinghouse Electric Company LLC. Therefore, withholding of information in this topical report in accordance with 10 CFR Section 2.390 of the Commission's regulations is not requested.

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If you require further information, please contact Mr. Paul Hijeck in the Westinghouse Owners Group Program Management Office at 860-731-6240.

Sincerely,

Paul Hijeck for.

Frederick P. "Ted" Schiffley, II, Chairman
Westinghouse Owners Group

FPS:PJH:las

Enclosure

cc: C. Brinkman, Westinghouse
P. Hijeck, Westinghouse
F. Ferraraccio, Westinghouse
V. Paggen, Westinghouse
G. Shukla, NRC (1 NP)
Steering Committee
Operations Subcommittee
Project Management Office

Westinghouse Non-Proprietary Class 3

WCAP-15872-NP-A
Revision 0

February 2005

Use of Alternate Decay Heat Removal in Mode 6 Refueling

Westinghouse

LEGAL NOTICE

WCAP 15872-NP-A
Revision 0

Use of Alternate Decay Heat Removal in Mode 6 Refueling

Task 2075 / PA-ASC-0207

February 2005

Author: F. P. Ferraraccio

Approved: W. M. Turkowski

Westinghouse Owners Group
Member Participation* for WOG Task 2075 / PA-ASC-0207

Utility Member	Plant Site(s)	Participant	
		Yes	No
AmerenUE	Callaway (W)		✓
American Electric Power	D.C. Cook 1&2 (W)		✓
Arizona Public Service	Palo Verde Unit 1, 2, & 3 (CE)		✓
Constellation Energy Group	Calvert Cliffs 1 & 2 (CE)	✓	
Constellation Energy Group	Ginna (W)		✓
Dominion Connecticut	Millstone 2 (CE)	✓	
Dominion Connecticut	Millstone 3 (W)		✓
Dominion VA	North Anna 1 & 2, Surry 1 & 2 (W)		✓
Duke Energy	Catawba 1 & 2, McGuire 1 & 2 (W)		✓
Entergy Nuclear Northeast	Indian Point 2 & 3 (W)		✓
Entergy Operations South	Arkansas 2, Waterford 3 (CE)	✓	
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Florida Power & Light Group	St. Lucie 1 & 2 (CE)		✓
Florida Power & Light Group	Turkey Point 3 & 4, Seabrook (W)		✓
Nuclear Management Company	Prairie Island 1 & 2, Point Beach 1 & 2, Kewaunee (W)		✓
Nuclear Management Company	Palisades (CE)	✓	
Omaha Public Power District	Fort Calhoun (CE)		✓
Pacific Gas & Electric	Diablo Canyon 1 & 2 (W)		✓
Progress Energy	Robinson 2, Shearon Harris (W)		✓
PSEG - Nuclear	Salem 1 & 2 (W)		✓
Southern California Edison	SONGS 2 & 3 (CE)		✓
South Carolina Electric & Gas	V.C. Summer (W)		✓
South Texas Project Nuclear Operating Co.	South Texas Project 1 & 2 (W)		✓
Southern Nuclear Operating Co.	Farley 1 & 2, Vogtle 1 & 2 (W)		✓
Tennessee Valley Authority	Sequoyah 1 & 2, Watts Bar (W)		✓
TXU Power	Comanche Peak 1 & 2 (W)		✓
Wolf Creek Nuclear Operating Co.	Wolf Creek (W)		✓

*** Project participants as of the date the final deliverable was completed. On occasion, additional members will join a project. Please contact the WOG Program Management Office to verify participation before sending this document to participants not listed above.**

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UNITED STATES
NUCLEAR REGULATORY COMMISSION
WASHINGTON, D.C. 20555-0001

November 30, 2004

Mr. Gordon Bischoff, Manager
Owners Group Program Management Office
Westinghouse Electric Company
P.O. Box 355
Pittsburgh, PA 15230-0355

SUBJECT: FINAL SAFETY EVALUATION FOR TOPICAL REPORT WCAP-15872-NP, REV. 00, "USE OF ALTERNATE DECAY HEAT REMOVAL IN MODE 6 REFUELING" (TAC NO. MB9020)

Dear Mr. Bischoff:

On May 12, 2003, as supplemented on November 18, 2003, the Westinghouse Owners Group (WOG) submitted Topical Report (TR) WCAP-15872-NP, Rev. 00, "Use of Alternative Decay Heat Removal in Mode 6 Refueling" to the staff for review. On July 22, 2004, the NRC provided the WOG a copy of the staff's draft safety evaluation (SE). Subsequently, on August 13, 2004, a corrected SE regarding our approval of WCAP-15872-NP was provided for your review and comments. By e-mail dated September 8, 2004, Mr. Virgil Paggen of the WOG commented on the draft SE. The WOG comments on the draft SE were discussed in a conference call on September 14, 2004, and it was agreed upon between Mr. Virgil Paggen (WOG) and Mr. Yuri Orechwa (NRC) that no changes were required to the final SE enclosed with this letter.

The staff has found that WCAP-15872-NP is acceptable for referencing in licensing applications for Westinghouse-designed pressurized water reactors to the extent specified and under the limitations delineated in the TR and in the enclosed SE. The SE defines the basis for acceptance of the TR.

Our acceptance applies only to material provided in the subject TR. We do not intend to repeat our review of the acceptable material described in the TR. When the TR appears as a reference in license applications, our review will ensure that the material presented applies to the specific plant involved. License amendment requests that deviate from this TR will be subject to a plant-specific review in accordance with applicable review standards.

In accordance with the guidance provided on the NRC website, we request that the WOG publish an accepted version of this TR within three months of receipt of this letter. The accepted version shall incorporate this letter and the enclosed SE between the title page and the abstract. It must be well indexed such that information is readily located. Also, it must contain historical review information, such as questions and accepted responses, draft SE comments, and original TR pages that were replaced. The accepted version shall include a "-A" (designating accepted) following the TR identification symbol.

If future changes to the NRC's regulatory requirements affect the acceptability of this TR, the WOG and/or licensees referencing it will be expected to revise the TR appropriately, or justify its continued applicability for subsequent referencing.

Sincerely,

Herbert N. Berkow, Director
Project Directorate IV
Division of Licensing Project Management
Office of Nuclear Reactor Regulation

Project No. 694

Enclosure: Safety Evaluation

cc w/encl:
Mr. James A. Gresham, Manager
Regulatory Compliance and Plant Licensing
Westinghouse Electric Company
P.O. Box 355
Pittsburgh, PA 15230-0355

UNITED STATES
NUCLEAR REGULATORY COMMISSION
WASHINGTON, D.C. 20555-0001

SAFETY EVALUATION BY THE OFFICE OF NUCLEAR REACTOR REGULATION

WCAP-15872-NP, REV. 00, "USE OF ALTERNATE DECAY HEAT REMOVAL IN MODE 6 REFUELING"

WESTINGHOUSE OWNERS GROUP

PROJECT NO. 694

1.0 INTRODUCTION

By letter dated May 12, 2003, and its supplement dated November 18, 2003, the Westinghouse Owners Group (WOG) submitted Topical Report (TR) WCAP-15872-NP, Rev. 00, "Use of Alternative Decay Heat Removal in Mode 6 Refueling," for staff review and approval of an alternate method for shutdown cooling during Mode 6 plant operations as specified in the current technical specifications (TSs) for the plant. The alternate decay heat removal method may be used to supplement or to substitute for the shutdown decay heat removal system during refueling operations. The TR describes a computational methodology for assessing the necessary conditions for entry into and operation under the alternate heat removal alignment. These conditions are governed by a combination of factors such as decay heat generation rate, heat removal capabilities, temperature of the refueling pool, and the heat sink temperatures. The computational model of the alternate heat removal alignment is formulated as a series of one-dimensional control volumes within which the fluid mass, momentum, and energy are conserved. The model describes the transfer, by natural convection, of the decay heat from the reactor cavity to the refueling pool, and then by forced convection into the cooling system aligned via the alternate cooling method.

The validity of the one-dimensional formulation is dependent on the estimation of the values of two parameters:

- mixing coefficient for the fluid from the reactor cavity, and
- bypass coefficient for the fluid in the refueling pool.

These values are plant and alternate decay heat removal alignment dependent. The values for these coefficients are computed via multi-dimensional computational fluid dynamics calculations.

The methodology has been validated through a comparison of predicted-to-recorded data at the Calvert Cliffs Nuclear Power Plant (CCNPP) Unit 2 during the March 2001 refueling outage. The applicability of the methodology in general is predicated on a plant-specific validation similar to the one given in WCAP-15872-NP, Rev. 00 for the CCNPP, Unit 2.

2.0 REGULATORY EVALUATION

The methodology presented in WCAP-15872-NP, Rev. 00, "Use of Alternate Decay Heat Removal in Mode 6 Refueling," addresses the computational issues associated with demonstrating compliance with the requirements for a residual decay heat removal system set forth in General Design Criterion (GDC) 34. In particular, the numerical values computed with this methodology may be used to support the demonstration that the transfer of fission product decay heat and other residual heat from the reactor core is at a rate such that specified acceptable fuel design limits are not exceeded. The approval of the computational methodology in WCAP-15872-NP, Rev. 00 is consistent with the requirements set forth in Appendix B to Part 50 of Title 10 of the Code of Federal Regulations (10 CFR Part 50) "Quality Assurance Criteria for Nuclear Power Plants and Fuel Reprocessing Plants." WCAP-15872-NP describes actions necessary to provide adequate confidence that the alternate heat removal system will perform satisfactorily in service.

3.0 SUMMARY OF WCAP-15872-NP, REV. 00

The TR discusses the operational and technical issues associated with the introduction of an alternate decay heat removal system which takes suction from and discharges to the refueling pool while in Mode 6, with the refueling pool fully flooded. Standard decay heat removal in Mode 6 is provided by the shutdown cooling system. In this system, suction is taken from the hot leg, and the flow is fed to the shutdown cooling pump, and passed through a shutdown cooling heat exchanger. Cooled water is then returned to the reactor coolant system through a nozzle located in the cold leg. The alternate heat removal alignment is a specific alignment of existing plant systems as a substitute for conventional decay heat removal by the shutdown cooling system. In the alternate heat removal alignment, the core decay heat circulates from the open reactor vessel by natural circulation into the flooded refueling pool. The refueling pool is then cooled by an alternate cooling system. In the alternate cooling alignment, a pump takes suction from the refueling pool, then after passing through a heat exchanger, the flow is directed back into the refueling pool. The specific locations of the suction pipe from the refueling pool and the refill pipe to the refueling pool can be optimized depending on the specific plant design. In the case of CCNPP Unit 2, the alternate heat removal alignment consists of the spent fuel pool pump that takes suction from the refueling pool, then after passing through the spent fuel pool heat exchanger, the flow is directed back into the refueling pool. This flow is directed into the refueling pool through piping near the bottom of the pool. The suction from the refueling pool to the spent fuel pool cooling line is through a drain in the bottom of the refueling pool, at the side of the pool opposite the inlet point. This arrangement results in cooled water inventory drawn across the pool region directly above the open vessel.

Activation of the alternate heat removal alignment is dependent on the ability of the decay heat to circulate from the open reactor vessel (upper guide structure removed) by natural circulation and constrained by the water level in the refueling pool, the pool temperature, and the residual decay heat of the reactor core. Factors influencing the performance of the alternate heat removal alignment include the heat transfer ability of the spent fuel pool cooling system when aligned to the refueling pool, the pumped flow rates, and the ultimate heat sink temperature.

3.1 Computational Method

The computational methodology described in WCAP-15872-NP, Rev. 00 addresses the requirements for a residual decay heat removal system set forth in GDC 34. The computation in particular evaluates the capability of an alternate decay heat removal system to transfer decay heat and other residual heat from the reactor such that fuel design limits are not exceeded. The computational methodology consists of two interrelated models. A one-dimensional, time-dependent, lumped-parameter model of the core coupled to the refueling pool, and a three-dimensional, steady-state, computational fluid dynamics (CFD) model of the refueling pool.

3.1.1 One-Dimensional Model

The one-dimensional model divides the refueling pool and the reactor vessel internals into a series of control volumes that describe the upper guide structure, core and refueling pool. Ten state points that represent natural boundaries between the control volumes are defined in the model. These are consistent with the set of assumptions used to reduce the refueling pool and core coupled circulation problem to a mathematically tractable form. Conservation of mass, momentum, and energy are solved for these control volumes to predict the mass flow rate between the reactor vessel and the refueling pool. Temperatures of the refueling pool, the suction and discharge are calculated. The flow rate through the alternate decay heat removal system is also calculated. The model also considers the heat lost at the pool surface due to natural convection and evaporation from the free surface.

3.1.2 Computational Fluid Dynamics Model

The one-dimensional model cannot account for the geometric effects of the pool regions where the cooler fluid near the bottom of the pool does not fully mix with the hot plume rising from the core. Thus, two empirical coefficients, a mixing and a bypass coefficient, are introduced. The mixing coefficient accounts for the portion of the reactor cavity fluid that does not mix with the core flow. The bypass coefficient accounts for the alternate decay heat removal train flow that does not mix with the core exit flow. The values of these coefficients are specific to the geometry of the refueling pool and the alternate heat removal alignment. A three-dimensional CFD model of the refueling pool and boundary conditions consistent with the one-dimensional nodal model of the refueling pool and reactor cavity, are used to compute these coefficients.

4.0 TECHNICAL EVALUATION

Key elements of the methodology described in the TR, such as the mixing and bypass coefficients, are plant and alternate heat removal alignment specific. The model validation presented in the TR is based on a comparison of model predictions with data recorded at CCNPP Unit 2 during the March 2001 refueling outage. Under limited conditions, CCNPP units were permitted to use an alternate refueling pool cooling system during Mode 6 with the refueling pool flooded and with the shutdown cooling secured. Test data were recorded for two days during which the alternate pool cooling alignment was in use. Fluid temperatures in the refueling pool were recorded by thermocouples located at the reactor vessel flange level, at mid-level in the pool and close to the pool surface. The temperatures and shutdown cooling

flow rates were recorded as a function of time. Switching from the conventional shutdown cooling decay heat removal, both before and after the head is removed, followed by switching to the alternate decay heat removal are taken into account via the following sequence of operations:

1. reduce shutdown cooling flow for vessel head removal
2. restore full shutdown cooling flow
3. initiate alternate heat removal cooling flow, continue shutdown cooling flow
4. secure shutdown cooling flow, continue alternate heat removal cooling flow
5. secure alternate heat removal flow, restore shutdown cooling flow

4.1 Validation of the Computational Method

During the alternate heat removal alignment the refueling pool temperature data, at different elevations above the reactor vessel flange, indicate that the pool temperature decreases with elevation. This suggests that the hot plume from the core thermally mixes with the colder refueling pool water and cools as it rises to the top of the pool. The CFD predictions of the refueling pool water temperatures at locations corresponding to the measurement points compare favorably with the measured temperatures.

The variation with time of the computed and measured temperatures (shutdown cooling outlet, spent fuel pool outlet, and refueling pool average) and flow rates, over the sequence of operations that define entrance into steady-state operation and exit from the alternate decay heat removal alignment during the CCNPP Unit 2 March 2001 refueling outage, agree well. Some of the differences can be explained as due to the uncertainties in decay heat values and initial refueling pool temperatures at the time the head is removed. Thus, the mixing and bypass coefficients based on the CFD calculations account well for the non-uniform dynamic effects in the refueling pool in the one-dimensional analysis.

4.2 Alternate Heat Removal System Entry Conditions

The key factors that govern entry into the alternate heat removal alignment are decay heat generation rate, heat removal capability, the temperature of the refueling pool, and the heat sink temperature. The limiting time for entry into alternate heat removal is when the decay heat is first low enough to satisfy the refueling pool temperature limit given by the TS for a given heat sink temperature. At CCNPP the calculational methodology, described above and in WCAP-15872-NP, Rev. 00 has been employed with plant-specific data to determine the minimum time after shutdown for entry into the alternate heat removal alignment corresponding to the limiting refueling pool temperature versus ultimate heat sink temperature and other variables. The good agreement between predictions and measurements of the average refueling pool temperatures during the March 2001 refueling outage at CCNPP Unit 2 demonstrate the efficacy of the methodology for computing the conditions for entry into the alternate heat removal alignment at CCNPP.

4.3 Effect of Pool Fluid Velocity on Fuel Movement

Due to thermal convection between the core and refueling pool and the subsequent mixing with the pool circulation flow, a fuel assembly can become tilted and difficult to insert into the core. Limiting values of tilt angle as a function of time after shutdown are computed based on the predicted one-dimensional model flow rates due to natural convection between the core and the refueling pool. The allowable window for the initiation of the alternate heat removal alignment is computed consistent with temperature limits. The allowable window may require further refinement based on the computed tilt angles so as to preclude problems with the insertion of fuel assemblies. The specific limiting values of tilt angle depend on plant-specific experience with fuel assembly insertion.

5.0 CONCLUSIONS

The staff has reviewed WCAP-15872-NP, Rev. 00 and the supporting documentation submitted in response to its request for additional information. On the basis of this review, the staff only approves the computational methodology, together with its validation, as described in WCAP-15872-NP, Rev. 00 for referencing in licensing actions with regard to implementing an alternate method for shutdown cooling during routine Mode 6 operations at CCNPP. Application of the methodology for referencing in licensing actions to other plants is conditional on the validation of the methodology by the licensee on a plant-specific basis and a review by the staff of the licensee's validation in the license amendment request using the methodology.

This validation by the licensee for each plant-specific alternate decay heat removal system and refueling pool flow configuration entails:

- A quantitative validation of the CFD model of the refueling pool with respect to measurements comparable to those described in Appendix C of WCAP-15872-NP, Rev. 00.

- A quantitative comparison of the results of the computational model (as described in Appendix A of WCAP-15872-NP, Rev. 00) to measurements comparable to those described in Appendix B of WCAP-15872-NP, Rev. 00.

- An estimate of the sensitivity of the bypass and mixing coefficients of the computational model to model assumptions and the effects of this sensitivity on the computed results.

Principal Contributor: Yuri Orechwa

Date: November 30, 2004

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List of ACRONYMS

AHR ..... Alternate Heat Removal
CCNPP ..... Calvert Cliffs Nuclear Power Plant
CCW ..... Component Cooling Water
CDF ..... Core Damage Frequency
CFD ..... Computational Fluid Dynamics
DAS ..... Days after Shutdown
DHR ..... Decay Heat Removal
EOP ..... Emergency Operating Procedure
FPCS ..... Fuel Pool Cooling System
gpm ..... Gallons per Minute
HPSI ..... High Pressure Safety Injection
HX ..... Heat Exchanger
LCO ..... Limiting Condition for Operation
LOCA ..... Loss of Coolant Accident
LPSI ..... Low Pressure Safety Injection
MEEL ..... Minimum Essential Equipment List
NPSH ..... Net Positive Suction Head
NRC ..... Nuclear Regulatory Commission
NSSS ..... Nuclear Steam Supply System
RCS ..... Reactor Coolant System
RFP ..... Refueling Pool
RV ..... Reactor Vessel
SDCS ..... Shutdown Cooling System
SFP ..... Spent Fuel Pool
SW ..... Service Water
T_{amb} ..... Containment ambient temperature
TAS ..... Time after Shutdown
T_{HS}, THS ..... Heat Sink Temperature
TRM ..... Technical Requirements Manual
TS ..... Technical Specifications
UGS ..... Upper Guide Structure
ε_{mix} ..... Ratio of mixed RFP mass to total RFP mass
ε_{bypass} ..... Ratio of AHR flow bypassing core to total AHR flow

1.0 INTRODUCTION

This report establishes the technical bases for the use of an alternate method of decay heat removal from the refueling pool while in Mode 6 with the refueling pool fully flooded, and outlines the conditions when the alternate heat removal alignment may be employed. The alternate heat removal alignment provides a parallel heat removal path that may be used to supplement or replace the conventional shutdown cooling system during refueling operations. Normal shutdown cooling remains the principal means of decay heat removal. Activation of the alternate heat removal alignment is based on limits established by the refueling pool temperature and the decay heat load.

The primary use of the alternate heat removal alignment is to supplement or supplant shutdown cooling, either for expediency of fuel movement in Mode 6 or for outage flexibility. Another potential use is to facilitate limited leak rate testing on common valves in the shutdown cooling lines while in Mode 6. In one such case, it was estimated that 10 hours of critical path outage time was saved since a limited leak rate test could be performed that otherwise would have to be performed in Mode 4. Other uses include avoiding full core off-loads if repairs are needed in the shutdown cooling lineup, or augmenting shutdown cooling as a backup to enhance overall shutdown safety. Such augmentation can decrease plant risk, which can permit relaxing performance based requirements that involve the loss of shutdown cooling. One such requirement is closing all containment penetrations with direct access to the atmosphere within 4 hours after a loss of shutdown cooling, including the containment equipment hatch. Having alternate heat removal available can preclude or delay the need for such containment isolation actions. Use of the alternate heat removal alignment can also result in shorter refueling outages if, for example, fuel movement is allowed while simultaneously performing maintenance on both shutdown cooling trains.

After fuel movement has been completed, Technical Specifications require both trains of shutdown cooling to be operable (with one train operating) to support decay heat removal as the refueling pool is drained. Use of the alternate heat removal alignment would be discontinued at some point during pool drain down to avoid pump cavitation; the specific conditions under which alternate heat removal may not be used depend on plant-specific geometry and the available net positive suction head. Outage safety in the event of an inadvertent loss of shutdown cooling can also be improved through use of an alternate heat removal system since, depending on the decay heat rate, either the refueling pool time to boil will be extended or boiling will be prevented.

2.0 DECAY HEAT REMOVAL SYSTEM DESCRIPTION

The conventional decay heat removal system, termed the "shutdown cooling" or "residual heat removal" system, installed in CE designed NSSSs employs redundant capacity pumps, valves, and heat exchangers to transfer decay heat from the reactor core to the

component cooling water system and finally to the ultimate heat sink. A typical shutdown cooling system arrangement is illustrated schematically in Figure 1.

Entry into Mode 4, for shutdown cooling operation, is controlled by the reactor coolant system temperature as stated in the Technical Specifications or the technical requirements manual. The plant cooldown rate is governed by the pressure-temperature constraints given by the low temperature overpressure protection analysis.

2.1 SHUTDOWN COOLING SYSTEM

Decay heat removal in Modes 5 and 6 is provided by the shutdown cooling system (Figure 1). Suction is taken from one (or more) hot leg(s), fed to the LPSI / shutdown cooling pump(s), and passed through a shutdown cooling heat exchanger. Cooled water is then returned to the reactor coolant system through nozzle(s) located in the cold leg(s). Temperature control is accomplished by bypassing the shutdown cooling heat exchanger as needed with a portion of the total flow. A typical shutdown cooling flow rate is 3000 gpm, though this may be as low as ~1000 gpm under certain outage activities and conditions of reduced decay heat removal. Plants may also use the shutdown cooling system as a backup to the spent fuel pool cooling.

Technical Specifications typically require both shutdown cooling trains to be operable, with one train operating, in Modes 5 and 6. An exception is when the refueling cavity is flooded (typically to 23 feet above the top of the core); in this case only a single shutdown cooling train is required to be operating. With a single train operating, in Mode 6, fully flooded the second train is not required. Only during Mode 5 and Mode 6, not fully flooded, does the second train function as a backup to the operating train should a loss of cooling occur.

When moving fuel in the vicinity of the hot legs, Technical Specifications permit securing the operating shutdown cooling train for one (1) hour during any 24-hour period. This limitation recognizes that hydrodynamic forces from the shutdown cooling flow across a fuel bundle being moved in the vicinity of a reactor vessel nozzle may interfere with controlled fuel movement, and hence allows the flow to be stopped for a limited period of time. The limitation also implicitly recognizes that that the fuel in the reactor vessel can be safely cooled for a limited period of time without forced shutdown cooling flow through the reactor vessel. Under these conditions, the decay heat is safely removed from the reactor by natural convection and is stored in the refueling pool. Only a limited heat-up of the refueling pool will occur (about 10°F / hour at one week after shutdown) during the time that shutdown cooling flow is interrupted.

Maintenance may be performed on the non-operating shutdown cooling train during a refueling outage, with the operating train typically being "swapped out" during the refueling interval. With the refueling pool flooded, the large thermal mass of the water provides a substantial margin of safety relative to the time to boil, which is about 13 hours at one week after reactor shut down. In addition, the time before boil-off would bring the

refueling pool water level down to the top of the core, should an unrecoverable loss of shutdown cooling occur, is about 4 days at one week after shutdown.

2.2 ALTERNATE HEAT REMOVAL ALIGNMENT DESCRIPTION

The alternate heat removal alignment is a specific alignment of existing plant systems to substitute for conventional decay heat removal as performed by the shutdown cooling system. When aligned in the alternate heat removal alignment, the plant can remove the shutdown cooling system from service for any purpose. While this report is intended to support plant licensing amendments to permit both trains of the shutdown cooling system to be inoperable, the alternate heat removal alignment can also be used to supplement the shutdown cooling system or simply be recognized as a standby or backup means of heat removal. These secondary purposes can benefit plants where the alternate heat removal alignment performance is not sufficient to meet the requirements established in this report without plant modification.

The alternate heat removal alignment is where the core decay heat circulates from the open reactor vessel by natural convection into the flooded refueling pool. The refueling pool is then cooled by an alternate cooling system. Such systems could be a cross connection alignment of a train of the spent fuel pool cooling system or a skid mounted temporary system. For the specific plant case analyzed for this report, the CCNPP units are permitted to use an alternate heat removal alignment during Mode 6 with the refueling pool flooded and with shutdown cooling secured. In this alternate cooling alignment the spent fuel pool pump takes suction from the refueling pool, then after passing through the spent fuel pool heat exchanger, the flow is directed back into the refueling pool. This flow is directed into the refueling pool through piping near the bottom of the pool. The suction from the refueling pool to the spent fuel pool cooling line is through a drain in the bottom of the refueling pool, at the side of the pool opposite the inlet point. This arrangement results in cooled inventory drawn across the pool region directly above the open vessel. The particular connection arrangement at CCNPP is not specifically required to achieve acceptable heat removal results. Plants with other possible means and capacity of removing the convected decay heat from the refueling pool can take advantage of an alternate heat removal alignment with an appropriate analytical basis.

The alternate heat removal alignment is intended to operate as a dedicated heat removal mechanism for the refueling pool. This process may either supplement the normal shutdown cooling system, or operate independently as a stand-alone heat removal system. Activation of the alternate heat removal alignment is constrained by the water level in the refueling pool, the pool temperature, and the residual decay heat resident in the reactor core. Factors influencing the performance of the alternate heat removal alignment include the heat transfer ability of the spent fuel pool cooling system when aligned to the refueling pool, the pumped flow rates, and the ultimate heat sink temperature.

The alternate heat removal alignment functions by circulating the refueling pool water, typically at a flow rate of approximately 1000 gpm, through a pump and heat exchanger

before returning the cooled water to the refueling pool. Natural convection and mixing are used to transfer decay heat from the reactor core to the refueling pool water. A simple schematic of the alternate heat removal flow path is shown in Figure 2.

Natural circulation cooling of the reactor core while the refueling cavity is flooded and the normal shutdown cooling system not in service will result in a thermal plume centered approximately above the reactor vessel. This plume will mix with the refueling pool water resulting in a thermal distribution that varies depending on the refueling pool fluid temperature and local flow velocities within the refueling pool resulting from the alternate cooling alignment.

A model has been developed to calculate the natural convection flow between the core and the refueling pool; this model is described in Appendix A and is baselined against data obtained from tests performed at CCNPP Unit 2, as described in Appendix B. The natural circulation function of the alternate heat removal alignment already exists in that this passive process is inherently brought into play to remove decay heat from the core each time the shutdown cooling system is deliberately secured when in a refueling mode. The resulting natural circulation flow rates through the core are found to be as much as the traditional shutdown cooling flow rate of 3000 gpm, which ensures adequate core cooling. Mixing of the forced cooling flow (from the spent fuel pool cooling system) through the refueling pool with the thermal plume from the core assures adequate heat removal if a proper orientation of the forced flow path is chosen in conjunction with an adequate flow rate. A secure way to remove heat from the refueling pool then completes the alternate heat removal alignment.

Controlled tests of the alternate heat removal system alignment in operation at CCNPP Unit 2 were performed and data collected during the Spring 2001 refueling outage. These tests were used to verify theoretical predictions of the refueling cavity temperatures when using the alternate heat removal alignment. Test results showed good agreement with predictions, thus confirming the technical bases for the alternate heat removal alignment. These test results also support the bases for the proposed changes to the Technical Specifications.

Alternate heat removal can also be considered to include any non-traditional uses of either the shutdown cooling system or shutdown cooling flow. An example of this occurred at the Millstone-station, Unit 2, where a limited leak rate test was conducted on valves in the shutdown cooling suction line. The test is usually run in Mode 4 after shutdown cooling operation has been completed and the shutdown cooling suction line is available for the test. Conducting the leak rate test in Mode 4 is difficult due to high reactor coolant system temperatures. Therefore, performing the test in Mode 6 saved approximately ten hours of critical path outage time. For this application the shutdown cooling flow was realigned to bypass the normal suction line, and instead used the fuel transfer tube and the spent fuel pool as a flow path. The plant has the ability to cross connect the shutdown cooling system to the spent fuel pool cooling system using a temporary spool piece. In effect, the only change made was to bypass the shutdown cooling suction line off the RCS hot leg with the shutdown cooling flow through the transfer tube. Technical Specifications allowed

the shutdown cooling flow to be temporarily secured while the alternate flow path alignment was aligned and the leak rate test successfully completed.

2.3 OUTAGE FLEXIBILITY IMPROVEMENT

Refueling outage flexibility can be enhanced by having available an alternate heat removal alignment. A partial list of opportunities provided by such capability includes:

- Fewer full core off-loads when encountering shutdown cooling related problems (e.g., a stuck safety injection valve requiring that shutdown cooling flow be secured for repairs).
- Conducting limited leak rate tests in Mode 6 rather than Mode 4.
- Shorter outages if all LPSI/shutdown cooling system maintenance can be performed simultaneously with fuel movement.
- Avoiding the need for immediate containment closure if shutdown cooling operability is lost and alternate heat removal is operable.
- Less use of LPSI pumps when in a prolonged outage and fuel remains in the reactor vessel.
- More opportunities to leave fuel in the reactor vessel for specific outage needs, especially if the spent fuel pool cannot accept a full core off-load.

2.4 QUALIFICATION OF ALTERNATE HEAT REMOVAL MODEL

Validation of the alternate heat removal model is based on comparison of predicted results with data recorded at CCNPP Unit 2 during the spring 2001 refueling outage. The results of this test show good agreement with predictions, as illustrated in Appendix B.

A further validation of the alternate heat removal model is given in Appendix C where predictions of refueling pool temperatures using a commercial computational fluid dynamics computer code, are compared with test data recorded at CCNPP Unit 2. The computer model predictions show that the thermal plume from the core rapidly mixes with the refueling pool water, with the strongest circulation occurring in the pool region above the core.

Variations in the alternate heat removal suction and discharge pipe locations in the refueling pool were investigated using the computational fluid dynamics code and the geometry of the CCNPP refueling pool. The influence of the alternate flow paths on pool temperature distributions is predicted by the code using a one-dimensional model of the core and refueling pool above the open vessel in conjunction with a detailed computational fluid dynamics code model of the refueling pool. The combined models describe the interaction of the core flow with the refueling pool by means of mixing and bypass coefficients. Details of this analysis and results of the alternate heat removal piping alignment, seen in Appendix D, show good mixing of the coolant circulating through the core with refueling pool water.

Appendix E describes the thermal hydraulics analysis used to establish the time after shutdown when the alternate heat removal alignment may be activated. This parametric analysis relates the decay heat rate, pool temperature and heat removal rate based upon consideration of current CCNPP limiting pool temperature of 140°F.

3.0 QUALITATIVE ASSESSMENT OF RISK

The Maintenance Rule (10 CFR 50.65) requires that a risk assessment be performed each time a safety significant system such as the shutdown cooling system is deliberately removed from service, even when allowed by Technical Specifications. Since the utilities that are participants in this task do not have a shutdown PRA for the plants, such assessment is necessarily qualitative in nature. In general the risk of core damage during the time frame that the refueling pool is filled is very low when compared to the remainder of plant outages and power operation. The length of time necessary to uncover the core on loss of cooling is well over twenty-four hours and inventory makeup to the pool is relatively simple. The use of alternate heat removal is shown to be generally risk-neutral for shutdown risk assessments, as is illustrated in Appendix F for CCNPP Units 1 and 2.

3.1 RISK-SENSITIVE ISSUES

The information presented below summarizes the pertinent issues which must be weighed on a plant specific basis to assess the total impact of using alternate heat removal on plant risk. The qualitative risk assessment includes consideration of the cooling system integrity such as those provided by the reactor vessel cavity seals and steam generator nozzle dams.

3.1.1 Alternate Heat Removal Simplicity and Cooling Reliability

Shutdown cooling, as a traditional safety grade system, is a complex system. In addition to being the plant's primary means of decay heat removal, much of the shutdown cooling system also supports the low pressure safety injection system for accident mitigation.

By contrast, alternate heat removal lends itself to simpler operations, has only a single function to perform, and is not encumbered by numerous other interface issues as is the shutdown cooling system. Note also that there is no need to realign shutdown cooling trains when using alternate heat removal while in Mode 6. Shutdown cooling system alignment requires the successful operation of flow control valves and/or temperature control valves. As alternate heat removal via the spent fuel pool cooling system is generally controlled by manual valves it has fewer failure modes. Due to this inherent simplicity, the alternate heat removal alignment is believed to be equally or less likely to lose cooling under Mode 6 refueling conditions than is shutdown cooling.

Also, for those few plants that still maintain an automatic closure interlock on the valves in the suction piping, the inadvertent actuation and suction valve closure can cause a loss of

decay heat removal (shutdown cooling). With the alternate cooling alignment, this interlock cannot disrupt decay heat removal.

3.1.2 Required Core Offload

For many plants, shutdown cooling system repairs or local leak rate testing in the shutdown cooling suction lines may necessitate a full core offload and a reload. With the alternate heat removal alignment available, many such repairs or tests could be performed without removing the fuel from the vessel. Avoiding a core offload can save about a week of time, as well as eliminating the risk of fuel handling errors.

In some cases a full core offload is no longer possible due to limited spare space available in the spent fuel pool. Alternate heat removal alignment will allow fuel movement in Mode 6 refueling situations and can avoid entering a Technical Specification LCO where an unplanned shutdown cooling system outage occurs. An alternate heat removal alignment can also provide a pre-arranged and approved method of removing decay heat in an extreme situation where shutdown cooling is declared inoperable.

3.1.3 Loss of Inventory

Given the large inventory available when the refueling pool is filled, and the low decay heat, the only credible sequences that lead to core damage involve loss of inventory. In Mode 6, the potential for gross inventory loss can exist for conditions such as failure of the reactor vessel flange seal or any of the steam generator nozzle dams. Gross inventory loss can also occur due to inadvertent draindown during plant evolutions which involve cooling train alignments or draining the RCS (and the refueling pool). Also to be considered is the potential for a heavy load drop or other inadvertent maintenance activity, damaging the seal or a nozzle dam to cause a rapid draindown. Generally, in these events, the traditional shutdown cooling system should continue to function, while in many cases the alternate heat removal capability would be unavailable.

When using shutdown cooling, a large reactor vessel cavity seal failure would essentially drain the entire refueling pool (except the deep end) to the level of the vessel flange; a large nozzle dam failure would further drain the RCS to slightly above[1] mid-loop. In either event, shutdown cooling would likely continue to function and any fuel out of the vessel could be either repositioned back in the vessel or placed in the deep end of the refueling pool. In the case of the loss of the nozzle dam integrity, there could potentially be a loss of suction and temporary loss of cooling since the hot legs, the location of the shutdown cooling suction line, would likely remain only partially full.

