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NRC-NSD-97-5126
DCP/NRC0864
Docket No.: STN-52-003

May 14, 1997

Document Control Desk
U.S. Nuclear Regulatory Commission
Washington, DC 20555

ATTENTION: T. R. QUAY

SUBJECT: REVISED RESPONSE TO RAI 440.120 FOR RAPID BORON DILUTION SCENARIOS

References:
1. Letter from NRC to Westinghouse (Huffman to Liparulo), "AP600 Boron Dilution Transient Analyses," dated 9/24/96.
2. NSD-NRC-97-5062 (DCP/NRC0809), "AP600 Shutdown Evaluation Report (WCAP-14837) and Response to RAI 440.53", dated 4/15/97.

Dear Mr. Quay:

Attached is the revised response to RAI 440.120 regarding rapid boron dilution scenarios. This revision reflects resolution of issues presented in Reference 1 and discussed during an October 25, 1996, telecon involving Messrs. Huffman, Sun, and Attard of the NRC and Messrs. Corletti, Kemper, Hill, Prokopovich, Carlson, Deutsch and Ms. Nydes of Westinghouse.

The revision to item b of the response was provided previously by Reference 2 and is repeated in this transmittal. In Revision 1 of the RAI 440.120 response, deletions from Revision 0 are noted with a line through the deleted text, while additions appear in bold italics.

With this revised response, the Westinghouse status for DSER open item tracking system item 3960 is changed to "Action N". NRC is requested to review this response and provide Westinghouse with feedback regarding the status of this item.

Please contact Robin K. Nydes at (412) 374-4125 if you have any questions regarding this transmittal.

Brian A. McIntyre, Manager
Advanced Plant Safety and Licensing

jml

Attachment

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E004

cc: William C. Huffman, NRC (w/Attachment)
Summer Sun, NRC (w/Attachment)
Anthony C. Attard, NRC (w/Attachment)
Nicholas J. Liparulo, Westinghouse (w/o Attachment)

Item No	Branch	DSER Section Question	Type	Title/Description Detail Status	Resp Engineer	(W) Status	NRC Status	Letter No. / Date
3960	NRR/SRXB	15	TEL-OI		Novendstern/SAR-Ch15	Action N	Action W	NTD-NRC-97-5126

Letter from Bill Huffman to Nick Liparulo of 9/24/96, AP600 Boron Dilution Transient Analyses, requests additional information to what was provided in response to RAI 440.120 (what we refer to as the rapid boron dilution RAI).

review of additional questions is in progress. rkn 10/10/96
Status Update: We had a video conference call with the NRC on 10/28/96 and have finished incorporating all comments from that call except for enhancing the Finnish Center Scenario section to provide more details regarding the small break LOCA analysis. Since the NOTRUMP test simulations are behind schedule, the SSAR cases which will provide the reference transient for this RAI revision are not yet available. rkn 1/15/97
Revised RAI response in review. Letter in typing. rkn 5/6/97.
Revised RAI response provided May 14 by NSD-NRC-97-5126 (DCP/NRC0864). W status changed to Action N. rkn 5/14

Question 440.120

The staff is concerned with boron dilution events for PWR designs. A slow, inadvertent dilution due to a malfunction of the chemical and volume control system (CVCS) or faulty operator actions is a design basis event that must be shown to satisfy stringent acceptance criteria. Recently, the question of whether additional failures or scenarios other than the CVCS malfunction events might lead to inadvertent criticality and fuel damage has received considerable attention in Europe and the United States. For example, a preliminary study by the Finnish Center for Radiation and Nuclear Safety indicates that an inherent mechanism for boron dilution exists in the cold leg loop seals or transients and accidents, e.g., a small break LOCA, involving heat removal by reflux- or boiler-condensation natural circulation. Under certain conditions and scenarios, such as during the restart of RC pumps, substantial boron dilution could result in the core, leading to a reactivity induced accident.

a. Although the AP600 design does not have a loop seal in the cold leg, has Westinghouse evaluated the possibility of accumulating deborated (a highly dilute slug) water in the reactor coolant loop, especially in the steam generator cold leg channel head, as a result of reflux/boiler condensation natural circulation in an accident? Address this concern.

