# CATEGORY 1

REGULATORY INFORMATION DISTRIBUTION SYSTEM (RIDS)

ACCESSION NBR:9710200108 DOC.DATE: 97/10/14 NOTARIZED: YES DOCKET #
FACIL:50-261 H.B. Robinson Plant, Unit 2, Carolina Power & Light C 05000261
AUTH.NAME AUTHOR AFFILIATION
WILKESON,T.M. Carolina Power & Light Co.
RECIP.NAME RECIPIENT AFFILIATION
Document Control Branch (Document Control Desk)

See EMF-94-157
EMF-94-157(P)

SUBJECT: Forwards response to request for addl info re switchover of emergency core cooling sys from injection to recirculation phase.Non-proprietary EMF-94-157 & proprietary EMF-94-157(P) repts encl.Proprietary rept withheld,per 10CFR2.790.

DISTRIBUTION CODE: AP01D COPIES RECEIVED:LTR 1 ENCL 1 SIZE: 21+72
TITLE: Proprietary Review Distribution - Pre Operating License & Operating R

NOTES:

| | RECIPIENT ID CODE/NAME | COPIES LTTR | COPIES ENCL | RECIPIENT ID CODE/NAME | COPIES LTTR | COPIES ENCL |
|---|---|---|---|---|---|---|
| | PD2-1 LA | 1 | 1 | PD2-1 PD | 1 | 1 |
| | MOZAFARI,B | 1 | 1 | | | |
| INTERNAL: | FILE CENTER 01 | 1 | 1 | OGC/HDS3 | 1 | 0 |
| EXTERNAL: | NRC PDR | 1 | 1 w/out prop | | | |

C A T E G O R Y 1 D O C U M E N T

NOTE TO ALL "RIDS" RECIPIENTS:
PLEASE HELP US TO REDUCE WASTE. TO HAVE YOUR NAME OR ORGANIZATION REMOVED FROM DISTRIBUTION LISTS OR REDUCE THE NUMBER OF COPIES RECEIVED BY YOU OR YOUR ORGANIZATION, CONTACT THE DOCUMENT CONTROL DESK (DCD) ON EXTENSION 415-2083

TOTAL NUMBER OF COPIES REQUIRED: LTTR 6 ENCL ~~4~~ 5

**CP&L**

**Carolina Power & Light Company**
Robinson Nuclear Plant
3581 West Entrance Road
Hartsville SC 29550

Robinson File No: 13510
Serial: RNP-RA/97-0208
OCT 14 1997

United States Nuclear Regulatory Commission
Attn: Document Control Desk
Washington, DC 20555

H. B. ROBINSON STEAM ELECTRIC PLANT, UNIT NO. 2
DOCKET NO. 50-261/LICENSE NO. DPR-23
RESPONSE TO REQUEST FOR ADDITIONAL INFORMATION REGARDING SWITCHOVER OF THE EMERGENCY CORE COOLING SYSTEM FROM INJECTION TO RECIRCULATION PHASE

Gentlemen:

By letter dated August 26, 1997, the NRC requested that H. B. Robinson Steam Electric Plant (HBRSEP), Unit No. 2 provide information to justify the implementation of an emergency procedure that allows operators 30.5 minutes to complete the transfer from the injection phase of the Emergency Core Cooling System (ECCS) to the recirculation phase with respect to the effects that thermal cycling would have on the fuel cladding, and, particularly, criterion (4) of 10 CFR 50.46. The NRC further requested that a discussion, results, and references to cladding performance tests or experiments to support this action be provided.

Implementation of the procedure was supported, in part, by a Siemens Power Corporation (SPC) analysis described in the report, EMF-94-157(P), "Robinson Unit 2 Extended Transfer to Cold Leg Recirculation Following a Large Break LOCA," September 1994. This analysis report, and a non-proprietary companion document are enclosed. SPC considers the information in EMP-94-157(P) to be proprietary because it reveals certain distinguishing aspects of the SPC licensing methodology which secure competitive advantage to SPC for fuel design and methodology. It is requested that EMP-94-157(P) be withheld from public disclosure in accordance with 10 CFR 2.790; an affidavit from SPC in support of this request is enclosed.

The attached discussion provides the information requested by the NRC.

A001

change: Ltr encl
PDR | 1 w/o prop.

If you have any questions concerning this matter, you may contact me or Mr. H. K. Chernoff of my staff.

Very truly yours,

Terry M. Wilkerson

T. M. Wilkerson
Manager - Regulatory Affairs

JSK/jk
Attachment
Enclosures

c: Mr. B. B. Desai, USNRC Senior Resident Inspector, HBRSEP
Ms. B. L. Mozafari, USNRC Project Manager, HBRSEP
Mr. L. A. Reyes, Regional Administrator, USNRC, Region II

H. B. Robinson Steam Electric Plant, Unit No. 2
Response to Request for Additional Information Regarding Switchover of the Emergency Core Cooling System From Injection to Recirculation

Table of Contents

H. B. Robinson Steam Electric Plant, Unit No. 2
Response to Request for Additional Information Regarding Switchover of the
Emergency Core Cooling System From Injection to Recirculation

## 1.0 Event Description

During a postulated LBLOCA, primary Reactor Coolant System (RCS) pressure rapidly decreases as significant coolant inventory is lost through the limiting break; for HBRSEP, this is a 0.8 Double Ended Cold Leg Guillotine (DECLG) break. RCS inventory is partially made up by the flow from Safety Injection (SI) pumps until primary pressure drops below 600 psia at which point the accumulators discharge into the RCS. As pressure further decreases, the Residual Heat Removal (RHR) pump shutoff head of 130 psia reached, at which time the RHR pumps begin delivering flow. During the time when RCS pressure is decreasing, containment pressure is increasing due to RCS inventory and energy being discharged into containment, and containment spray is used to control containment pressure. During this time, the Emergency Core Cooling System (ECCS) pumps are taking suction from the Refueling Water Storage Tank (RWST), and the LBLOCA analysis of record indicates that these systems, including effects of single failure assumptions, will successfully mitigate the initial blowdown portion of the LOCA event by reflooding the core and keeping it covered.

