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Docket No.: STN-52-003

June 20, 1997

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

ATTENTION: MR. T. R. QUAY

SUBJECT: AP600 MAIN CONTROL ROOM DOSE ANALYSIS

Dear Mr. Quay:

In Westinghouse letter, Brian McIntyre to T. R. Quay, dated March 14, 1997, Westinghouse indicated main control room dose analyses were being completed with the design changes implemented to address control room habitability in the post-72 hour time frame after an event.

The AP600 design for the emergency habitability system includes sufficient compressed air storage to keep the main control room (MCR) pressurized with clean air for 72 hours. After 72 hours an ancillary fan will be used to draw 1700 cfm of unfiltered air from the MCR air intake and direct it to the MCR. The MCR door will be opened to allow the air to exhaust through the vestibule. The impact of opening the MCR in this manner following a postulated accident has been evaluated to demonstrate that dose accumulation by the operators would be within the 5.0 rem whole body dose limit (or equivalent to any organ).

The postulated LOCA with core melt is the limiting design basis accident for doses to the operators in the MCR. At 72 hours into the accident virtually all of the activity in the aerosol form and most (99.5%) of the iodine in the elemental form would have been removed from the containment atmosphere. The only significant activity remaining in the containment atmosphere and available for leakage to the environment is from the noble gases (which have been depleted greatly from radioactive decay) and from iodine in the organic form. The LOCA dose analysis, including the determination of doses to the MCR operators based on the MCR operating with 1700 cfm unfiltered inleakage after 72 hours, is addressed in SSAR subsection 15.6.5.3, Revision 13. The dose to the operators in the MCR was determined to be <5.0 rem TEDE from all pathways (containment purge release, containment leakage, direct radiation from activity in surrounding buildings, air-scattering of the radiation streaming from the top of the shield building, and iodine releases due to spent fuel pool boiling)

SSAR subsection 15.6.5.3 does not include a discussion of the potential for iodine reevolution from residual water volume remaining in the IRWST after drain-down of the tank is complete. However, when including the dose contribution from iodine reevolution, the total dose to the operators in the MCR remains bounded by the dose reported in the SSAR. A detailed discussion of the pH history that has been calculated for the IRWST residual water volume following a LOCA and the impact of low pH in this solution on the LOCA doses is provided in the attached response to RAI 470.31.

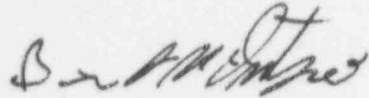
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June 20, 1997

The NRC is requested to review the attached RAI and provide any further comments to Westinghouse by July 15, 1997. Please contact Susan V. Fanto on (412) 374-4028 if you have any questions concerning this transmittal.



Brian A. McIntyre, Manager
Advanced Plant Safety and Licensing

jml

Attachment

cc: W. Huffman, NRC
N. J. Liparulo, Westinghouse (w/o Enclosure)



Question 470.31

Re: Provide the Westinghouse pH calculations that show the water volumes, chemical reactions, amounts of chemicals, mixing efficiencies, acid generations (hydrochloric and sulfuric acids) resulting from radiolysis of organic cable insulation materials, and resulting pH values for the entire duration of a DBA (30 days).

Response:

Westinghouse has analyzed three different post accident cases. All three cases take into account the initial water mass and boric acid from the reactor coolant system and from the passive core cooling system injection supplies, trisodium phosphate (TSP) added by the passive core cooling system, hydrochloric acid from electrical cable degradation, cesium hydroxide formed from the fission products released from the core, and nitric acid produced by irradiation of water and air. The formation of hydrochloric and nitric acids is based on the models described in NUREG-CR-5950 (Reference 470.31-1). These different cases evaluate a range of mixing considerations.

Case 1 - Large LOCA with Complete Mixing

Summary

This case assumes a large LOCA which releases the source term into the containment which maximizes the initial activity concentrations in the containment. This case assumes that all of the water in the containment is well mixed including the residual pool of water in the IRWST. This case is performed to determine the amount of trisodium phosphate required to maintain the solution pH at ≥ 7.0 for the 30 day accident duration.

It was determined that 196 ft³ (10,580 lb) of TSP is needed to maintain the pH above 7.0 following the postulated LOCA. The AP600 TSP baskets have been modified to store a combined volume of 214 ft³ (total TSP mass of 11,550 lb).

Two TSP baskets are provided, each with one half of this volume. The location of the baskets remains between the two loop compartments which is an area that is flooded post-LOCA.