b. For those transients or accidents that may result in the accumulation of a deborated water slug in the RCS loop, provide an analysis to demonstrate that recriticality will not occur as a result of the deborated water slug entering the core, either through natural circulation or by restarting the pump(s). The analysis should include an evaluation of the degree of mixing between the deborated water slug and the existing borated concentration, the reactivity insertion, and the total reactivity. Describe the methodologies used in the analysis.

c. If recriticality occurs, provide an analysis of the consequence, such as whether the calculated peak fuel enthalpy (due to insertion of reactivity) has exceeded the limiting value of 280 calories per gram.

d. What emergency operating procedures are there to prevent the restart of RC pump that could result in criticality during transients and accident events? What are other protective measures?

Response:

Several different scenarios for all PWR designs have been postulated that could cause the accumulation of unborated water in the ***reactor coolant system*** (RCS) loops. The postulated scenarios addressed herein, which include those that are unique to the AP600 design, are:

- The "Finnish Center" scenario, which is addressed by item (a.) below, with supplementary analytical discussions given in item (b.).

- The introduction of relatively unborated water is possible as a result of reverse break flow following a steam generator tube rupture (SGTR). This scenario is discussed in items (b.) and (d.) below.

- It can be postulated that the actuation of the AP600 ***core makeup tanks (***CMTs***)*** could potentially yield pockets of coolant that may not receive the higher concentration borated water. Thus, subsequent loop recovery under cold conditions may be a concern if the critical boron concentration for the temperature of interest is higher than the boron concentrations present in the stagnant regions of the loop(s). This postulated situation is discussed in items (b.) and (d.).

- During a dilution to criticality, if a loss of power occurs, the subsequent ~~emergency~~ ***standby*** diesel generators startup and loading would allow the charging/make-up pumps to continue the dilution without the ***reactor coolant pumps (***RCPs***)*** in operation, thus providing the means to accumulate unborated water in the RCS loop(s). This situation, which has been referred to as the "French" scenario in other studies/reports, is discussed in item (d.).

- Various RCS maintenance procedures have the potential for low, or zero boron concentration water to accumulate in the RCS. This situation is also discussed in item (d.).

These five scenarios are addressed with respect to the AP600 design below. This response has been structured as items (a.) through (d.), which correspond to the four parts of this RAI question.

(a.) "Finnish Center" Scenario

The AP600 is not subject to the "Finnish Center" scenario during small break ***loss of coolant accidents (***LOCA***s)*** ~~events~~. The AP600 design possesses no loop seals entering the reactor coolant pumps (RCPs). Only a small amount of low boron content water could collect in the bottom of the four RCP casings (approximately 21 ft^3 per RCP casing; this equates to approximately 1.8% of the AP600 reactor ***downcomer and*** vessel inlet plenum volume) and potentially be present in small break LOCA scenarios for sudden transport into the reactor vessel upon RCP restart.

The "Finnish Center" scenario as such is not ~~relevant~~ ***of concern*** to the AP600 because the steam generators are not cooling the RCS to ~~potentially~~ generate boron-free condensate for ~~any significant~~ ***an extended*** length of time during a LOCA event. During small break LOCAs in conventional PWRs, decay heat is removed through the steam generator safety valves ***for long periods of time***. In AP600, the ***passive residual heat removal heat exchanger (*** PRHR***)*** rapidly becomes the dominant RCS heat sink following the generation of an "S" signal during postulated small break LOCA events. The steam generators become heat sources rather than heat sinks ***as the RCS depressurizes***. A potential means for generating a volume of unborated water during a small break LOCA is via operation of the PRHR. Steam condensed in the PRHR is delivered to the Loop 1 steam generator outlet plenum during small break LOCA events. However, with no