[1] The potential loss of refueling pool inventory is not dependent on the specific method of decay heat removal being used, and the existing makeup capabilities will not be able to refill the refueling pool for such an event which is low in the system. Additionally, inventory could be lost from the spent fuel pool for a large loss of inventory event. However, weirs are incorporated into spent fuel pool designs to explicitly prevent uncovery of stored fuel.

When using alternate heat removal, the consequences of a large loss of inventory event are significant since alternate heat removal needs the refueling pool inventory to function. Both events would potentially drop refueling pool levels below the suction and discharge locations of the aligned alternate cooling system (spent fuel pool cooling) making the system inoperable. The lost inventory would collect in the containment sump and be available for pumping back into the RCS, where depending on the assumed size of leakage from the seal or dam, an acceptable level could be maintained to sustain the alternate cooling alignment.

Where the system integrity is judged as potentially inadequate, such that large loss of inventory situations must be addressed, operator actions could use a feed-and-bleed alignment to recover the water spilled to the containment sump. This will inject the lost inventory back into the reactor coolant system, thereby maintaining core cooling in the short term as the inventory heats up. Since the inventory lost is being recovered in the sump, the time to boil is measured in hours, the same as if the inventory were still in the refueling pool. Heat removal will be needed to prevent boiling, thus the cooling system lineup for feed and bleed must include a heat exchanger. This could be the shutdown cooling heat exchanger, the heat exchanger being used for alternate heat removal, or any other appropriate heat exchanger.

Many plants have either installed permanent reactor vessel flange seals or have upgraded existing seals to address concerns with seal integrity, reducing the probability of catastrophic failure. Similarly, many plants have upgraded their nozzle dams or have installed improved dams, including backup bladder gas supplies where appropriate, again making catastrophic failure unlikely. Where a plant has both improvements, significant loss of inventory situations are viewed as not credible. Otherwise, consideration must be given to the consequences of such an event while using alternate heat removal. Small amounts of pool seal or nozzle dam leakage, when using either shutdown cooling or alternate heat removal, are acceptable since plants already provide borated makeup for this possibility. Where system integrity is not considered to be as reliable, operator actions can be credited to recover, cool and inject lost inventory collected in the containment sump into the reactor coolant system using a feed and bleed process. Fuel being moved when a feed and bleed cooling process is initiated could be promptly placed in a secure location of the refueling pool (in the deep end near the transfer tube).

In plants where the improvements in reactor cavity seals and steam generator nozzle dams have been implemented, the frequency of rapid draindown events is driven by human error in system alignments. This risk is only a concern when relevant plant evolutions are in progress. The only relevant evolutions will be aligning alternate heat removal cooling or securing it and aligning normal shutdown cooling. The use of the alternate heat removal cooling for the refueling pool is currently allowed per existing Technical Specifications (for some CE NSSS plants, including CCNPP). Thus, these evolutions are already allowed. The difference is that a shutdown cooling train will not be available as a backup. Thus, there is no additional human error potential for causing a draindown event for plants.

Another potential for a rapid draindown is a maintenance induced break, such as a heavy load drop. The use of alternate heat removal cooling will not increase the probability of a maintenance induced break that causes a rapid draindown. Thus, the overall probability of a rapid draindown event is not increased.

For plants that do not currently allow the use of alternate cooling, the potential for an increased probability of a rapid draindown event causing a loss of cooling must be addressed. Alternate heat removal systems have flow rates of approximately 1000 gpm. With refueling pool volumes over 300,000 gallons it would take at least five hours to challenge core cooling due to an improper alignment of the alternate heat removal system. Given the long time frame required to drain the pool, complete draindown is extremely unlikely. There are multiple indications available that the improper lineup has occurred (RWT alarms, sump alarms, spent fuel pool and refueling pool level alarms). Further, it is expected that direct observation of pool levels will be performed during cooling alignment changes. Given all the indications available, and the time available, a draindown significant enough to cause loss of cooling is not credible during a cooling system alignment change to alternate heat removal cooling.

This change does remove one potential source of makeup to the RCS when a loss of inventory occurs. The typical current plant practice is to have two means of providing makeup to the core. For example this means two HPSI pumps, or one containment spray pump and one HPSI pump. These are required to have independent power supplies. These pumps can take suction from the containment sump. One containment sump flow path is required to remain available. When a LPSI pump is providing shutdown cooling it can also be aligned to the sump to provide makeup. This change will eliminate one makeup source which can take suction from the containment emergency sump. Thus, there is the potential for increased CDF due to reduced redundancy of makeup pumps.

This change also causes there to be less redundancy in cooling the RCS when recirculating from the Containment Sump. A Shutdown Cooling heat exchanger could be used to cool the core when recirculating water from the Containment Sump. Alternate cooling trains cannot be aligned to this sump to provide cooling. However, as noted previously, the large volume of water in the Containment (Over 300,000 gallons) and the low decay heat, will allow recirculation to maintain the core cooling for extended periods.

3.1.4 Loss of Circulation

Various pumps may be used as part of the alternate heat removal alignment. For some plants, a LPSI or a HPSI pump could be used which would provide a very reliable flow for alternate heat removal. At CCNPP, a spent fuel pool cooling pump is used which is also very reliable. In general, the reliability of the flow process for alternate heat removal must be comparable to that for conventional shutdown cooling to provide a risk-neutral qualitative evaluation. With fewer interfaces, e.g., automatic closure interlock for shutdown cooling valves, and a simpler design function, it is believed that the alternate heat removal system reliability can easily be equivalent to that of the shutdown cooling

system. The large amount of water in the refueling pool allows ample recovery times for either alternate heat removal or shutdown cooling if flow is lost.

3.1.5 Boron Dilution

The use of either the shutdown cooling system or the alternate heat removal alignment to remove decay heat does not change the probability of a boron dilution event.

For a boron dilution event, the safety analyses assume an inadvertent injection of unborated water into the reactor coolant system via the charging system. The acceptance criteria for the event then determine if limits on charging pump availability are needed in Modes 5 and 6. Since charging pumps are not in service during Mode 6 refueling, (the charging and letdown system is not used) the possibility of a boron dilution event is not considered credible.

3.1.6 Time to Boil

Time to boil is the basis for the Technical Specification LCO that only a single shutdown cooling train needs to be operable when the refueling pool is fully flooded. Following a loss of shutdown cooling, the time to boil when the refueling pool is flooded varies from approximately 16 hours at 15 days after shutdown, to nearly 20 hours at 25 days after shutdown. For comparison, the time to boil after loss of alternate heat removal with the refueling pool flooded ranges from approximately 13 hours at 15 days after shutdown, to nearly 17 hours at 25 days after shutdown. Using alternate heat removal results in a shorter time to boil since the refueling pool temperature is predicted to be warmer when using an alternate heat removal alignment than when the shutdown cooling system is in operation. If decay heat removal is not restored, the time to core uncovery by boiling is measured in days for either loss of shutdown cooling or loss of alternate heat removal. Thus, a few hours difference in time to boil resulting from loss of alternate heat removal as compared with loss of shutdown cooling is not significant in terms of the total time to core uncovery.

3.1.7 Fuel Bundle Handling

When using alternate heat removal, fuel handling is simplified when moving bundles in the vicinity of a hot leg as there is no shutdown cooling flow. Fluid currents in the refueling pool of approximately one foot/second may exist when using alternate heat removal; such currents are larger than the essentially zero flow rate in the refueling pool when using shutdown cooling. The flow-induced horizontal hydrodynamic forces on a fuel bundle (estimated at ~10 pounds) when using alternate heat removal is insignificant when compared to the approximate 1100 pound wet weight of a bundle. On this basis, the risks of a fuel handling accident caused by hydrodynamic loads under either method of decay heat removal are judged essentially equal.

3.1.8 Visibility of Refueling Pool Cavity Water

Thermal gradients within the refueling pool ("heat waves") may diffract light, thereby introducing an optical distortion that could affect the operator's view when identifying fuel bundles. However, experience with the alternate heat removal alignment experience at CCNPP has shown such optical distortion to be minor and has not caused operational problems. Based on these observations, visibility when using the alternate heat removal alignment will not hinder fuel movement.

3.1.9 Other Considerations

A number of other factors must be weighed when judging the change in plant risk when alternate heat removal is substituted for shutdown cooling. Some of these considerations include:

- Personnel safety in performing any required manual manipulations for initiating alternate heat removal.
- Equipment separation issues.
- Security of alternate heat removal equipment.
- Cable routing.
- Chemistry requirements.
- Electrical reliability.
- Common support systems.
- Reduced number of shutdown cooling starts.
- Event recovery times.
- Stagnant or relatively cool water in part of the reactor coolant system as a result of alternate heat removal use; such stagnation may also exist when using shutdown cooling.

3.2 QUALITATIVE RELIABILITY SUMMARY

A qualitative evaluation of the above risks is provided for the CCNPP units in Appendix F. When compared with the more complicated but also highly reliable shutdown cooling process, it has been qualitatively concluded that the use of the alternate heat removal alignment is risk neutral when compared to use of the shutdown cooling system.

4.0 ALTERNATE HEAT REMOVAL ENTRY CONDITIONS

Entry into alternate heat removal is governed by a combination of factors including decay heat generation rate, heat removal capabilities, the temperature of the refueling pool, and the heat sink temperatures. For each refueling pool geometry, inlet temperature, flow rate, and decay heat rate there is a corresponding steady-state temperature distribution within the refueling pool. Based on test results from CCNPP, the refueling pool will have a

distribution of temperatures with the highest pool temperature in the thermal plume immediately above the core. Because of mixing, this plume temperature will diffuse before reaching the refueling pool surface levels. The refueling pool temperature must be at or below the lower of the refueling pool limit, or the plant Technical Specification Mode 6 defining limit. As described in Appendix E, 140°F has been used as the limiting refueling pool temperature.

4.1 REFUELING CAVITY FLOW RATE, MIXING AND TEMPERATURES

Each utility, when deciding to implement alternate heat removal, must evaluate its expected refueling pool forced flow rates, the flow path entry and exit locations, and the resulting temperatures versus decay heat levels. Based on the refueling pool data predicted for CCNPP in Appendix A of this report, a minimum flow rate of 1000 GPM will generally be needed to remove decay heat loads corresponding to one week after shutdown.

For a given refueling pool geometry, inventory and temperature, each alternate heat removal flow rate will correspond to a limiting heat load before a limiting refueling pool temperature is reached. Situations could also occur where the heat removed by the alternate heat removal alignment is limited by inadequate fluid mixing in the refueling pool, or by the ability of a secondary system to absorb such heat.

4.2 INITIATION OF ALTERNATE HEAT REMOVAL

The limiting time to initiate alternate heat removal is a function of the refueling pool temperature, the decay heat rate, and the ability to reject heat to the ultimate heat sink. The limiting time for entry into alternate heat removal will be when the decay heat is first low enough to satisfy the refueling pool temperature limit for a given heat sink temperature. For some situations, as when the ultimate heat sink is at its lowest winter/early spring temperatures, alternate heat removal entry may be allowed at or before the outage itself is ready to use alternate heat removal. For other situations, the outage schedule will be constrained by the capability of the plant specific alternate heat removal to first achieve the limiting temperature in the refueling pool. Plant specific results based on CCNPP data are developed to assist in determining the time after shutdown corresponding to the limiting refueling pool temperature versus ultimate heat sink temperature and other variables. Figures 3, 4, and 5 illustrate the general relationship of the refueling pool temperature to the ultimate heat sink temperature, and also show the determination of the earliest allowed alternate heat removal entry time. Appendix E shows the refueling pool temperatures at CCNPP Unit 2 versus time after shutdown for a refueling pool inlet (the spent fuel pool cooling return) temperature of 90°F. Note that different curves or limiting temperatures could be developed to allow for lower than full decay heat loads or for increased containment venting or cooling.

4.2.1 Temperature Distribution Assessment

An assessment of the temperature distribution in the refueling pool is made as a function of decay heat, forced flow refueling pool flow rate, and inlet temperature to the refueling pool. If a specific refueling pool flow has been selected based on plant equipment availability, then the temperature distributions will be the elements of a two-dimensional matrix (inlet temperature and decay heat rate). Initial calculations for results will use an appropriate CFD model in conjunction with an appropriate one-dimensional core flow model. The core model can be that developed for this report, or any other suitable model which couples refueling pool temperature in the vicinity of the top of the reactor vessel periphery to decay heat to give a core flow and exit temperature from the core to the refueling pool. After developing a set of initial calculations for a given refueling pool inlet temperatures, results are then extended to other refueling pool inlet temperatures and other decay heat levels, as shown in Figure 3. A hydraulic analysis of the refueling pool in conjunction with the one-dimensional core flow model shown in Appendix A is used to calculate the refueling pool temperature as a function of pool inlet temperature for CCNPP.

The refueling pool inlet/outlet temperatures and refueling pool flow rate are then coupled to the rest of the alternate heat removal heat removal process, so that a specific ultimate heat sink temperature corresponds to the previously used refueling pool inlet temperature. Conservative allowances must also be made for other outage-related heat loads. The specific ultimate heat sink temperature will correspond to the specific decay heat and the refueling pool temperatures. This process yields a second matrix that relates the decay heat loads and ultimate heat sink temperatures to the refueling pool temperature distribution. This matrix is the same as the first matrix described in the previous paragraph, except that the ultimate heat sink temperature (with allowances for other outage heat loads) replaces refueling pool inlet temperature. Figure 4 illustrates this process.

Finally, knowing the refueling pool temperature distribution versus the ultimate heat sink temperature, the locus of the limiting refueling pool temperature can be determined. A cross-plot of the corresponding ultimate heat sink temperature versus time after shutdown will then yield the limiting (earliest) allowable alternate heat removal entry time for any given ultimate heat sink temperature. This cross-plot will be part of the plant procedures to be used as part of the alternate heat removal process. Figure 5 is a sketch of the curve, showing the earliest time to enter alternate heat removal based on the ultimate heat sink temperature.

5.0 TECHNICAL SPECIFICATIONS

5.1 CURRENT TECHNICAL SPECIFICATIONS

Most plant Technical Specification LCOs do not currently allow shutdown cooling flow to be turned off during refueling mode operations, except for a one-hour period to permit fuel

movement in the vicinity of a hot leg. However, some early generation CE NSSS plants are permitted by their Technical Specifications to secure shutdown cooling flow when in Mode 6, fully flooded, without an LCO time limit. The alternate heat removal alignment is used to remove decay heat when the shutdown cooling system is not operating. Technical Specifications for these few plants currently allow use of the alternate heat removal alignment only when working on the shutdown cooling piping containment penetration, or when working on valves in the common shutdown cooling suction line. Fuel movement is not allowed in this configuration. Also, a single train of shutdown cooling is still required to be operable.

To implement an alternate heat removal alignment in a condition that permits sole dependence for decay heat removal, changes are needed to the Technical Specifications that define the:

- Conditions under which the alternate heat removal alignment may be used,
- Requirements for removing the shutdown cooling system from service,
- Fuel movements allowed when using the alternate heat removal alignment, and
- Time limits for interrupting the alternate heat removal alignment cooling flow.

It would be advantageous for plants with Technical Specifications allowing shutdown cooling to be secured for purposes of using alternate heat removal, to amend their Technical Specifications to allow fuel movement when shutdown cooling is deliberately secured and alternate heat removal is being used. In addition, outage length could be reduced if, in specific situations, Technical Specifications are modified to accommodate situations other than maintenance or repairs on the common shutdown cooling line.

Plants with proper piping may wish to augment shutdown cooling with an alternate heat removal alignment, using the corresponding reduction in risk to justify relaxed Technical Specification requirements. One such example is the 4-hour closure requirement of all containment openings upon loss of shutdown cooling. This Technical Specification is based on time to boil, which can be approximately four hours when early in an outage. Forced containment closure on loss of shutdown cooling is a major disruption during an outage and could be avoided if alternate heat removal is available.

5.2 ALTERNATE HEAT REMOVAL TECHNICAL SPECIFICATION

Technical Specifications require a decay period between the time of plant shutdown and when fuel offload may begin. A corresponding restriction will also apply to the time after shutdown before alignment to the alternate heat removal alignment will be permitted. This limitation on time to initiate alternate heat removal alignment must be incorporated either into a Technical Specification LCO or the Technical Requirements Manual.

Technical Specification or Technical Requirements Manual limitations must establish the maximum allowable refueling pool temperature when operating in the alternate heat removal mode. Based on experience at CCNPP Unit 2, a maximum pool temperature of

140°F is maintainable as an upper limit for operation of the alternate heat removal alignment. Higher temperature limits may be considered provided all consequences are considered, such as containment habitability and humidity, etc. This temperature is monitored by the refueling pool outlet temperature to the spent fuel pool cooling cross connection. Adequate heat rejection through the alternate heat removal alignment will be confirmed by monitoring the temperature change of the refueling pool.

6.0 CONCLUSION

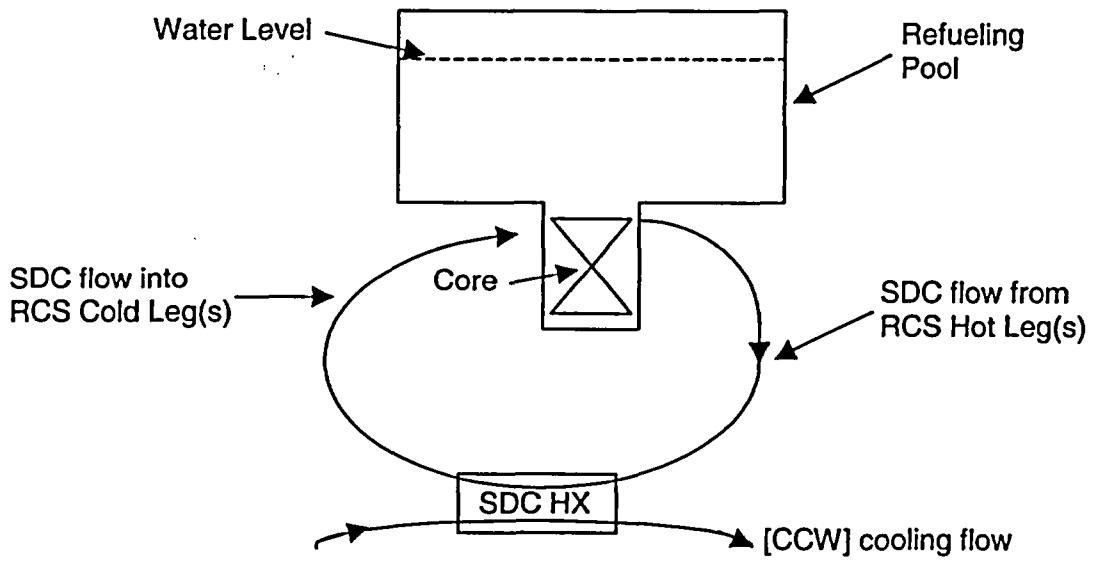
An alternate refueling pool heat removal path permits certain maintenance activities to be performed on the shutdown cooling system in parallel with other plant operations while in Mode 6, refueling. Such capability provides flexibility in scheduling and performing maintenance and can avoid entry into Technical Specification action statements. The resulting benefits include better utilization of plant resources, outage flexibility, reduced personnel exposure and increased safety.

It has been shown that an alternate heat removal alignment can be effectively and safely used when in Mode 6, refueling, to supplement or supplant the normal decay heat removal system. The alternate heat removal alignment described in this report is based on the arrangement in use at CCNPP Unit 2. Tests performed on this system during the Spring 2001 refueling outage substantiate the capabilities of the alternate heat removal alignment and support the technical basis for this report.

Installed alternate heat removal alignments have not encountered operational problems, have improved outage workflow and allow flexibility when performing inspection, test and maintenance activities. Implementing an alternate heat removal alignment may entail modifications to plant hardware and piping configurations, Technical Specification changes, and updates to plant procedures.

Figure 1

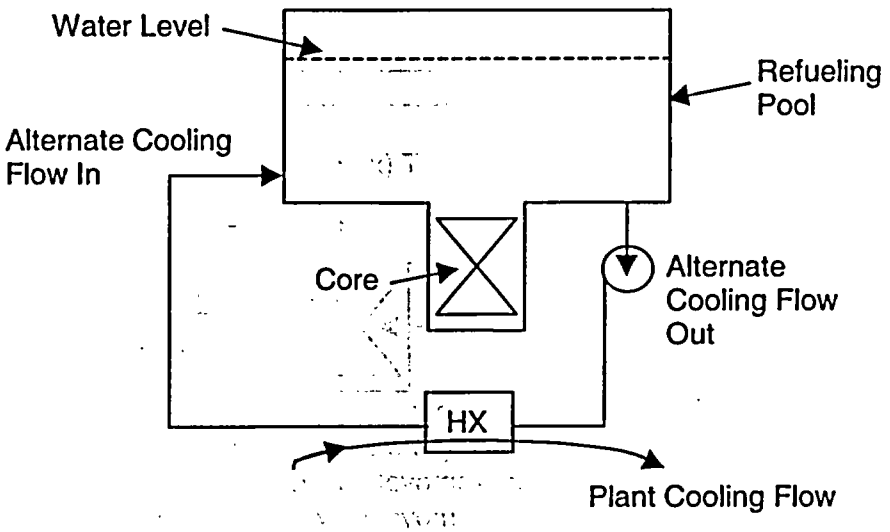
Schematic of Conventional Decay Heat Removal (Shutdown Cooling) in Mode 6 Fully Flooded



Note: SDC/LPSI pumps not shown.

SDC System aligned for Decay Heat Removal

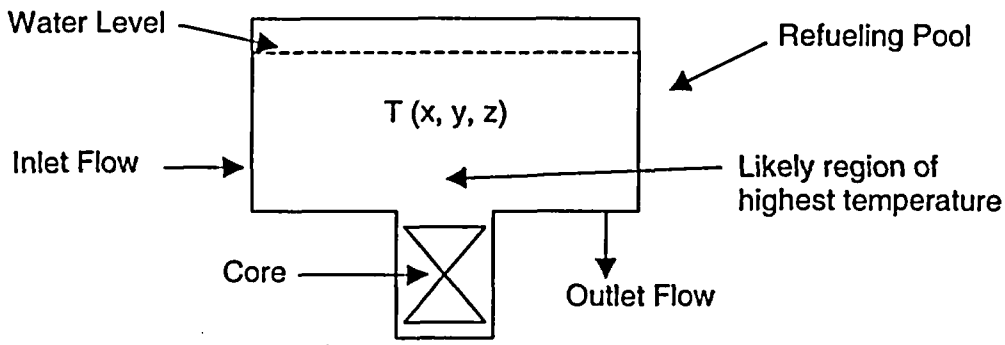
Figure 2
Schematic of Alternate Heat Removal in Mode 6 Fully Flooded



SDC Flow not operating

Alternate Cooling Aligned for Alternate Heat Removal

Figure 3
Development of Refueling Pool Temperature versus Inlet Temperature



T(x,y,z)* Depends on:

- Decay heat load (time after shutdown)
- Alternate heat removal flow rate
- Alternate heat removal flow inlet temperature
- Refueling pool geometry
- Flow inlet and outlet locations/orientations

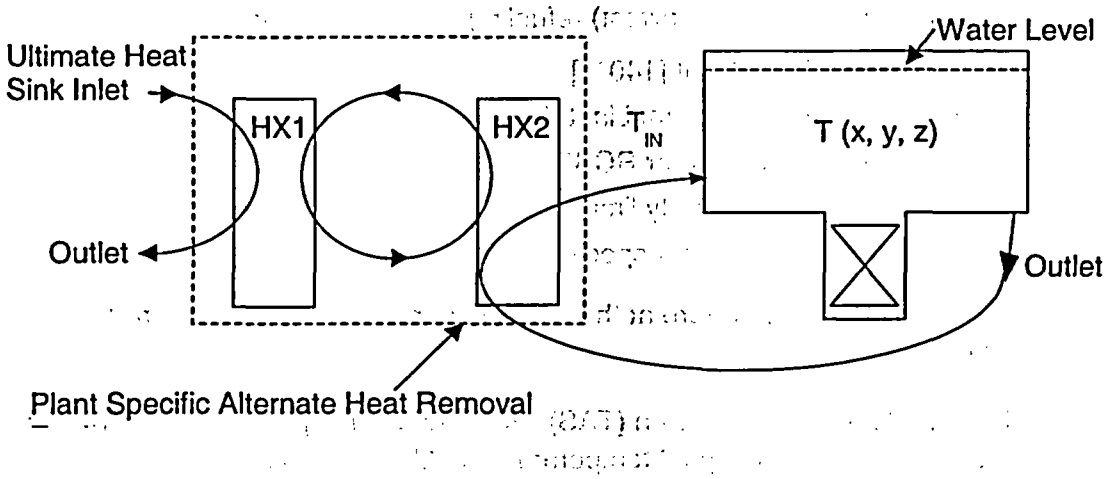
Matrix I Result: Temperature versus T_{IN} & Time after Shutdown			
T_{IN}, °F	Time after Shutdown, Days		
	5	10	15
70	T(5,70)	T(10,70)	T(15,70)
80	T(5,80)	T(10,80)	T(15,80)
90	T(5,90)	T(10,90)	T(15,90)
100	T(5,100)	T(10, 100)	T(15,100)

*Note: Where the mixing in the refueling pool is good, an average temperature can be used in lieu of the distribution.

Illustrative values of T_{IN} and Time after Shutdown are shown.

Figure 4

Development of Refueling Pool Temperature versus Heat Sink Temperature



HX1: [Service Water Heat Exchanger]
HX2: [Spent Fuel Pool Heat Exchanger] used for alternate heat removal cooling
Not Shown: Other outage heat loads on HX1

Matrix II Result: Temperatures versus T_{HS} & Time after Shutdown			
T_{HS}, °F *	Time after Shutdown, Days		
	5	10	15
50	T(5,50)	T(10,50)	T(15,50)
60	T(5,60)	T(10,60)	T(15,60)
70	T(5,70)	T(10,70)	T(15,70)
80	T(5,80)	T(10,80)	T(15,80)

* Each heat sink temperature (T_{HS}) shown corresponds to a refueling pool inlet temperature, (T_{IN}) for a given heat load on HX1. Again, illustrative values are used to show the process. As shown, a heat sink temperature of 50°F corresponds to a refueling pool inlet temperature of 70°F (Matrix I) and T(5,50) here is the same as T(5, 70) from Matrix I, etc

Figure 5

Development of Limiting Ultimate Heat Sink Temperature (T_{HS}) vs. Time after Shutdown (TAS)

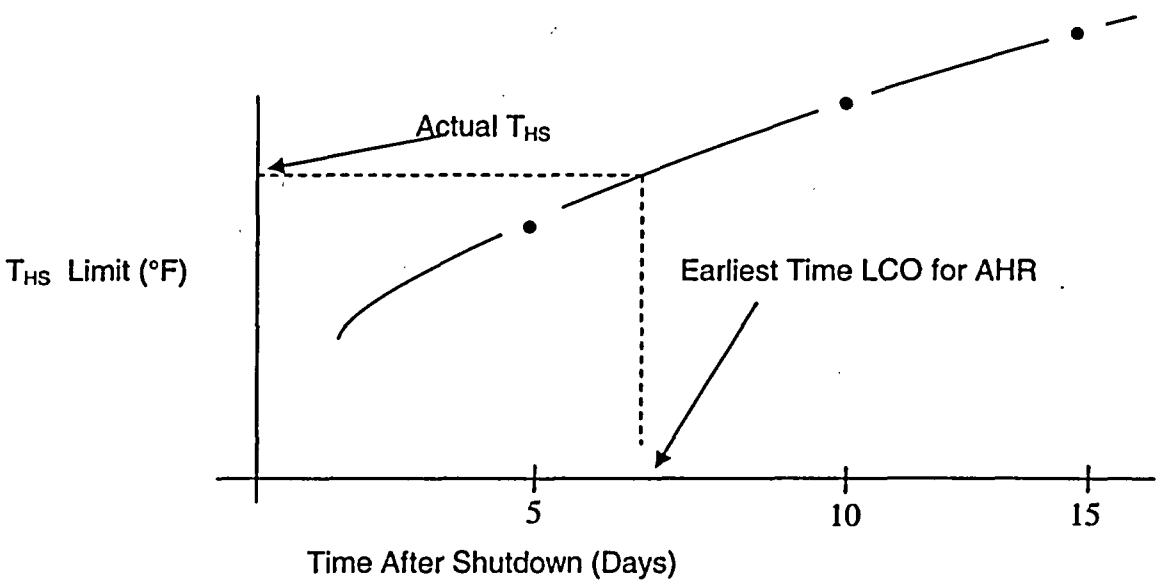
1. Select the most limiting (lowest) refueling pool temperature:
   - Traditional Plant Limit [140°F]
   - Refueling pool structural Limit (if any)
   - Mode 6 defining limit for RCS*
   - Containment habitability limit
   - Other plant limits (plant specific)

   * Possibly the temperature at the core outlet region, either measured or calculated.

2. Keeping time after shutdown (TAS) fixed, find Limiting T_{HS} corresponding to most limiting refueling pool temperature via Matrix II results.

3. Plot T_{HS} Limit vs. TAS.

4. Result: LCO earliest time to enter Alternate Heat Removal Alignment based on Actual T_{HS}.



APPENDIX A

ALGORITHM FOR NATURAL CONVECTION BETWEEN CORE AND REFUELING POOL

APPENDIX A

ALGORITHM FOR NATURAL CONVECTION BETWEEN CORE AND REFUELING POOL

A.1 MODEL

In Modes 5 and 6, forced convection provided by the shutdown cooling system is used to transport decay heat from the reactor core to the ultimate heat sink. In the absence of shutdown cooling flow during Mode 6 refueling operations with the refueling pool flooded, the reactor core decay heat is transported by natural circulation into the refueling pool water. The buoyancy force causing this natural circulation is driven by the density difference between the cooler, denser, fluid in the refueling pool and the hotter, less dense, flow through the core. Interaction between the natural circulation flow through the core with the circulating currents in the refueling pool results in a variation of fluid temperatures and velocities within the refueling pool. Properties controlling the natural convection from the reactor to the refueling pool as well as natural convection and evaporation from the free surface are primarily functions of temperature.

The model described in this Appendix has been developed to calculate the natural convection flow between the core and refueling pool that occurs during Mode 6 refueling conditions when the shutdown cooling system is not in operation. This model divides the reactor vessel and refueling pool into a series of control volumes that describe the upper guide structure, core and refueling pool, Figure A-1. Mass flow rates and inlet temperatures are prescribed for the alternate heat removal flow path. Conservation of mass, momentum and energy for these control volumes are solved to predict the mass flow rate between the reactor vessel and refueling pool. Temperatures are calculated for the refueling pool, the flow into and out of the pool, and the flow rate through the alternate heat removal alignment. The model also considers the heat lost at the pool surface due to natural convection and evaporation from the free surface. Dependent and independent variables are defined in Table A-1.

The flows into and out of the control volumes are assumed one-dimensional. However, the natural convection flow being driven by the temperature difference between the core and refueling pool is allowed to vary with time. This heat storage is accounted for in the mass of coolant in the pool as well as the coolant and structural masses for the upper guide structure and the core. Without active heat removal provided by the alternate heat removal alignment, the temperature of the refueling pool would continue to increase until the boiling point is reached. With active heat removal, steady state temperatures are eventually reached for core, pool and outlet flow.

The geometry of the pool results in regions where the cooler fluid near the bottom of the pool does not fully mix with the core flow. This is modeled by defining a mixing coefficient, ε_{mix}, which is defined as the ratio of the effective mass of coolant in the refueling pool that mixes with the reactor vessel flow to the total mass of coolant in the refueling pool. Therefore, the

mixing coefficient is the effective fraction of the pool water that participates in the core-to-pool flow process.

$$\varepsilon_{mix} = M/M_{refueling\ pool}$$

The effective mass is determined by engineering judgment from the temperature and velocity distributions in the computational fluid dynamics model used to address the refueling pool. The flows between the core and the fraction of the mass of fluid in the refueling pool, defined by the value ε_{mix}, which participates in the fluid transfer, are assumed to be fully mixed. Analysis shows the majority of the refueling pool inventory mixes with the natural convection flow from the core, resulting in a value for the mixing coefficient of about 0.90.

In addition, not all the flow from the alternate cooling path mixes with the natural convection driven flow from the core. This is accounted for by defining a bypass fraction, defined as the ratio of the flow bypassing the core plume flow to the total pumped alternate heat removal flow, or:

$$\varepsilon_{bypass} = m_{bypass\ flow} / m_{AHR\ flow}$$

The value of the bypass coefficient is determined from the computational fluid dynamics model. Analysis shows that essentially all of the alternate heat removal cooling flow injected into the refueling pool mixes with the natural circulation plume above the vessel, resulting in a bypass coefficient close to zero.

A.2 ALGORITHM

The solution algorithm solves for the core exit temperature, T_4, and the pool temperature, T_6, for each time step, $t_{n+1} = t_n + \Delta t$. The algorithm iterates on core exit temperature at each time step, with the following basic steps;

- Select Q_{core}
- Assume T_4 ($\equiv T_{out\ of\ core}$) > T_6 ($\equiv T_{pool} \equiv T_{into\ core}$) = T_1
- Solve for ρ (T_4)
- Solve for $\dot{m}_{core}$
- Solve for new T_4 ($\equiv T_{new\ out\ of\ core,\ new}$)
- Iterate until $T_{core\ new}$ minus $T_{core\ old}$ is within the convergence criteria (0.10ºF)
- Solve for new pool temperature, $T_{6,\ new}$

This algorithm, Figure A-2, is evaluated for each time step until a steady state or until the saturation temperature is reached, $T_4 = T_{core\ new} = T_{sat}$.

Values for the independent variables for CCNPP Units 1 or 2 are listed in Table A-2. Sample cases for four combinations of shutdown cooling and alternate heat removal flow are listed in Table A-3. The upper guide structure has been removed in all cases. Thus, values of structural mass and loss factors for the upper guide structure are taken as zero. Selection of

values for the time step (15 seconds) and convergence criteria (0.10ºF) are based on a convergence study. Output parameters are defined in Table A-4. Sample results are shown in Table A-5.

Results for average refueling pool temperatures and natural circulation flow are shown in Figures A-3 and A-4. Case 1 represents normal alignment for active shutdown cooling. In Case 2, both the alternate heat removal and shutdown cooling are active, resulting in the lowest values of refueling pool temperature. Case 3 is for alternate heat removal alone. The refueling pool temperatures remain below saturation in all cases. Case 4, with both shutdown cooling and alternate heat removal flow secured, represents the condition for no active cooling of the refueling pool.

With shutdown cooling flow in operation, the flow rate between the core and refueling pool due to natural circulation is approximately 2000 gpm; with shutdown cooling flow secured this natural circulation flow rate increases to approximately 4000 gpm as shown on Figure A-4. These flow rates are driven by the temperature difference between the core and refueling pool. Cases 1 and 2, where shutdown cooling is active, have lower flows and lower temperature differences. Case 4, with no forced cooling flow, has the largest natural circulation flow through the core and the largest values of temperature difference.