Detailed Discussion

The initiating accident in this case is a large LOCA. The accumulators and core makeup tanks are assumed to work properly such that the core refloods with water and is cooled down. The IRWST injection valves (squib or check valves) are assumed to fail due to common mode failure. This failure is beyond design basis and results in the core uncovering and melting. When the core exit thermocouples reach high levels, the operators initiate IRWST drain to the containment to provide ex-



vessel cooling. The initiation of IRWST drain occurs about 2 hours after the LOCA and the drain takes about 4 hours.

The production of HCl (hydrochloric acid as a gas) from degradation of electrical cable jacket material (Hypalon) is calculated based on the NUREG/CR-5950 methodology and a 27,000 lb Hypalon inventory (based on the assumption that 90% of the cabling is located above the flood-up level). Per the modeling of NUREG/CR-5950, the amount of HCl produced by the radiation of electrical cable can be estimated as 4.6×10^{-4} g-mol of HCl per pound of jacketing per Mrad of dose. The overall extent of HCl production is dependent on the total dose delivered to the cable jacketing. A 30-day duration was assumed. The AP600 integrated dose for both gamma and beta radiation is used to estimate the HCl production for a 30 day post-accident interval. The total integrated dose is 320 Mrad. Using this integrated dose, the NUREG/CR-5950 conversion factor, and 27,000 pounds of Hypalon, the total HCl production for a thirty day interval is 319 pounds.

At the end of 30 days the following masses of water, acids, and bases are calculated to be present:

	Mass (lb)
H ₂ O	6.34×10^6
H ₃ BO ₃	1.1×10^5
CsOH	267
HNO ₃	211
Na ₃ PO ₄	4567 (10,580 lb of Na ₃ PO ₄ - 12 H ₂ O)
HCl	319

With this amount of TSP, the pH of the post-accident solution remains above 7.0 for 30 days accident duration. To provide margin, the AP600 TSP basket design has been modified to store a volume of 214 ft³ (total TSP mass of 11,550 lb) in the two baskets.

Case 2 - Small LOCA with Poor Mixing of IRWST Residual Water

Summary

This case assumes that all of the core activity release is delivered to the full IRWST and captured there. The IRWST is then assumed to be drained, with less than 20% of the water remaining in the IRWST after drain-down is complete. The initial chemical composition in the IRWST residual water changes with time due to the condensation of steam on the containment shell and its delivery to the IRWST. The flow of condensate water provides dilution of the IRWST residual water and a motive force for flow out of the tank to the containment. The condensate is also assumed to carry hydrochloric acid, generated in the high radiation environment, into the IRWST.



In this case the solution in the IRWST is initially at a pH of 6.2 at the beginning of drain-down (i.e., at 2 hours into the accident). At 12 hours the pH is 5.4 and at 24 hours it decreases further to 4.8. After 24 hours the pH remains relatively constant in the range of 4.8 to 4.6.

When the pH of the IRWST residual water is below 6.0, it can promote the conversion of cesium iodide to elemental iodine. Elemental iodine is subject to reevolution into the IRWST gas space and to formation of organic iodine forms. At the initial pH of 6.2 there is virtually no conversion of cesium iodide into elemental iodine but, as the pH decreases, there is an increasing conversion to the elemental form. The calculated doses associated with the releases are less than 0.1 rem TEDE at the LPZ boundary and less than 0.5 rem TEDE to the operators in the main control room. These doses are far below those reported in SSAR subsection 15.6.5.3 for the design basis LOCA in which the activity is assumed to be released directly to the containment atmosphere.

Detailed Discussion

This case assumes a small LOCA, some operation of ADS stages 1, 2, & 3 and no operation of ADS stage 4. As a result, all of the source term is discharged into the IRWST. This case maximizes the iodine initially deposited in the IRWST. It is performed to determine if poor mixing results in excessive long term offsite or control room doses.

Shortly after the in-vessel fission product is released to the IRWST (about 2 hours), draining of the IRWST is initiated. The IRWST drains to its equilibrium level with the containment level in about 4 more hours. The IRWST draining reduces the IRWST level from about 30 feet of water to about 5 feet. The IRWST level remains constant for the remainder of the 30 day calculation. The bulk solution in the containment which contains TSP is assumed not to mix with the residual water in the IRWST (although some mixing between the two volumes is expected to occur which would result in TSP entering the IRWST).

The steam condensing on the containment shell is assumed to be collected by the gutters and delivered to the IRWST. This flow mixes with the IRWST water and displaces an equal volume of water which flows back into the containment through the IRWST drain lines. This process creates a "feed and bleed" of the IRWST water inventory which results in a slow removal of cesium iodine from the IRWST. In about nine days essentially all of the cesium iodine is removed from the IRWST. The other chemical species (boric acid, CsOH, etc.) are also slowly removed from the IRWST by the same process.