RCP loop seals the AP600 layout is such that the PRHR effluent will drain continuously from the steam generator channel head into the Loop 1 cold legs and flow into the reactor vessel. A deborated water slug cannot accumulate in the RCS loop cold legs. Within the reactor vessel the cold leg fluid entry point is above the direct vessel injection line elevation, which receives passive safety injection water from the ~~core makeup tank~~ ***CMT***s and/or accumulators with a high boron concentration which provides a significant reactivity margin to recriticality. ~~Since the downcomer annulus remains full to approximately the core top elevation or higher throughout~~ ***For*** the AP600 small break LOCA events, the dilute PRHR water must pass through and mix with ~~more than~~ ***approximately*** twelve ***cubic*** feet of borated water present in the downcomer prior to reaching the lower plenum and then the core. The relatively low flow rate of fluid from the downcomer into the core during the post-RCP trip ***natural circulation*** phase of AP600 small break LOCA events enable***s*** mixing to occur in the core and lower plenum. No unmixed "slugs" of highly dilute liquid from the PRHR are present in the downcomer to enter the core during LOCA design basis scenarios.

~~In the later stages of a small break AP600 LOCA event, once ADS stages 1-3 are active, the PRHR receives very little flow (Reference 440.120-1). Therefore, the downcomer boron concentration will not diminish significantly due to continued PRHR operation. Moreover, once ADS fourth stage valves are actuated, the PRHR receives even less flow and produces even less condensate, so no substantial boron dilution occurs within the core.~~

In assessing the potential for boron dilution during LOCAs, an important consideration is delivery of boron from the CMTs (and the accumulators, when active) during the transient once they actuate on an "S" signal. The ambient boron concentration in the reactor vessel and RCS increases significantly from the initial value because both CMTs inject their total of 240000 lbm of water inventory containing boron at the 3400 ppm (minimum) Technical Specification value into the RCS, which initially contains approximately 350000 lbm of water. The minimal impact of this PXS boron injection on the RCS boron concentration occurs for the case in which the RCS is initially at its critical boron concentration for full power operation (approximately 1600 ppm, at beginning of life). Under the conservative assumption that the break removes mass at the mixed average boron concentration over the entire transient, the ambient boron concentration for this limiting case increases by 730 ppm when the CMTs have fully injected their inventory.

The one-half inch break case presented in SSAR Chapter 15 represents a small break LOCA case subject to possible boron dilution due to condensation. In general, the smaller the break size of the postulated LOCA, the longer the RCS remains elevated in pressure and the steam generators and PRHR remain effective heat sinks. Condensation occurs in both the PRHR and in the steam generators during this break transient. During the initial 11500 seconds of the transient, the natural circulation flow through the steam generators and PRHR is essentially single phase liquid. No mechanism exists for any pockets of dilute liquid to occur during this natural circulation period before the steam generators drain.

The non-PRHR-loop steam generator continues as a heat sink while it drains between 11500 and 13700 seconds. Condensate formed in the tubes in this time period flows back into the vessel upper plenum as part of the liquid backflow associated with the steam generator draining. Of the total 24000 lbm of non-PRHR-loop steam generator drain liquid flow into the reactor vessel upper plenum during this period, approximately 4000 lbm are condensate. The condensate is well mixed in the hot leg with the liquid accompanying it, and no pockets of dilute liquid occur. The upper plenum is full to the hot leg level and contains approximately 30000 lbm in this time interval. Since the ambient boron concentration has increased due to CMT injection, the liquid in the upper plenum exhibits a higher than initial boron concentration event with the ongoing dilution of the total mass in the upper plenum. Furthermore, during this steam generator drain period, a natural circulation flow of almost 200 lbm/sec directs mass from the upper plenum into the PRHR loop hot leg, and flow is from the core into the upper plenum. Therefore, boron dilution due to the 4000 lbm condensate backflow is not of concern.

During the initial 11000 seconds of the transient, the PRHR receives essentially single phase liquid from the hot leg. The average quality of fluid entering the PRHR is less than 1% during this time interval. From 11000 - 17000 seconds a significant amount of condensation occurs in the PRHR, and a smaller amount occurs in the PRHR-loop steam generator. During this interval, 30000 lbm of steam present in the two-phase mixture circulating into the PRHR is condensed there. A large liquid flow rate is predicted in this time period from the upper plenum through the PRHR, so the condensate is well-mixed with liquid at the ambient boron concentration in the PRHR return line and cold legs.