Once the core has been reflooded, and while the RWST inventory lasts, the core and system conditions become relatively stable, with a steadily decreasing RCS pressure and core decay heat on the decline. This condition closely matches the conditions modeled by Small Break LOCA (SBLOCA) evaluation models, where the sources of water supply can keep up with the mass flow rates of the break, but allow the RCS pressure to decay. In the case of the LBLOCA, the RWST inventory will eventually be exhausted, requiring a switchover from RWST suction to containment sump suction. At HBRSEP, with the assumption of early Containment Spray (CS) actuation and maximum CS flow, depletion of the RWST may occur about 21 minutes after initiation of the LBLOCA event. During the switchover of the RHR pumps to the sump, only one SI pump is assumed to be drawing suction from the RWST. Thus, during switchover, a situation reoccurs where the large break flow exceeds the capacity of the SI pump, and core uncovery again becomes an issue. In the specific case of HBRSEP, procedure End Path Procedure (EPP) - 9, "Transfer to Cold Leg Recirculation," Revision 19, allows 30.5 minutes to perform the various valve alignments necessary to supply sump suction to the RHR pumps, while the limiting LBLOCA break size leads to the beginning of a second fuel heatup at about 21 minutes into this 30.5 minute period.

While these two phases are part of the same event, conservative assumptions have been made for the modeling of each phase separately. For instance, single failure assumptions during the initial blowdown phase involve a failure which prevents some pump(s) from delivering replacement inventory to the RCS. However, for the switchover analysis, it is conservatively assumed that the maximum number of pumps have been running as long as possible during the early part of the event to deplete the RWST as quickly as possible. This provides the maximum amount of decay heat, and therefore, the fastest inventory boil-off in the RCS, during the switchover. Initiating the single failure at the time of switchover, instead of immediately during the blowdown removes the possibility of running a second SI pump to maintain inventory, and allows only one RHR pump to return to service after alignment, conservatively limiting the rate of RCS inventory makeup.

## 2.0 Description of Switchover Analysis

The Large Break Loss of Coolant Accident (LBLOCA) analysis with a switchover to recirculation is a composite of two methodologies which models two distinct phases of one event. The switchover analysis described in Reference 2.3.1 is a continuation of the LBLOCA analysis. It was performed to confirm that the second core heat-up does not exceed the acceptance criteria specified in 10 CFR 50.46. The analysis is based on SPC's SBLOCA methodology, as described below.

### 2.1 Methodology

The transfer to cold-leg recirculation occurs about 21 minutes after the initial core heat-up and recovery of RCS inventory by the ECCS system in the LBLOCA. When the RHR pump is turned off to perform the transfer of the pump suction from the RWST to the containment sump, the only water being delivered to the core comes from a single SI pump. If the break flow exceeds the SI pump capacity a slow boil-off of the core inventory will occur. This boil-off may lead to core uncovery. The mechanisms which come into play during this phase of the LBLOCA are similar to those which determine the outcome of the SBLOCA.

The SPC SBLOCA methodology (i.e., Reference 2.3.2) is used to perform the evaluation of the switchover phase of the LBLOCA. The SBLOCA methodology is limited to breaks which have a flow area less than 10% of the cold leg flow area. The limitation was imposed to prevent use of the SBLOCA model to evaluate the blowdown portion of the LBLOCA scenario. At the time that switchover occurs, the break size is no longer a determining factor, and the event behaves very much like the SBLOCA during the period following loop seal clearing. The SPC system response code, ANF-RELAP, is a proprietary version of RELAP5/MOD2, which was developed by Idaho National Engineering Laboratory (INEL) for use in evaluating LOCAs. The major difference between this LBLOCA switchover phase and an SBLOCA is that the switchover event is evaluated at very low pressures (i.e., approximately 25 psia) compared to the higher pressures (i.e., >200 psia) which are typical of SBLOCA analysis. Since the LBLOCA switchover and the SBLOCA condition after loop seal clearing are both slow boil-off analyses, with some steam condensation in the steam generators, the controlling mechanisms are water properties and, to a lesser extent, heat transfer to the steam generator tubes. ANF-RELAP has water property tables and heat transfer tables which extend into the range of interest for the switchover analysis. Because of the similarity of the modeling requirements for this event to those of the SBLOCA, and because of the insensitivity of this portion of the event to break size, use of the SBLOCA methodology to evaluate the switchover is acceptable.

The limiting single failure assumption for the initial blowdown portion of the HBRSEP LBLOCA is the loss of a single SI pump. To ensure conservatism, the single failure assumed for the switchover portion of the LBLOCA was the loss of a diesel generator at the time switchover was initiated. This limited RCS makeup to only one SI and one RHR pump during and after the switchover.

SBLOCA methodology uses the following three computer codes:

RODEX2, which is used to calculate fuel temperatures, fission gas release and gap conductance;

ANF-RELAP, which is used to model the system responses; and

TOODEE2, which is used to calculate the cladding temperature and oxidation levels based on the boundary conditions provided by ANF-RELAP.

### 2.1.1 LBLOCA Model

Since the LBLOCA, as analyzed using the SPC LBLOCA methods, has occurred significantly prior (i.e., 21 minutes) to the period of interest, the primary input from the initial LBLOCA analysis provided to this event is the state of the RCS inventory (i.e., collapsed liquid level in the core and general thermal/pressure characteristics of the statepoint) and the state of the fuel rods regarding oxide thickness and burst condition, as applicable.

The LBLOCA analysis, per se, covers about the first three and one half minutes of the event. During this period, the cladding undergoes a rapid heat-up to around 2,000°F (the analysis in Reference 2.3.3 reports a Peak Cladding Temperature (PCT) value of 2064 °F). The heating ramp rates at a ruptured node during this phase are about 10 - 15°F/sec on the average, but approach 30°F/sec near the peak temperature. This temperature increase is terminated by moisture carried up to the Peak Cladding Temperature (PCT) elevation by the steam flow through the core. Once the peak temperature is reached, a subsequent cooldown continues through the same mechanism of steam/moisture carryover from the lower regions of the core. As a result, the cool-down is relatively gradual, with the cool-down rates not being appreciably faster than the heat-up rates had been. When the PCT node is not the rupture node, the heat-up and cool-down rates are usually substantially lower.