The condensate dilutes the solution in the IRWST (both the cesium hydroxide and the boric acid) and also brings hydrochloric acid into the IRWST. The evolution of hydrogen chloride is calculated in containment based on the total integrated dose history and a 27,000 lb hypalon inventory (based on the assumption that 90% of the cabling is located above the flood-up level). Nitric acid formation is assumed to take place in the water and there is thus no airborne component to be transported to the



IRWST. The nitric acid in the IRWST is a result of the activity in the IRWST residual water pool. The chemical inventories in the IRWST are shown below for the first 20 days after the LOCA.

IRWST Chemical Inventory (lbm)					
Time (days)	H ₂ O	H ₃ BO ₃	CsOH	HNO ₃	HCL
0.083	4.96E6	8.28E4	201	0.37	0.005
0.5	8.71E5	1.22E4	44.6	0.98	17.0
1.0	8.71E5	8.21E3	30.0	1.2	38.0
2.0	8.71E5	3.86E3	14.0	1.0	39.0
3.0	8.71E5	1.98E3	7.2	0.71	39.0
5.0	8.71E5	7.57E2	2.8	0.4	46.0
10.0	8.71E5	83.6	0.3	0.07	28.0
20.0	8.71E5	10.0	0.03	0.01	16.0

At 10 days the only chemical significantly affecting solution pH is the hydrochloric acid. At 20 days essentially all the chemicals except for hydrochloric acid have been removed. A significant amount of hydrochloric acid remains in the IRWST because it continues to be produced in the containment and transferred to the IRWST with the condensate.

The pH of the solution as a function of time is:

Time (days)	pH
0.083	6.2
0.5	5.4
1.0	4.8
2.0	4.7
5.0	4.6
10.0	4.8

The high initial pH is due to the cesium hydroxide released into the IRWST from the damaged core. The pH drops with time as a result of the flow of condensate into the IRWST from the gutter which brings hydrochloric acid into the IRWST and forces solution from the IRWST into the containment through the IRWST drain lines. Beyond ten days, the pH will continue to gradually increase as the concentration of hydrochloric acid decreases.



When the pH in the IRWST residual water is below 6.0 there is the potential for conversion of the non-volatile cesium iodide into the elemental iodine form which is volatile. The extent to which cesium iodide would convert to the elemental form depends on both the pH and the iodine concentration and which are both varying with time. During the first 12 hours, the conversion to the elemental form is 3% and after 12 hours 11% of the iodine is calculated to convert to the elemental form (per Figure 3.1 of NUREG/CR-5950). The elemental iodine is assumed to partition readily to form an equilibrium between the liquid and the IRWST air space (a partition factor of 5 was determined using the model in NUREG/CR-5950). The elemental iodine which reevolves into the IRWST gas space can then be transported into the containment atmosphere where it is readily removed by deposition onto surfaces in the containment. (As shown in SSAR Appendix 15B, a deposition removal coefficient of 2.0 hr^{-1} is applicable to elemental iodine.) However, consistent with NUREG-1465, three percent of the elemental iodine is assumed to convert to the organic form which is not readily removed and is assumed to remain available for release to the environment due to containment leakage.

The air space in the IRWST is assumed to be purged by steam generated from the decay heat produced by the fission products in the IRWST residual water and this purge of the IRWST gradually transports the iodine from the gas space of the tank to the general containment atmosphere where the assumed containment leakage results in releases to the environment.

The calculated doses associated with the releases are less than 0.1 rem TEDE at the LPZ boundary and less than 0.5 rem TEDE to the operators in the main control room. These doses are far below those reported in SSAR subsection 15.6.5.3 for the design basis LOCA in which the activity is assumed to be released directly to the containment atmosphere.

Case 3 - Large LOCA with Poor Mixing

Summary

This case assumes a large LOCA which releases the source term into the containment atmosphere. The airborne cesium iodide (and other aerosols) are removed primarily by deposition onto the containment shell. The steam condensing on the containment shell is assumed to be collected by the gutters and delivered to the IRWST. This effectively transports the deposited activity from the containment shell into the IRWST. Because of the continuing removal of airborne activity and transportation of this activity to the IRWST, the inventory of iodine (and other activity) in the IRWST at the end of drain-down is higher than for Case 2.

The pH history for the IRWST residual solution is bounded by that of Case 2 since there is more activity in the IRWST residual water and the higher level of cesium hydroxide would increase the pH in the IRWST.



The doses associated with iodine reevolution are less than 0.2 rem TEDE at the LPZ boundary and less than 1.0 rem TEDE to the operators in the main control room. When these doses are added to those resulting from the initial release of activity into the containment, the resulting total doses are bounded by the values reported in SSAR subsection 15.6.5.3.