Between 11500 and 13700 seconds, approximately 5000 lbm of steam condenses in the PRHR-loop steam generator tubes and drains into the hot leg together with steam generator liquid. The fluid from steam generator draining enters the PRHR along with the fluid from the vessel upper plenum. After 13700 seconds the steam generators become heat sources, and no further condensation occurs there. Overall, the total mass flow through the PRHR in this interval is greater than 430000 lbm. Since the total condensate combined due to PRHR and steam generator heat transfer in the interval is about 35000 lbm, less than 10% of the PRHR outlet flow is condensate. That portion which is condensate is well-mixed within the circulating flow returning to the cold leg. Moreover, the ambient boron concentration in the reactor vessel and RCS is higher than the initial value because both of the core makeup tanks have injected their entire inventory of boron at the 3400 (minimum) ppm Technical Specification value. The increase in boron content from the injection of CMT boron to an RCS which initially contains liquid at a maximum boron concentration of 1600 ppm means that the 40000 lbm of condensate produced does not cause a decrease in the RCS boron content below the initial value. After ADS actuation at 16600 seconds, the PRHR is no longer effective in condensing steam, and no mechanism for further boron dilution occurs. In fact, RCS boron concentration is increased by actuation of the accumulators shortly after ADS actuation.

The small break LOCA cases presented in SSAR Chapter 15.6 do not model the PRHR once automatic depressurization system (ADS) stage 4 is active. This approach, which is consistent *with the NOTRUMP validation against AP600 integral test results, conservatively eliminates a depressurization source. To identify possible boron dilution effects, a two-inch cold leg break case in which the PRHR is modeled throughout the transient was examined. This case exhibits more condensation in the PRHR than occurs in the one-half inch break SSAR case described above (53500 lbm). Due to the RCS depressurization, the steam generators become heat sources rather than heat sinks within 500 seconds of transient time. Of the total PRHR condensation, 35000 lbm forms before accumulator injection, and 14500 lbm more condensate forms before the actuation of ADS stage 4 at 2200 seconds. Until this time, the PRHR flow is two-phase natural circulation. The liquid flow entering the PRHR exceeds the condensation amount through 1800 seconds, so no pockets of dilute boron liquid will form in the piping.*

As previously noted, injection of borated water from the CMTs increases the ambient boron level above its initial value. A time of minimum boron in the RCS is just before the start of accumulator injection, when the dilute PRHR return stream can be accommodated by partial CMT injection alone. The CMT injection at the time of accumulator injection is enough to increase the ambient boron concentration by at least 540 ppm, which is adequate to maintain the RCS boron level above the initial concentration. The accumulators rapidly inject borated water into the RCS, increasing the downcomer, core, and RCS boron concentrations. By the time that the condensate mass dominates the PRHR return flow stream, both the accumulators have injected completely, raising downcomer boron concentration high enough to accommodate the 7000 lbm condensate that is delivered from the PRHR after 1800 seconds and before ADS Stage 4 actuation.

By 2200 seconds into the transient, the accumulators and CMTs have delivered their inventories of borated water to the RCS, and the boron content in the downcomer is approximately 900 ppm above the maximum initial concentration. The 3000 lbm of PRHR condensate which enters the downcomer prior to the start of in-containment refueling water storage tank (IRWST) injection at a rate averaging 3 lbm/sec comprises less than 10% of the total lower plenum/downcomer mass inventory. Furthermore, during the interval between the CMT empty time at 2460 seconds and the start of IRWST injection at 3400 seconds, only 20% of the downcomer mass inventory passes from the downcomer node into the lower plenum. Therefore, no pockets of dilute liquid form. When the IRWST becomes active, it provides highly borated water to the vessel downcomer. Therefore, the dilution associated with the PRHR condensation during ADS stage 4 operation is insignificant. Based on the examination of the above cases, no boron dilution occurs within the core for any AP600 postulated LOCA scenario.

(b.) Transients or Accidents Addressed by Analysis

The safety-related method for decay heat removal for the AP600 consists of heat transfer to the IRWST by the PRHR, and borated makeup water addition to the RCS from the CMTs. Operation of the CMTs require that the RCPs are tripped. As the residual heat from the core is removed by the PRHR and CMTs, boric acid is added to the RCS by CMT injection flow. The RCS flow associated with the operation of the PRHR and CMT systems is caused by the thermal driving heat established by the convective heat transfer. Analyses have been performed (Reference 440.120-2) to investigate the flow behavior throughout the RCS while the PRHR and CMT systems are removing core decay heat, ~~in order~~ to quantify the resulting boron distributions ***that could form as convective flow rates approach stagnation.*** For this study a loss of normal feedwater ***(LONF)*** transient was chosen.