Following the first three and one half minutes, the ECCS flow (i.e., RHR, SI and accumulators combined) fills the downcomer of the vessel and raises the mixture level in the core until it is completely quenched.

During the initial blowdown of the primary system, the majority of the primary inventory is lost in about 20 seconds, and the mechanical forces exerted on the fuel rods are at their highest. The peak flow rates for the core mid-plane occur quite early, with flows reaching as high as 18,000 lbm/sec.

Subsequent to the LBLOCA analysis reported in Reference 2.3.5, the PCTs for the LBLOCA were evaluated for the impact of changing the heat transfer coefficient during the reflood phase of the event. These evaluations showed that the PCT for the initial blowdown portion of the LBLOCA analysis would remain below 2,200 °F. As discussed above, the results of the switchover phase of the analysis is not sensitive to the initial blowdown PCT (except for the secondary effect of the small changes that a short duration, but slightly higher PCT might have on the oxide thickness at the interface between the LBLOCA and SBLOCA model), so the switchover analysis was not re-performed to evaluate the potential consequences of this LBLOCA model change in detail.

### 2.1.2 Modeling for Switchover Analysis

The switchover analysis begins at the end of the LBLOCA analysis. Using ANF-RELAP, the statepoint conditions from the LBLOCA analysis at the point just prior to the initiation of switchover are simulated with both the SI and RHR running. The switchover is initiated by terminating the flow from the RHR system. The event is simulated for both the Middle of Cycle (MOC) and End of Cycle (EOC) core axial power shapes. A Beginning of Cycle (BOC) chopped cosine shape is not considered since having the power lower in the core than these top peaked distributions will not produce a significant challenge to acceptance criteria. After about 20 more minutes, a total of 41 minutes following the initiating LBLOCA event, the core begins to uncover again at the peak power point, i.e., 8.75 feet for the MOC power shape and 9.72 feet for the EOC shape. The core continues to heat-up for another 10 minutes.

TOODEE2 models the fuel rod heat-up. The oxidation of the peak rods and the rupture blockage corresponding to the LBLOCA analysis of record, the LBLOCA analysis from Reference 2.3.5 for the switchover analysis performed in Reference 2.3.1, are used in the TOODEE2 model to reflect that the core has already undergone a LBLOCA.

During this phase of the LBLOCA, the mechanical loads on the core are significantly lower than they were for the blowdown portion of the event. The maximum mass flow out of the break at this stage in the scenario is approximately 500 lbm/sec. This is approximately 3% of the flow at the core mid-plane during the blowdown.

The hot rod has already ruptured during the initial LBLOCA phase. A conservatively high strain and bulge/blockage model is used in the TOODEE2 modeling of the rod. The blockage has little effect on the heat transfer and PCT during the switchover heatup, but the increased strain results in a larger portion of the cladding being subject to metal-water reaction on both sides of the clad. The amount of oxidation, and the maximum PCT are both increased by allowing the metal-water reaction to occur over this large area.

### 2.1.3 Modeling Conservatisms

The modeling of this event incorporates appropriate conservatism in accordance with by 10 CFR 50, Appendix K.

The decay heat is consistent with the American Nuclear Society (ANS) Standard 5.1, "Proposed ANS Standard - Decay Energy Release Rates Following Shutdown of Uranium-Fueled Thermal Reactors," with 20% augmentation. By using the plus 20% decay heat added to the ANS 5.4 correlation, the boil-off rate during switchover is increased from approximately 60 lbm/sec to about 75 lbm/sec. With the 45 lbm/sec SI makeup flow used in the analysis, the RCS inventory "deficit" of 15 lbm/sec is increased to about 30 lbm/sec by this 20% decay heat addition. This shows that the additional 20% decay heat reduced the realistically expected time to core uncovery, and beginning of the second heatup, by about one half. Nevertheless, the conservative ANS 5.1 plus 20% decay heat was used as conservatism.

The axial power shapes are highly top-peaked, while in actuality the decay heat would be much more uniformly distributed over the core length. While decay heat is generally located in the areas of maximum power generation prior to shutdown, the 10 CFR 50, Appendix K conservative assumptions for power shape artificially peaked both parameters in the conservative (i.e., maximum PCT) direction. More realistic power and decay heat axial profiles, even using the same peak Linear Heat Generation Rate (LHGR), would result in lower PCTs due to the more effective steam/moisture carryover from the lower regions of the core.

No axial heat transfer is used. Realistically, axial heat transfer out of the hot nodes in such an extremely top peaked power distribution would have enhanced the cooling of the hot rod and at the PCT location, and thus reduced the calculated PCT. The axial conductivity of the metal clad was neglected in the analysis.

The inventory in the reactor vessel is modeled such that it is conservatively low at the beginning of the switchover. At the end of the LBLOCA analysis, the downcomer level corresponds to the bottom of the cold leg piping. When the analysis was re-started with the SBLOCA ANF-RELAP model, the downcomer level was initialized by the code at a somewhat lower level, even though collapsed liquid level in the core was preserved. The SBLOCA model for the upper downcomer tends to mix the steam flow from the core with the water at the top of the downcomer, and to carry this mixture out through the break. This results in a conservatively low total inventory for overall equivalent initial conditions at the interface between the LBLOCA and SBLOCA models. At the fixed boil-off rate governed by the decay heat, the core water level at which heatup begins is therefore reached sooner.

The time at which switchover is begun is conservatively short. As a deliberate conservatism, the single failure for the switchover portion of the analysis was not assumed to occur until after all pumps and containment sprays had emptied the RWST to approximately 27% volume. This contrasts with the single failure assumed in the initial LBLOCA portion of the event which acted to reduce the makeup to the RCS from the RWST, to ensure that the maximum loss of RCS inventory and earliest uncovery of the fuel occurred.