Table A-1
Definition of Variables

ANALYSIS	DEFINITION	QBASIC	UNITS
T_1	UGS inlet temperature	T_{pnew}	°F
T_2	Core inlet temperature	T_{pnew}	°F
T_4	Core outlet temperature	T_{cnew}	°F
T_5	UGS outlet temperature	T_{cnew}	°F
T_6	Refueling pool temperature	T_p	°F
T_7	SFP flow inlet temperature	T_{pin}	°F
T_8	SFP flow outlet temperature	T_{pout}	°F
T_9	SDC flow inlet temperature	T_{sdcin}	°F
T_{10}	SDC flow outlet temperature	T_{cnew}	°F
m_{core}	Core flow due to natural convection	m_{core}	lbm/sec
m_7	SFP flow rate	m_{pdot}	lbm/sec
m_{sdc}	SDC flow rate	m_{sdc}	lbm/sec
M_{24}	Mass of water & metal in the core	M_{cf} ,M_{cm}	lbm
M_{16}	Mass of water & metal in the UGS	M_{ugsf} M_{ugsm}	lbm
M_6	Mass of water in the refueling pool	M_p	lbm
P_{amb}	Containment pressure	P_c	psia
T_{amb}	Containment temperature	T_c	°F
Q_{fuel}	Decay heat	Q_c	btu/sec
Q_{surf}	Heat loss at pool surface due to natural convection and evaporation	$Q_{pnc+pevap}$	btu/sec
Δt	Time step	Δt	sec
ε_{bypass}	Alternate heat removal cooling flow bypass coefficient	ε_{bypass}	Note 1
ε_{mix}	Refueling pool mixing coefficient	ε_{mix}	Note 2

Notes:

1 No bypass = 0, all bypassed = 1
2 No mixing = 0, complete mixing = 1

Table A-2
Input for CCNPP Units 1 & 2

COMPONENT	PARAMETER	SYMBOL	VALUE	UNITS	NOTES*
Containment	Pressure	P_{amb}	14.7	psia	1
	Ambient Temp	T_{amb}	75	°F	1
Refueling Pool	Water mass	Mf1	3084708	lbm	
	Water depth	L1	23	ft	
	Free surface	A_{surf}	1750	ft^2	
	Wetted Perimeter	P_{wet}	190	ft	
	Equiv Length	L_{eq}	9.21	ft	2
	SFP flow rate	Q_{sfp}	-	gpm	Case dependent
	SFP inlet Temp	T_{sfpin}	-	°F	Case dependent
	Mixing Coefficient	$0 < \varepsilon_{mix} \leq 1$	0.90	-	
	Natural Conv		> 0	-	> 0 = yes
	Evaporation		> 0	-	>0 = yes
	Bypass Coefficient	$0 < \varepsilon_{bypass} \leq 1$	0	-	
	Initial Temp.	T_{rfpl}	$T \geq T_{amb}$	°F	Case Dependent
UGS	Metal Mass	Mm2	0	lbm	3
	Water Mass	Mf2	0	lbm	3
	Flow Area	A2	0.9565	ft^2	3
	Height	L2	13.375	ft	
	Loss Factor	K2	2.173	ft	3, 5
Core	Metal Mass	Mm3	303800	lbm	
	Water Mass	Mf3	46488	lbm	
	Flow Area	A3	53.46	ft^2	
	Height	L3	12.917	ft	
	Loss Factor	K3	12.328	-	
	SDC flow rate	Q_{sdc}	0, 3000	gpm	Case dependent
	SDC inlet Temp	T_{sdcin}	75	°F	Case dependent
	Thermal Load	Q/Q_o	0.20	%	4, 8
Calculations	Time Step	Δt	< 15	Seconds	6
	Maximum Time	t_{max}	-	Minutes	
	Temp error	ΔT	< 0.5	°F	6
	Print	NPRT	> 0	print output	
	Print per time	$< N_{max}$	-		7
	Plot	NPLT	> 0	to .txt file	
	Plot per time	$<N_{max}$	-		7

* See Table A-2 NOTES next page.

Notes for Table A-2
Input for CCNPP Units 1 & 2

Table A-2 Notes	
1	P_{amb} used in calculation of subcooled boiling temperature
2	$L_{eq} = A_{surface}$ / Wetted Perimeter
3	UGS removed; Loss factor & Area included for information only
4	$Q_o = 2754 \times 10^6$ watts-thermal = 9399×10^6 btu/hr
5	K= 6787 when based on core flow area of 53.46 ft^2
6	Number of time steps = $t_{max} * 60 / \Delta t = N_{max}$
7	Recommended values based on convergence study (0.10ºF)
8	0.20% selected for test cases.

Table A-3
Sample Case Input Listing

Cases	SDC		SFP		RFP	Containment
	Q_{sdc}, gpm	T_{sdcin}, °F	Q_{sfp}, gpm	T_{sfpin}, °F	T_{sfpi}, °F	T_{amb}, °F
Case 1	3000	75	0	NA	75	75
Case 2	3000	75	1200	75	75	75
Case 3	0	NA	1200	75	75	75
Case 4	0	75	0	75	75	75

Q_{sdc} Shutdown Cooling System flow
T_{sdcin} Shutdown Cooling System inlet temperature
Q_{sfp} Spent Fuel Pool flow
T_{sfpin} Spent Fuel Pool inlet temperature
T_{sfpi} Initial Refueling Pool temperature
T_{amb} Containment ambient temperature

Table A-4
Output Parameters

PARAMETERS	VAR[A]	DEFINITION
As functions of Time		
Tcore (°F)	T_4	Core outlet Temperature
Tpool (°F)	T_6	Refueling Pool Temperature
Core (gpm)	$\dot{Q}$	Natural Circulation Flow Rate
Tpumpo (°F)	T_8	Spent Fuel Pool Outlet Temperature
Tavgc (°F)	$T_4 + T_8$	0.50 x (Tcore-in + Tcore-out)
Error Q(~)		
At the last time step		
Core Outlet Temperature (°F)	T_4	Core Outlet Temperature
Subcooled Boiling Temperature (°F)	T_{4SC}	Tsat = f (Pressure at top of core)
Pool Bulk Temperature (°F)	T_6	Refueling Pool Temperature
Surface Heat Loss[NC+Evap] (Btu)	Qsurf	Surface Heat Loss
Surface Natural Convection (Btu)	Qnc	Heat Loss due to Natural Convection
Evaporation (lbm)	Mevap	Amount of Surface Evaporation
Surface Evaporation (Btu)	Qevap	Heat Loss due to Evaporation
Spent Fuel Pool Pump Heat Load (Btu)	Qsfp	Total SFP Heat Removal
SDC Heat Load (Btu)	Q_1	Total SDC Heat Removal
Core Convection Heat Load (Btu)	Q_2	Convection Heat Transfer Core-RFP[1]
Qcoretotal = Qcstored + Qsdctot + Qcnctot (Btu)	Q_3	Total Heat Transfer from Core[1]
Qpooltotal = Qpstored + Qsfpumptot + Qnctotal(Btu)	Q_4	Total Heat Transfer from the RFP[1]
Decay Heat = Qd * Time (Btu)	Q_5	Total Heat Generation from Core[1]
Heat Balance: (Qcore - Qdecay) / Qdecay (%)	-	Change in Core Heat = Decay Heat
Heat Balance: (Qpool - Qnacore) / Qnccore (%)	-	Change in Heat to RFP = Core Convection
Time Constant (minutes)	τ_{rfp}	Time Constant for RFP Heat Up[2]

[A] Variable in the analysis, see Table A-1.

Note 1: The following heat balances must be satisfied:
SDC + Core Convection:
$Q_1 + Q_2 = Q_5$;
Core convection = Decay Heat,
$Q_2 = Q_4$.

Note 2: Time constant = $M_{RFP}/m_{natural\ circulation}$

Table A-5

Sample Results

DECAY HEAT REMOVAL BY NATURAL & FORCED CIRCULATION
Version CCNPP2G; CEOG Task 1153
DATE= 07-11-2001
TIME= 15:15:07
RUN ID= 3475611

INPUT PARAMETERS;
CASE NUMBER = 1
PLANT; Calvert Cliffs
POOL; Mass = 3084708, Mixing = 1, Depth(ft) = 23
Natural Convection from Pool Surface = 1
Evaporation from Pool Surface = 1
Upper Guide Structure; Mass/Fluid = 0, Metal = 0, Depth(ft) = 13.375
Flow Area(ft^2) = 0.9565, Loss Factor = 0
CORE; Mass/Fluid = 46488, Metal = 303800, Length(ft) = 12.917
Flow Area(ft^2) = 53.46, Loss Factor = 12.328
Decay Heat; 0.2% of 2754 MWt(Btu/hr) = 1.879881E+07
SFP ; Volume Flow (gpm) = 0, Tin (F) = 75, By-pass = 0
SDC ; Volume Flow (gpm) = 3000, Tin (F) = 75
CONT; Pamb (psia) = 14.7, Tamb (F) = 75
CALC PARAMETERS; Time step(sec) = 15, Tmax(min) = 720, Terr(F) = 0.5

OUTPUT VALUES;

Time(min)	Tcore(F)	Tpool(F)	Core(gpm)	Tpumpo(F)	Tavgc(F)	Error
Q(%)						
0.000	75.000	75.000	0.000	75.000	75.000	0.000
30.000	82.333	76.324	2583.512	76.334	79.328	0.000
60.000	82.978	77.499	2482.191	77.508	80.239	0.000
90.000	83.535	78.529	2385.125	78.537	81.032	0.000
120.000	84.017	79.435	2292.467	79.442	81.726	0.000
150.000	84.433	80.232	2203.765	80.238	82.332	0.000
180.000	84.795	80.935	2119.723	80.940	82.865	0.000
210.000	85.109	81.556	2039.614	81.561	83.332	0.000
240.000	85.382	82.107	1963.465	82.111	83.744	0.000
270.000	85.620	82.596	1891.286	82.600	84.108	0.000
300.000	85.828	83.031	1822.575	83.035	84.430	0.000
330.000	86.010	83.419	1757.233	83.422	84.715	0.000
360.000	86.170	83.766	1695.651	83.769	84.968	0.000
390.000	86.310	84.077	1636.627	84.079	85.194	0.000
420.000	86.434	84.355	1581.009	84.357	85.395	0.000
450.000	86.543	84.606	1528.008	84.607	85.574	-0.000
480.000	86.640	84.831	1477.607	84.833	85.735	-0.001
510.000	86.725	85.035	1429.769	85.036	85.880	-0.001
540.000	86.801	85.219	1384.441	85.220	86.010	-0.002
570.000	86.868	85.385	1341.546	85.387	86.127	-0.002
600.000	86.928	85.537	1300.304	85.538	86.233	-0.002
630.000	86.982	85.674	1261.228	85.676	86.328	-0.003
660.000	87.030	85.800	1223.800	85.801	86.415	-0.003
690.000	87.073	85.914	1188.551	85.915	86.493	-0.003
720.000	87.111	86.018	1154.527	86.019	86.565	-0.004

Core Outlet Temperature = 87.11127 (°F) at Time = 720.25 (minutes)
Subcooled Boiling Temperature = 251.1587 (°F)
Pool Bulk Temperature = 86.01913 (°F)
Surface Heat Loss [NC + Evap] (Btu) = 89211.67
Surface Natural Convection (Btu) = 88943.32
Evaporation (lbm) = 0.2565402
Surface Evaporation (Btu) = 268.3284
SFPump Heat Load (Btu) = 0.0
SDC Heat Load (Btu) = 1.912908E+08
CORE Convection Heat Load (Btu) = 3.415335E+07
Qcoretotal = Qcstored + Qsdctot + Qcnctot (Btu) = 2.256724E+08
Qpooltotal = Qpstored + Qsfpumptot + Qnctotal (Btu) = 3.408258E+07
Decay Heat = Qd * Time (Btu) = 2.25664E+08
Heat Balance: (Qcore - Qdecay) / Qdecay (%) = - 3.708168E-03
Heat Balance: (Qpool - Qnacore) / Qnccore (%) = 0.20723
Time Constant (minutes) = 321.2215

Figure A-1
One-Dimensional Model of Core and Refueling pool

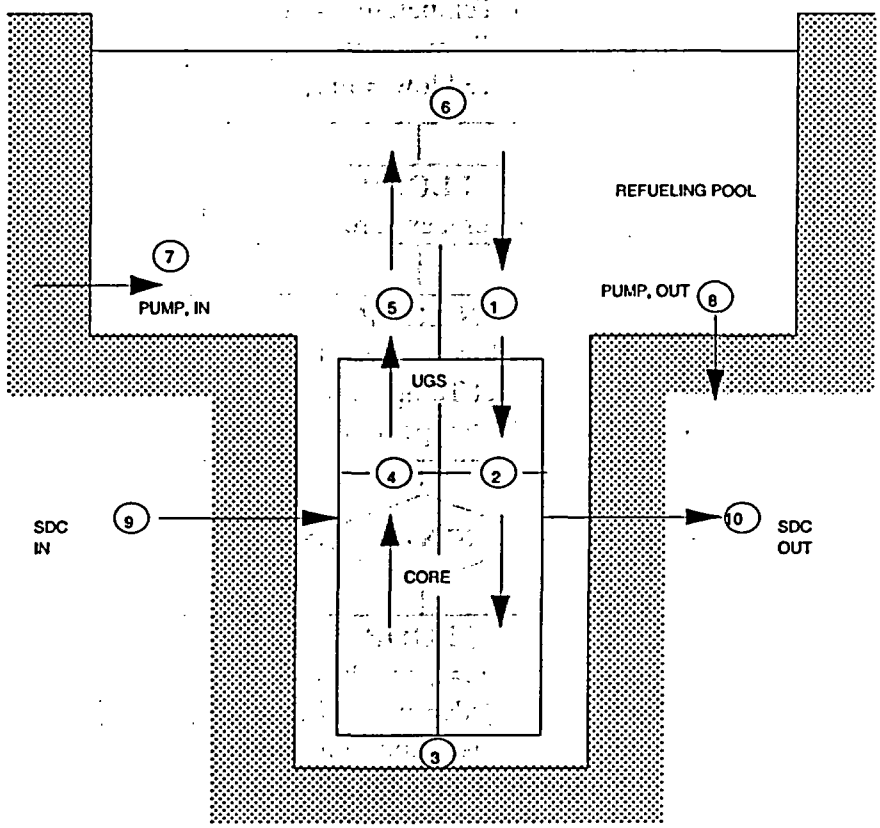


Figure A-2

Flow Chart for Algorithm

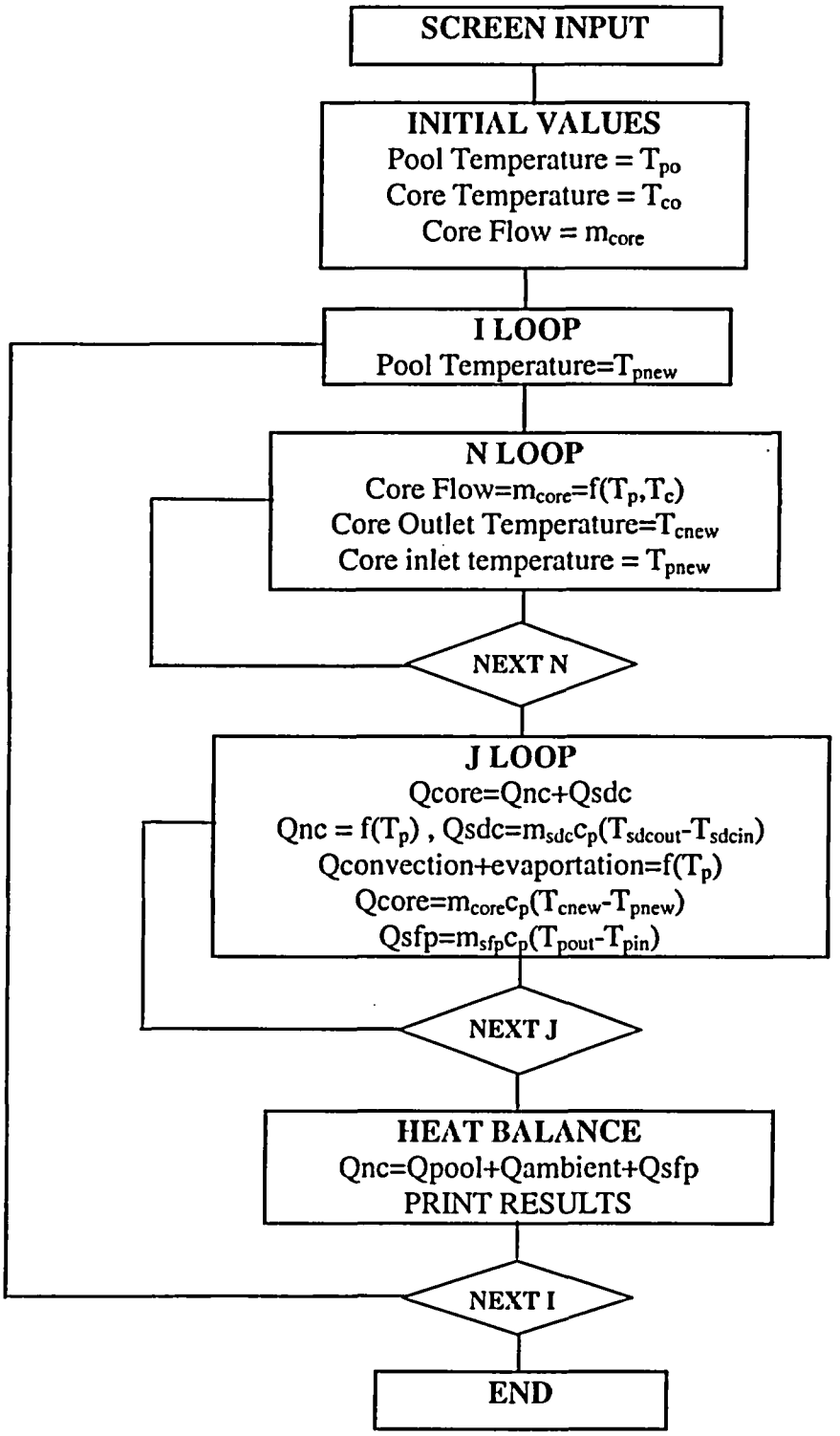


Figure A-3
Sample Cases: Average Refueling Pool Temperature

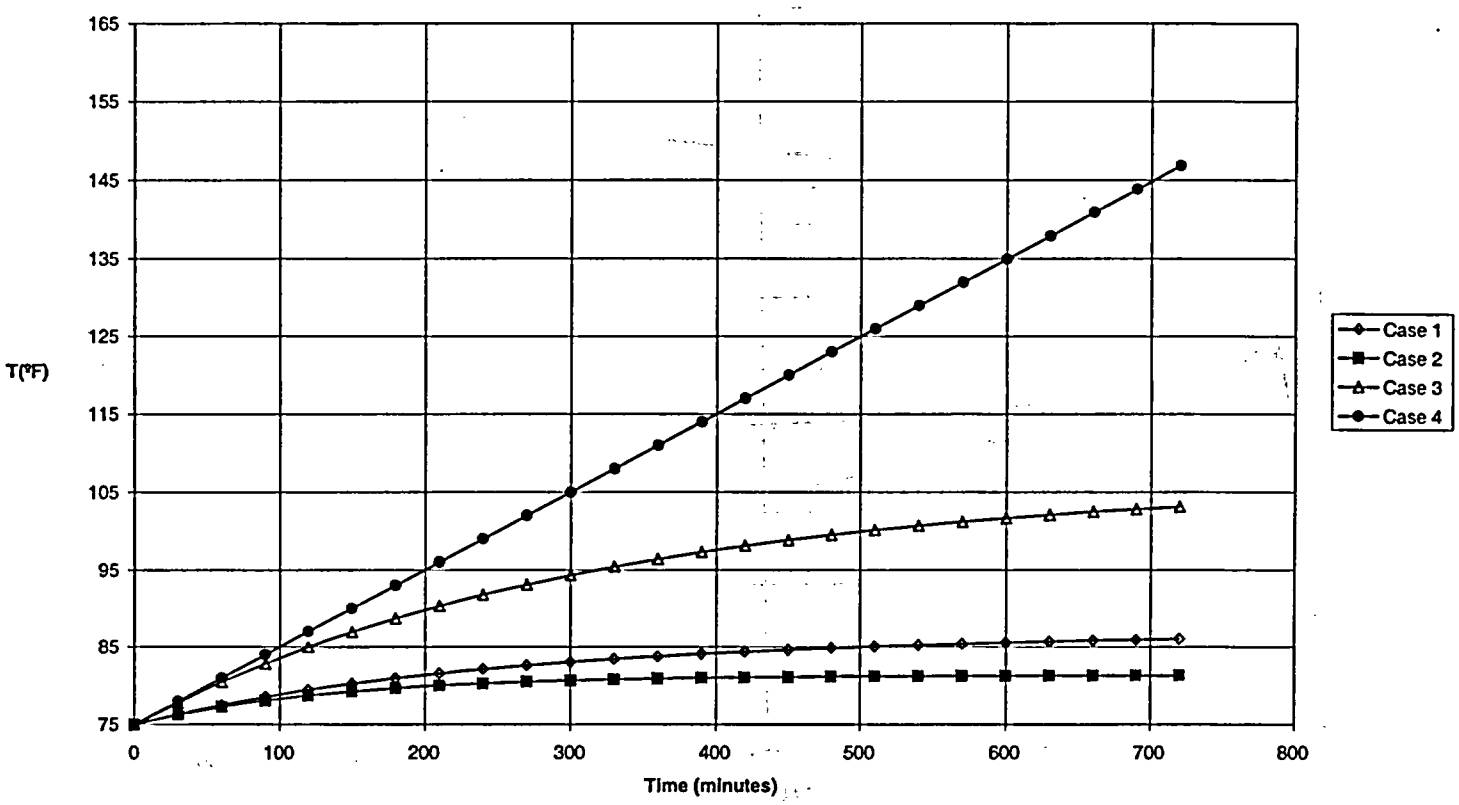
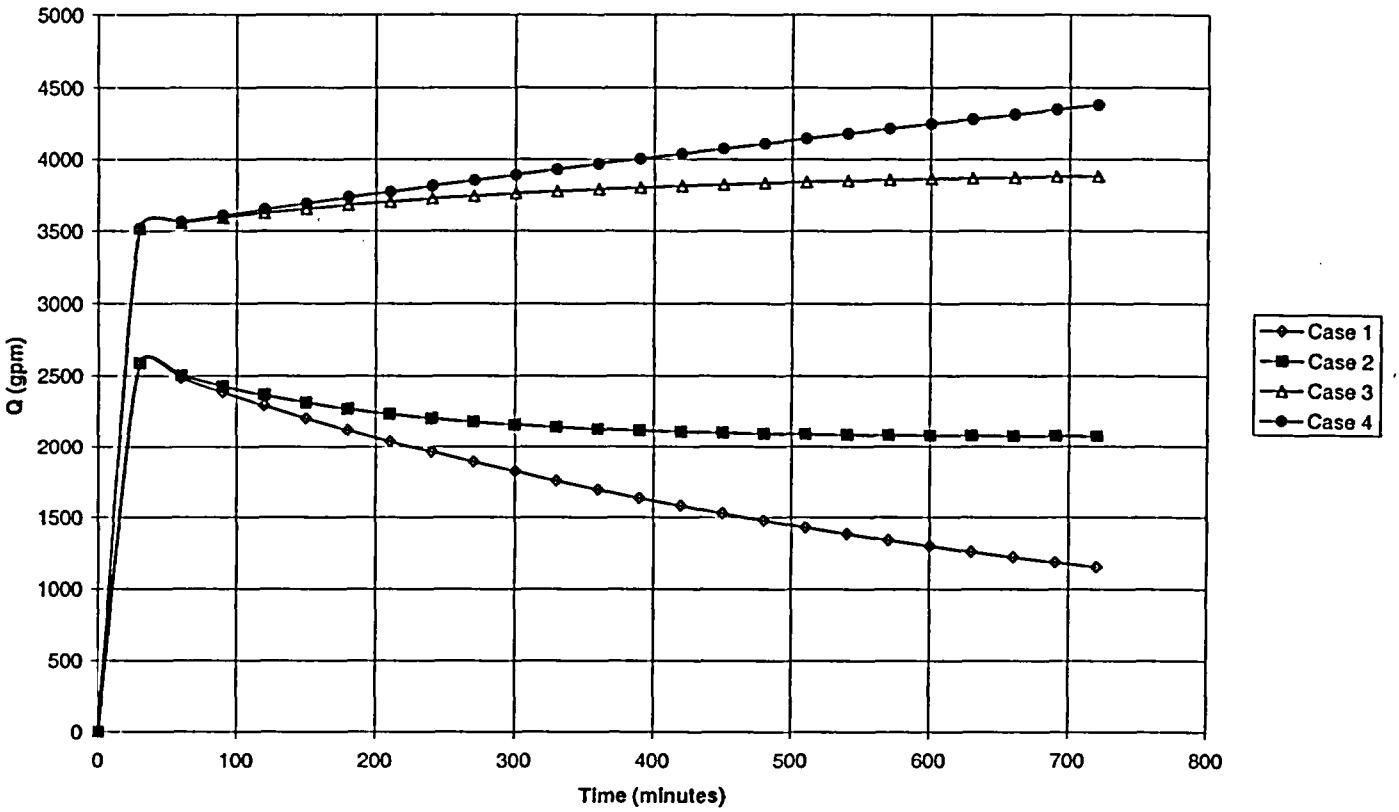


Figure A-4

Sample Cases: Natural Circulation Flow between Core and Refueling Pool



APPENDIX B

COMPARISON OF PREDICTIONS WITH TEST DATA

APPENDIX B

COMPARISON OF PREDICTIONS WITH TEST DATA

B.1 TEST DATA

Validation of the model developed in Appendix A is based on a comparison with data recorded at CCNPP Unit 2 during the March 2001 refueling outage. Under limited conditions, CCNPP units are permitted to use an alternate refueling pool cooling system during Mode 6 with the refueling pool flooded and with shutdown cooling secured. In this alternate cooling alignment a train of the spent fuel pool cooling system is manually aligned so that the spent fuel pool cooling pump takes suction from the refueling pool. After passing through the spent fuel pool cooling heat exchanger, the flow is directed back into the refueling pool. This flow is directed into the refueling pool through piping near the bottom of the pool (Figure B-1). The suction from the refueling pool to the spent fuel pool cooling line is through a drain in the bottom of the refueling pool, at the side of the pool opposite the inlet point.

Test data were recorded for two days during which the alternate pool cooling alignment was in use. Fluid temperatures in the refueling pool where recorded by thermocouples located at the reactor flange level, at mid-level in the pool, and close to the pool surface. Approximate locations of these thermocouples are noted in Figure B-2. Additional parameters recorded are listed in Table B-1.

The approximate time for initiation and securing of both shutdown cooling and refueling pool flows are listed in Table B-2. Measurements of flow rates and temperatures versus time, in days after shutdown (DAS) are shown in Figures B-3, B-4 and B-5.

Figure B-3 shows shutdown cooling flow rates, plus inlet (into the cold leg) and outlet (out of the hot leg) temperatures versus time. Note the reduction in shutdown cooling flow from 3000 gpm to 1500 gpm at about 6 days into the shutdown to facilitate flooding the refueling pool, and detensioning and removing the head. Once the head is removed, natural convection between the core and refueling pool starts. Thus predictions are only valid after the head is removed[2].

Figure B-4 gives alternate heat removal cooling system flow rates and temperatures into the refueling pool and out of the refueling pool. These data were taken about 17 to 20 days into the outage. As shown in this figure, both the shutdown cooling system and the alternate heat removal cooling system are activated near the start and end of the time period. This is to assure that the switchover into and out of the alternate alignment is successful.

Figure B-5 shows the average refueling pool temperatures at each of the three elevations. As expected, the fluid temperatures are highest at the reactor flange and decrease toward the pool surface.

[2] Heat removal via the SDC indicates a decrease of about 17% after removal of the head. This reduction is due to natural circulation flow between the core and refueling pool.

B.2 COMPARISON of PREDICTIONS with TEST DATA

Switching from the conventional shutdown cooling decay heat removal, both before and after the head is removed, followed by switching to the alternate decay heat removal are represented for the following cases:

Case 1: Reduce shutdown cooling flow for vessel head removal.

Case 2: Restore full shutdown cooling flow.

Case 3: Initiate alternate heat removal cooling flow, continue shutdown cooling flow.

Case 4: Secure shutdown cooling flow, continue alternate heat removal cooling flow.

Case 5: Secure alternate heat removal flow, restore shutdown cooling flow.

Temperatures and flow rates for these cases are listed in Tables B-3 and B-4. Predictions for shutdown cooling and spent fuel pool (alternate heat removal) outlet temperatures versus time, Figures B-6 and B-7, compare well with outage data. Time-averaged values of the shutdown cooling, spent fuel pool cooling (alternate heat removal) and refueling pool temperatures are compared in Table B-5. With the exception of Case 1, the predicted shutdown cooling and refueling pool temperatures are in reasonable agreement as shown in Figure B-8. The 10% difference in SDC predictions and data are related to uncertainties in decay heat values and initial refueling pool temperatures at the time the head is removed.

A comparison of predicted and measured average refueling pool temperatures is shown in Figure B-7. Experimental values are taken as the numerical average of the readings shown in Figure B-5. Agreement is good except for the initial portion where variations in the data are due to operator controlled changes in the SDC flow to reach an acceptable operating point.

Table B-1

Measured & Calculated Parameters based on CCNPP2 Data

MEASURED			CALCULATED
PARAMETER		DESCRIPTION	HEAT BALANCES
SFPin	T_{SFPI}	T-into the RFP	
SFPout	T_{SFPO}	T-out of the RFP	
SFPflow	M_{RFP}	Flow into the RFP	$Q_{RFP} = M_{RFP}C_P (T_{RFPO} - T_{RFPI})$
SWin	T_{SWI}	T-into SW-HX	
SWout	T_{SWO}	T-out of SW-HX	
SWflow	M_{SW}	Flow thru SW-HX	$Q_{SW} = M_{SW}C_P (T_{SWO} - T_{SWI})$
SDCout	T_{SDCI}	T-out of RV hot leg	
SDCin	T_{SDCO}	T-into RV cold leg	
SDCflow	M_{SDC}	Flow in SDC	$Q_{SDC} = M_{SDC}C_P (T_{SDCO} - T_{SDCI})$

Table B-2

Event Time Related to CNNP2 Outage

EVENT	DATE	TIME[a] (hr:min)	DAS (Days)	QDECAY (btu/hr)	DECAY HEAT[b] (%)	Refueling Pool Cooling Load
MODE 5	03/16/2001	23:55	0.000	2.264E+08	2.409%	Full Core
SDC start	03/19/2001	09:01	2.000	4.630E+07	0.493%	
HEAD removed	03/23/2001	04:30	5.750	3.089E+07	0.330%	
RFP start	04/03/2001	22:00	17.625	1.320E+07	0.140%	125 Assy
SDC secured	04/04/2001	13:00	18.208	1.303E+07	0.139%	
AHR steady-state	04/05/2001	00:00	18.715	1.290E+07	0.137%	
SDC restored[c]	04/07/2001	13:40	20.486	1.248E+07	0.133%	
AHR end data	04/07/2001	14:42	20.722	1.238E+07	0.132%	
RFP secured	04/08/2001	05:00	21.358	1.223E+07	0.130%	

a. Approximate times
b. Q_o = 9.399E+09 btu/hr
c. End of steady state period

Table B-3

Average Values Based on Experimental Data

CASE		TIME (hours)		TEMPERATURE (°F)					FLOW (gpm)		Qpower = 9.399E+09 (btu/hr)	
	Range	Tstart	Tend	SDC in	SDC out	SFP in	SFP out	RFP	Qsdc	Qsfp	Qdecay	%decay
1	Reduce SDC flow	0	11	73.58	102.90	NA	NA	NR	1521.87	0	2.034E+07	0.216%
2	Full SDC flow	11	285	92.01	102.73	NA	NA	NR	3071.05	0	1.572E+07	0.167%
3	SDC + AHR flow	285	298	99.00	103.30	92.03	96.78	101.30	3088.98	1195.65	1.313E+07	0.140%
4	AHR flow only	298	348	NA	NA	78.16	92.95	99.26	0	1194.23	1.276E+07	0.136%
5	SDC, AHR = 0	348	375	96.72	102.89	NA	NA	NR	0	0	1.231E+07	0.131%

NA = Not Applicable
NR = Not Recorded

Table B-4

Input for Algorithm Cases

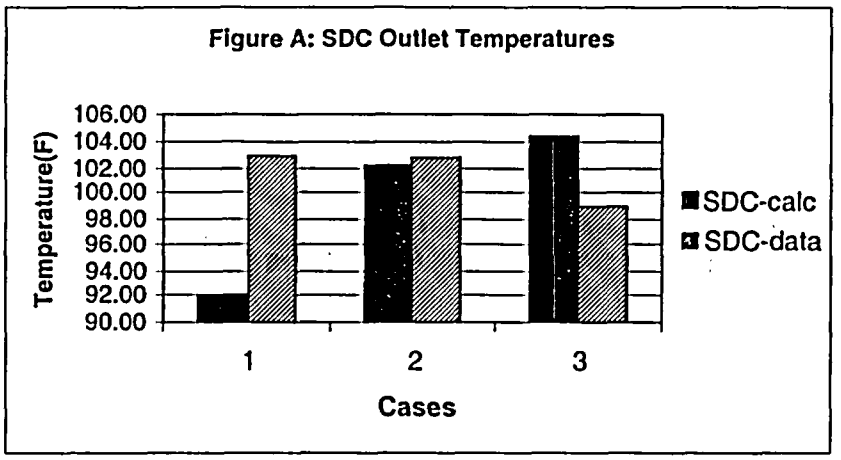
CASE		TIME (minutes)		TEMPERATURE (°F)			FLOW (gpm)		Decay Heat
	Range	ΔTime	Time	SDC In	SFP[3] In	RFPI	Qsdc	Qsfp[3]	(%)
1	Reduce SDC flow	660	660	73.58	NA	75	1521.87	0	0.216%
2	Full SDC flow	16440	17100	92.01	NA	92.3[1]	3071.05	0	0.167%
3	SDC + AHR flow	780	17880	99.00	92.03	102.03[1]	3088.98	1195.65	0.140%
4	AHR flow only	3000	20880	NA	78.16	100.25[1]	0	1194.23	0.136%
5	SDC, AHR = 0	1680[2]	NA	NA	NA	99.52[1]	0	0	0.136%

1. RFP average temperature taken from prior Case.
2. Time when RFP temperature reaches 212°F.
3. SFP In, Qsfp refer to AHR flow.