The Reference 440.120-2 analysis effort utilized the TRAC-PF1/MOD2 code to perform transients that are very similar to the design basis LONF transient ***that is presented in the SSAR*** Section 15.2.~~6~~7 ***(Reference 440.120-3)*** ~~(Reference 2,)~~. ***A description of the AP600 TRAC-PF-1 thermal/hydraulic and neutronic models is presented in Reference 440.120-2 Sections 3.1 and 3.2, respectively.*** Conditions corresponding to beginning of life, equilibrium cycle, no xenon were assumed, as this would be the most limiting plant conditions in the event core recriticality were predicted. Benchmarking between the TRAC-PF1 code with the SSAR data, which is based upon output from the Westinghouse LOFTRAN-AP code, indicated good agreement. ***A detailed discussion of the thermal/hydraulic comparison between the TRAC-PF1 calculations and the SSAR data (i.e., reference LONF) is presented in Reference 440.120-2 Section 4.3.1 (pages 4-26 through 4-47).*** An acceptable comparison of the neutronic model was obtained with Westinghouse reference core data. ***Specifically, the TRAC-PF1 calculated power distributions and rod worth values agreed within 6 to 7% of reference Westinghouse calculations. This degree of agreement for the neutronic model is acceptable given that this study focused on the mixing aspects of boron in the AP600 design and a detailed neutronic response as a result of a boron dilution was not necessary. A return to criticality was not challenged; thus a high level of agreement with the reference Westinghouse data is not necessary. Furthermore, the TRAC-PF1 calculated reactivity was normalized to the reference Westinghouse data, as discussed on Reference 440.120-2 pages 5-48 and 5-49.***

The results ***(see Reference 440.120-2 Section 5.1)*** of the loss of normal feedwater transients indicate that all regions of the RCS become sufficiently borated following RCP trip and CMT actuation as a result of RCS flow remaining high enough in all regions of the AP600 primary side system for a sufficient duration. The affects of reduced decay heat were also included in the analysis ***(Reference 440.120-2 Section 5.2).*** The low decay heat analysis arbitrarily assumed 1% of the ANS 1979 decay heat curve. Reduced heat generation in the core results in the passive cooling systems to lose their thermal driving head earlier in the transient, thereby providing a shorter duration for the CMTs to inject the higher concentration boron into the RCS. The results demonstrate that boron concentrations throughout the RCS were greater than the critical boron concentration required for cold (200°F) N-1 rods inserted (most reactive RCCA assumed to be stuck out of the core), no Xenon conditions. Therefore, it can be concluded that subsequent RCS loop recovery, following CMT actuation and RCS cooldown to equilibrium temperatures, will not pose a recriticality potential.

Additional analysis were performed as part of the Reference 440.120-2 study to quantify the volume of unborated water that could collect in the RCP casings and steam generator channel head without resulting in localized core inlet boron concentrations to decrease to the critical boron concentration following the restart of the RCPs. ***These additional analyses are discussed in Reference 440.120-2 Section 5.3.*** The affects of nominal and reduced decay heat situations were also considered. The initial conditions for these investigations were obtained from the pseudo-equilibrium conditions (i.e., transient times > 4000 seconds) for the loss of normal feedwater transients discussed previously. The findings of this unborated water investigation can be directly applied to the SGTR reverse break flow scenario and also supplement the previously discussed "Finnish Center" scenario, ***(which is the subject of part (a.) of this response),*** as discussed below.