A conservatively low RHR capacity was used. At the time this analysis was performed, the single RHR pump flow used in the LBLOCA analysis was set to 45 lbm/sec, consistent with the assumption that the minimum circulation flow path remained open, and that there was no branch line flow balancing between the intact and broken loops. This was an insignificant, but conservative, assumption for the initial LBLOCA portion of the event since this portion of the event is not sensitive to SI flow. In carrying over this conservatively low RHR flow to the switchover phase, the time at which the core uncovers and the time at which the second heatup begins are minimized, and thus the maximum uncovery/PCT is calculated. The current approved SPC methodology and input value selection, if this analysis were to be repeated with today's methods and plant description, would require the modeling of the RHR input to three loops based on system pressure in each cold loop, and spilling of the SI flow into the broken loop. Also, the EPP-9 procedure requires closure of the minimum circulation line as one of its early "Critical Steps" to accomplish in the switchover portion of the LBLOCA event. These "Critical Steps" are to be accomplished before terminating LHSI and beginning the sump suction valve lineups. When analyzed on a scoping basis, the difference in flow (i.e., 45 lbm/sec vs. expected flow of almost 70 lbm/sec) is enough to move the beginning of the core heat-up out in time from approximately 21 minutes into the realignment phase, to greater than 30.5 minutes into switchover, which would eliminate any significant second heat-up.

#### 2.1.4 Interface of the Switchover Analysis

The two methodologies used to evaluate the LBLOCA and the switchover to the containment sump recirculation mode are significantly different. The only interfaces between them are in the initial conditions assumed for the vessel inventory and for the condition of the fuel rods, specifically the oxide thickness.

### 2.2 Results

The LBLOCA analyses which were used as a basis for evaluating the switchover portion of the LBLOCA reported in Reference 2.3.1 were performed in 1991 (i.e., Reference 2.3.5). Several minor changes have been made to the LBLOCA analysis models and inputs since the switchover analysis was performed. However, these changes have resulted in only changes to the value of the initial PCT, but have not affected timing and the general behavior of the event.

Figures 2.1 and 2.2 show the temperature trends at the PCT node for the initial phase and the second heat-up, respectively. The initial phase trace was taken from the HBRSEP, Cycle 17 LBLOCA Analysis performed in 1995 (Reference 2.3.4), and the second heat-up trace was taken from the switchover analysis (Reference 2.3.1). In the case of the Reference 2.3.4 analysis, the PCT was approximately 2,006°F. The Reference 2.3.5 LBLOCA initial phase PCT was approximately 2178°F, indicating that the switchover analysis used a conservatively high "initial phase oxidation state" in its analysis, relative to what would be used today.

2.2.1 Initial LBLOCA Blowdown PCT

The PCT for the initial portion of the LBLOCA event calculated in 1996 (Reference 2.3.3), was 2064°F and it occurred at approximately 1 minute (61.1 seconds) following the break. The maximum oxidation for any axial node on the hot rod was 3.86% and the hot rod average was 0.674%. The PCT node and the rupture node coincided for the MOC case at 8.75 feet. These analysis results continue to show that the switchover analysis (Reference 2.3.1) used a conservatively high "oxidation state" of the fuel rods in its initialization for the switchover.

2.2.2 Switchover PCT

The switchover is initiated 21 minutes from the beginning of the transient. The calculated switchover PCT was 2,102°F and it occurred at about 30.5 minutes (1,832 seconds) following initiation of switchover (total time since LBLOCA of 51.5 minutes) at an elevation of 9 feet. The additional local maximum oxidation was 3.67% and the additional rod average oxidation was 0.79%. The EOC case, which had its peak power higher in the core reached essentially the same temperature at 1,836 seconds into the event at an elevation of 10.5 feet.

At the time of PCT, the core and the hot rod were immersed in steam (i.e., void fractions ~ 1) and the flow regime of the coolant was misty flow. Mass flows are quite low compared to the initial blowdown, being determined by the rate at which coolant can boil-off.

The PCTs reached during switchover are nearly the same as those reached during the initial blowdown phase. The switchover heat-up was much slower, averaging about 3°F/sec. When the RHR was turned back on, the core reflooded rapidly and the PCT node was quenched more rapidly than the heat-up. The cool-down rate following the second peak was comparable to the cool-down rate following the first peak (~27°F/sec).

2.2.3 Overall Impact on Fuel Rods

The peak fuel rod was twice taken to a temperature in excess of 2,000°F and then quenched. The total oxidation for the peak rod was less than 8% at the 9-foot elevation. The aggregate oxidation on the hot rod was 1.5%. 10 CFR 50.46 criterion (b)(2) requires that "total oxidation of the cladding shall nowhere exceed 0.17 times the total cladding thickness before oxidation." Comparison of the 8% and 1.5% calculated values to this 17% limit shows ample margin to the limit.

2.2.4 Core Parameters

The peak rod had a PCT during the second heatup of over 2,100°F, assuming a radial peaking factor of 1.8. The bulk of the fuel rods in the core do not experience temperatures as high as the peak rod. For example, the number-weighted average core temperature is only about 1,120°F.

Figure 2.3 shows the fraction of the core which would be expected to exceed a given temperature. This curve shows that only about 15% of the core would have a temperature of 1,600°F or more.

2.3 References

2.3.1 EMF-94-157(P), "Robinson Unit 2 Extended Transfer to Cold Leg Recirculation Following a Large Break LOCA" September 1994.

2.3.2 XN-NF-82-49(P)(A), "Exxon Nuclear Company Evaluation Model Revised EXEM PWR Small Break Model," Revision 1, Supplement 1, December 1994.