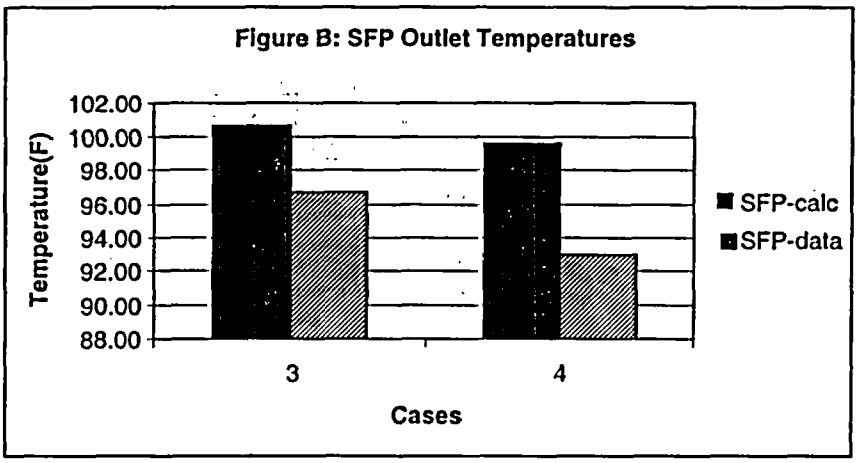
Table B-5

Comparison between Predictions and CCNPP2 Data for Average Temperatures

	Tsdc-outlet (°F)		Tsfp-outlet (°F)		Trfp-average (°F)	
CASE	CALC	DATA	CALC	DATA	CALC	DATA
1	91.98	102.84	NA	NA	NA	NR
2	102.14	102.74	NA	NA	NA	NR
3	104.39	99.00	100.59	96.78	100.59	101.07
4	NA	No Data	99.60	92.95	99.60	99.23
Ref:	Figure A (next page)		Figure B		Figure C	



Figures A, B and C correspond to data in Table B-5



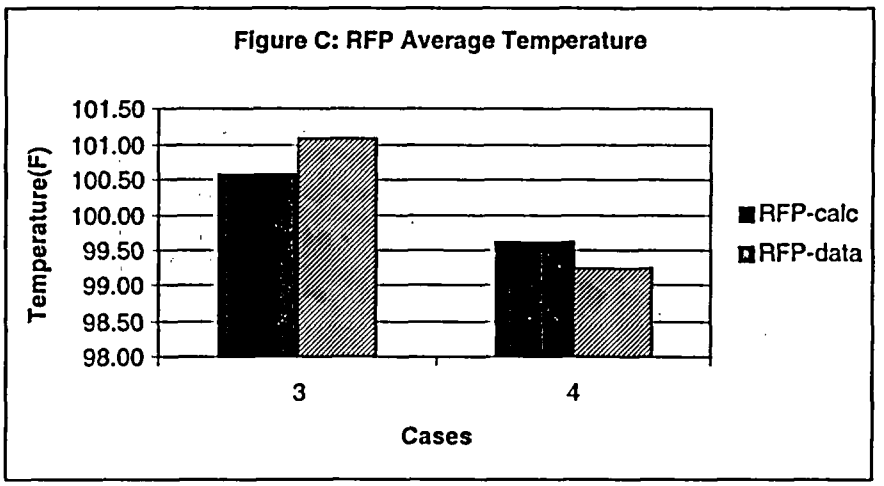


Figure B-1

CCNPP Unit 2 Outage Tests: Flow Alignments

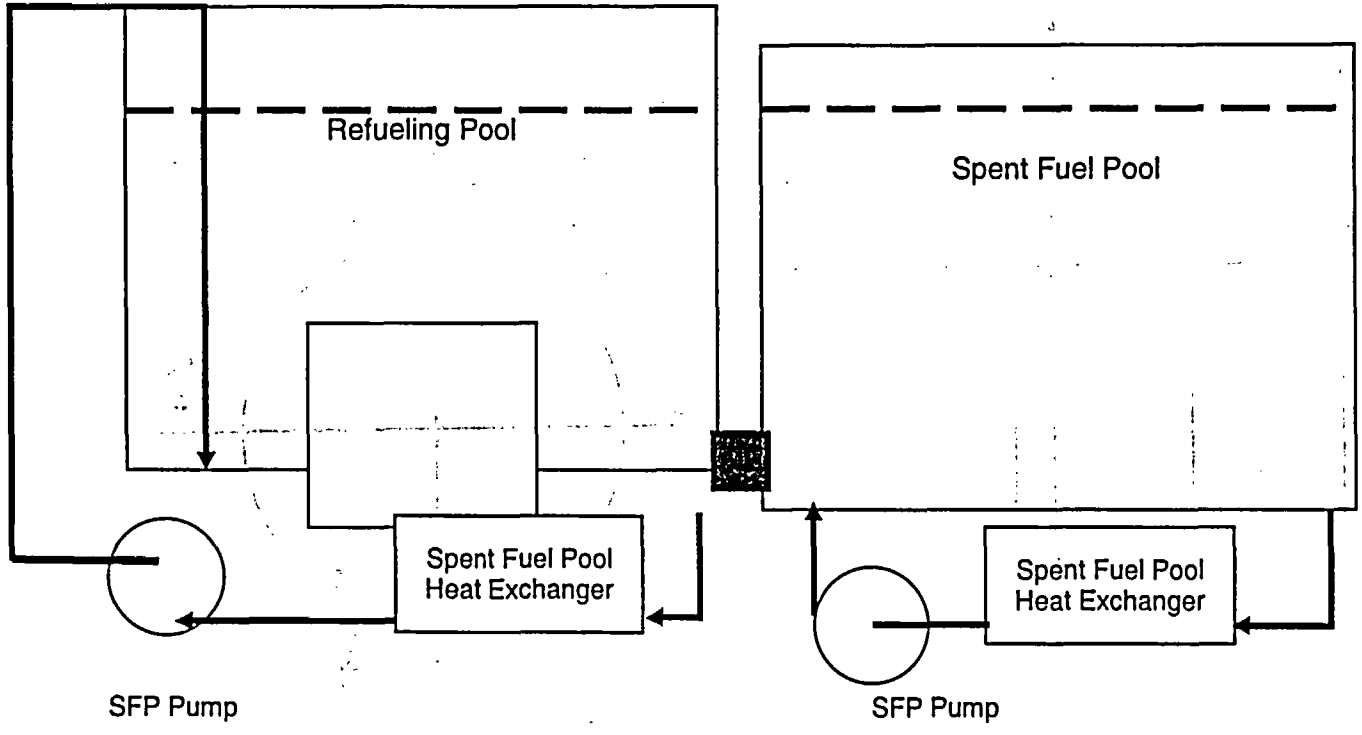


Figure B-2

CCNPP2 Outage Tests: Thermocouple Locations

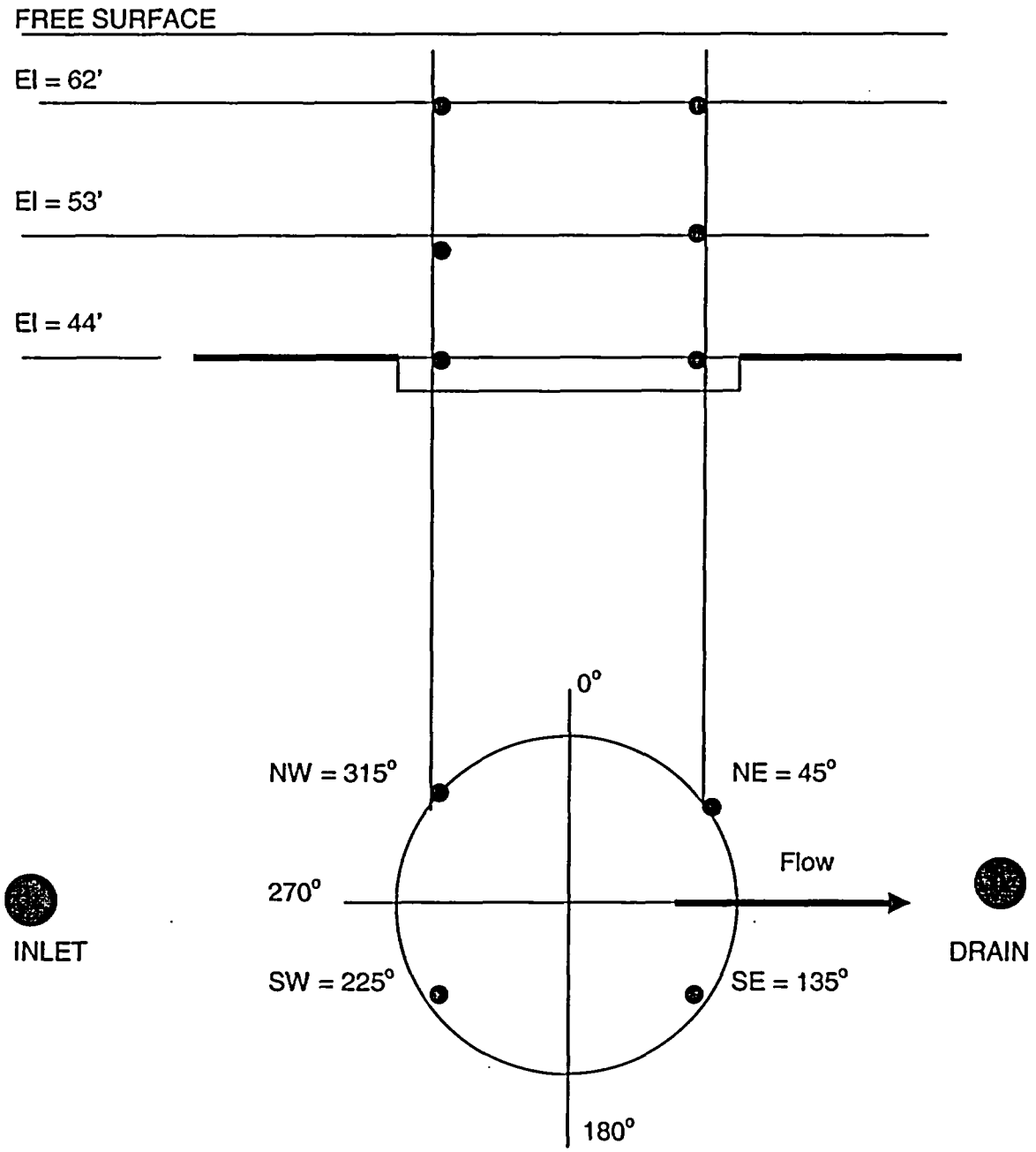


Figure B-3

CCNPP2 Outage Tests: SDC Flow Rate and Temperature vs. Time

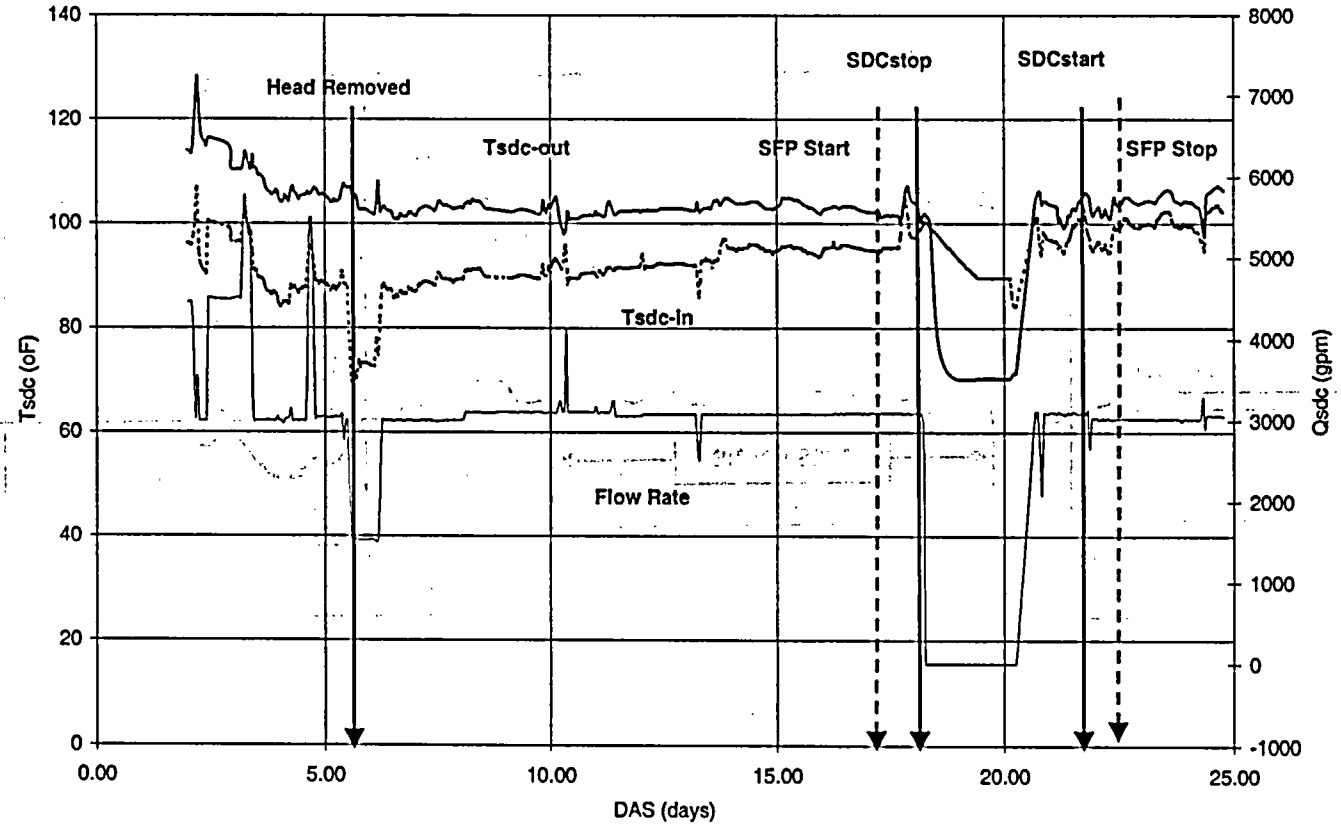


Figure B-4

CCNPP Unit 2 Outage Tests: Spent Fuel Pool Flow Rate and Temperature versus Time

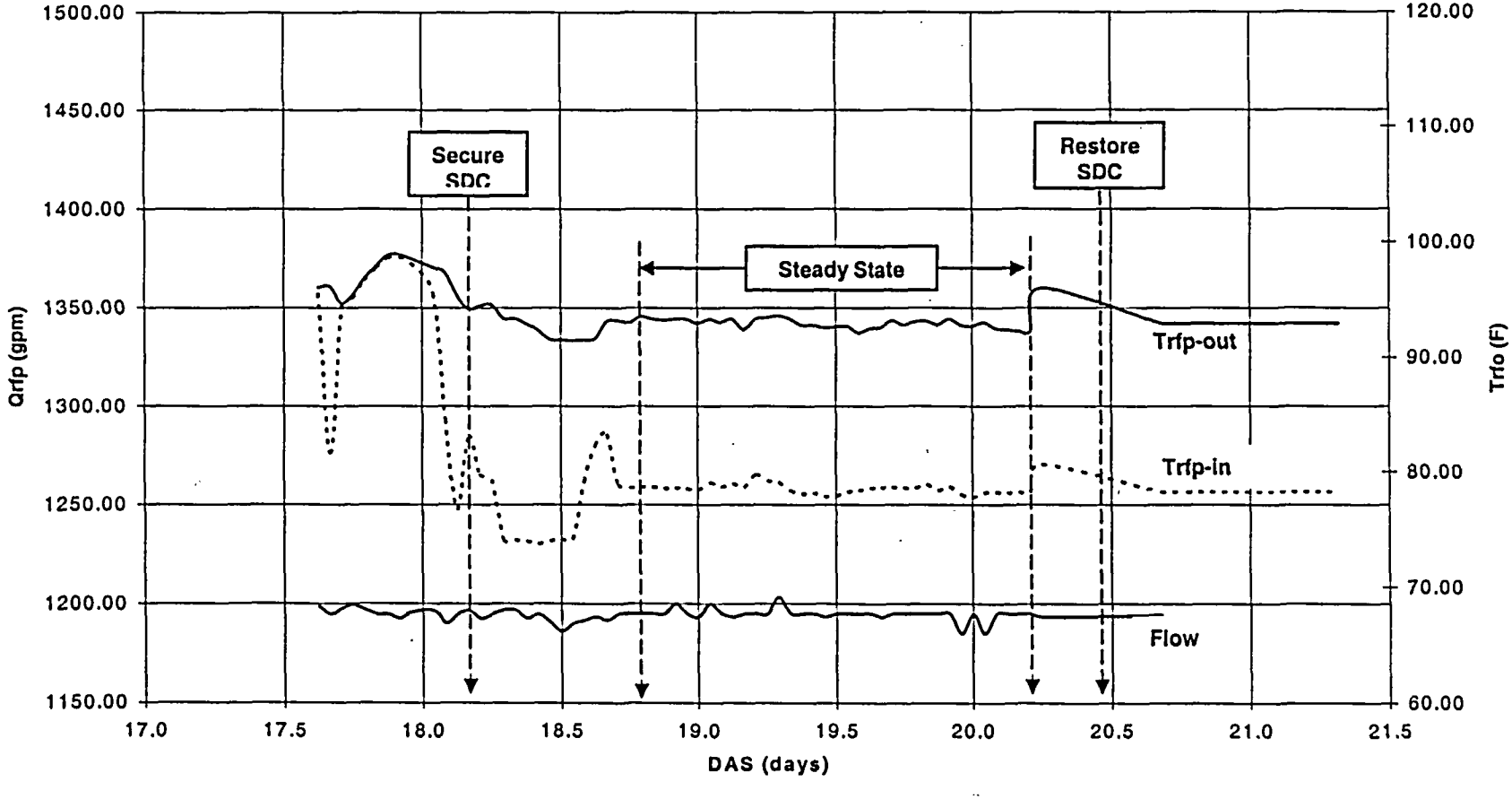
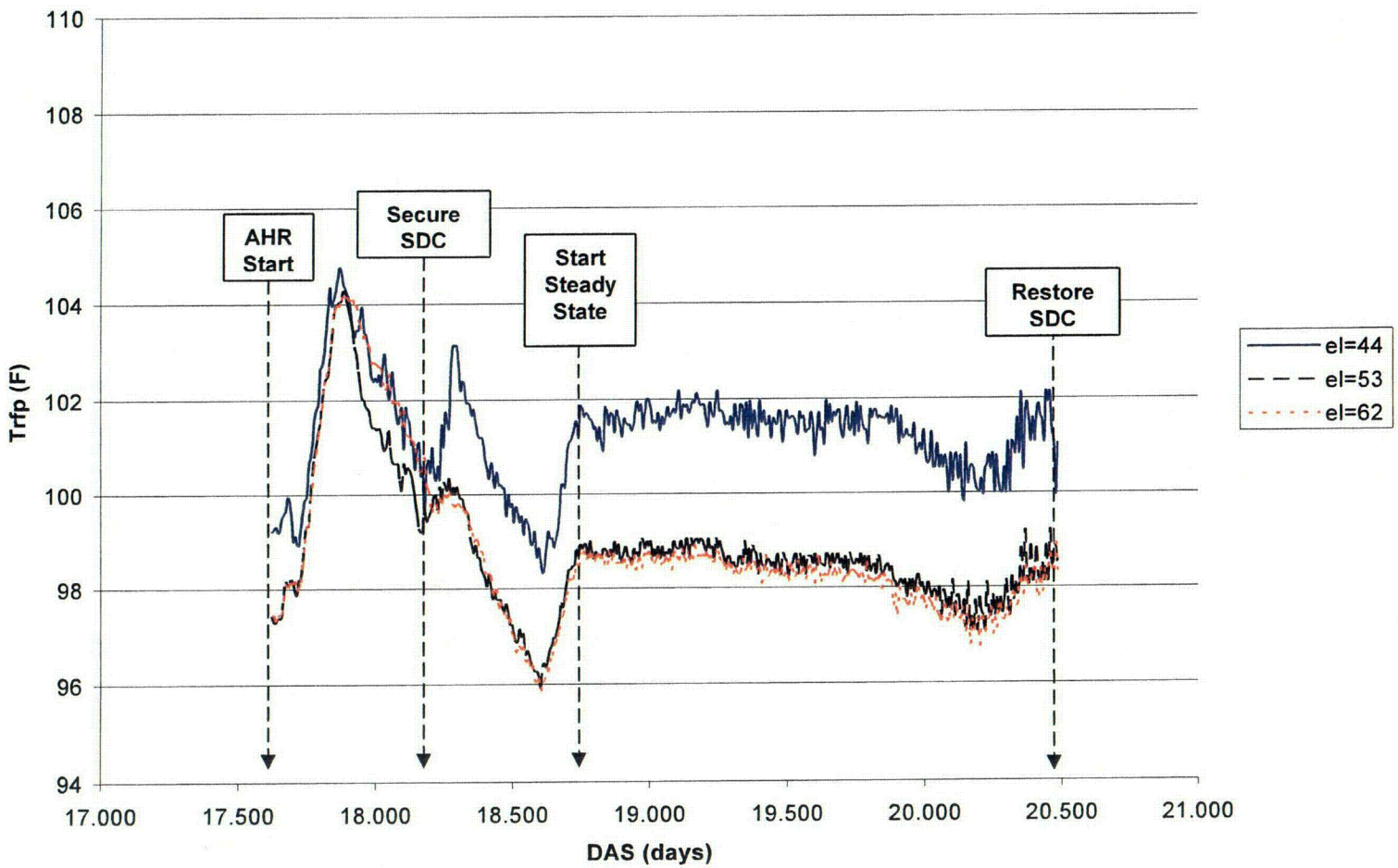


Figure B-5

CCNPP Unit 2 Outage Tests: Average Refueling Pool Temperatures versus Time



C01

Figure B-6

Predictions for Shutdown Cooling and Spent Fuel Pool Temperatures versus Time

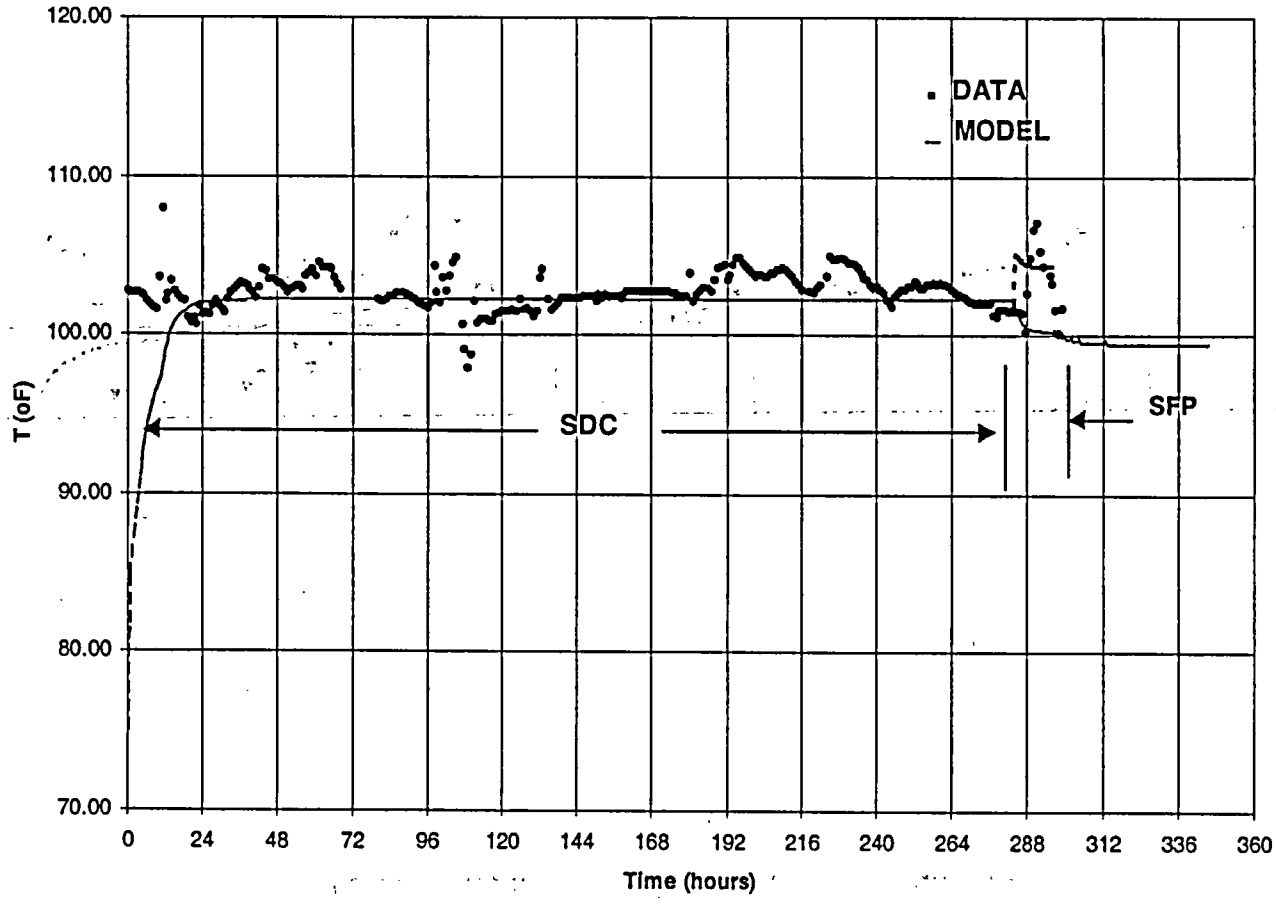


Figure B-7

Predictions of Refueling Pool Temperature versus Time

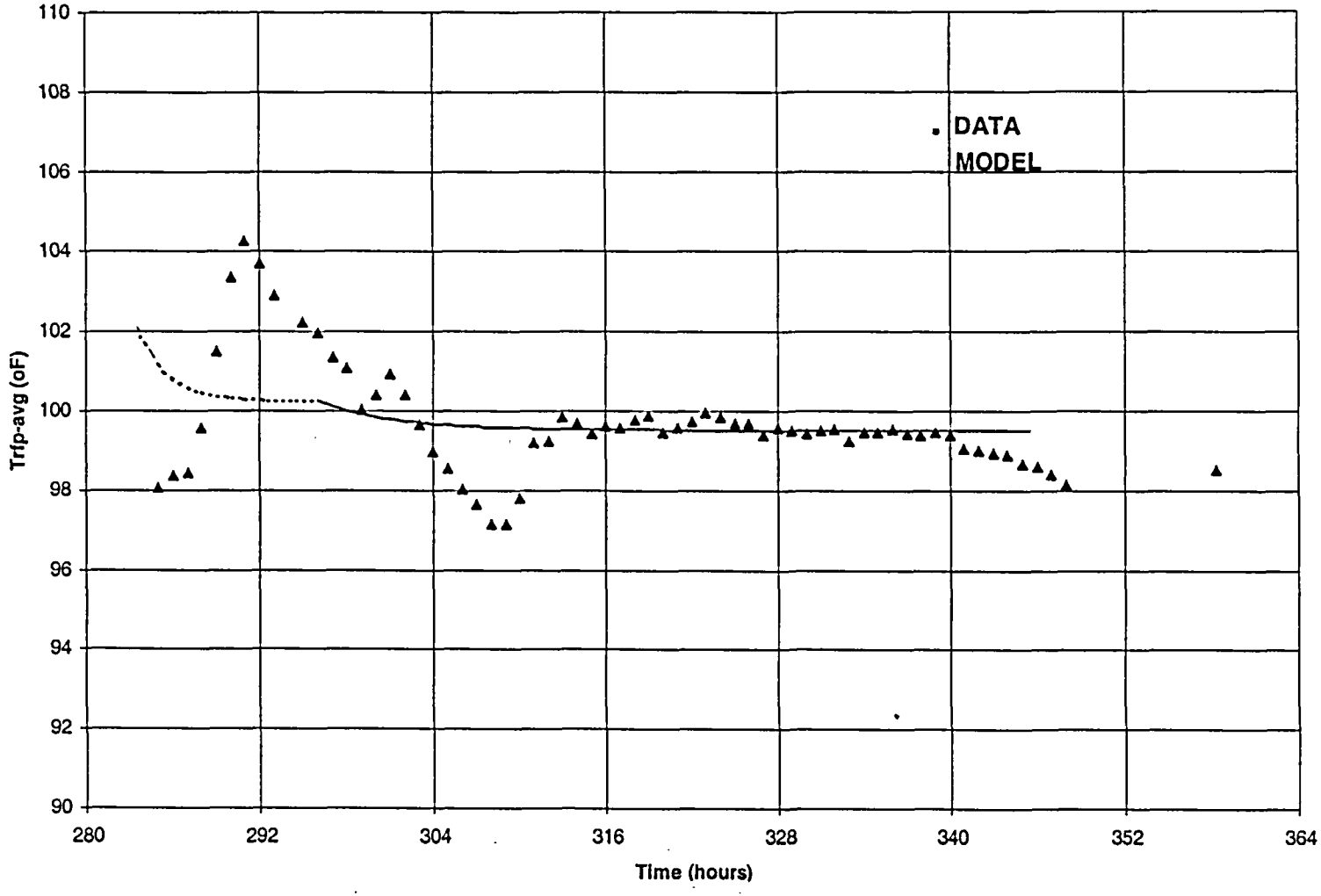
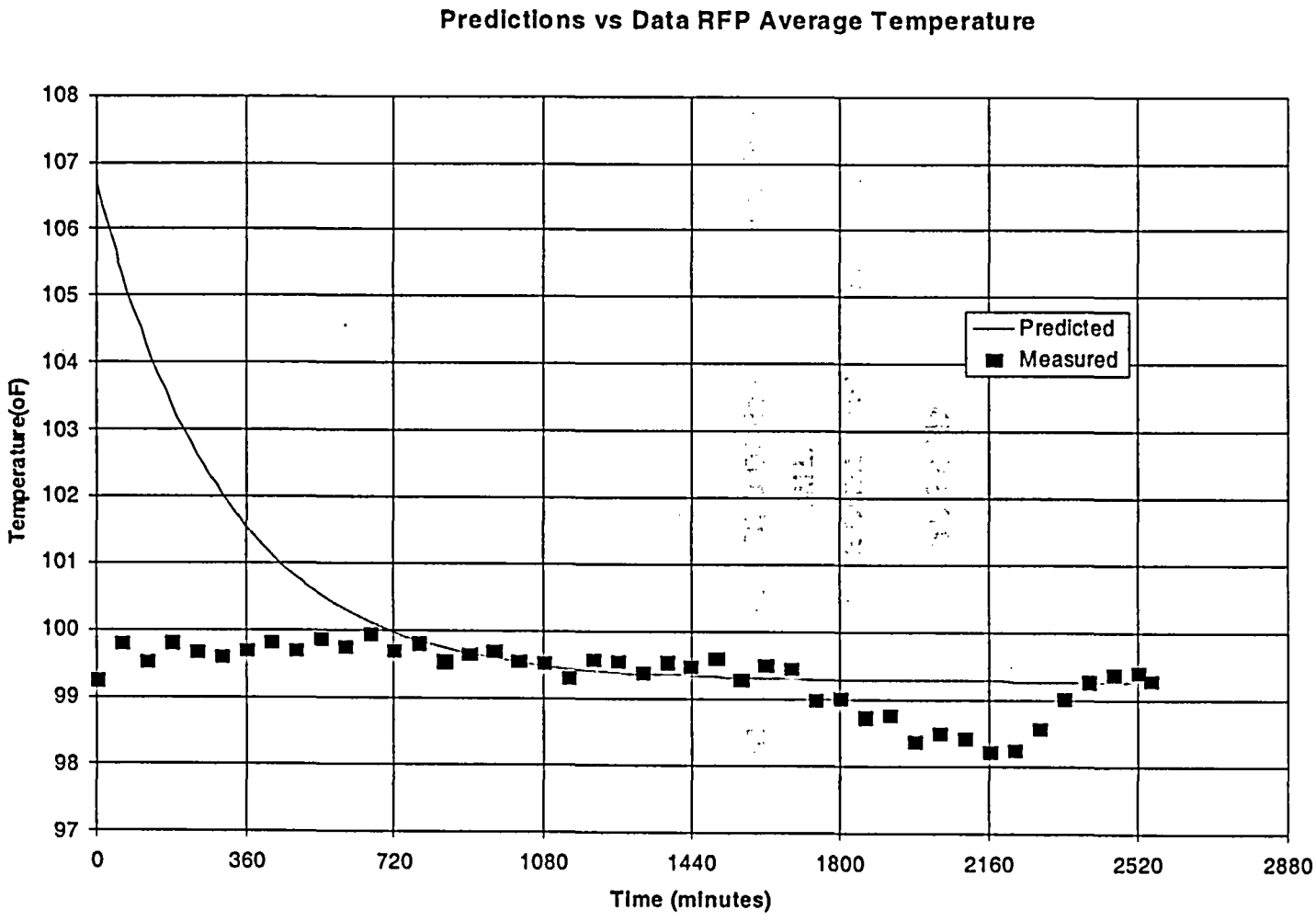


Figure B-8

CCNPP Unit-2 Outage Tests: Predictions and Data for Refueling Pool Temperatures



APPENDIX C

COMPARISON OF CCNPP UNIT 2 TEST DATA
WITH
COMPUTATIONAL FLUID DYNAMICS PREDICTIONS

APPENDIX C

COMPARISON OF DATA WITH COMPUTATIONAL FLUID DYNAMICS PREDICTIONS

This Appendix provides a comparison of CCNPP Unit 2 test data with predictions based on a computational fluid dynamic model of the refueling pool.

The geometry of the CFD model (Figure C-1) for the refueling water pool preserves the volumes of the refueling pool. Core flow rate and heat generation rate, from the lumped parameter model, are applied as boundary conditions.

Computational fluid dynamics computations based on a decay heat generation rate of 0.0946% predict a temperature difference between the refueling pool outlet and inlet of 15.0°F, approximately 1% above an average of the measured temperature difference of 14.82°F (Table C-1).

Refueling pool temperature data at different elevations above the reactor vessel flange indicates that the pool temperature decreases with elevation. This suggests that the hot plume from the core thermally mixes with the colder refueling pool water and cools as it rises to the top of the pool.

Computational fluid dynamics predictions of the refueling pool water temperatures at locations corresponding to the measurement points compare favorably with the measured temperatures, as shown in Table C-1. In general, computational fluid dynamics predictions are higher than measured values. The highest differences occur in the SE-NE quadrants (0° to 180°) due to a non-uniform distribution of the inlet (in the 180° to 270° quadrants) to outlet (in the 270° to 360° quadrants) over the reactor. (Refer to Figure B-2 for quadrant orientation.) Measurements being lower than predictions indicate a higher degree of mixing and a more uniform distribution of inlet flow than predicted by the computational fluid dynamics model.

Features of thermal hydraulic mixing in the refueling water pool are depicted in Figures C-2 and C-3, which show the temperature distribution of the thermal plume from the core in a vertical plane and through a series of horizontal planes. (Note: the temperature scale shown is in degrees Rankine; subtract 460 to obtain Fahrenheit). These temperature distributions illustrate the thermal plume rising above the core and then being transported downstream toward the drain. In Figure C-3, the bias of flow around the core to the SW and NW result in the lower temperatures predicted for those two locations.

Predicted values of fluid temperatures decrease with rising elevation above the vessel and are higher on the downstream side (angles of 45° and 135°) than the upstream side (angles of 225° and 315°). These differences are due to heating of the alternate cooling flow as it crosses the core and mixing not being as complete in the CFD model as in the refueling pool. Predicted values are, on the average, about 3% higher than measurements.

In general, the thermal plume is predicted to rapidly mix in the vertical direction while the cavity of the pool that is associated with the incoming core flow remains cold. Some of this cold mass does short-circuit the core to the cavity on the drain side. Within the drain cavity, the pool temperature is warmer and reduces to the drain temperature at 94°F. At the surface of the pool, the maximum temperature is 103°F and the volume weighted average temperature is 94°F. As noted from Figure C-4, the test data shows temperatures are more uniform in the vertical direction than those predicted by the computational fluid dynamics model.

Circulation due to the thermal plume results in the predicted values for fluid velocity in the vertical plane (Figure C-5) and horizontal plane (Figure C-6) being the highest in the region above the reactor flange. These velocity profiles above the core are an indication of the strong mixing and recirculation occurring in that region. CFD results show the highest fluid velocity in the natural circulation plume to be approximately 0.2 feet/second.