A high order solute tracker, which is described extensively in Reference 440.120-4 (and is also included as Appendix D of Reference 440.***120-2), and discussed to a lesser degree in Section 2.2 of Reference 440.120-2,***~~120-21),~~ was employed to significantly reduce numerical diffusion. This high order solute tracking method employed for the unborated slug investigation has been benchmarked against experimental mixing data from a 1/5 scale model of a three-loop Westinghouse PWR, ~~also discussed further in~~ ***The benchmark against the experimental data is described in Reference 440.120-2 Section 4.2.3.*** The results of the comparison between the TRAC-PF1 high order solute tracker with the experimental data clearly demonstrate that the high order method is conservatively under-predicting the mixing that would occur, as indicated by the experimental mixing data. This is primarily due to the fact that the high order solute tracker calculations do not account for the mixing that results ~~form~~ ***from*** the impinging jet of coolant onto the downcomer walls of the reactor vessel. As such, the application of the high order solute tracker to the mixing transient calculations discussed below ~~have~~ ***has*** significant conservatism inherent in the results. Furthermore, the mixing that would occur from the highly turbulent flow caused by the RCP impellers has not been credited. Thus, larger volumes of unborated coolant could be shown to be acceptable if the mixing that would occur from these ignored effects (i.e., inlet coolant jet impingement on the downcomer and RCP impellers), were explicitly modeled.

This high order solute tracking scheme was not employed for the previously discussed loss of normal feedwater transients, ***as the natural convection flow tends to distribute the boron being injected by the CMTs quite rapidly. This eliminates sharp fronts in the boron concentration and results in a steadily rising system boron concentration in a uniform way. Thus, numerical diffusion plays a very small role,***~~as the boron transport was determined to be mainly convective, and numerical diffusion plays a very small role,~~ if any, in driving the solute distribution within the system. As such, the runs not modeling unborated slugs of coolant were not repeated with the high order solute transport methods, since the expected results would be basically the same.

The results of this unborated slug analysis, where the RCPs were started in the loop containing the unborated water ***(see Reference 440.120-2 Section 5.3.1),*** yielded unborated volumes greater than 115 ft^3 for the situation where nominal decay heat had been assumed, and unborated volumes greater than 66 ft^3 for the situation where the decay heat had been assumed to be 1% of the ANS 1979 curve. In contrast, one RCP casing can collect less than 21 ft^3 before be[illegible]ed to the cold leg connection to the RCP casing. In the absence of cold leg loop seal piping, volumes of unborated water larger than 21 ft^3 per RCP casing, would begin to spill into the cold leg piping to be mixed with the borated coolant in the RCS before reaching the reactor vessel. Thus, the maximum volume of unborated water that could collect in a steam generator channel head region cannot be greater than 42 ft^3 (i.e., two RCPs per steam generator outlet channel head; this equates to approximately 3.5% of the AP600 reactor vessel inlet plenum volume). The analysis results presented above indicate that approximately one and one-half times this credible value can be accommodated (i.e., this volume can theoretically accumulate and not result in the core inlet boron concentration dropping below the critical concentration following RCP restart in the affected adjacent loops) under low decay heat conditions, and more than two and one-half times as much under nominal decay heat conditions.

Unborated slug analyses were also performed assuming that the unborated slug of coolant existed in one loop, and the RCPs were restarted in the opposite loop, ***as described in Reference 440.120-2 Section 5.3.2.*** The findings from this set of analyses is directly applicable to SGTR recovery, as the recovery procedures regarding RCP restart will identify that the RCPs in the intact RCS loop must be restarted first. This analysis demonstrated that the resulting mixing due to the reverse flow through the faulted steam generator and associated RCS loop can accommodate ~~extremely~~ large volumes of unborated water in the faulted steam generator U-tubes and channel head and localized core inlet boron concentrations remain ~~well~~ above the critical boron concentration.

(c.) Recriticality has not been predicted for the rapid boron dilution mechanisms / scenarios addressed herein.

(d.) Protective Measures; EOPs, Others

The Emergency Operating Procedures (EOPs) will be written by the combined license applicant. Westinghouse provides input to the EOPs through the Emergency Response Guidelines (ERGs). The ERGs stipulate that prior to restarting RCPs, there must be indication of subcooling based upon core exit thermocouple readings, and indication of pressurizer level. These two conditions allow for single phase natural circulation. The results of the analyses discussed in part (b.) of this response demonstrate that adequate mixing of the boron injected from the CMTs occurs under natural circulation conditions, even assuming a low level of decay heat.