2.3.3 EMF-96-060, "H. B. Robinson Unit 2 Large Break LOCA Analysis," May 1996.

2.3.4 EMF-95-040, "H. B. Robinson Unit 2 Large Break LOCA Analysis for Cycle 17," March 1995.

2.3.5 ANF-91-016, "H. B. Robinson Unit 2 Large Break LOCA/ECCS Analysis," February 1991.

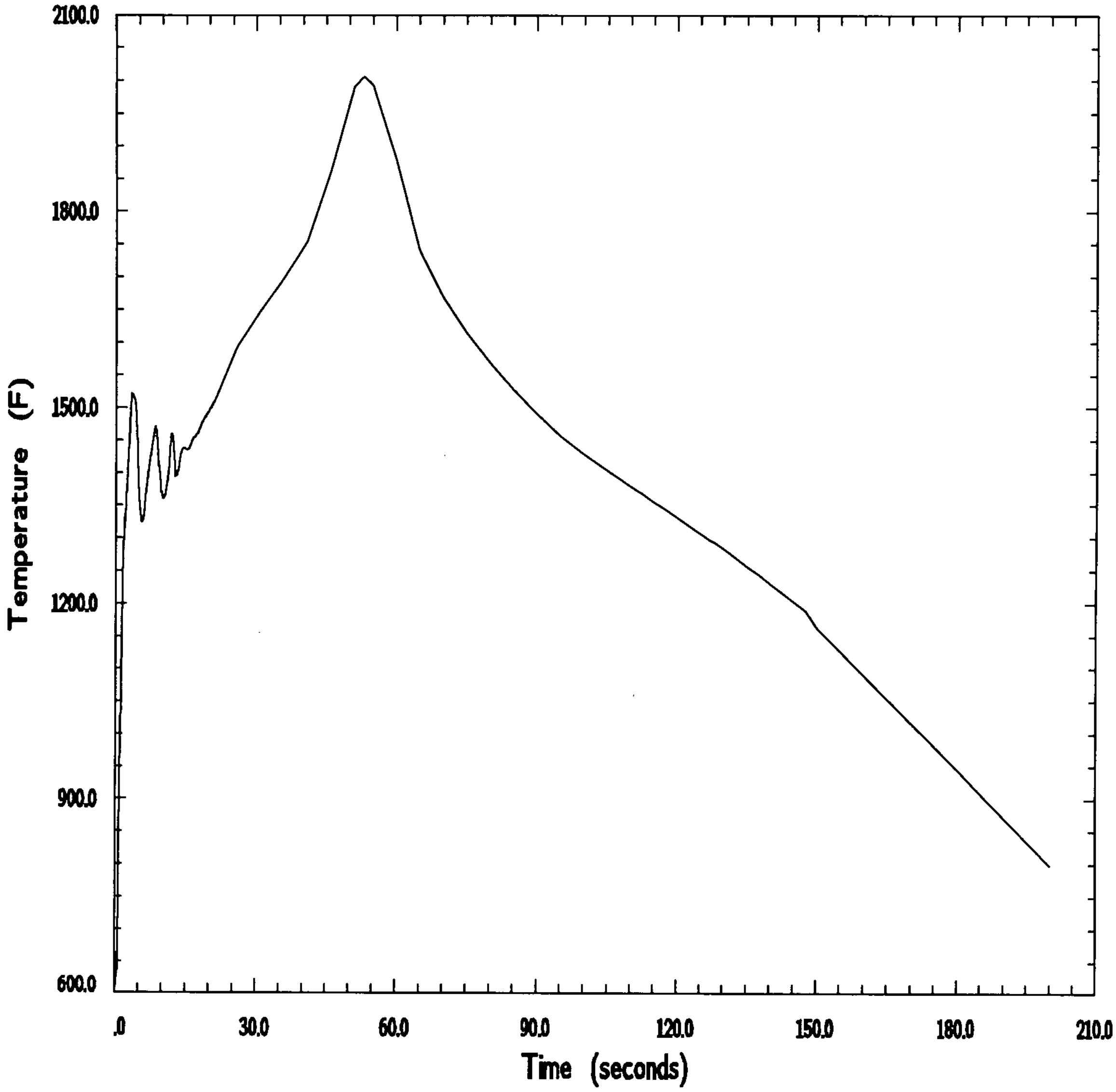


Figure 2.1 Cladding Temperature at PCT Node (8.75 ft) - Initial Phase
(Data taken from Reference 2.3.4 LBLOCA initial blowdown phase)