Table C-1

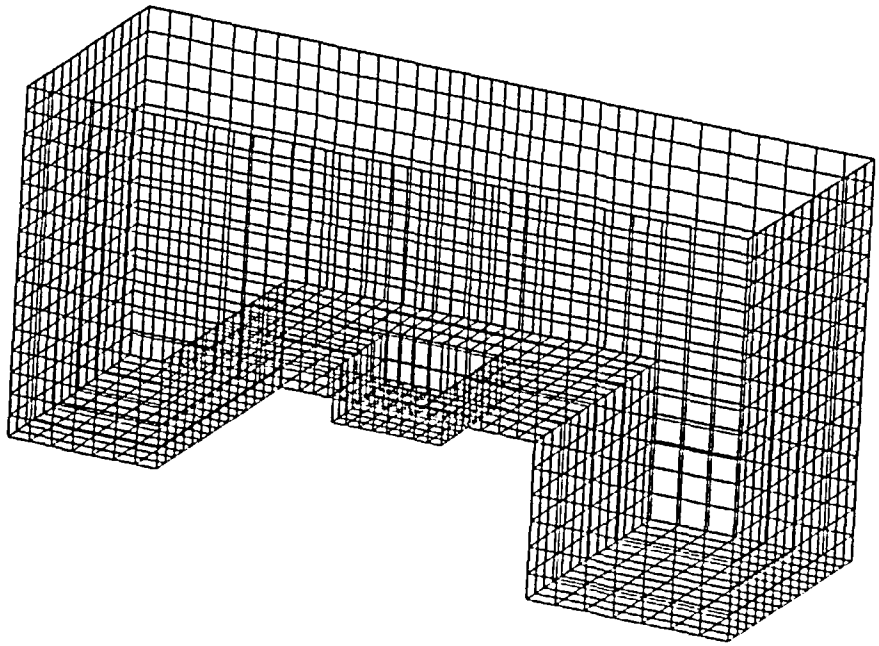
Comparison of Thermocouple Data with Computational Fluid Dynamics Predictions

Location	TEMPERATURES (ºF)													
Direction	NE		SE		SW		NW		Average		Alternate Cooling Flow			
Angle	45°		135°		225°		315°				IN		OUT	
Elevation	DATA	CFD	DATA	CFD	DATA	CFD	DATA	CFD	DATA	CFD	DATA	CFD	DATA	CFD
44-ft	101.42	108.71	101.31	107.68	101.93	100.78	100.74	102.95	101.35	105.03	78.82	78.57	93.39	93.57
53-ft	99.49	101.34	98.30	101.70	97.50	93.73	98.71	95.05	98.50	97.96				
62-ft	98.77	100.69	98.57	101.75	97.72	97.55	98.77	98.51	98.46	99.63				

Refer to Figure B-2 for quadrant orientation.

Figure C-1

CFD Model of Refueling Pool



z y x	FUEL2 Grid (15 X 37 X 17)	Nov 05 2001 Fluent 4.56 Fluent Inc.

Figure C-2

CFD Predictions for Fluid Temperature on a Vertical Plane

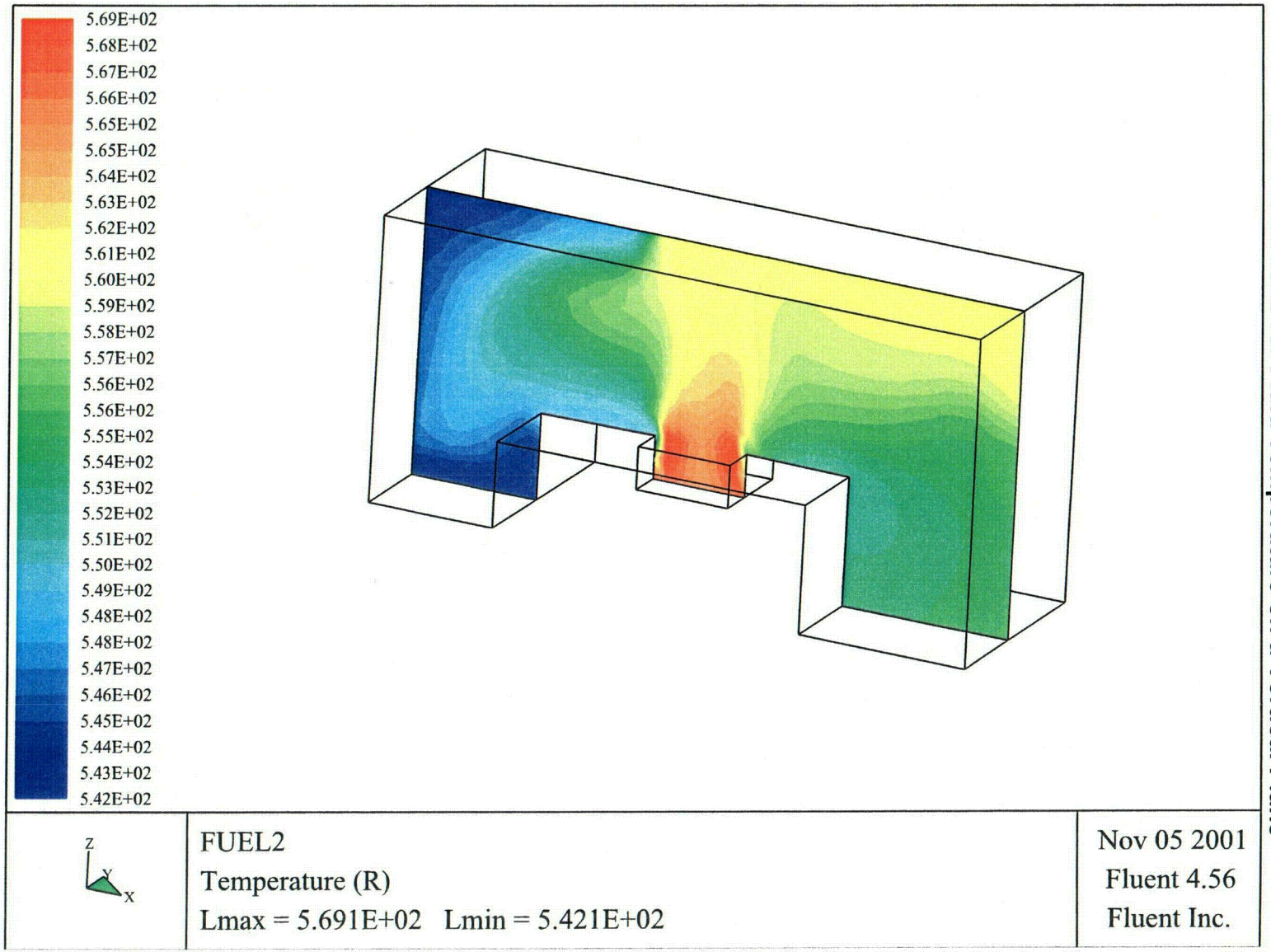


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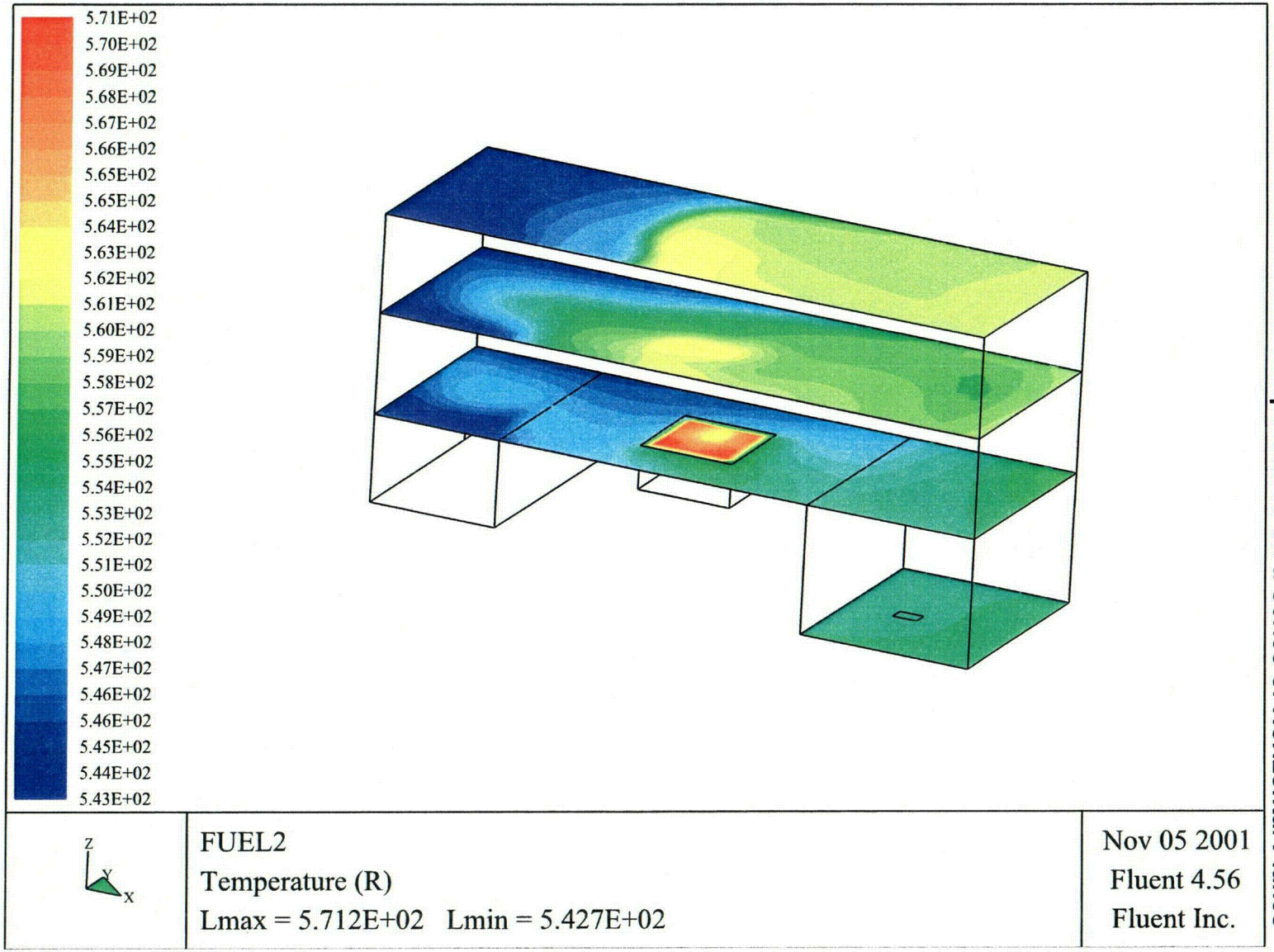
Figure C-3

CFD Predictions for Fluid Temperatures on a Series of Horizontal Planes



C03

Figure C-4

CCNPP2 Outage Tests: Measured and CFD Predictions for Refueling Pool Temperatures

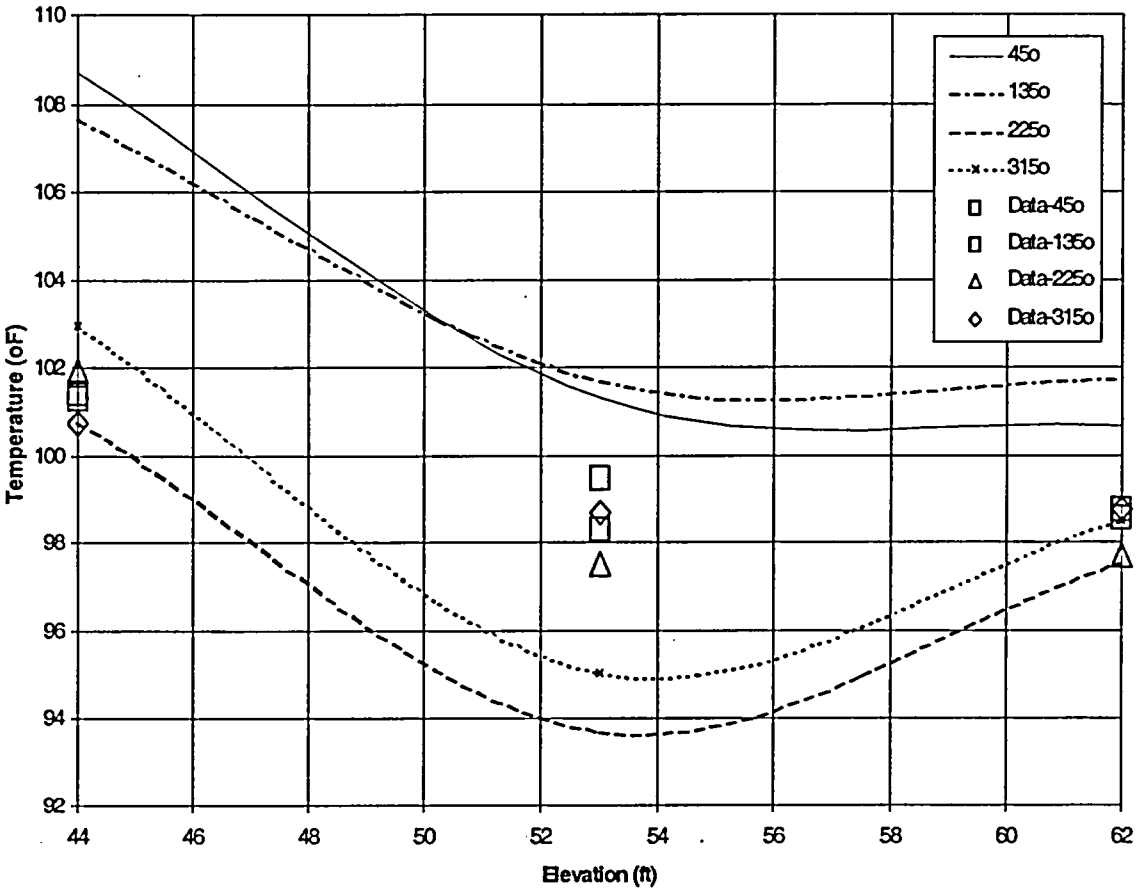
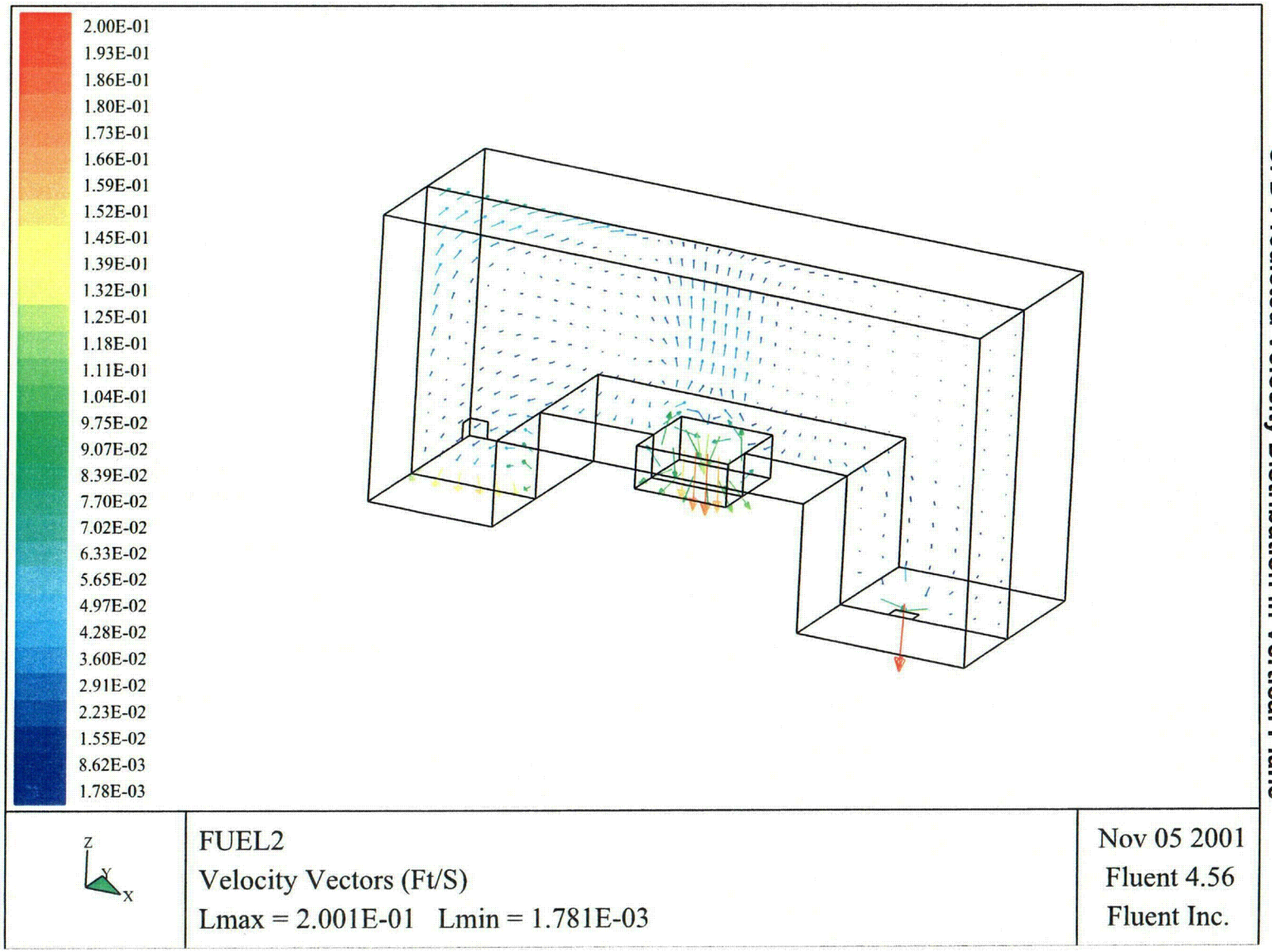


Figure C-5

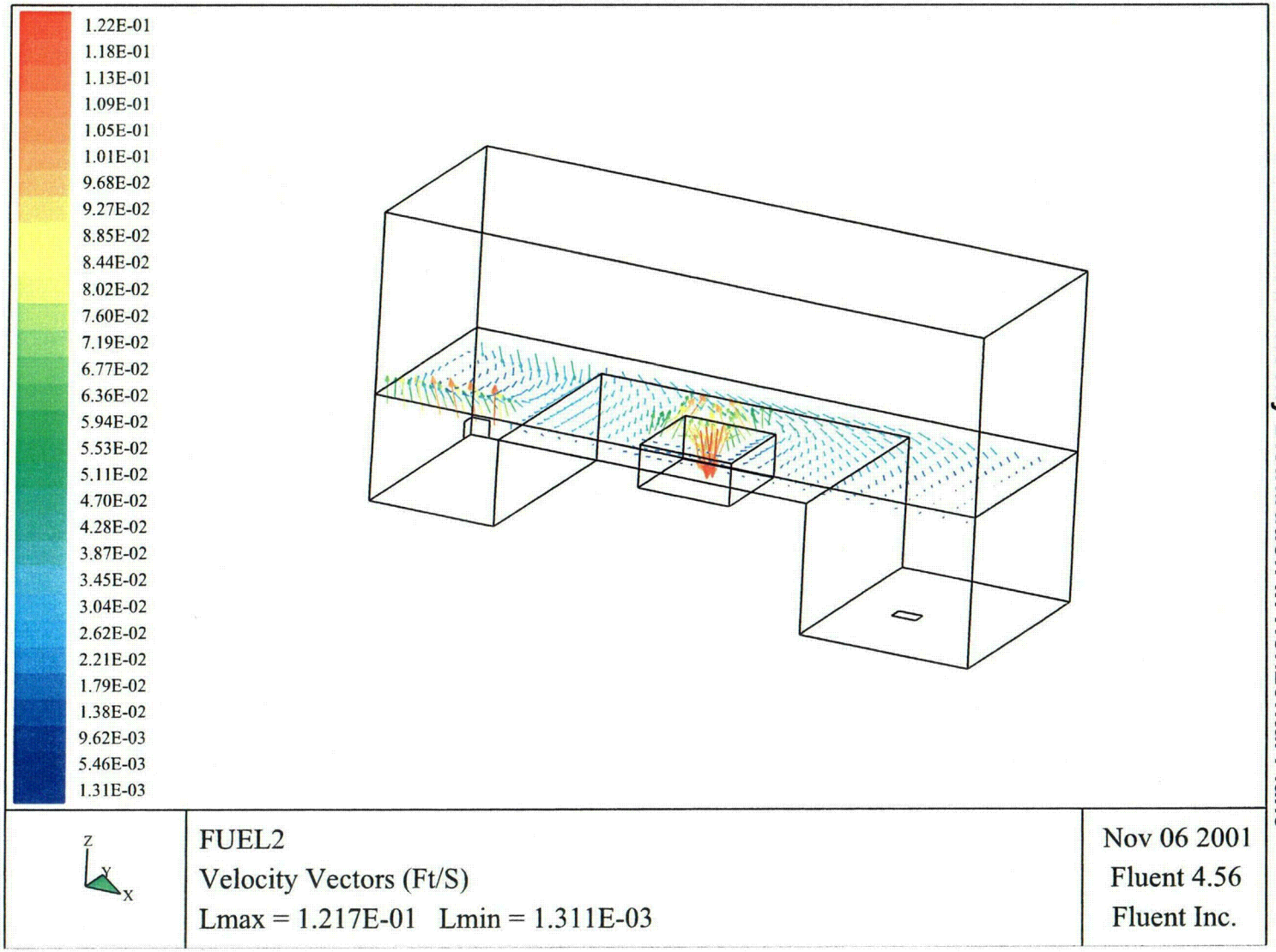
CFD Predicted Velocity Distribution in Vertical Plane



C04

Figure C-6

CFD Predicted Velocity Distribution in Horizontal Plane



C05

APPENDIX D

EVALUATION OF ALTERNATIVE HEAT REMOVAL ALIGNMENTS

APPENDIX D

EVALUATION OF ALTERNATIVE HEAT REMOVAL ALIGNMENTS

The objective of this Appendix is to document predictions of fluid temperature at a value of 0.315% decay heat, seven days after reactor shutdown, considering four alternatives for location of the inlet and suction. In all cases the analysis is based on the parameters for the CCNPP refueling pool /reactor cavity geometry.

D.1 REACTOR CAVITY CONFIGURATIONS

The four configurations to be analyzed are described in Table D-1, shown schematically in Figure D-1. The selection of configurations were chosen to represent a variety of possible conditions that may exist and that none of these configurations represent the exact configuration of the CCNPP units when they are aligned for alternate heat removal. The analyzed configurations are identified as follows:

Configuration A: Alternate Piping: Suction across core.
Configuration B: Alternate Piping: Suction same side.
Configuration C: Transfer Tube: Suction across core.
Configuration D: Transfer Tube: Suction on same side.

The influence of the different flow paths on the one-dimensional model is manifested through the mixing and bypass coefficients. To evaluate these coefficients, computational fluid dynamics models are prepared for each of the configurations. The following are the assumptions used for these one-dimensional evaluations:

- Containment temperature = 100°F
- Inlet temperature = 85°F
- Decay heat = 0.315% (seven days after shutdown)
- Alternate heat removal flows; 200 gpm and 2000 gpm

D.2 ONE-DIMENSIONAL MODELING

The one-dimensional computational fluid dynamics model uses mixing and bypass coefficients to incorporate the mixing of the core flow with the reactor cavity fluid and the alternate cooling flows. The mixing coefficient, ε_{mix}, accounts for the portion of the reactor cavity fluid that does not mix (remains close to the initial pool temperature) with the refueling pool. The bypass coefficient, ε_{bypass}, accounts for the alternate heat removal flow that does not mix (remains close to the inlet temperature) with the core exit flow. The bypass flow path is shown schematically for Configuration A in Figure D-2.

The one-dimensional model assumes values for the mixing and bypass coefficients. This model is independent of locations of the inlet and drain for the alternate cooling paths. Thus, computational fluid dynamics models of the various arrangements must be

used to re-evaluate these coefficients for use, in what is an iterative procedure, in the next one-dimensional model calculations.

The relationship between the definition of the mixing coefficient and temperatures in the computational fluid dynamics model is shown below. The mixing coefficient is expressed in terms of the pool average temperatures for the one-dimensional and computational fluid dynamics analyses as,

$$\varepsilon_{mix} = M / M_6 = (\overline{T}_{CFD} - T_i)/(\overline{T} - T_i)$$

where T_i is the initial pool temperature.

The bypass coefficient represents the fraction of the alternate heat removal cooling flow that does not mix with the flow out of the core. Conservation of energy for the mixed and unmixed flows then gives the outlet temperature for this flow as,

$$(1-\varepsilon_{bypass})m_{sfp}c_p\overline{T} + \varepsilon_{bypass}m_{sfp}c_pT_{pi} = m_{sfp}c_pT_{po}$$

The bypass coefficient is solved for as,

$$\varepsilon_{bypass} = (\overline{T} - T_{po})/(\overline{T} - T_{pi})$$

where $\overline{T}$ is the pool average temperature for either the one-dimensional or computational fluid dynamics models. For the computation fluid dynamics model, the alternate heat removal cooling flow that does not mix with the core plume flow is,

$$\varepsilon_{bypass,CFD} = (\overline{T}_{CFD} - T_{po,CFD})/(\overline{T}_{CFD} - T_{pi})$$ a, c

where po and pi refer to the refueling pool outlet (drain) and inlet temperatures.

A one dimensional calculation with the mixing coefficient equal to one and the bypass coefficient equal to zero is used to determine the core flow rate that is applied as a boundary condition to the computational fluid dynamic evaluation of the alternate cooling flow alignments. For an assumed 0.315% decay heat level, the predicted core flow rates for alternative cooling flow rates of 200 and 2000 gpm are 10408 and 8563 gpm, respectively.

D.3 COMPUTATIONAL FLUID DYNAMICS MODEL EVALUATION

The mixing coefficient is meant to represent the influence of a non-uniform distribution of fluid temperature on the transient behavior of the fluid in the reactor cavity. The bypass coefficient is intended to represent the alternate cooling flow that may not transport heat from the core. It is assumed that the mixing and bypass coefficients are independent. Thus, the mixing coefficient may be determined based on no transport flow into or out of the cavity. However, evaluation of the bypass coefficient is dependent on the flow rate and the pool configuration. Results of this evaluation, based on the

following core flow rates corresponding to the one-dimensional flow rates for perfect mixing, $\varepsilon_{mix} = 1$, and no bypass, $\varepsilon_{bypass} = 0$, are shown in Tables D-2 and D-3.

AHR flow rate = 200 gpm Qcore = 10408 gpm
AHR flow rate = 2000 gpm Qcore = 8563 gpm

Inlet flow to the refueling water pool from the alternate heat removal flow path may be introduced from either a pipe at the upper surface of the pool or from a low-level inlet in one of the pool cavities. Cooling flow may exit the pool through one drain which may be in either pool cavity. Since the CCNPP pool is nearly symmetric, four configurations bound the general possibilities for inlet and exit flow locations. For each inlet location, the drain location may be in the same cavity or in the cavity on the opposite side of the reactor vessel. With the inlet and exit in the same cavity, the alternate heat removal cooling flow may short circuit the reactor vessel. With the inlet and exit on opposite sides of the reactor vessel, the alternate heat removal cooling flow must at least pass by the open vessel. The slight non-symmetry of the refueling water pool, principally due to different depths of the cavities and the off-center location of inlets, should not be significant to these computations. These configurations are defined in Table D-1 and shown schematically in Figure D-1.

Results of this analysis, in the form of temperature profiles for the four configurations at the 2000 gpm alternate heat removal flow rate, are shown in Figures D-3 to D-6.

D.4 BYPASS AND MIXING COEFFICIENTS

Results for the bypass coefficients are documented in Table D-2. For Configuration A, the flow that crosses the core and mixes with the flow from the core is reflected in a value of the bypass coefficient of about zero for both high and low alternate heat removal flow rates. In contrast, for Configuration B the majority of the alternate heat removal flow goes directly to the drain, which is reflected in values of the bypass coefficients close to unity.

Configurations C and D represent the arrangement where the alternative cooling path enters the refueling pool from a low level, such as through the fuel transfer tube. In Configuration C the flow is forced up and over the core. Computational fluid dynamics analysis indicates that forcing the flow across the core results in the inlet flow into the core being closer to the spent fuel pool temperature of 85°F rather than the refueling pool average temperature assumed in the one-dimensional analysis. For this case, the resulting temperature of the flow out of the core is predicted to be lower than the average pool temperature.

In the alternate cooling mode, decay heat is transported by natural circulation from the core into the refueling pool. A bypass coefficient having a value greater than zero denotes that a portion of the alternate cooling flow bypasses the natural circulation thermal plume above the core. For example, the alternate heat removal cooling inflow in Configuration B enters near the pool surface with the drain at the bottom of the refueling

pool on the same side as the inlet. The temperature distribution for this configuration, shown in Figure D-4, suggests that most of the alternate cooling inflow only mixes with refueling pool water on the inlet side of the pool then exits the pool without significant mixing with the core thermal plume. Thus, a bypass coefficient greater than zero represents a reduction in the alternative cooling flow that interacts to remove decay heat from the core thermal plume and results in a higher pool average temperature, Tcfd, as shown in Table D-2.

In Configuration C the flow enters through a low-level location such as the transfer tube and exits through a drain at the bottom on the opposite side of the core. The temperature distribution in Figure D-5 shows a portion of the flow entering from the low-level inlet remains near the bottom of the cavity, but most of the flow goes up and over the core. This cooler flow mixes directly with the natural circulation from the core before being drawn to the outlet. The higher rate of cooler flow passing by the core inlet results in lower values of core outlet temperatures. This may be reflected in the one-dimensional model by a value of the bypass coefficient less than zero, which is equivalent to increasing the mass flow entrainment of alternate heat removal flow in the one-dimensional model.

Results for Configuration D, where the drain is on the same side as the low level inlet, are similar to Configuration B. In both cases, the alternate heat removal cooling flow short-circuits directly to the reactor cavity drain. The thermal effects of this short-circuiting are manifested in low temperatures in the path between the alternate heat removal inlet and outlet and relatively higher temperatures elsewhere (Figures D-4 and D-6). Configurations B and D remove heat from the vicinity of the reactor core through the action of recirculation currents and turbulent diffusion in the active cavity of the refueling water pool that are produced by the natural circulation plume resulting from the core heat generation.

Values of the mixing coefficients are all close to unity. Based on this data, a value of 0.90, close to the minimum value of 0.88, was selected for use with the one-dimensional model.

Table D-1

Refueling Water Pool Cooling Configurations

Configuration	Inlet Location	Drain Location
A	Pipe flow directed downward in upper corner of pool	Drain in floor of cavity on opposite side of reactor vessel
B	Pipe flow directed downward in upper corner of pool (same as A).	Drain in floor of cavity on same side of reactor vessel
C	Transfer tube (low elevation in the pool)	Drain in floor of cavity on opposite side of reactor vessel
D	Transfer tube (low elevation in the pool)	Drain in floor of cavity on same side of reactor vessel

Refer to Figure D-1 for a schematic of these configurations.
Note that these configurations do not represent the specific configuration of the pool at the CCNPP Units.

Table D-2

CCNPP Unit 2 Bypass Coefficients Based on CFD Analysis

Config	A		B		C		D	
Flow(gpm)	2000	200	2000	200	2000	200	2000	200
Ti (°F)	85	85	85	85	85	85	85	85
Tsfp (°F)	85	85	85	85	85	85	85	85
Tmax (°F)	138.3	396.8*	170.1	444.6*	134.4	397.9*	193.8	421.8*
Tcfd (°F)	114.3	371.4*	149	418.9*	104.9	369.6*	156	393*
To (°F)	115	383.8*	110.3	377.3*	115	383*	108.9	382.7*
Tsurf (°F)	115.5	376.3*	149.3	423.9*	110.7	376.7*	166	400.8*
ε_{bypass}	- 0.024	-0.043	0.605	0.125	-0.508	-0.047	0.663	0.033

* i.e., 200 GPM is insufficient to prevent boiling for the decay heat used.