Detailed Discussion

This case assumes a large LOCA which releases the source term into the containment atmosphere. The airborne cesium iodide (and other aerosols) are removed primarily by deposition onto the containment shell. The steam condensing on the containment shell is assumed to be collected by the gutters and delivered to the IRWST. This effectively transports the deposited activity from the containment shell into the IRWST. It is assumed that drain-down of the IRWST is initiated at the end of the gap release phase and that the tank drains to its minimum level in about four hours. Because of this assumption, a significant portion of the airborne activity does not enter the IRWST until after drain-down is complete - this increases the amount of iodine that would be in the tank and subject to conversion to volatile forms. The higher activity level also increases the decay heat generation in the IRWST resulting in a higher purge rate from the tank to the containment. The inventory of iodine (and other activity) in the IRWST at the end of drain-down is over 30% of that released to the containment which is higher than for Case 2. In addition, the continuing removal of airborne activity to the IRWST sustains the activity level in the IRWST solution for several hours after drain-down. Only after the airborne activity level is substantially reduced does reduction of the IRWST solution activity begin.

The pH history for the IRWST residual solution is bounded by that of Case 2 since there is more activity in the IRWST residual water. The higher level of cesium hydroxide would increase the pH in the IRWST above that in Case 2.

When the pH in the IRWST residual water is below 6.0 there is the potential for conversion of the non-volatile cesium iodide into the elemental iodine form which is volatile. The extent to which cesium iodide would convert to the elemental form depends on both the pH and the iodine concentration and which are both varying with time. During the first 12 hours, the conversion to the elemental form is 3% and after 12 hours 15% of the iodine is calculated to convert to the elemental form (per Figure 3.1 of NUREG/CR-5950). The elemental iodine is assumed to partition readily to form an equilibrium between the liquid and the IRWST air space (a partition factor of 5 was determined using the model in NUREG/CR-5950). The elemental iodine which reevolves into the IRWST gas space can then be transported into the containment atmosphere where it is readily removed by deposition onto surfaces in the containment. (As shown in SSAR Appendix 15B, a deposition removal coefficient of 2.0 hr^{-1} is applicable to elemental iodine.) However, consistent with NUREG-1465, three percent of the elemental iodine is assumed to





convert to the organic form which is not readily removed and is assumed to remain available for release to the environment due to containment leakage.

The air space in the IRWST is assumed to be purged by steam generated from the decay heat produced by the fission products in the IRWST residual water and this purge of the IRWST gradually transports the iodine from the gas space of the tank to the general containment atmosphere where the assumed containment leakage results in releases to the environment.

The doses associated with iodine reevolution are less than 0.2 rem TEDE at the LPZ boundary and less than 1.0 rem TEDE to the operators in the main control room. When these doses are added to those resulting from the LOCA without consideration of iodine reevolution, the resulting total doses are lower than those reported in SSAR subsection 15.6.5.3 for the design basis LOCA.

Conservatism Associated with Calculation of Hydrochloric Acid Production

A key conservatism included in the hydrogen chloride production assessment is the use of the total integrated gamma and beta dose. A location at the center of the containment was used to estimate the dose rates and integrated doses. Thus, the location at which the integrated dose was calculated was surrounded on all sides by the radiation field. For cabling located on the containment boundary or at an internal wall there would be a reduction in the radiation field due to the positioning within the containment. More importantly, while beta radiation constitutes a large fraction of the total integrated dose, it has only a limited ability to penetrate thick electrical insulation jackets or stacks of cables in a cable tray. Since hydrogen chloride production is directly proportional to the actual absorbed dose, the calculated production of hydrogen chloride from cable degradation is highly conservative.

Conservatism Associated with Determination of the Fraction of Iodine Converting to the Elemental Form

As shown in NUREG/CR-5950 (Reference 1), the fraction of iodine converting to the elemental form is dependent on solution iodine concentration and pH. These factors were taken into account when determining the fraction of iodine in the IRWST residual water pool that would convert to the elemental form. NUREG/CR-5950 also discusses the impact of solution temperature on the formation of elemental iodine. At higher temperatures the formation of elemental iodine can be significantly smaller than at lower temperatures. One referenced test showed ~45% of iodine converting to I_2 at 86°F but only ~10% conversion at 158°F. The curves in Figure 3.1 of NUREG/CR-5950 show the elemental iodine fraction as a function of pH and iodine concentration but at a low temperature of 77°F. The temperature of the water in the IRWST is assumed to be initially at 120°F and it would eventually increase to close to the saturation temperature. The use of the curves from NUREG/CR-5950 leads to an overprediction of the formation of elemental iodine by a estimated factor of between two and four.



References

- 470.31 NUREG/CR-5950, "Iodine Evolution and pH Control," 12/92, E. C. Beahm, R. A. Lorenz, & C. F. Weber

SSAR Revision: NONE