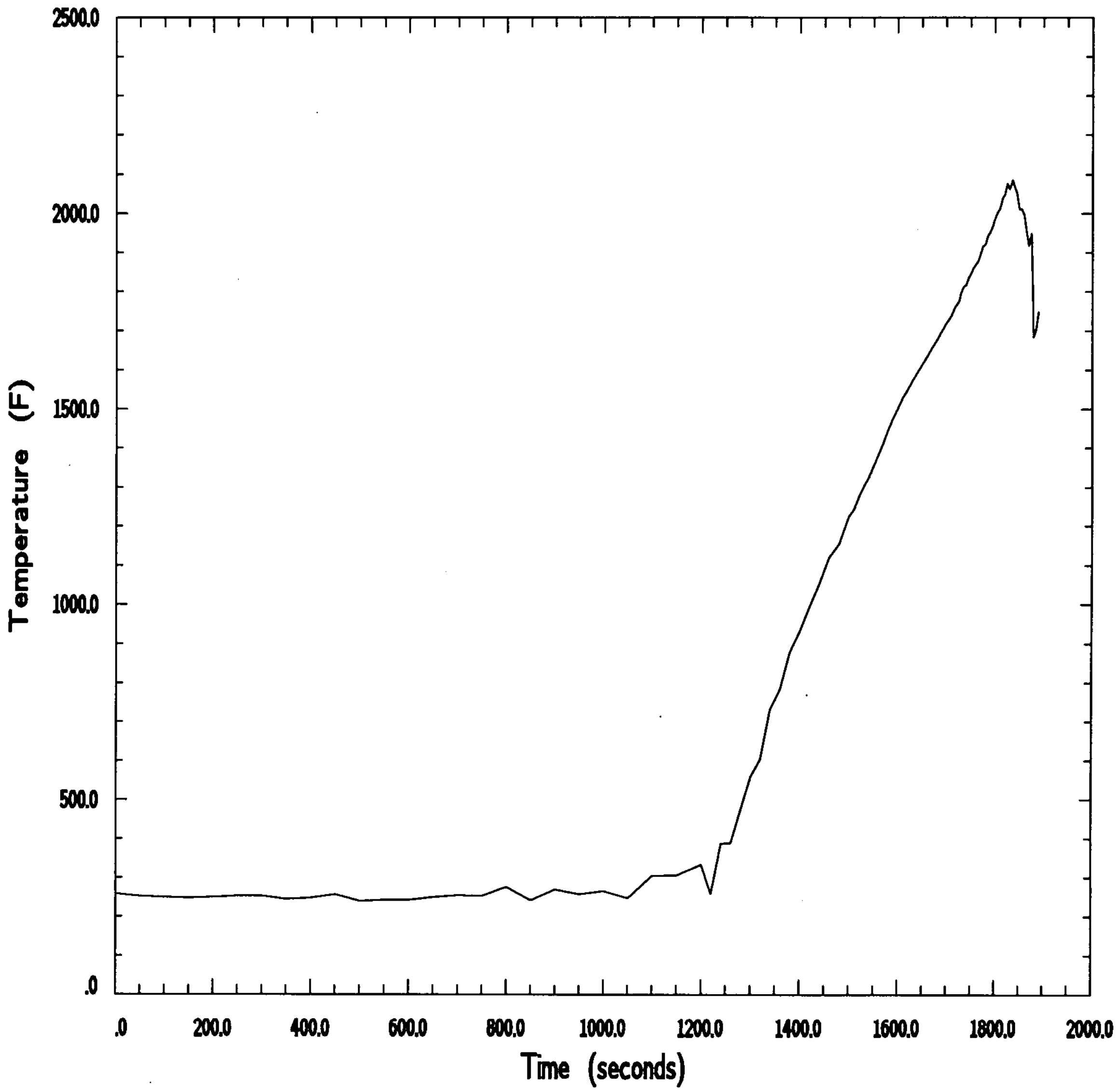


Figure 2.2 Cladding Temperature at PCT Node (8.75 ft) - Switchover Phase
(Data taken from Reference 2.3.1 Switchover analysis)

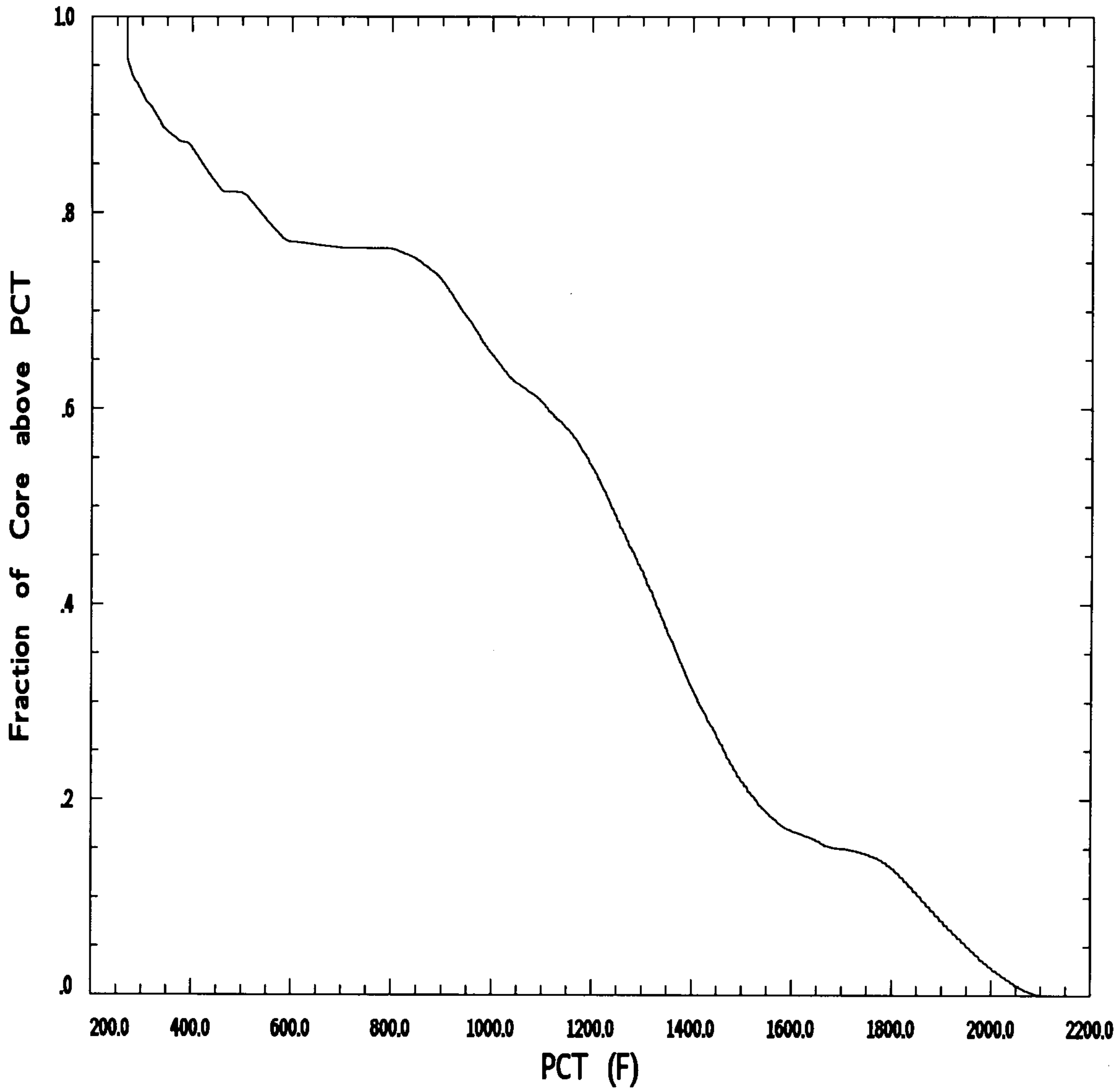


Figure 2.3 Fraction of Core Exceeding a PCT
(Data taken from Reference 2.3.1 Switchover analysis for EOC Radial power conditions)