Table D-3
CCNPP Unit 2 Mixing Coefficient Based on CFD Analysis

Analysis	Computational Fluid Dynamics			1-D
Location	Core Exit	Pool Surface	Pool Bottom	Uniform
Time (min)	750	833	874	886
Tsaturation (°F)	215	214	212	214
Taverage (°F)	197	209.4	215.5	212
ε_{mix}	0.88	0.98	1.03	1.0

Figure D-1

Alternate Reactor Cavity Flow Configurations

(Refer to Table D-1 and the text for a description of these conditions)

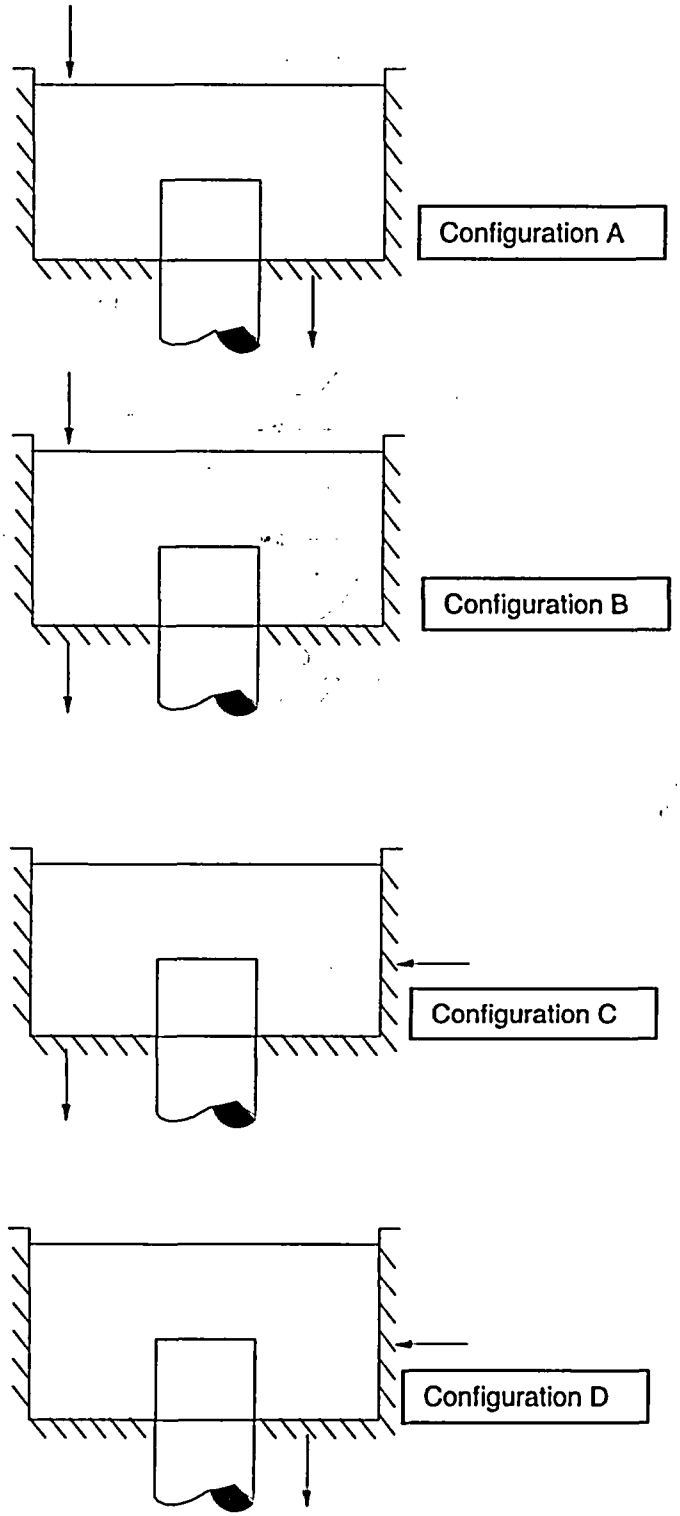


Figure D-2
Flow Paths for Bypass Flow

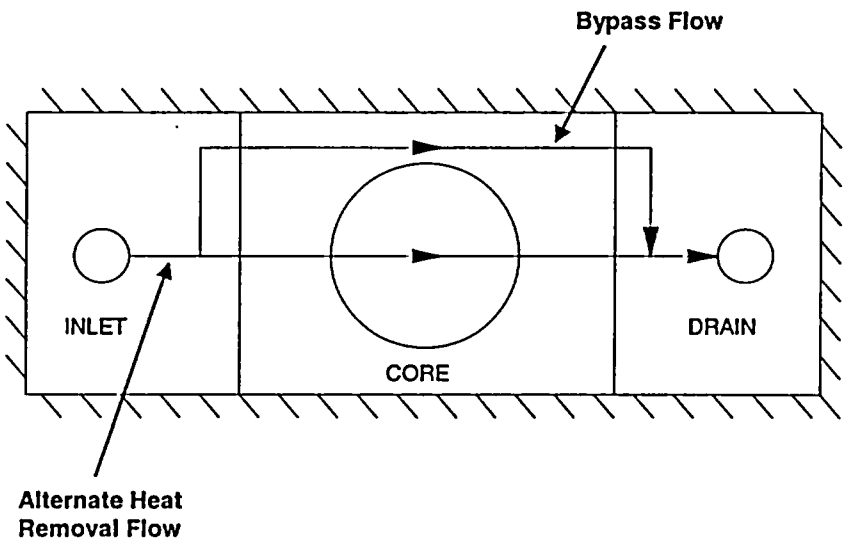
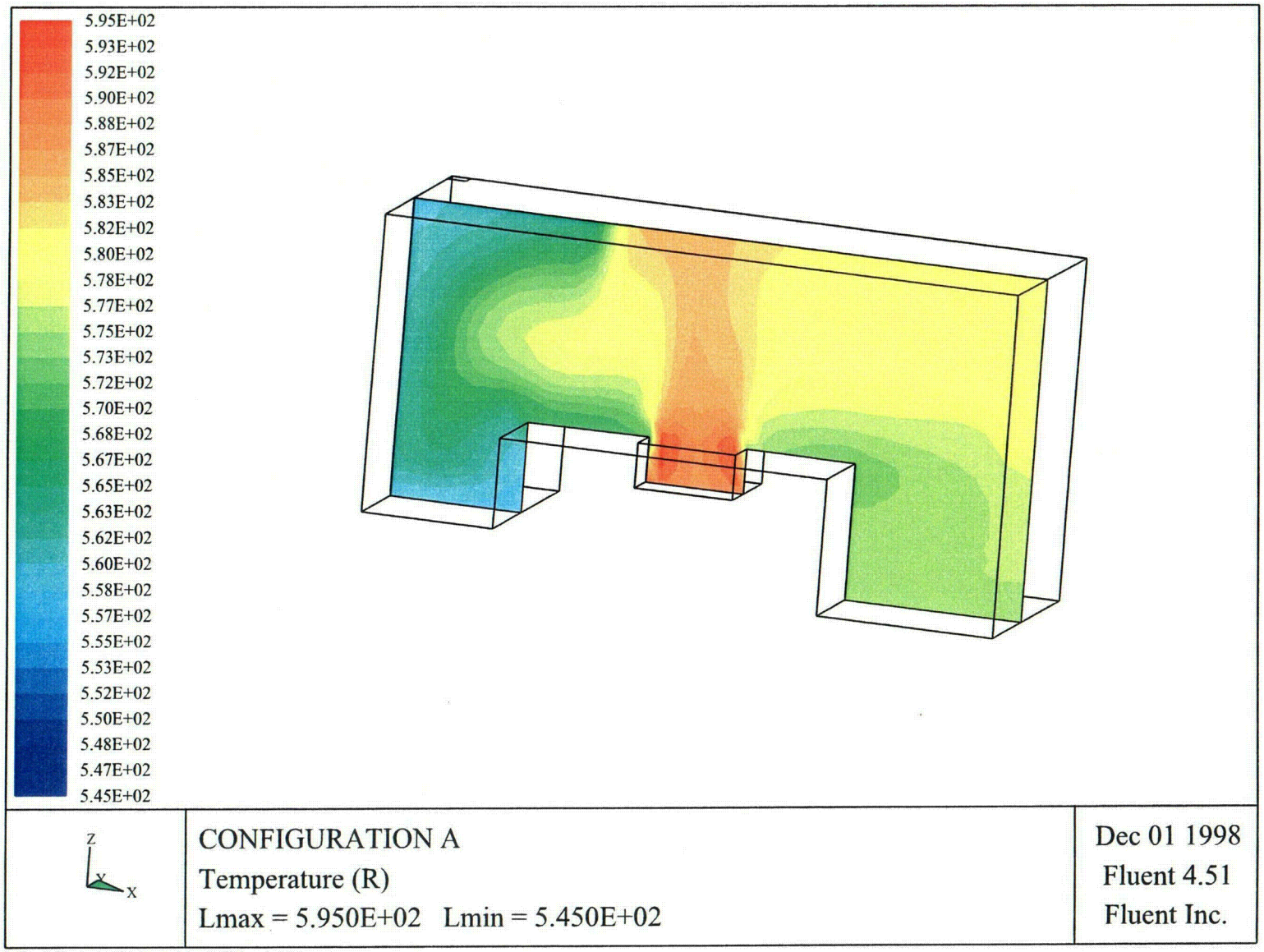


Figure D-3

Computational Fluid Dynamics Configuration A: Temperature Profiles



C06

Figure D-4

Computational Fluid Dynamics Configuration B: Temperature Profiles

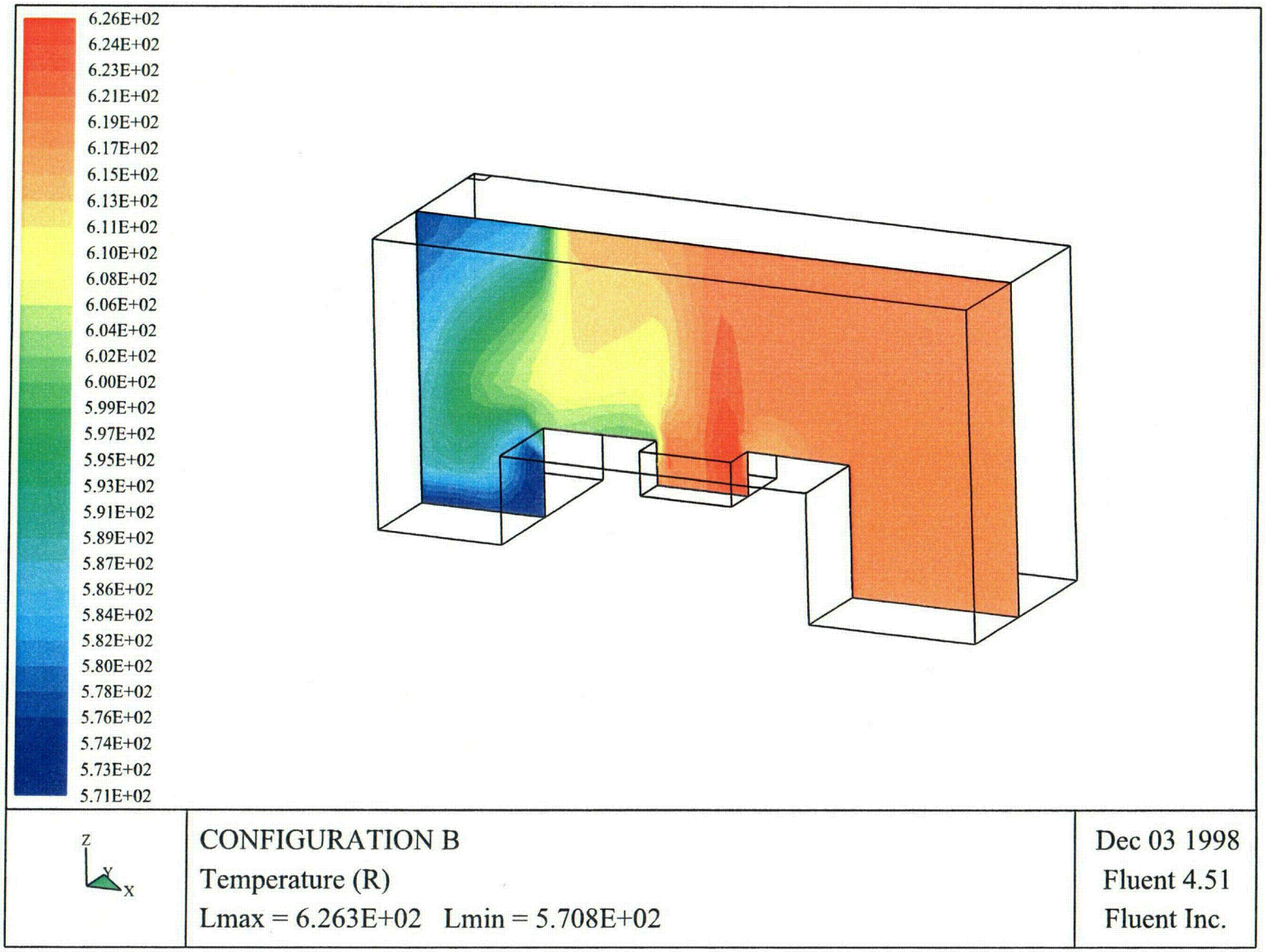


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Figure D-5

Computational Fluid Dynamics Configuration C: Temperature Profiles

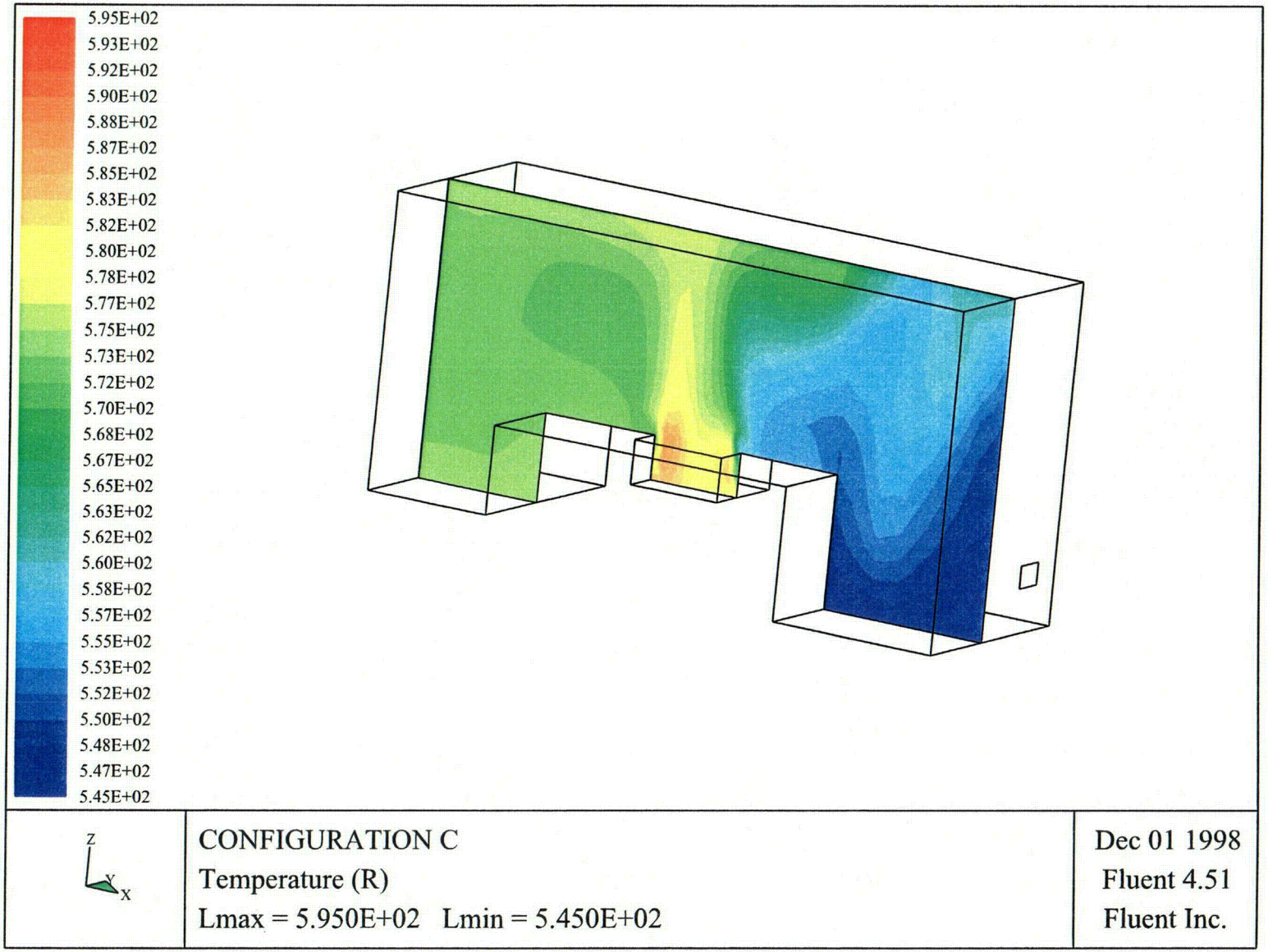

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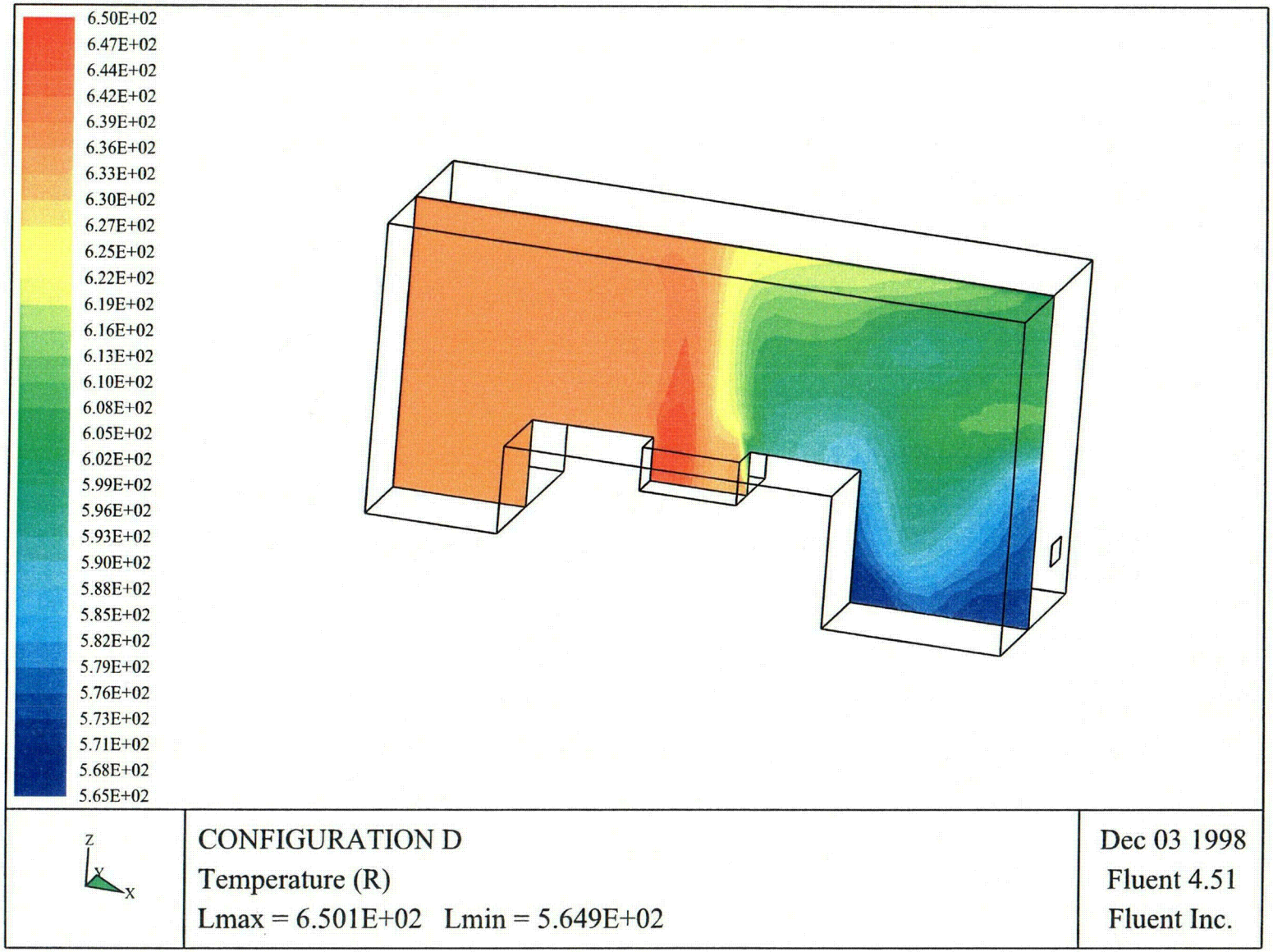
Figure D-6

Computational Fluid Dynamics Configuration D: Temperature Profiles



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APPENDIX E

CCNPP SPECIFIC EVALUATION OF CONDITIONS FOR ALTERNATE DECAY HEAT REMOVAL IN MODE 6

APPENDIX E

CCNPP SPECIFIC PARAMETRIC EVALUATION OF CONDITIONS FOR ALTERNATE DECAY HEAT REMOVAL IN MODE 6

This appendix presents the results of several evaluations testing the sensitivity of various parameters on performance of normal decay heat removal and the alternate heat removal alignment for the CCNPP Units. Limits on the use of the alternate alignment for the removal of decay heat, while removing one or both trains of shutdown cooling from service, and the possibility of moving fuel, all depend on the temperatures in the refueling pool. At CCNPP Units 1 and 2 the alternate heat removal alignment is accomplished with a train of the spent fuel pool cooling system (FPCS). Hard piped connections from the FPCS are available to establish dedicated coolant circulation with the refueling pool.

Per Section 4.0 of the body of this report, the limits on the use of the alternate alignment for the removal of decay heat, while removing one or both trains of shutdown cooling from service, and moving fuel, depend on the temperatures in the refueling pool. The refueling pool temperature, in turn, depends on the ability of the aligned cooling systems to reject heat to the ultimate heat sink. This heat rejection is a function of the performance of the heat exchangers used to reject the heat and the heat sink temperature (T_{HS}). Limits on refueling pool temperatures are discussed in Section 4.1. Steps in determining refueling pool temperatures for values of heat sink temperatures are outlined in Section 4.2.

Removal of one or both trains of shutdown cooling from service will be limited by the fluid temperature reaching some value that represents the margin between the selected value and the core becoming uncovered. For the CCNPP Units the operating limit has been set at a value of 140°F, coincident with the limiting temperature for the spent fuel pool.

Temperatures and time to reach specific temperature limits can be predicted based on the one-dimensional, lumped parameter algorithm developed to predict refueling pool and core outlet temperatures versus time as described in Section 2.2. The algorithm contains provisions for the usual Mode 6 shutdown cooling alignment as well as an alternate alignment utilizing spent fuel pool cooling.

Fuel assembly movement during refueling operations can depend on local fluid velocities due to the thermal convection between the core and refueling pool and subsequent mixing with the local pool fluid circulation. The limiting fluid velocity is such that it is below values at which the fuel assembly can become tilted and difficult to insert into the core.

Changes in the Technical Specifications, discussed in Section 5.0, needed to support implementation of alternative heat removal and evaluation of limiting conditions for operation to meet these requirements, include:

- Conditions under which the alternate heat removal alignment may be used.

  Limiting conditions are a function of decay heat as a function of days after shutdown, refueling pool temperature as a function of heat sink temperature, flow rate and inlet temperature for the alternate heat removal alignment (Section E.1).

- Requirements for removing the shutdown cooling system from service.
- Time limits for interrupting the alternate heat removal flow.

  Limiting conditions for operation are based on time to reach a limiting value of refueling pool temperature (Section E.4).

- Fuel movements allowed when using alternate heat removal alignment.

  Limiting conditions for operation are based on fluid velocities induced by natural convection, in the region above the core, and the influence of the resulting fluid forces on alignment of the fuel assembly with its core location (Section E.5).

The following outlines the procedures and methodology for determining the above conditions. Values presented are based on calculations for CCNPP Unit 2.

E.1 RFP TEMPERATURES VS. INLET TEMPERATURE

With the head off, at assumed times after shutdown, the refueling pool (RFP) temperature is a function of the decay heat, shutdown cooling (alternate heat removal) flow and inlet temperature, and refueling pool initial temperature.

$$T_{RFP} = f(Q_{decay}, m_{SDC}, T_{SDCi}, T_{RFPi})$$

Decay Heat: Based on assumed values of time after shutdown, values of decay heat are obtained from the decay heat curve, assumed for conservatism, for a full core, for example Figure E-1.

Conventional Decay Heat Removal: Values are calculated for refueling pool temperature versus time, at different values of days after shutdown, and constant values of shutdown cooling system flow (3000 gpm), inlet temperature (90°F) and initial refueling pool temperature (90°F), for example in Figure E-2. The values of steady state temperatures, in this case at a constant value of T_{SDCi} of 90°F, are shown in Figure E-3.

E.2 RFP Temperatures vs. Heat Sink Temperature

Alternate Decay Heat Removal: Values of the spent fuel pool temperature, TSFPi, are a function of the performance characteristics of the heat exchanger(s) used to remove heat from the refueling pool and the final (ultimate) heat sink. Thus, upon switching to

the alternate cooling alignment, at assumed times after shutdown, the refueling pool temperatures are calculated as a function of the decay heat, spent fuel pool (alternate heat removal) cooling system flow rate and inlet temperature and steady state temperature of the refueling pool at the time of the switch-over:

$$T_{RFP} = f(Q_{decay}, m_{SFP}, T_{HS}, T_{RFPi})$$

Predicted values of refueling pool temperatures versus time, are shown in Figure E-4 and steady state values in Figure E-5. Both figures are based on a heat exchanger effectiveness and flow, multiplied by specific heat ratio, Cr, of one, so that TSDCi = THS.

As with conventional heat removal the calculation is repeated for values representing the expected high and lower limits of the heat sink temperature, THS.

Limiting THS vs. TAS: Repeated calculations for RFP temperatures result in a family of curves such as shown in Figure E-4. Refueling pool equilibrium temperatures will decrease with lower values of heat sink temperature and increase with higher values of heat sink temperatures. Selection of a limiting value of refueling pool temperature results in the time after shutdown that the alternate heat removal alignment can be aligned and not exceeds this limit. For a limiting value of 140°F, based on Figure E-5, the limiting condition of operation for entering alternate heat removal alignment with a 90°F heat sink temperature is about 5 days.

E.3 TIME TO REACH LIMITING TEMPERATURES

Results in Figure E-5 show that, for CCNPP Unit 2, the alternate heat removal alignment is sufficient to keep the refueling pool temperatures below the values of both the selected limiting value of 140°F and saturation (212°F) temperatures. However, the time to reach saturation decreases the higher the steady state values of the refueling pool temperatures. With loss of alternate heat removal alignment, refueling pool temperature versus time, for a constant value of heat sink temperatures, is a function of the decay heat and temperature of the pool at the time alternate heat removal cooling is lost;

$$T_{RFP} = f(Q_{decay}, T_{RFPi})$$

Refueling pool temperature as a function of time, at constant values of days after shutdown is shown in Figure E-6. Parametric relationships between the time, Δt, to reach, either the limit on SFP temperature of 140°F or a value of 212°F, are shown in Figure E-7.

$$\Delta t = f(DAS, Q_{decay}, m_{SFP}, m_{SDC}, T_{SFPi}, T_{SDCi}, T_{RFPi})$$

The outage schedule calls for initiation of alternate heat removal alignment from 15 - 25 days into the shutdown, for a duration of 5 days. Times to reach limits on temperature during this operating period are as follows:

Time after Shutdown	Time to Reach Temperature Limits	
	140°F	212°F
15 days	1.67 hrs	13.3 hrs
25 days	6 hrs	16.7 hrs

E.4 FUEL MOVEMENT

Fuel movement depends on fluid velocities due to the thermal convection between the core and refueling pool and subsequent mixing with the pool circulation flow. The fuel assembly can become tilted and difficult to insert into the core when these local fluid velocity values are below limits. The limiting condition can be determined as follows.

Tilt Angle: With reference to Figure E-8, the horizontal component of drag force on a fuel assembly titled from vertical by an angle θ is given by:

$$F_D = \frac{C_D}{2}\rho V^2 \cdot A_P \cos\theta$$

where C_D is the drag coefficient, ρ the fluid density in units (lbm/ft^3), V the average velocity over the length of the bundle, in units (ft/sec), A_P the projected surface area (bundle height times width) of the bundle, in units (ft^2).

Upon equating the drag force, the component of weight in the same direction as the drag component,

$$\frac{C_D}{2}\rho V^2 \cdot A_P \cos\theta = M_{FA} g \cdot \sin\theta$$

where M_{FA} is the mass, in units (lbm), of the fuel assembly and g the acceleration of gravity (32ft/sec^2). The tilt angle is then given by,

$$\theta = \tan^{-1}[(C_D \rho V^2 A_P)/(2M_{FA} g)]$$

This relationship is shown in Figure E-9.

Evaluation: The maximum value of 2.4 for the drag coefficient, is based on the assumption of the fuel assembly being modeled as an infinite beam, with a square cross section rotated 45° to the flow. The density, based on a refueling pool temperature of 100°F, is 62.4 lbm/ft^3. Tilt angle as a function of fluid velocity is shown in Figure E-10. While the angles are small, the limiting value will depend on plant specific experience with insertion of fuel assemblies during refueling.

Fluid Velocity: Based on the CFD analysis, the maximum velocity occurs in the thermal plume region above the core. Furthermore, the velocities tend to be higher the closer to the top of the vessel. Based on the assumption that the velocities are proportional to the natural convection flow, Q_{NC}, from the vessel, the velocity is,

$$V_{max} = Q_{NC}/A_{FLOW}$$

Based on the model in Figure E-11, the flow area corresponds to a circular flow area of about 6 feet in diameter, which corresponds to about half the flow area at the top of the vessel.

Predictions based on the one-dimensional model, of flow rate due to natural convection between the core and refueling pool, of 2900 gpm result in a velocity of about 0.2 feet per second. Review of the CFD analysis indicated that the velocities in both the vertical and radial directions are about equal.

Limiting Conditions: Values of tilt angle as a function of time after shut down are calculated as follows.

The natural convection flow rates between the core and the refueling pool is a function of the decay heat, Figure E-1. Corresponding flow rates as a function of days-after-shutdown, DAS, are shown in Figure E-12.

Based on these flow rates, maximum velocity as a function of DAS is calculated from,

$$V_{max} = Q_{NC}/A_{FLOW}$$

where A_{FLOW} is taken as 29 ft^2.

Corresponding values of tilt angle can then be computed based on the following relationship.

$$\theta = \tan^{-1}[(C_D \rho V^2 A_P)/(2M_{FA} g)]$$

Limiting values of tilt angle will depend on plant specific experience with fuel assembly insertion. Values of velocities and corresponding tilt angles are shown in Figure E-13.

The allowable window for initiation of AHR should be based on temperature limits and then determine if the tilt angles are sufficiently small so as not to result in problems with insertion of fuel assemblies.

Figure E-1

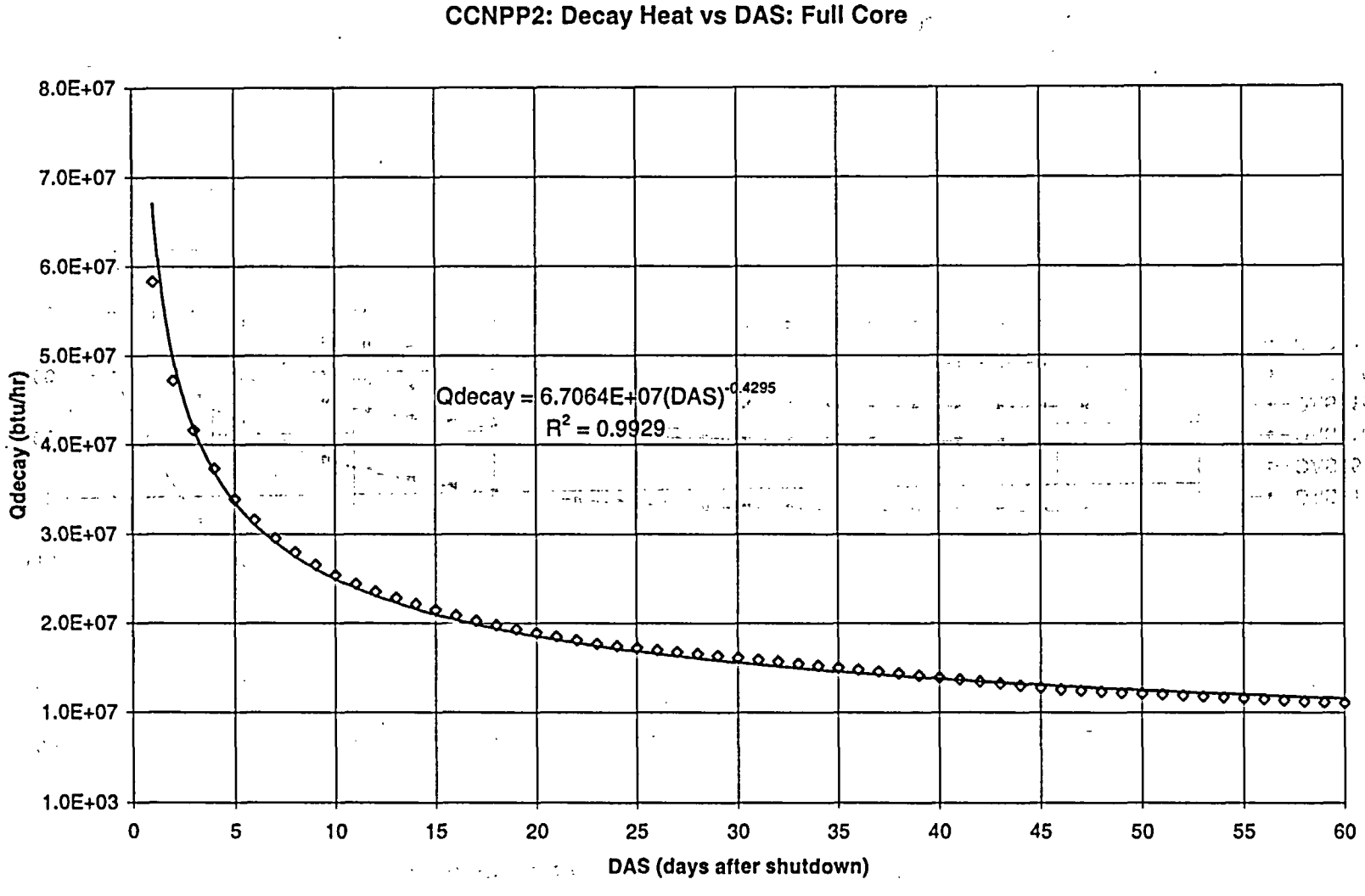

CCNPP2: Decay Heat vs DAS: Full Core
Qdecay = 6.7064E+07(DAS)^-0.4295
R² = 0.9929
Qdecay (btu/hr)
8.0E+07
7.0E+07
6.0E+07
5.0E+07
4.0E+07
3.0E+07
2.0E+07
1.0E+07
1.0E+03
0
5
10
15
20
25
30
35
40
45
50
55
60
DAS (days after shutdown)

Figure E-2

RFP Temperature vs Time: with Shutdown Cooling

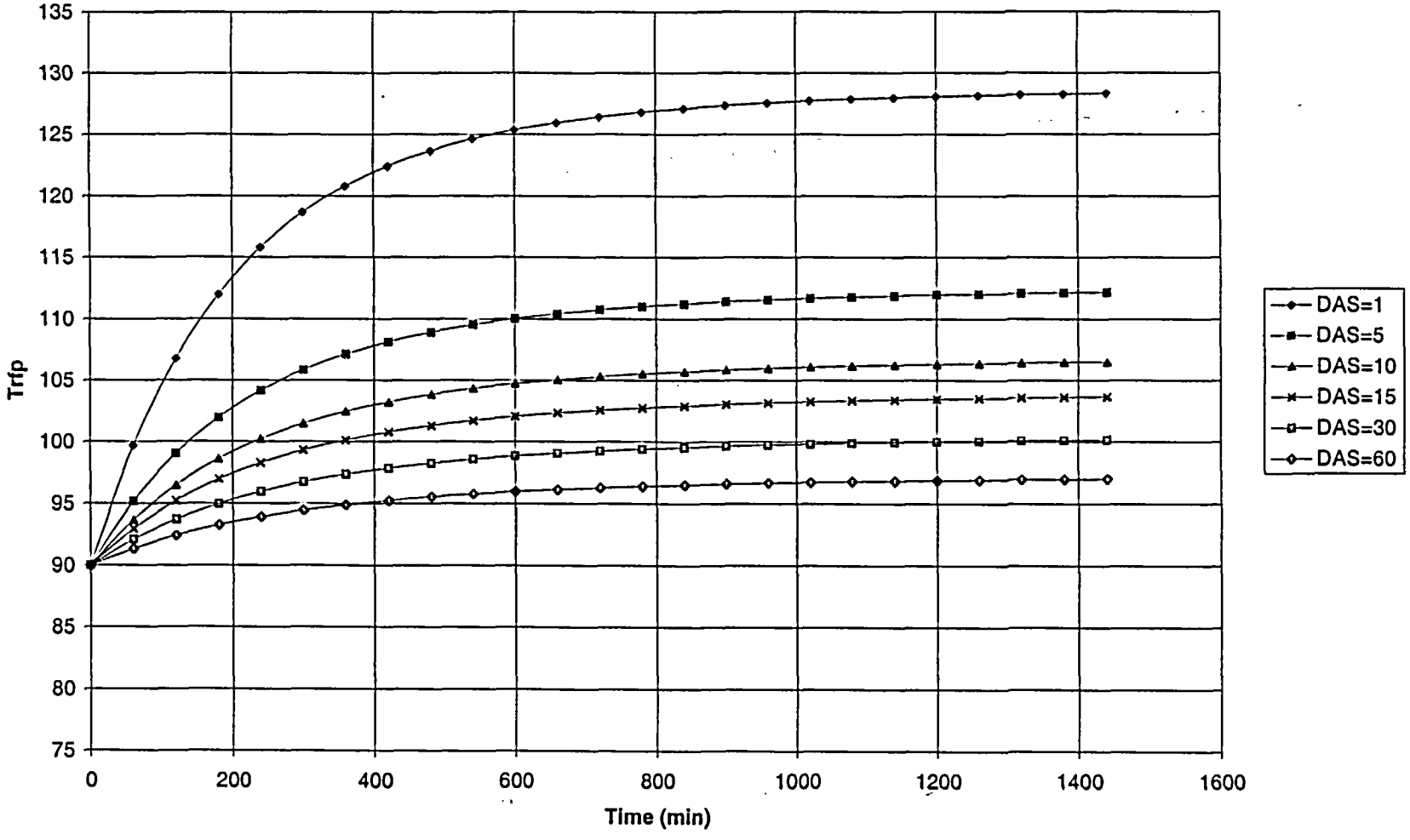


Figure E-3

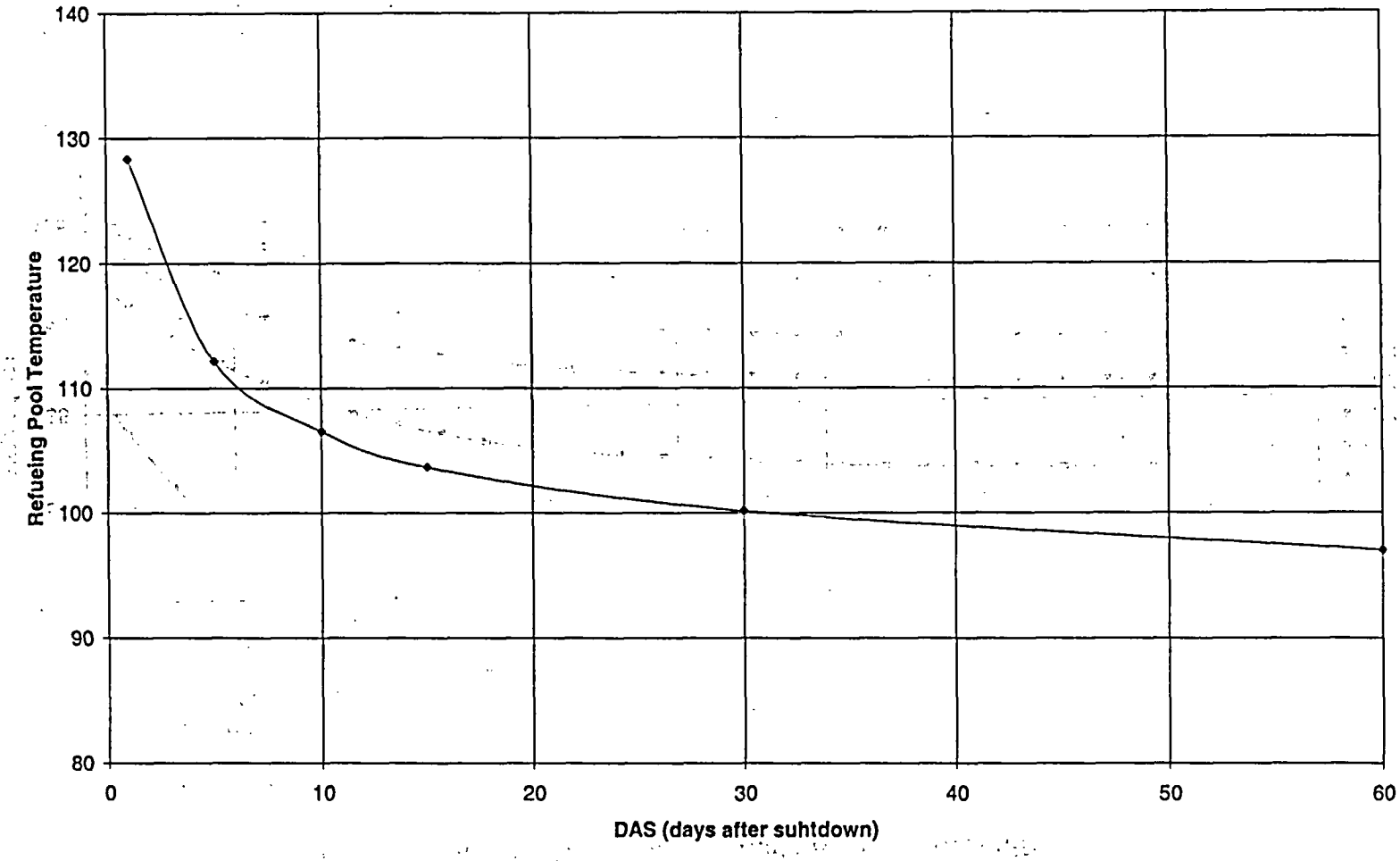

RFP Temperature - SDC Decay Heat Removal
Refueing Pool Temperature
140
130
120
110
100
90
80
0
10
20
30
40
50
60
DAS (days after suhtdown)