RCP re-start is specifically addressed for the steam generator tube rupture accident by ERG AE-3 (Reference 440.120-5). Steps include a note of caution regarding the potential of inadvertent criticality following any natural circulation or PRHR cooldown if the first RCP started is in the ruptured loop. This potential is ~~significantly~~ reduced when the first RCPs restarted are those in the intact loop, which is supported analytically as noted previously in section (b.) of this response.

Regarding the postulated loss of AC power during a dilution to criticality (also referred to as the "French" scenario), it is assumed that the emergency diesel generators startup and provide power for the CVCS pumps. The addition of unborated makeup water to the RCS would continue without the RCPs in operation, thereby providing the means to accumulate unborated water in the RCS loop(s). ~~However, i~~ *I*t should be noted that the AP600 design includes a Battery Charger Input Voltage Low signal which causes the ~~DWS~~ demineralized water supply isolation valves to close and aligns the ~~BAT~~ boron acid tank to the makeup pumps. Therefore, this postulated scenario is not a concern with respect to the AP600 design, as logic exists to prevent such an occurrence.

Concerns of RCP restart following maintenance that has a potential for the formation of low, or zero boron concentration water to accumulate in the RCS, are recommended to be addressed procedurally, for any PWR design, as discussed in Reference 440.120-6. The means to prevent such a maintenance initiated scenario is that steps be included as part of the maintenance procedures to remove/mix this low, or unborated water volume. Measures include, but are not limited to, verifying that sufficient mixing will be present outside of the vessel, using feed and bleed, or drain and fill of the affected area(s).

Regarding other protective measures, there will be interlocks in the logic controlling the RCP power supply. These interlocks, together with the AP600 ERGs/EOPs, will preclude the inadvertent restart of the RCPs following the actuation of the passive core cooling systems.

Conclusions

It has been demonstrated that after a loss of heat sink event, following CMT actuation and RCS cooldown to equilibrium temperatures, RCS loop recovery will not pose a recriticality potential, as the boron addition from the CMTs becomes sufficiently mixed with the entire RCS. It has also been shown that unborated water accumulated upstream of idle RCPs, as is postulated during the "Finnish Center" scenario, to volumes approximately one and one-half times that physically possible to stagnate in the AP600 RCP casings of one of the steam generators, will not result in recriticality following RCP restart. Furthermore, conservatively calculated unborated volumes greater than the entire primary-side of a steam generator can be accommodated without recriticality concerns under reverse RCS loop flow circumstances (i.e., the RCPs are restarted in the loop opposite from that containing the unborated coolant). The exceptional mixing that occurs in the RCS loops under the reverse flow configuration is utilized procedurally for those instances where it will be apparent to the operator where the low, or unborated water volume may exist (e.g., the ~~steam generator tube rupture~~ *SGTR* ERGs). Therefore, the AP600 design has shown that substantial boron dilution can occur, however unlikely, without leading to recriticality. Even though analyses indicate recriticality would not occur, additional steps have been prescribed to minimize boron dilution potential, thereby maintaining a "defense in depth."

References

440.120-1 Andreychek, T. S., et al., "AP600 Low-Pressure Integral Systems Test at Oregon State University Test Analysis Report," WCAP-14292, Revision 1, September 1995.

440.120-2 Macian, R., K. Ivanov, and G. E. Robinson, "Analysis of Boron Dilution Transients in the AP600", The Pennsylvania State University, Nuclear Engineering Department, June 1996.

440.120-3 Simplified Passive Advanced Light Water Reactor Plant Program, AP600 Standard Analysis Report, Section 15.2.7, "Loss of Normal Feedwater Flow," Revision 5, February 29, 1996.

440.120-4 Macian, R., and John H. Mahaffy, "High Order Numerical Modeling of Solute Transport in System Codes", The Pennsylvania State University, Nuclear Engineering Department, September 1995.

440.120-5 "Revision 1 of the AP600 Emergency Response Guidelines," NTD-NRC-95-4525 (DCP/NRC0376), ~~Docket No.: STN-52-003,~~ August 9, 1995.

440.120-6 Burnett, Toby, et al., "Risk of PWR Inadvertent Criticality During Shutdown and Refueling," NSAC-183, Westinghouse Electric Corporation, Electric Power Research Institute, December 1992.

SSAR Revision: None