## 3.0 Cladding Mechanical Evaluation; Effect of Heat-ups on Oxide and Phase Transformations

### 3.1 Introduction

Hypothetical LOCA scenarios project that the temperature of the fuel cladding reaches 1093°C (2000°F) or higher. For Zircaloy, with about 1300 ppm oxygen, the low temperature hexagonal phase (i.e., alpha phase) is stable below about 830°C (1526°F), and the body centered cubic phase (i.e., beta phase) is stable above about 950°C (1742°F). At intermediate temperatures, there is a mixture of the alpha and beta phases. During the high temperature oxidation of Zircaloy-2 and Zircaloy-4 in a steam environment, the uptake of oxygen is partitioned between the outer zirconium oxide layer, the underlying alpha phase layer which is stabilized at higher temperatures by the addition of oxygen, and the inner beta phase region, which transforms back to the alpha phase when the temperature is reduced. HBRSEP uses Zircaloy-4 cladding.

### 3.2 Theoretical Evaluation

The current case to be considered consists of a LBLOCA temperature heat-up to about 1093°C (about 2000°F) in about one minute followed by rapid quenching and then a switchover temperature heat-up to 1149°C (2100°F) in about 10 minutes followed again by a rapid quench. The isothermal oxidation of Zircaloy in steam at these temperatures has been measured by several investigators. The references cited in this discussion represent work performed at Oak Ridge National Laboratory. The zirconium oxide which is formed is brittle and will not bear any load. The oxygen stabilized alpha Zircaloy layer, up to 26% oxygen, which is formed immediately beneath the oxide layer is also brittle and cannot bear any load. The ductility of the beta Zircaloy inner layer, at the oxidation temperature, is also affected by the extent to which oxygen is incorporated into the microstructure. This layer transforms to alpha Zircaloy when the cladding is cooled to room temperature, and the mechanical integrity of the oxidized cladding is dependent upon this alpha Zircaloy portion of the cladding wall. Pawel (Reference 3.6.1) has combined his oxidation modeling with the results of mechanical testing to determine the limiting time as a function of temperature for which room temperature ductility is maintained after two sided (i.e., inner and outer) oxidation of Zircaloy cladding.

The hypothesized temperature heat-ups occur very rapidly. The temperature dependence of a temperature activated process, such as oxidation and diffusion, is described by an Arrhenius equation using the activation energy of the process; $k = k_0 \times \exp(-Q/RT)$. For example, the oxidation rate constant (k) equals a constant ($k_0$) times the exponential of the activation energy (Q ) divided by the gas constant (R) times the temperature (T). Using the activation energy for the oxidation process (Reference 3.6.2), the transient temperature profile can be equated to an effective time at the peak temperature for each temperature heat-up by integrating the Arrhenius equation with the temperature as a function of time and dividing by the Arrhenius equation for the maximum temperature. When this is done, the LBLOCA heat-up to 1093°C (2000°F) is equivalent to about 25 seconds at that peak temperature. The switchover heat-up to 1149°C (2100°F) is equivalent to about one minute at the peak temperature.

The effect of irradiation damage of the cladding before the hypothesized temperature heat-ups is not important because the irradiation damage is annealed out at the temperatures which are being considered. Van Houton (Reference 3.6.3) has observed that the out-of-pile behavior can be used to predict the in-reactor behavior for a LOCA situation. Carpenter and Watters (Reference 3.6.4) have reported that recovery of the irradiation damage is complete at a temperature of about 500°C (932°F). These observations support using the results of Reference 3.6.1 to estimate the effect of the temperature heat-up on the mechanical behavior of the Zircaloy cladding.

Based on the requirement that some room temperature ductility is maintained after a high temperature heat-up, Pawel (Reference 3.6.1) has obtained "critical time" as a function of temperature for two-sided oxidation for Zircaloy-4 cladding which is 0.686 mm thick. The nominal cladding thickness for HBRSEP is 0.762 mm. Thus the results from Pawel are extremely conservative because the HBRSEP cladding is somewhat thicker and there is only concern with having corrosion at the outer surface for the vast majority of rods which do not burst on their initial heat-up. At 1093°C (2000°F), the critical time is about 11 minutes; and at 1149°C (2100°F), the critical time is about 7.5 minutes. These times are much greater than the equivalent times at temperature calculated for the suggested temperature heat-ups. It would appear that a margin of a factor of five is obtained on the assumption of two-sided corrosion, and the more realistic case of one-sided corrosion would give a margin of a factor of ten.

## 3.3 Experimental Evaluation

SPC performed simple quenching experiments with subsequent mechanical testing using typical laboratory controls. After two temperature heat-ups into the beta phase temperature region followed by rapid quenching, Zircaly-4 cladding samples taken from the same manufacturing lot were heat treated and subjected to a tensile test. The cladding wall thickness was 0.029 inch which is 0.001 inch less than the nominal wall thickness of the Robinson cladding. Each sample was heat treated by inserting the cladding in a small tube furnace with a quartz tube for one or five minutes, and quickly removing and quenching the cladding in a container of water. The furnace tube was connected to a flask of boiling water so that steam was flowing around and through the cladding. A peak temperature of about 1100°C (2012°F) was used. Two of the cladding samples were heated for one minute and quenched; and two were heated for one minute, quenched, reheated for five minutes, and requenched. Open tubing was used, so oxidation occurred conservatively, on both the outer and inner surfaces. Tensile tests were performed to measure the ultimate tensile strength (UTS) and the elongation (two inch gage length) at room temperature for the two samples that had received one quench, the two samples that received two quenches, and for one sample of the material as received, as a reference. The results are provided in the following table.