Figure E-4

RFP Temperature vs Time: with Alternate Heat Removal (FPC Pump)

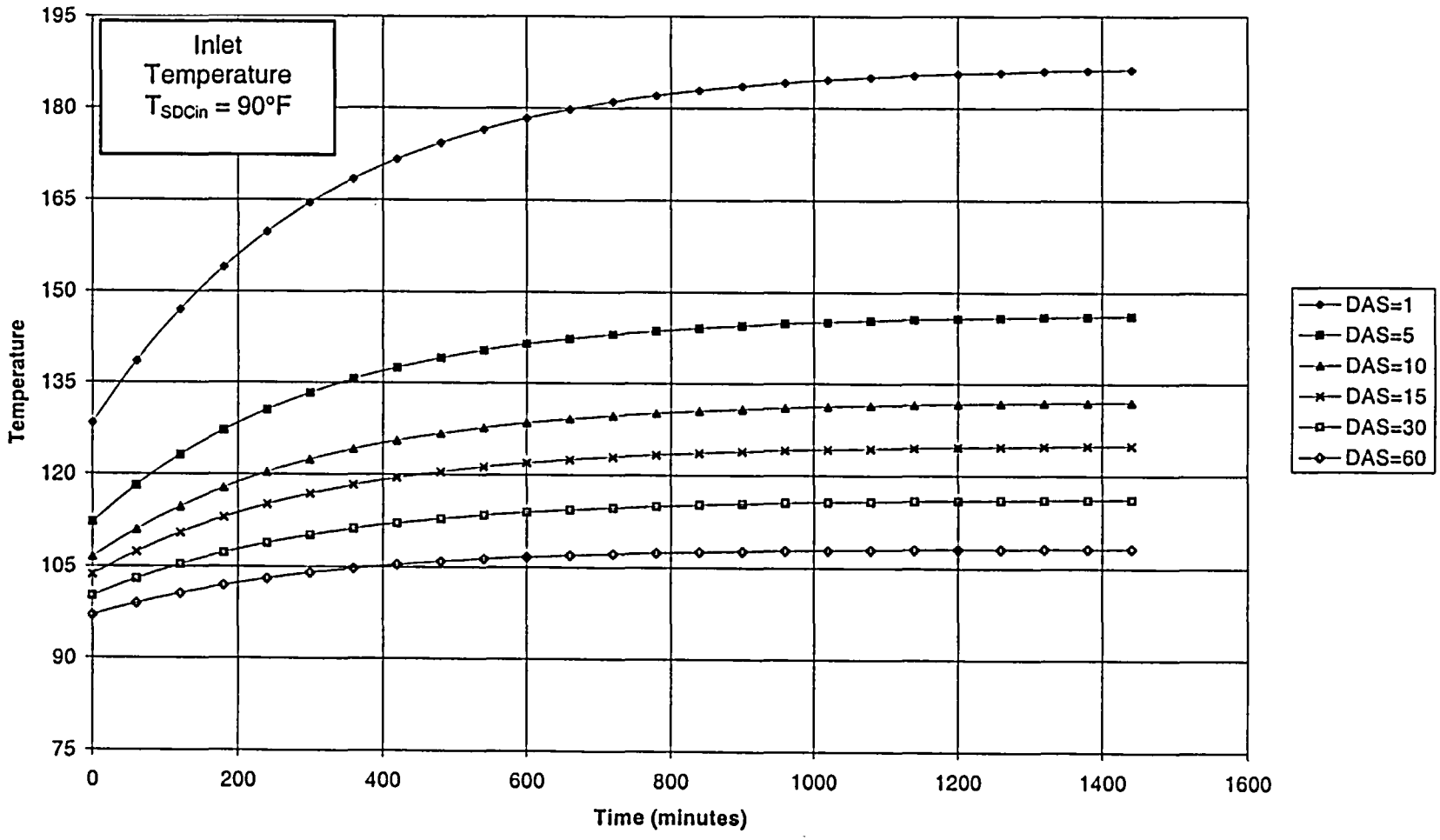


Figure E-5

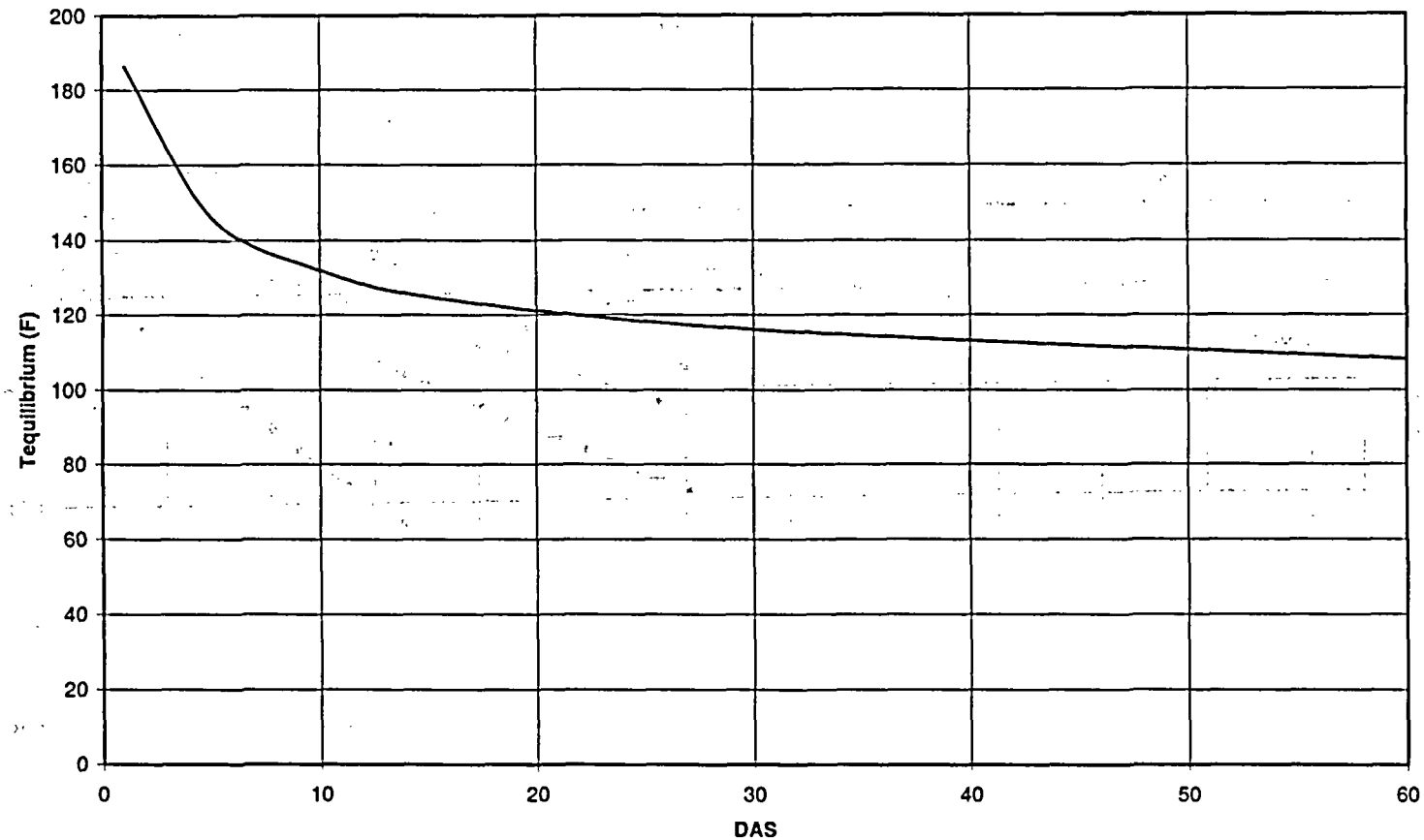

Equilibrium Temperature vs DAS with AHR
Tequilibrium (F)
200
180
160
140
120
100
80
60
40
20
0
0
10
20
30
40
50
60
DAS

Figure E-6

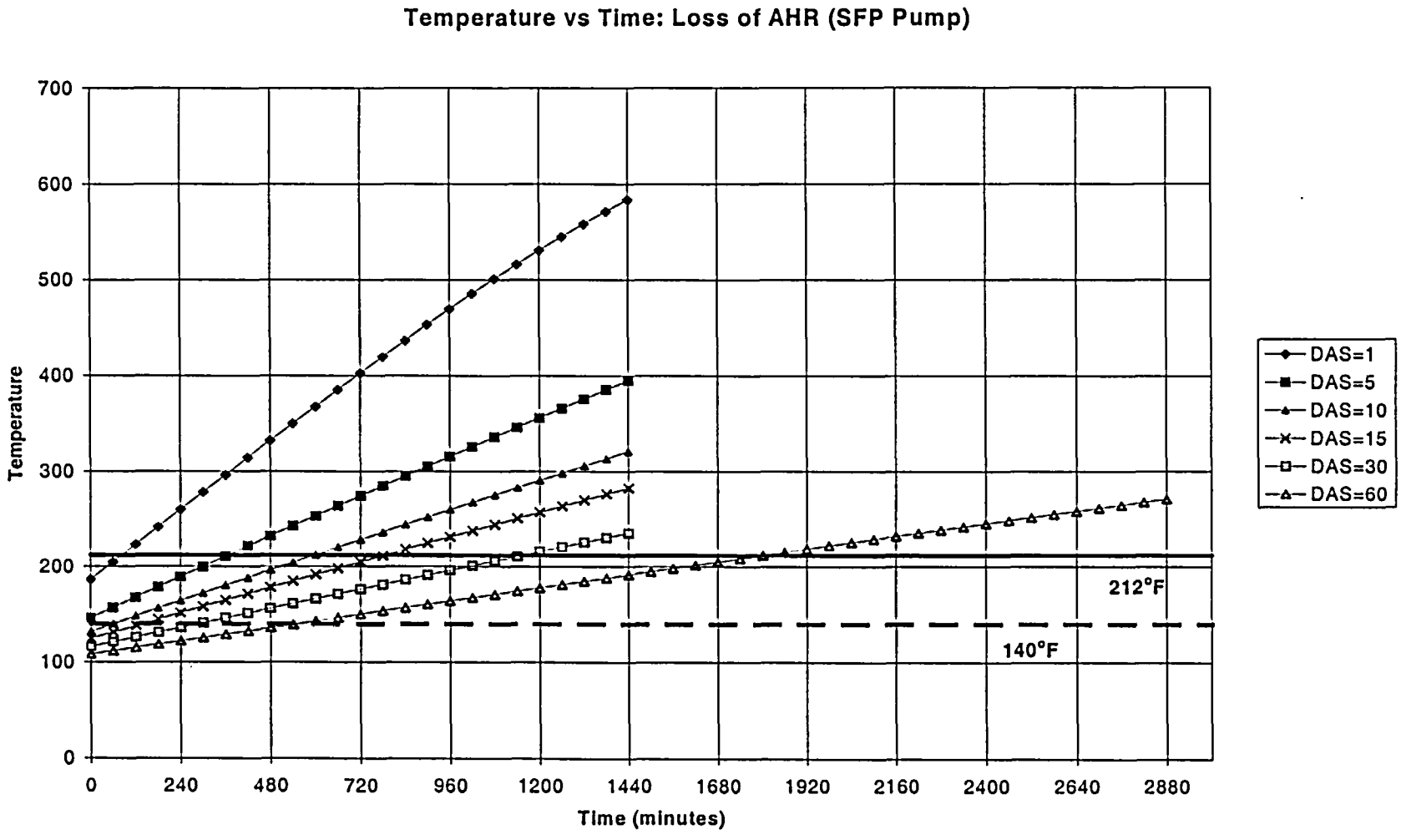

Temperature vs Time: Loss of AHR (SFP Pump)
Temperature
Time (minutes)
0
100
200
300
400
500
600
700
0
240
480
720
960
1200
1440
1680
1920
2160
2400
2640
2880
212°F
140°F
DAS=1
DAS=5
DAS=10
DAS=15
DAS=30
DAS=60

Figure E-7

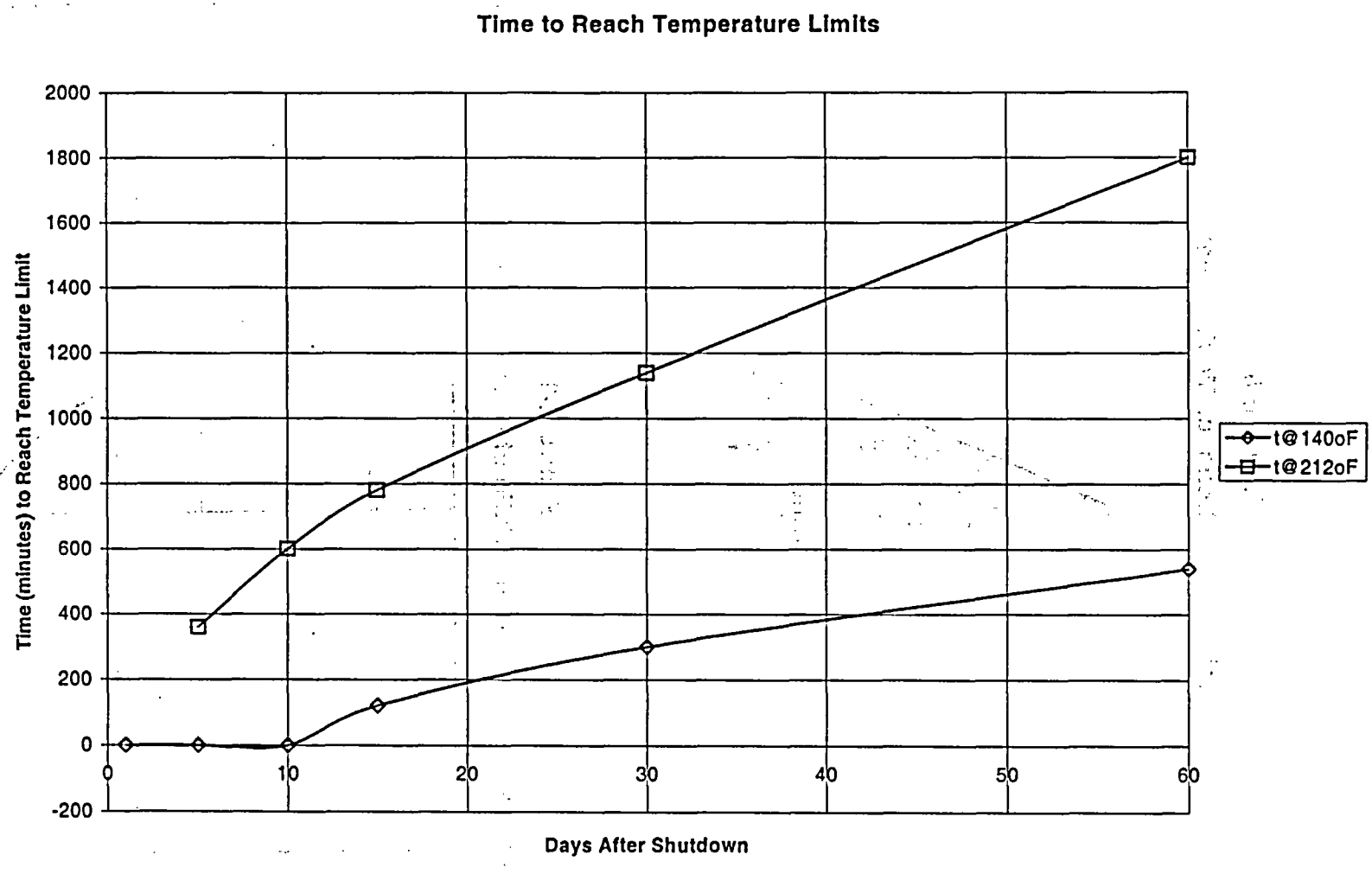

Time to Reach Temperature Limits
Time (minutes) to Reach Temperature Limit
2000
1800
1600
1400
1200
1000
800
600
400
200
0
-200
0
10
20
30
40
50
60
Days After Shutdown
t@140oF
t@212oF

Figure E-8
Limiting Conditions for Moving Fuel

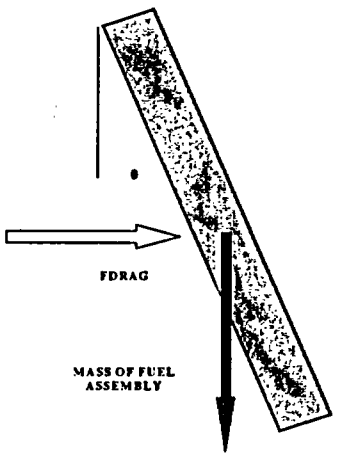


Figure E-9
Tilt Angle as a Function of the Ratio of Drag Force to Fuel Assembly Mass

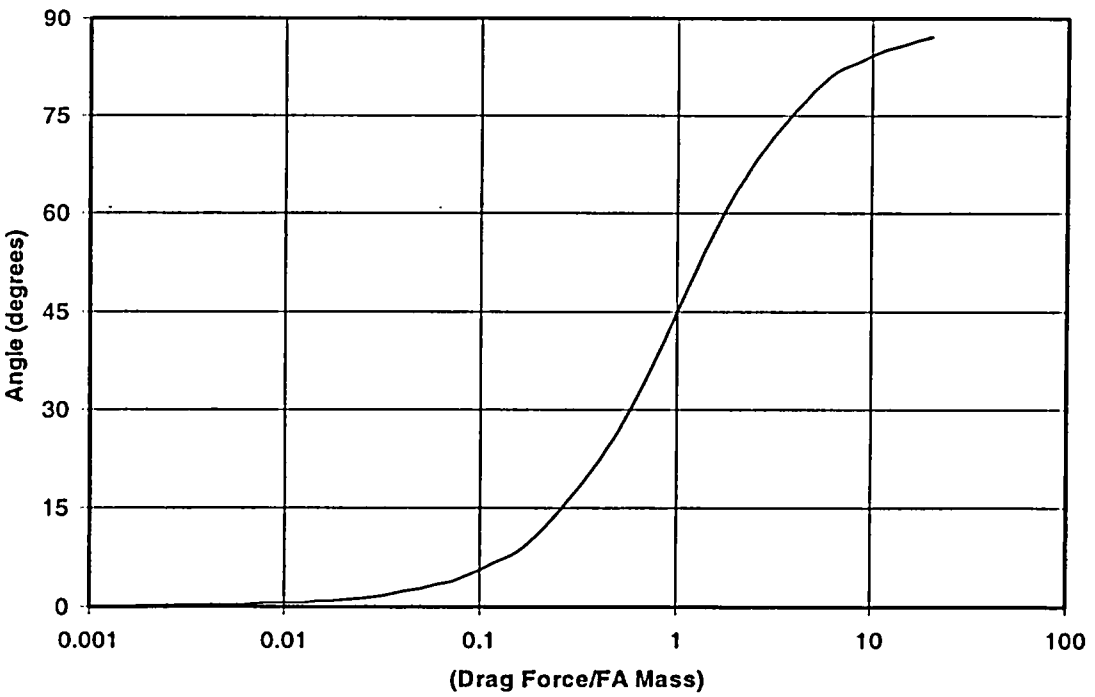


Figure E-10

Tilt Angle as a Function of Fluid Velocity

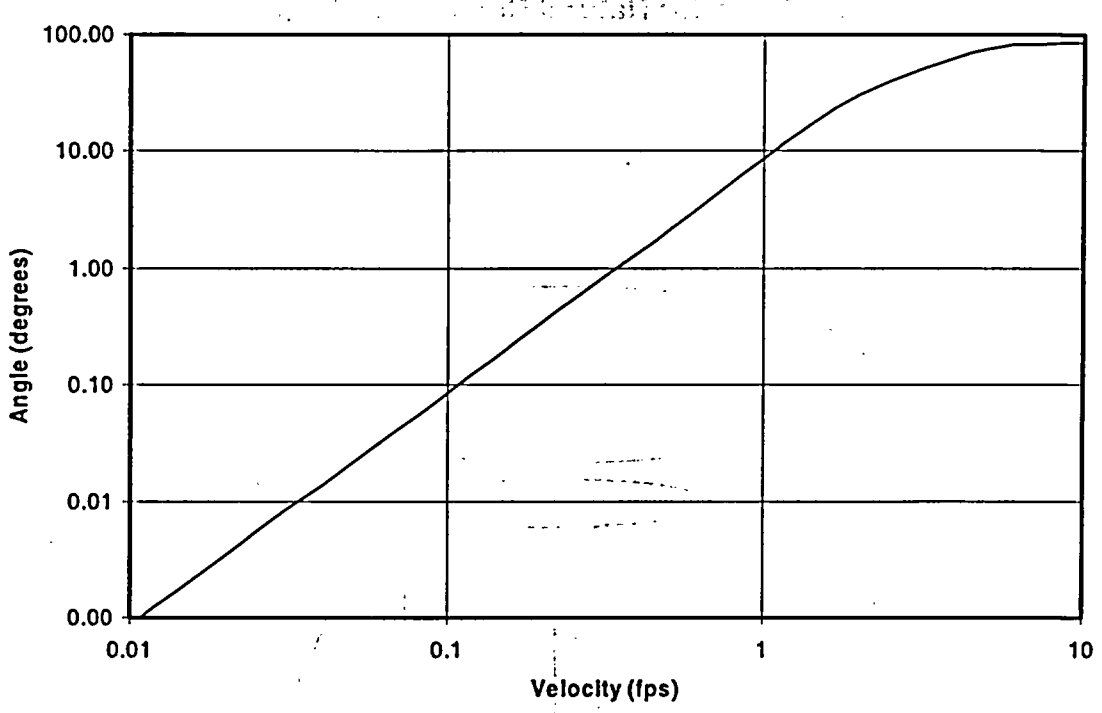


Figure E-11

Flow Areas for Natural Convection Flow

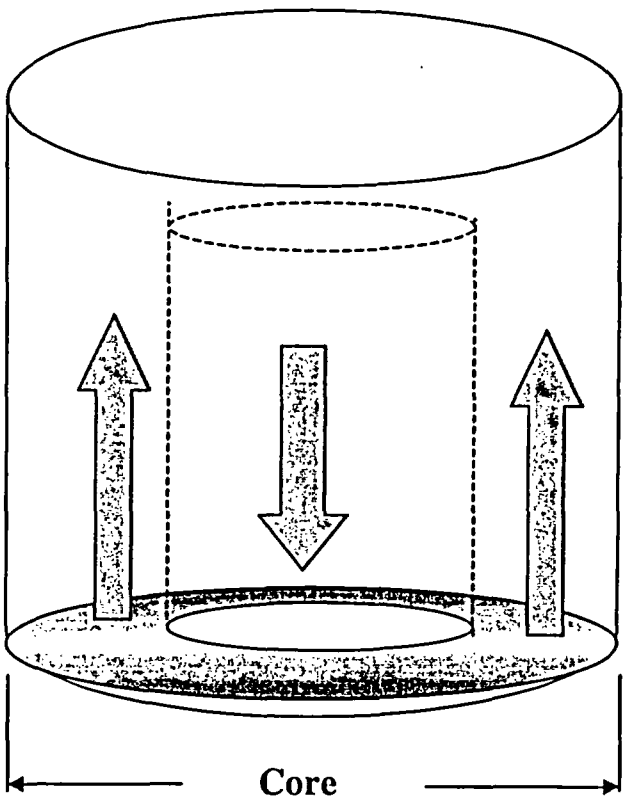


Figure E-12

Volume Flow and Maximum Velocity Due to Natural Convection between Core and RFP

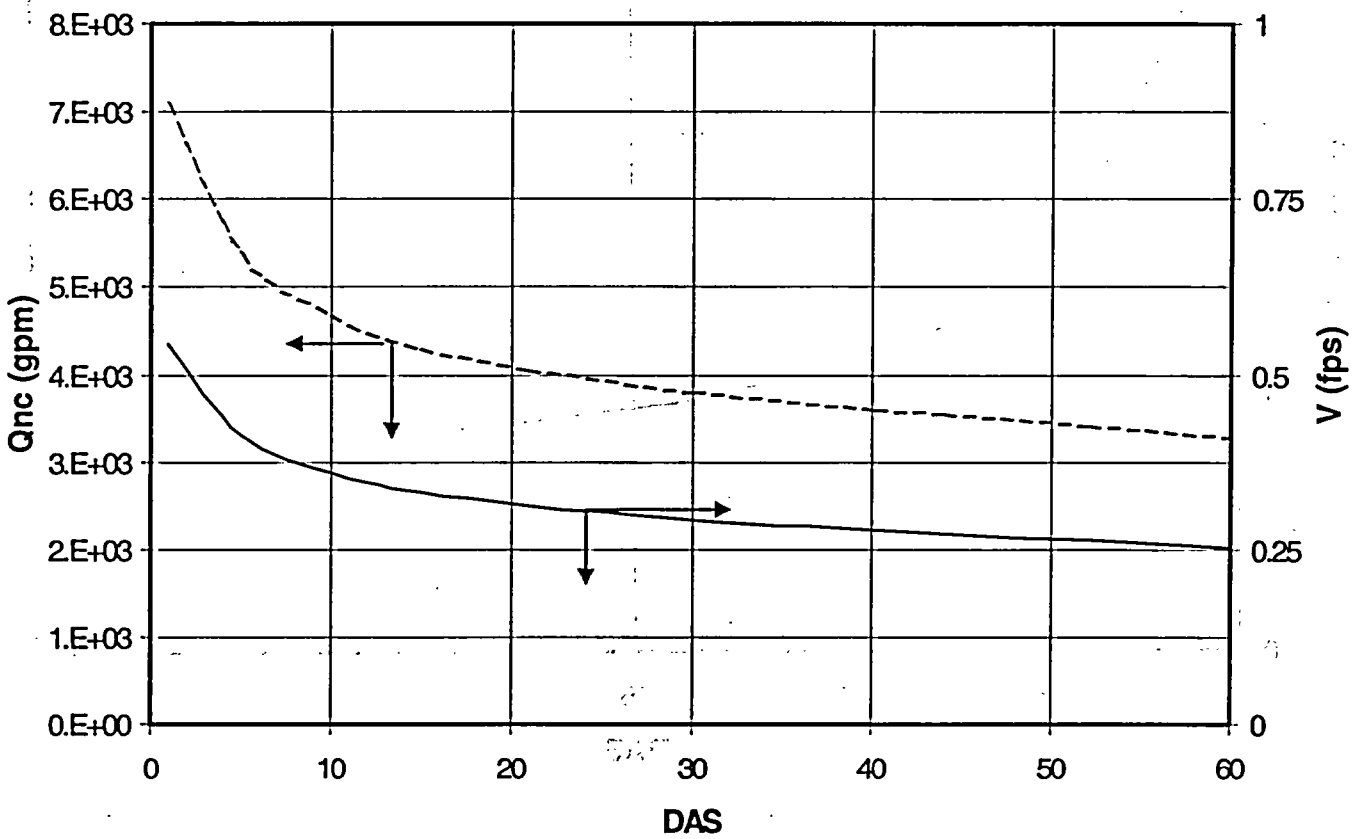
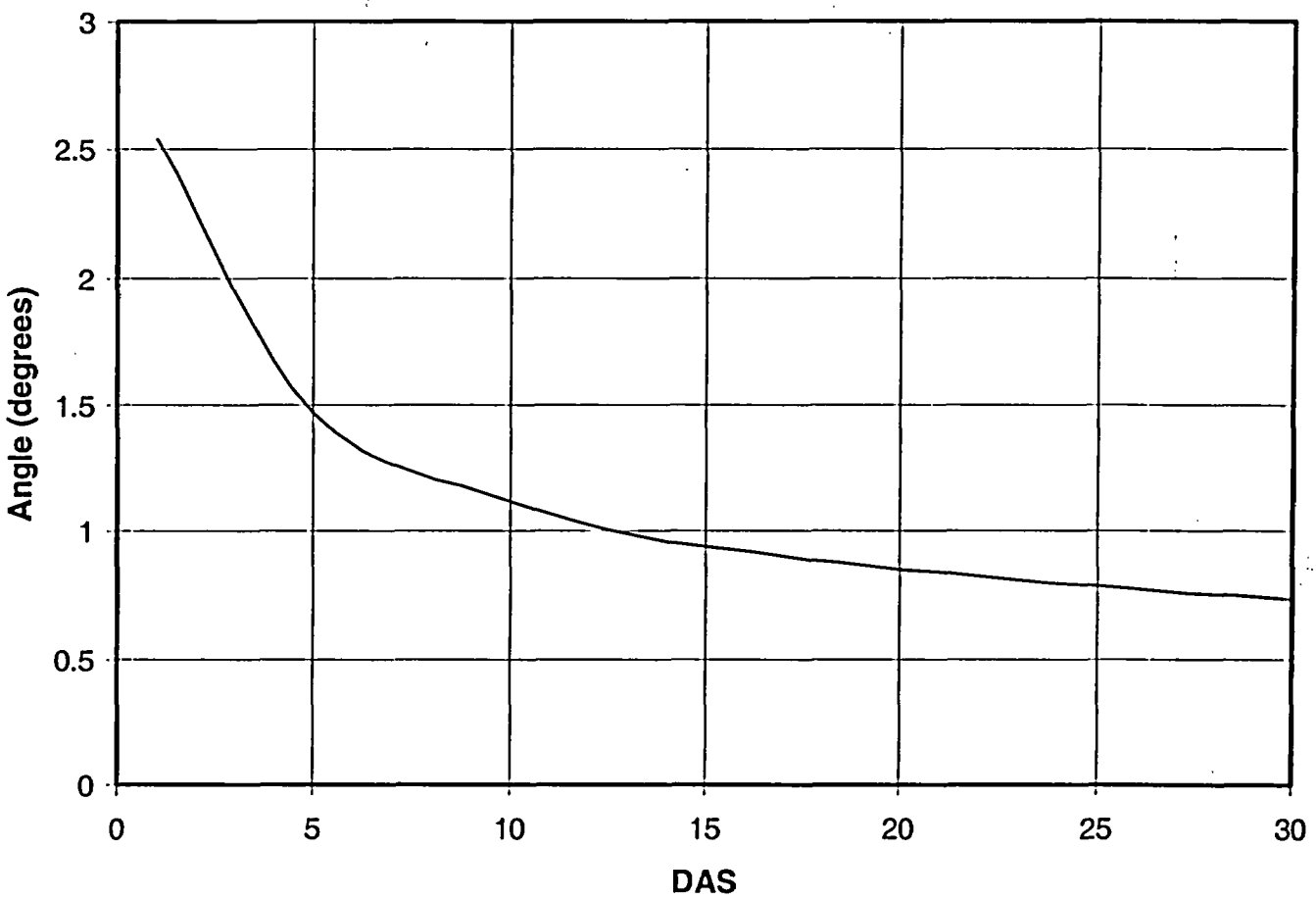


Figure E-13

Tilt Angle



APPENDIX F

CCNPP QUALITATIVE RISK EVALUATION

APPENDIX F

CCNPP QUALITATIVE RISK EVALUATION

The table below summarizes the key risk issues for CCNPP. The individual topics of the table match the issues addressed within Section 3.0 of the body of this report. Further details of the topics are described in the body, while the CCNPP specific application of the topic is presented in this table. In the Relative Risk Change column, a "D" indicates a relative risk decrease (in favor of using alternate heat removal versus shutdown cooling), while "N" is a risk neutral evaluation. Though not identified for CCNPP, an "I" would indicate a relative risk increase.

CCNPP – Alternate Heat Removal Alignment versus Shutdown Cooling Qualitative Risk Assessment Matrix		
Topic Evaluated	Relative Risk Change	Comments
1. Alternate heat removal simplicity and cooling reliability	N	The risk of losing cooling is less when using alternate heat removal at CCNPP due to alternate heat removal simplicity. Alternate heat removal at CCNPP uses the fuel pool cooling system (FPCS) aligned to the refueling pool. The fuel pool cooling system at CCNPP is a safety grade system designed to cool the spent fuel pool. Its simplicity and reliability for alternate heat removal use have been well established, including the documented test results from the Spring 2001 outage where decay heat removal was via alternate heat removal for several days. A loss of circulation has never occurred when using the FPCS for alternate heat removal. An operable shutdown cooling train requires successful operation of an air operated flow control valve and a separate air operated temperature flow control valve. The spent fuel pool cooling system (alternate heat removal) is throttled via a hand valve and no automatic operation is required. This is noted as an "N" (Neutral) based upon the preceding notes and that loss of cooling events with the refueling pool filled are extremely unlikely to cause core damage events due to the long period to core uncovery (well over 24 hours).