Comparison of Tested Parameters

| | | UTS (psi) | Elongation (%) |
|---|---|---|---|
| As-received reference sample | | 103,700 | 22.8 |
| One quench, | Sample 1 | 89,700 | * |
| | Sample 2 | 103,200 | 5.4 |
| Two quenches, | Sample 3 | 94,500 | 2.9 |
| | Sample 4 | 96,300 | 6.7 |

* This sample failed outside the scribed area on the sample, so the elongation could not be measured. However, the reduction in diameter was the same as for the other sample quenched one time. Therefore, the elongation was probably similar to the other sample also.

The temperature which was used in these tests approximates the temperature of the LBLOCA peak. The furnace could not reach the temperature of the switchover peak. However, the samples were held at temperature for five minutes before the second quench which is equivalent to about 1.6 minutes at the switchover peak of 1149°C (2100°F). Therefore, these results should be representative of the hypothesized LOCA event.

As expected, there is a decrease in the room temperature ductility of the Zircaloy-4 cladding when oxidized in steam in the beta phase temperature range. However, there does not appear to be any great difference in the ductility between the samples which were quenched twice and the one which was quenched once.

### 3.4 Results

The combined time at temperature for the two heat-ups of the HBRSEP cladding is bounded by previous industry testing and literature. The time at temperature will not significantly reduce the effective thickness of the ductile portion of the cladding nor will the loss in ductility be significantly different than that which results from a single heat-up event. This has been shown by a simple annealing and quenching experiment. Irradiation effects are eliminated as a result of the high temperature "anneal" which occurs as the cladding is heated.

### 3.5 Conclusion

The change in the cladding properties after the LBLOCA heat-up to after the switchover heat-up in the HBRSEP LOCA event are not significant. The core coolable geometry is not projected to be altered by the switchover heat-up in the event.

## 3.6 References

3.6.1. R. E. Pawel, "Oxygen Diffusion in Beta Zircaloy During Steam Oxidation," J. Nucl. Mat., vol 50, (1974) pp. 247-258.

3.6.2. R. E. Pawel, et al, "Diffusion of Oxygen in Beta-Zircaloy and the High Temperature Zircaloy-Steam Reaction," Zirconium in the Nuclear Industry, ASTM STP 633 (1977) pp. 119-133.

3.6.3. R. Van Houten, "Fuel Rod Failure as a Consequence of Departure from Nucleate Boiling or Dryout," NUREG-0562.

3.6.4. G. J. C. Carpenter and J. F. Watters, "Irradiation Damage Recovery in Some Zirconium Alloys," Zirconium in the Nuclear Industry, ASTM STP 551 (1974), pp. 400-415

## 4.0 Conclusions / Summary

The major effect of the thermal cycling would be on the oxidation thickness, which would affect the ductility of the rods. Irradiation effects anneal out at these temperatures and external mechanical forces (from the reflood, for instance) are significantly less during the second temperature rise. As a result of the conservatism in the analysis, the literature references, and the limited experimental data obtained by SPC that shows minimal impact on materials properties following the two short duration temperature excursions, it is concluded that long term coolable geometry is not jeopardized.

AFFIDAVIT

STATE OF WASHINGTON )
) ss
COUNTY OF BENTON )

I, H. D. Curet, being duly sworn, hereby say and depose:

1. I am Manager, Product Licensing, for Siemens Power Corporation ("SPC"), and as such I am authorized to execute this Affidavit.

2. I am familiar with SPC's detailed document control system and policies which govern the protection and control of information.

3. I am familiar with the Siemens Power Corporation information in the document EMF-94-157(P), "H. B. Robinson Unit 2 Extended Transfer to Cold Leg Recirculation Following a Large Break LOCA," dated September 1994, referred to as "Document." Information contained in this Document has been classified by SPC as proprietary in accordance with the control system and policies established by SPC for the control and protection of information.

4. The Document contains information of a proprietary and confidential nature and is of the type customarily held in confidence by SPC and not made available to the public. Based on my experience, I am aware that other companies regard information of the kind contained in the Document as proprietary and confidential.

5. The Document has been made available to the U.S. Nuclear Regulatory Commission in confidence, with the request that the information contained in the Document will not be disclosed or divulged.

6. The Document contains information which is vital to a competitive advantage of SPC and would be helpful to competitors of SPC when competing with SPC.

7. The information contained in the Document is considered to be proprietary by SPC because it reveals certain distinguishing aspects of SPC licensing methodology which secure competitive advantage to SPC for fuel design optimization and marketability, and includes information utilized by SPC in its business which affords SPC an opportunity to obtain a competitive advantage over its competitors who do not or may not know or use the information contained in the Document.

8. The disclosure of the proprietary information contained in the Document to a competitor would permit the competitor to reduce its expenditure of money and manpower and to improve its competitive position by giving it valuable insights into SPC licensing methodology and would result in substantial harm to the competitive position of SPC.

9. The Document contains proprietary information which is held in confidence by SPC and is not available in public sources.

10. In accordance with SPC's policies governing the protection and control of information, proprietary information contained in the Document has been made available, on a limited basis, to others outside SPC only as required and under suitable agreement providing for nondisclosure and limited use of the information.

11. SPC policy requires that proprietary information be kept in a secured file or area and distributed on a need-to-know basis.

12. Information in this Document provides insight into SPC licensing methodology developed by SPC. SPC has invested significant resources in developing the methodology as well as the strategy for this application. Assuming a competitor had available the same background data and incentives as SPC, the competitor might, at a minimum, develop the information for the same expenditure of manpower and money as SPC.

THAT the statements made hereinabove are, to the best of my knowledge, information, and belief, truthful and complete.

FURTHER AFFIANT SAYETH NOT.

SUBSCRIBED before me this 25th day of Sept, 1997.

~~Sue M. Galpin~~ Susan K McCoy
NOTARY PUBLIC, STATE OF WASHINGTON
MY COMMISSION EXPIRES: ~~2/27/00~~ 1/10/00

SUSAN K. MCCOY
COMMISSION EXPIRES
NOTARY
PUBLIC
JAN. 10, 2000
STATE OF WASHINGTON