CCNPP – Alternate Heat Removal Alignment versus Shutdown Cooling Qualitative Risk Assessment Matrix		
Topic Evaluated	Relative Risk Change	Comments
2. Required Core Off-loads	D	The number of required full core offloads due to shutdown cooling being inoperable or needing to be secured would definitely decrease with alternate heat removal alignment being available. A specific example at a plant other than CCNPP was that of a stuck safety injection system valve at Mode 5 conditions, which required the shutdown cooling flow through the valve to be secured for repairs to the valve. A full core offload was required for this.
3. Loss of Inventory	N	CCNPP has permanent RV cavity seals installed in Units 1 and 2. Additionally, the nozzle dam design has proven to be very reliable and is provided with backup to the air supplies for the second bladders. Accordingly, a large loss of inventory event is a very low probability event. Current CCNPP Technical Specifications allow use of FPCS. The only change is that SDC will not be required as a backup. Thus the probability of an inadvertent draindown is not increased. Further, plant procedures require monitoring of RFP and SFP levels on initiation of alternate cooling, preventing a significant inadvertent draindown of either pool. The decrease in redundancy in makeup sources will cause a minimal increase in CDF of less than 2E-07 per refueling outage. The overall change in risk when using alternate heat removal is believed to be minimal. CCNPP does not envision having to invoke feed and bleed in order to establish risk neutrality here, but may provide feed and bleed capability to further enhance safety. NSAC 176L, "Safety Assessment of PWR Risk During Shutdown Operations," uses a LOCA frequency of 3.5E-06 per hour (when the RCS is de-pressurized). Using CCNPP data it was determined, when using the worst case assumptions, that removing one train of makeup increased core damage frequency by approximately 2E-07 per year or refueling outage. This assumes 20 days (per refueling outage) where both shutdown cooling trains are not available, and that all LOCAs cause the entire RFP

CCNPP – Alternate Heat Removal Alignment versus Shutdown Cooling Qualitative Risk Assessment Matrix		
Topic Evaluated	Relative Risk Change	Comments
		inventory to be drained to the containment building floor. Actually, a large percentage of LOCA events will be recovered soon enough to leave significant levels in the RFP over the RCS. Also, the 3.5E-06 per hour frequency of events is for all LOCAs. Many of these LOCAs are smaller, and would not significantly challenge RFP level for many hours. For larger LOCAs no credit is taken for the leak isolation. Many of the LOCAs that are included in the data used for this frequency are isolable. Also, some of the LOCAs can occur outside of the containment building where suction from the containment sump is irrelevant. Another consideration is that taking suction from the containment building sump with the LPSI pumps is not a proceduralized evolution. These pumps are not designed for a NPSH this low and could require throttling of the header valves to prevent runout. Thus, the LPSI Pumps are not as reliable as other makeup trains. Operators would be hesitant to use them in this case, and may not understand the need to throttle the discharge if used. The 2E-07 risk increase does not take into account the lower reliability of the LPSI Pumps as a makeup train from the Containment Sump. If this were taken into account the base risk would increase and the delta risk would decrease. Given these conservatisms, a more realistic risk evaluation would show risk increases well below 1E-07 per year or refueling outage. The preceding description assumes that two makeup trains will remain available. The current MEEL allows use of a containment spray pump. It is presumed that this is not allowed to be credited when its flow path is not available due to the shutdown cooling heat exchangers being unavailable. CCNPP procedures require direct observation of pool levels during cooling alignment changes.

CCNPP – Alternate Heat Removal Alignment versus Shutdown Cooling Qualitative Risk Assessment Matrix		
Topic Evaluated	Relative Risk Change	Comments
4. Loss of Circulation	N	The fuel pool cooling system at CCNPP is a safety grade system designed to cool the spent fuel pool. Its reliability for alternate heat removal use has been well established, including the documented test results from the Spring 2001 outage where decay heat removal was via alternate heat removal for several days. A loss of circulation has never occurred when using the FPCS for alternate heat removal.
5. Boron Dilution	N	CCNPP puts all charging pumps into "pull to lock" status when using alternate heat removal to explicitly preclude a boron dilution event. This is not done when using shutdown cooling in order to provide borated makeup as needed. Since the boron dilution event is judged as not being a major threat to plant safety, the small improvement due to pull-to-lock is deemed as risk-Neutral for overall consideration.
6. Time to Boil	N	The fact that boiling occurs sooner when using alternate heat removal is largely negated by the very large times to boil involved, giving operators maximum opportunity to recover cooling. Hence, this is judged overall as Neutral.
7. Fuel Bundle Handling	N	Fuel handling errors are judged no more likely with alternate heat removal alignment than with the shutdown cooling system. This assumes that the good visibility when using alternate heat removal observed at lower power levels (2 to 3 weeks after shutdown) translates to 1 week after shutdown.
8. Refueling Pool Cavity Water Visibility	N	Refueling pool visibility has been very good when using alternate heat removal at CCNPP.

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APPENDIX G

SUGGESTED CHANGES TO CCNPP LCO 3.9.4

Notes:

1. For reference, Pages G-2 through G-4 are copies of the current CCNPP LCO 3.9.4, the ACTIONS, and the SURVEILLANCE REQUIREMENTS.

2. Pages G-5 through G-8 are a suggested new version, which allows alternate heat removal use; fuel movement would be allowed as part of alternate heat removal use.

3. The plant specific requirements that are contained in the BASES are:
   - (1) to take all changing pumps out of service when in alternate heat removal, * and
   - (2) to enter alternate heat removal only when bay water temperature is low enough. **

* Currently in TS BASES.
** To be placed in TS BASES.

3.9 REFUELING OPERATIONS

3.9.4 Shutdown Cooling (SDC) and Coolant Circulation-High Water Level

LCO 3.9.4 One SDC loop shall be OPERABLE and in operation.

---------- NOTES ----------

1. The required SDC loop may be not in operation for ≤ 1 hour per 8 hour period, provided no operations are permitted that would cause reduction of the Reactor Coolant System boron concentration.

2. The shutdown cooling pumps may be removed from operation during the time required for local leak rate testing of containment penetration number 41 pursuant to the requirements of SR 3.6.1.1 or to permit maintenance on valves located in the common SDC suction line, provided:

   a. no operations are permitted that would cause a reduction to Reactor Coolant System boron concentration,

   b. CORE ALTERATIONS are suspended, and

   c. all containment penetrations are in the status described in LCO 3.9.3.

APPLICABILITY: MODE 6 with the water level ≥ 23 ft above the top of the irradiated fuel assemblies seated in the reactor vessel.

ACTIONS

CONDITION	REQUIRED ACTION	COMPLETION TIME
A. One required SDC loop inoperable or not in operation.	A.1 Initiate action to restore SDC loop to OPERABLE status and operation.	Immediately
	AND	
	A.2 Suspend operations involving a reduction in reactor coolant boron concentration.	Immediately
	AND	
	A.3 Suspend loading of irradiated fuel assemblies in the core.	Immediately
	AND	
	A.4 Close all containment penetrations providing direct access from containment atmosphere to outside atmosphere.	4 hours

SURVEILLANCE REQUIREMENTS

SURVEILLANCE		FREQUENCY
SR 3.9.4.1	Verify one SDC loop is in operation and circulating reactor coolant at a flow rate of ≥ 1500 gpm.	12 hours

3.9 REFUELING OPERATIONS

3.9.4 Shutdown Cooling and Coolant Circulation-High Water Level

LCO 3.9.4

A: One shutdown cooling loop shall be OPERABLE and in operation.

----------NOTES----------

1. The required shutdown cooling loop may be not in operation for ≤ 1 hour per 8 hour period, provided no operations are permitted that would cause reduction of the Reactor Coolant System boron concentration.

OR

B: One alternate heat removal loop shall be OPERABLE and in OPERATION.

----------NOTES----------

1. The required alternate heat removal loop may not be in operation for ≤ 1 hour per 8-hour period.

2. a. No operations are permitted that would cause a reduction to Reactor Coolant System boron concentration.

   b. All containment penetrations are in the status described in LCO 3.9.3.

APPLICABILITY: Mode 6 with the water level ≥ 23 feet above the top of the irradiated fuel assemblies seated in the reactor vessel.

ACTIONS		
CONDITION	REQUIRED ACTION	COMPLETION TIME
A. One required shutdown cooling loop inoperable or not in operation.	A.1 Initiate action to restore shutdown cooling loop to OPERABLE status and operation.	Immediately
	AND	
	A.2 Suspend operations involving a reduction in reactor coolant boron concentration.	Immediately
	AND	
	A.3 Suspend loading of irradiated fuel assemblies in the core.	Immediately
	AND	
	A.4 Close all containment penetrations providing direct access from containment atmosphere to outside atmosphere.	4 hours

OR

ACTIONS		
CONDITION	REQUIRED ACTION	COMPLETION TIME
B. One required alternate heat removal loop inoperable or not in operation.	B.1 Initiate action to restore alternate heat removal loop to OPERABLE status and operation.	Immediately
	AND	
	B.2 Suspend loading of irradiated fuel assemblies in the core.	Immediately

SURVEILLANCE REQUIREMENTS		
SURVEILLANCE		FREQUENCY
SR 3.9.4.1	A: Verify one shutdown cooling loop is in operation and circulating reactor coolant at a flow rate of ≥ 1500 gpm.	12 hours
	OR	
	B: Verify one alternate heat removal loop is in operation and circulating reactor coolant at a flow rate of ≥ 1200 gpm.	12 hours

Appendix H

RESPONSE TO NRC REQUEST FOR ADDITIONAL INFORMATION DATED OCTOBER 2, 2003

APPENDIX H

REQUEST FOR ADDITIONAL INFORMATION DATED OCTOBER 2, 2003

Main Report

RAI 1. What is a shutdown cooling "train?" Describe the physical setting of the two "trains" mentioned in Sec 2.2 of the text when they are inoperable at the time of the initiation of the alternate heat removal alignment, and when they are supplementing the shutdown cooling system.

Response:

A shutdown cooling (SDC) train is a dedicated flow path consisting of piping, valves, a low pressure safety injection pump and a SDC heat exchanger that provides cooling of the reactor core during shutdown conditions in Modes 4, 5 & 6. Two such shutdown cooling trains constitute the shutdown cooling system installed at licensed plants. A brief description of the shutdown cooling system and the alternate cooling alignment for removing decay heat from the refueling pool during Mode 6 operation is given in Sections 2.1 and 2.2, respectively, of WCAP-15872.

Standard Technical Specifications, e.g., NUREG-1432, LCO 3.9.4, require that one of the two SDC system trains be operable and in operation during Mode 6 conditions with the refueling pool fully flooded. The alternate heat removal (AHR) alignment will function as a complete substitute for the SDC system, thereby permitting the shutdown cooling system to be taken out of service once decay heat removal using the alternate cooling alignment is placed in service. Thereby, AHR promotes outage schedule flexibility when maintaining plant equipment during Mode 6 operations.

The reference to supplementing the SDC system refers to the opportunity for a utility to ensure decay heat removal by having AHR capability available to support normal SDC, either in combination with an operable SDC train, or as stand-by should normal SDC become inoperable.

RAI 2. Is your methodology predicated on the use of the spent fuel pool cooling system as the alternate heat removal system?

Response:

The alternate heat removal system is predicated on use of any appropriate and available cooling system that has adequate heat removal capability, can be aligned to remove heat from the refueling pool, and is judged to be sufficiently reliable. In WCAP-15872, the alternate heat removal alignment is modeled after that of Calvert Cliffs, where a

spent fuel pool cooling train can be used as the alternate system to receive decay heat in Mode 6 with the refueling pool fully flooded.

Appendix A: Algorithm for Natural Convection between Core and Refueling Pool

For the one-dimensional model of the core and refueling pool:

RAI A1. Superimpose the nodalization that your methodology assumes on Fig. A-1. Demonstrate that it is robust.

Response:

The analysis is based on division of the refueling pool and reactor vessel internals into a series of control volumes. The state points for these one-dimensional control volumes are shown in Figure A-1 and identified as follows:

1 = Reactor vessel inlet at the level of the vessel flange.

2 = Core inlet at the level of the fuel alignment plate.

3 = Reactor vessel lower plenum at the bottom of the core.

4 = Core exit at the level of the fuel alignment plate.

5 = Reactor vessel exit at the level of the vessel flange.

6 = Bulk refueling pool.

7 = Alternate cooling inlet to pool.

8 = Alternate cooling exit from pool.

9 = Shutdown cooling inlet.

10 = Shutdown cooling exit.

These state points represent natural boundaries between the control volumes and are consistent with the set of assumptions used to reduce the refueling pool coupled circulation problem to tractable form. The robustness of this model is demonstrated by its close agreement with the test data obtained at Calvert Cliffs.

RAI A2. What are the assumed mass, momentum and energy equations for the related control volumes?

Response:

The one-dimensional model is based on the following general control volume formulations for conservation of mass, momentum and energy:

Conservation of mass,

$$\frac{\partial}{\partial t}\int_{cv} \rho dV + \int_{cs} \rho \vec{v} \cdot d\vec{A} = 0$$

Conservation of energy,

$$\dot{Q}_{CV} - \dot{W}_{CV} - \dot{W}_{SHEAR} + \int_{cv} q''' dV = \frac{\partial}{\partial t}\int_{cv} e\rho dV + \int_{cs}\left(e + \frac{p}{\rho}\right)\rho\vec{v} \cdot d\vec{A}$$

Conservation of momentum,

$$\sum_{CV} \vec{F} = \vec{F}_S + \vec{F}_B = \frac{\partial}{\partial t}\int_{cv} \vec{v}\rho dV + \int_{cs} \vec{v}\rho\vec{v} \cdot d\vec{A}$$

where W_{CV} is mechanical work, W_{shear} is work done by shear and $\dot{Q}_{CV}$ is the heat generation within the control volume.

These equations, based on the following assumptions and expressed in finite difference form, are solved using the algorithm shown in Figure A-2.

Assumptions involving flow through the core:

- Upper guide structure and fuel alignment plate have been removed.
- One-dimensional, steady-state flow with no horizontal cross-flow for vertical flow paths.
- Neglect changes in kinetic and potential energies of the water flowing through the core.
- Neglect any ambient heat loss, $\dot{Q}_{loss} = 0$.
- Heat generation is constant and uniformly distributed throughout the core control volume, $\int_{CV} q''' dV = \dot{Q}_{CV}$
- Work associated with rotating shafts and moving boundaries is zero, $\dot{W}_{CV} = 0$.
- Work due to shear stress is negligible, and shear stress on the surface of the control volume is uniformly distributed, $\tau \neq \tau(z)$.
- Temperature increases with depth for down flow path, $T_2 < T_3$ so that $\rho_2 > \rho_3$.
- Density varies linearly with elevation, $\rho = \rho_2 - \Delta\rho\frac{(z_2 - z)}{L}$, where $\Delta\rho = \rho_2 - \rho_3$, and $L = z_2 - z_3$.
- No heat storage in the fuel.

- The upflow and down flow areas are identical, $A_2 = A_3 = \frac{A_{core}}{2} \equiv A_{1/2\,core}$.
- Heat generation in the core control volume results in an increase in temperature, so that $\frac{\partial}{\partial t}\int_{CV} e\rho\, dV \neq 0$.

Refueling Pool: assumptions:

- One-dimensional, steady-state flow along a streamline.
- Change of momentum within CV, $\frac{\partial}{\partial t}\left[\int_{CV} \bar{V}(\rho dV)\right] = 0$.
- Frictionless flow, i.e., no viscous losses.
- Heat transfer from the pool surface due to natural convection and evaporation, $\dot{Q}_{CV} = -\left[h_\infty A_{surf}(T_6 - T_{amb}) + \dot{m}_{evap} h_{fg}\right]$.
- Neglect kinetic and potential energy changes of the water flowing through the pool. Neglect work due to shear.
- A fraction of the pool water, ε_{mix}, mixes with the core flow.

<u>For one-dimensional flow through the core, shown as flow path 3 – 4 on Figure A-1:</u>
Conservation of mass:

$$\dot{m}_3 = \dot{m}_4 = \rho_3 A_3 v_3 = \rho_4 A_4 v_4$$

Conservation of energy:

$$p_3/\rho_3 + v_3^2/2 + gz_3 = p_4/\rho_4 + v_4^2/2 + gz_4 + K_{34}\bar{v}^2/2$$

Conservation of momentum:

$$-p_4 A_4 + p_3 A_3 - \tau_{34} A_{surf\,34} - g\frac{\rho_3 + \rho_4}{2} A_{1/2core} L_{core} = \dot{m}_4 v_4 - \dot{m}_3 v_3$$

<u>For one-dimensional flow through the pool:</u>
Conservation of mass:

$$\dot{m}_5 = \dot{m}_6 = \rho_5 A_5 v_5 = \rho_6 A_6 v_6$$

Conservation of energy:

$$\varepsilon_{MIX} M_{pool} c_p \frac{d\bar{T}_6}{dt} + \dot{Q}_{surf} = \dot{m}_{core} c_p (T_5 - T_1) - \dot{m}_7 c_p (T_8 - T_7)$$

Conservation of momentum:

$$\frac{p_5}{\rho_5} + \frac{v_5^2}{2} + gz_5 = \frac{p_6}{\rho_6} + \frac{v_6^2}{2} + gz_6$$

The fraction of the alternate heat removal cooling flow that does not mix with the thermal plume is expressed by the bypass coefficient, ε_{bypass}. Thus, the refueling pool exit temperature, T_8, can be expressed in terms of the bypass coefficient, the pool average temperature, T_6, and the alternate heat removal inlet temperature, T_7, as:

$$T_8 = (1 - \varepsilon_{bypass})T_6 + \varepsilon_{bypass}(T_7)$$

When the bypass coefficient is zero, all alternate heat removal cooling flow mixes with the thermal plume, or T_8 equals T_6. If none of the alternate cooling flow mixes with the thermal plume, then ε_{bypass} equals one and the pool exit temperature T_8 equals T_7.

RAI A3. What is meant by "The effective mass is determined by engineering judgment?" How is the numerical value for use in the one-dimensional model computed?

Response:

The effective mass, defined as ε_{mix} times the pool mass, identifies the quantity of fluid in the refueling pool that mixes with the natural convection flow from the core. This mass is determined through CFD analysis when solving for the mixing coefficient. Engineering judgment refers to the review to ensure that predicted results are verified by test data.

RAI A4. What results show that the mixing coefficient $\dot{\varepsilon}_{mix}$ is about 0.90? What are the parameters to which the value of $\dot{\varepsilon}_{mix}$ is most sensitive? What is the sensitivity of $\dot{\varepsilon}_{mix}$ to these parameters?

Response:

The mixing coefficient is described in terms of the initial pool temperature and the pool average temperatures from one-dimensional and CFD computations. Since the mixing coefficient influences the rate of temperature change in the one-dimensional model, it was necessary to use a transient CFD case to evaluate ε_{mix}. For a refueling water pool cooling configuration typical of CCNPP but having no alternate cooling flow, the mixing coefficient was evaluated based on the time required for the average pool temperature to reach saturation as determined by the CFD model. Table D-3 illustrates the time required to reach the boiling point for three different pool elevations and the associated mixing coefficient as predicted by the CFD model. Based on this data, a mixing coefficient of 0.9 was selected as the best representative value for use in one-dimensional analyses.

The principal parameters affecting the mixing coefficient are the refueling pool cooling configuration and the mass flow rate driven by natural circulation between the core and the refueling pool. No alternate heat removal cooling flow was assumed when computing the mixing coefficients given above, which ensures conservative results for all alternate heat removal cooling configurations. In addition, parametric evaluations using the one-dimensional model based on arbitrary variations of the mixing coefficient did not produce significant variations in pool temperature or core flow rate.

With regard to the sensitivity of these parameters, based on the alternate heat removal conditions at Calvert Cliffs, an arbitrary reduction in core flow rate of 20% resulted in about a 10% reduction in the mixing coefficient. Also, for the same core flow rate, the mixing coefficient was found to vary approximately ± 5% when based on average temperatures at specific locations rather the entire refueling pool.

A typographical error was found in Table D-3. The temperatures shown in the column labeled "Bottom" should read 874°F, 212°F and 215.5°F, respectively. The CFD value for ε_{mix} should be 1.03, while the one-dimensional value for ε_{mix} is 1.0. Table D-3 has been revised to show these corrected values.

RAI A5. How is the value of the by-pass fraction $\dot{\varepsilon}_{bypass}$ computed? What "results show" that $\dot{\varepsilon}_{bypass}$ is close to 1.0? How close? What is the sensitivity of $\dot{\varepsilon}_{bypass}$ to key parameters?

Response:

The by-pass coefficient is defined in terms of mass flow rates and is computed using the expression for ε_{bypass} shown in Section D-2. Mass flow rates, in turn, are determined from pool temperatures predicted by the CFD model. For the Calvert Cliffs configuration modeled in this analysis and represented by Configuration A in Table D-2, results demonstrate that the value of the bypass coefficient is approximately zero for alternate heat removal cooling flow rates varied from 200 to 2000 gpm.

Table D-2 also shows that the value of the bypass flow coefficient depends strongly on the refueling pool configuration, specifically the relative locations of the inlet and outlet for the alternative cooling flow. Comparing configurations A and B, it is seen that a factor of ten difference in alternate cooling flow rate has a minor impact on the bypass coefficient when the coolant flow interacts with the natural convection plume from the reactor core, whereas configurations with the inlet and outlet on the same side of the pool have significant differences in the bypass coefficient. A similar result is seen when comparing configurations C and D, although computations indicate substantial entrainment of the pool water by the alternate cooling flow occurs for large flow rates in configuration C.

RAI A6. Are $\dot{\varepsilon}_{bypass}$ (in the equations) and β (Table A-1) the same coefficient?

Response:

The terms ε_{bypass}, β, and β_{bypass} as used in WCAP-15872 Rev 00 are the same coefficient. For consistency, the term "ε_{bypass}" is used to define the bypass coefficient in these RAI responses and in any revisions made to WCAP-15872.

RAI A7. Please show the derivation of the values of $\dot{\varepsilon}_{mix}$ and $\dot{\varepsilon}_{bypass}$ used in the results shown in Figs. A-3 and A-4 for Case 2 and Case 3.

Response:

The mixing and bypass coefficients are defined in Appendix A and derived as shown in Appendix D. However, for the results shown in Figure A-3 and Figure A-4, these coefficients were assumed well mixed, i.e., ε_{mix} =1.0 and all alternate heat removal flow fully mixed with the natural convection flow from the core, ε_{bypass} = 0.0. In Appendix A, Case 2 represents full SDC flow plus alternate cooling flow; Case 3 represents only alternate cooling flow. (Note that sample Cases 1 – 4 in Appendix A are not the same as test Cases 1 – 4 listed in Appendices B, C and D.)

Appendix B: Comparison of Predictions with Test Data

RAI B1. Fig. B-1 is confusing. Under the alternate cooling alignment do you have a separate spent fuel pool (SFP) pump and heat exchanger for both the refueling pool and the SFP, or do these represent separate alignments? Please indicate the complete flow paths of fluid associated both with the refueling pool and core, and the SFP. In your figure, how and when do you get flow "from the refueling pool to the spent fuel pool?"

Response:

Figure B-1 illustrates the specific alternate heat removal alignment at CCNPP. The figure describes the capability to align a "spare" spent fuel pool cooling train to cool the refueling pool while a second train remains aligned to the site's spent fuel pool.

The complete alternate heat removal process fluid flow path at Calvert Cliffs is where heat from the core exchanges with the refueling pool through natural convection, then forced flow from the pool through a train of the spent fuel pool cooling system (pump, heat exchanger and piping). The discharge from this alternate cooling alignment flow path is then returned to the refueling pool.

The statement in Section B.1, "The suction from the refueling pool to the spent fuel pool cooling line is through a drain in the bottom of the refueling pool, at the side of the pool opposite the inlet point," refers to the alternate heat removal alignment at Calvert Cliffs.

In this alignment, major components (pump, heat exchanger, piping) from one train of the spent fuel pool cooling system are cross-connected to suction and discharge fittings in the Calvert Cliffs refueling pool. A direct exchange of coolant between the spent fuel pool and the refueling pool is not relied upon to support the alternate heat removal process.

The actual configuration of the alternate cooling alignment implemented at other plants may vary depending upon the available plant equipment capabilities. Refer also to Figure 1 of WCAP-15872 which illustrates a generic shutdown cooling decay heat removal system, and to Figure 2 which illustrates the decay heat removal flow path when using the Alternate Heat Removal process. A different alternate heat removal alignment may be selected by other plants, depending on the heat removal loops available to cool the refueling pool. The alternate heat removal process does not envision altering the traditional method of cooling the spent fuel pool.

RAI B2. In Table B-1, what is "SW?"

Response:

The term "SW" refers to Service Water. This term is included in an updated acronym list for WCAP-15872.

RAI B3. You report average temperatures. These are averaged over what?

Response:

Temperatures given in Table B-1 are averaged over times recorded for the tests.

RAI B4. Table B-2, B-3 and B-4 report time in days, hours and minutes respectively. Also, the figures use two different time scales. Please resubmit for review all tables and figures based on one time scale. (If there is a specific reason, such as clarifying a relationship, state so.)

Response:

Time scales in Tables B-2, B-3 and B-4 are expressed in terms of clock time, total elapsed time and time in days after shutdown in order to expediently illustrate a particular result. For example, an event having a duration of minutes is not easily illustrated if expressed using a time-scale of days. Total elapsed time is used to compare measured and predicted values, while days after shutdown is the important parameter for tracking the point at which changes such as initiation and securing of shutdown cooling, head removal, initiation and securing of alternate cooling, and return to shutdown cooling occur.

RAI B5. Please give a table describing the physical conditions associated with each of the five cases. That is, for each of the five cases, give the initial and final time and the corresponding initial, final and average shutdown cooling and SFP temperatures (computed and measured), flows and core decay powers. For average values, give the explicit method by which they were computed.

Response:

The physical conditions, time, and temperatures associated with the test cases listed in Table B-3 are given below. The reactor is in Mode 6 with the refueling pool fully flooded for Cases 2 - 5.

Case 1: SDC flow reduced while the reactor vessel head is removed.

Case 2: SDC flow restored to value prior to head removal.

Case 3: AHR flow initiated, SDC flow continued.

Case 4: SDC flow secured, AHR cooling only.

Case 5: SDC flow restored, AHR flow secured.

Case	Event Date and Time	DAS (Days)	Analysis Time		Temperature (°F)				
			Start-hr	End-hr	SDC-in	SDC-out	AHR-in	AHR-out	RFP
1	03/23/01, 04:30	5.75	0	11	73.58	102.90	NA	NA	NR
2	0323/01, 15:30	6.21	11	285	92.01	102.73	NA	NA	NR
3	04/03/01, 22:00	17.62	285	298	99.00	103.30	92.03	96.78	101.30
4	04/04/01, 13:00	18.21	298	348	NA	NA	78.16	92.95	99.26
5	04/07/01, 13:40	20.49	348	375	96.72	102.89	NA	NA	NR

The purpose of Table B-3 is to document measured temperatures with their corresponding times. Table B-4 lists the analysis times used for predictions corresponding to Cases 1 - 4 in Table B-3.

Time histories of the data for each of these cases are documented in Figures B-3 (SDC flow and temperatures), B-4 (AHR temperatures and flow rate) and Figure B-5 (RFP temperatures). Predictions for Cases 2, 3 and 4 are shown in Figure B-6.

Appendix C: Comparison of CCNPP Unit 2 Test Data with Computational Fluid Dynamics (CFD) Predictions

RAI C1. For these calculations, please show the natural circulation flow path in the core region. Is that how is the core cooled?

Response:

Decay heat is transferred from the core to the refueling pool through natural circulation. While this heat removal is not dependent on the direction of the circulatory pattern through the core, good agreement between fluid temperatures based on the CFD analysis and the Calvert Cliffs test data at the reactor vessel flange elevation was predicted assuming a natural circulation path with down-flow in the center of the core and up-flow at the core periphery. This flow pattern was found to best represent the post-refueled conditions, where fresh fuel occupies a checkerboard arrangement in the core center, which existed during the alternate heat removal test phase at Calvert Cliffs.

RAI C2. The results from the lumped parameter model (core flow rate) are dependent on $\dot{\epsilon}_{mix}$ and $\dot{\epsilon}_{bypass}$. These two coefficients are determined via a CFD calculation. How does the CFD calculation of $\dot{\epsilon}_{mix}$ and $\dot{\epsilon}_{bypass}$ differ from the CFD calculation in this appendix?

Response:

The CFD evaluations of Appendices C and D are based on parameters for the CCNPP refueling pool/reactor cavity geometry. Appendix C contains an evaluation of the specific flow and temperature fields associated with the CCNPP flow alignment (similar to Configuration A of Appendix D) at the initial and boundary conditions associated with the CCNPP Unit 2 test data. Appendix D contains the evaluation of the heat removal capabilities of permissible flow alignments and includes the evaluation of the mixing and bypasses coefficients for each alignment. As such, Appendix C represents a validation of the CFD computations and the application of the mixing and bypass coefficients from Appendix D into the lumped parameter model which computes the core flow rate. Small changes in the initial and boundary conditions associated with the CCNPP2 test data, including a lower alternate cooling flow rate, do not substantially alter the computed mixing and bypass coefficients presented in Appendix D. Thus, the methods used to calculate the mixing and bypass coefficients given in Appendix C are the same as those for the remainder of WCAP-15872.

RAI C3. Is the CFD calculation in this appendix a steady-state calculation?

Response:

The CFD computations are steady state based on the observation that the refueling pool is in a quasi-steady state condition for the purposes of Appendix C.

RAI C4. The data appear to show no temperature gradient at the flange level, while the CFD calculation shows a distinct gradient. Your proffered explanation in paragraph eight is not clear. Please provide a drawing indicating the flows and temperatures that support your argument.

Response:

The application of a rectangular Cartesian grid to represent a cylindrical reactor vessel cavity accentuates local temperature differences when comparing CFD temperature predictions with thermocouple data at the flange level. Pool temperature data from CCNPP Unit 2 were taken in four strings starting just above the reactor vessel flange; these thermocouples are radially near, but not necessarily in, the rising thermal plume. The corner cells just above the reactor cavity and within the computed thermal plume are the closest representations in the CFD model to these thermocouple locations. As a consequence, the average temperature of the four computational cells would be expected to be higher than the average of the test data. This rationale is confirmed in Table C-1 where the average CFD temperature exceeds the data by only 3.6°F at the 44-ft elevation. The average temperatures are much closer at the mid-pool and pool-surface elevations since the CFD model can better represent the global turbulent diffusion and convective diffusion.

The horizontal temperature gradients at the flange level are more pronounced as a consequence of the rectangular grid approximation to the circular reactor cavity opening at the flange. The rectangular grid causes a more pronounced channeling of pool currents around the flange opening than might be expected from currents around a circular flange opening. As shown in Figure C-6, the channeling of current is evident as longer velocity vectors passing one side of the flange opening in the velocity distribution of the horizontal plane just above the flange. In turn, the enhanced channeling promotes a somewhat larger temperature difference between opposite sides of the flange, as evident in the temperature distribution in the horizontal plane just above the flange and seen in Figure C-3.

Both of these effects are localized at the reactor cavity opening. The turbulent thermal diffusion and convective diffusion of the thermal plume into the bulk refueling pool are otherwise well represented and indicated by the good agreement in temperatures at higher elevations.

RAI C5. How is the difference in mixing, described in C4 above, taken into account in your estimate of $\dot{\epsilon}_{mix}$?

Response:

The pool mixing coefficient is defined in terms of pool average temperatures. The impact of localized currents is accurately represented in the global mixing although the localized temperature results may not precisely correlate with the CCNPP data in the flange area.

Appendix D: Evaluation of Alternative Heat Removal Alignments

The key to your methodology is the estimation and validation of the mixing and bypass coefficients. Please define your terminology clearly; indicate the type of calculation and the results precisely so that the comparisons are clear.

RAI D1. Please describe the simplified one-dimensional computational model and its relation to the two-dimensional computational fluid dynamics model. How does it differ from the one-dimensional model discussed in Appendix A? When you say "computational fluid dynamics model" (without the adjective "one-dimensional") in D.3, what are you referring to - A 3D model? Figures D-3 through D-6 give 2D results. So, how are you treating the situation in Figure D-2?

Response:

The mixing and bypass coefficients reflect three-dimensional effects into the one-dimensional analysis, shown in Appendix A, for natural circulation flow rates and refueling pool temperatures. The mixing coefficient is a measure of the uniformity of the refueling pool temperature, while the bypass coefficient, represented schematically in Figure D-2, is an indicator of the flow rate from the alternate cooling alignment that bypasses the natural circulation plume from the core.

Predictions of refueling pool temperatures using the three-dimensional CFD model, described in Appendix C, are then used to calculate both mixing and bypass coefficients. These values are then used in the one-dimensional model. Final values are selected based on agreement between the one-dimensional predictions, the CFD analysis results, and the data.

RAI D2. You say "The one-dimensional evaluations based on perfect mixing ... are summarized in Table D-2," yet you show bypass flows that are not one-dimensional. In Table D-3 what is your point? The table indicates that the mixing coefficient is spatially dependent (given at different locations). How can that be when it is defined on page D3 in terms of pool average temperatures?

Response:

The statement referring to perfect mixing ($\varepsilon_{mix} = 1.0$) and all alternate cooling flow passing over the core ($\varepsilon_{bypass} = 0.0$) are assumptions used in the one-dimensional scoping analysis shown in Appendix A.

The mixing coefficient is defined in Appendix D in terms of the initial pool temperature and the pool average temperatures from one-dimensional and CFD computations. A number of CFD cases were run to evaluate the range of the mixing coefficient since the mixing coefficient influences the rate of pool temperature change in the one-dimensional

model. Results for the case selected to best represent the mixing coefficient are reported in Table D-3. In that table, a one-dimensional model with the mixing coefficient set equal to 1.0 establishes a time, 886 minutes, when the pool average temperature reaches saturation. By interpolation, the equivalent time predicted by the CFD model to achieve a pool average temperature of saturation is 851 minutes, which reasonably agrees with the one-dimensional prediction. Results of the CFD model at other times, which correspond to reaching the saturation temperature at an elevation representing the core exit, the free surface, and the bottom of the refueling pool are also shown in the table. For these locations, the mixing coefficient was found to be 0.88, 0.98, and 1.03, respectively, from which a representative value of 0.90 was selected for use in one-dimensional analyses.

Appendix E: CCNPP Specific Evaluation of Conditions for Alternate Decay Heat Removal in Mode 6

RAI E1. In section E.1, your discussion of Figure E-3 is inconsistent with the text. The text indicates that the initial refueling pool temperature is 75°F, while the value in the figure at t = 0 is 90°F.

Response:

The initial temperature of the refueling pool was taken as 90°F in the analysis. Page E3 of Appendix E has been corrected to be consistent with Figure E-3.

RAI E2. Where are the data that reflect the last statement on page E3? What is the basis for the "expected" high and low limits?

Response:

The statement concerning expected high and low limits is not needed and has been deleted.

RAI E3. What is the purpose of footnote 1 on page E4? Where and what is Reference 6.1?

Response:

The footnote was meant to reference standard methods used to determine heat exchanger effectiveness and outlet temperatures. This footnote and reference are not needed and have been deleted.

RAI E4. In the paragraph Limiting THS vs. TAS on page E4, Figure E-5 does not show a family of curves. What do you mean by a 90°F heat sink temperature when the refueling pool inlet temperature in also 90°F?

Response:

The statement has been corrected to refer to Figure E-4, not E-5. Figure E-5 is a cross-plot of the data shown on Figure E-4. The heat sink statement refers to the temperature of the heat sink for heat removal, which in this case is the inlet temperature to the spent fuel pool heat exchanger.

RAI E5. The time scale of minutes on the x-axis of the figures is inappropriate for the phenomena described on the figure. Please submit a revised figure that uses a consistent time scale (see Appendix B, Question B4).

Response:

The different time scales reflects differences in the information represented in the figures. For example, Figures E-1, E-3, E-5 and E-7 reflect the influence on the days after shutdown on the value of decay heat assumed in the subsequent analyses. Figures E-2, E-4 and E-6, reflect the time, the order of magnitude being minutes, for the refueling pool temperature to reach a new steady state value after the noted changes in operating conditions. Thus, the time scales selected are appropriate to the information represented and do not warrant changes to the report.

RAI E6. What is Reference 6.4 which gives the CFD analysis that establishes the maximum fluid velocity for the computation of the force on the fuel assembly?

Response:

The reference was for the CFD analysis and is not needed. This reference has been deleted.

RAI E7. How do you get from a one-dimensional model the flow rate in the core for a lateral velocity of 0.22ft/sec in the refueling pool? The precision is astounding!

Response:

The velocities were taken from the CFD analysis and are representative of the magnitude of lateral velocities that could be expected. The text has been revised to state that the velocity is approximately 0.2 ft/sec.

WCAP-15872-NP-A, Revision 0

Westinghouse Non-Proprietary Class 3

Westinghouse Electric Company, LLC
20 International Drive
Windsor, Connecticut 06095