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Your ref: Docket No. 52-006
Our ref: DCP/NRC1708

June 21, 2004

SUBJECT: Transmittal of Revised Responses to AP1000 DSER Open Items

This letter transmits Westinghouse revised responses for Open Items in the AP1000 Design Safety Evaluation Report (DSER). A list of the revised DSER Open Item responses transmitted with this letter is Attachment 1. The non-proprietary responses are transmitted as Attachment 2.

Please contact me at 412-374-4728 if you have any questions concerning this submittal.

Very truly yours,

A handwritten signature in black ink, appearing to read 'R. P. Vijuk'.

R. P. Vijuk, Manager
Passive Plant Engineering
AP600 & AP1000 Projects

/Attachments

1. List of the AP1000 Design Certification Review, Draft Safety Evaluation Report Open Item Responses transmitted with letter DCP/NRC1708
2. Non-Proprietary AP1000 Design Certification Review, Draft Safety Evaluation Report Open Item Responses

D063

June 21, 2004

Attachment 2

AP1000 Design Certification Review
Draft Safety Evaluation Report Open Item Non-Proprietary Responses

June 21, 2004

Attachment 1

**AP1000 Design Certification Review
Draft Safety Evaluation Report Open Item Non-Proprietary Responses**

Table 1 “List of Westinghouse’s Responses to DSER Open Items Transmitted in DCP/NRC1708”	
15.3-1 Response Revision 5 ACRS ISSUE 6 Revision 2	

June 21, 2004

Attachment 2

AP1000 Design Certification Review
Draft Safety Evaluation Report Open Item Non-Proprietary Responses

AP1000 DESIGN CERTIFICATION REVIEW

Draft Safety Evaluation Report Open Item Response

DSER Open Item Number: 15.3-1 Response Revision 5

Original RAI Number(s): 470.009, 470.011

Summary of Issue:

The staff has not completed its evaluation of the applicability of the AP600 aerosol removal coefficients to the AP1000 design. The staff will evaluate the impact of the differences in the AP1000 design as compared to the AP600 on the modeling of aerosol removal and will perform independent analyses of the estimated aerosol removal rates. Upon resolution of issues with the determination of aerosol removal rates in containment, as discussed in RAIs 470.009 and 470.011, the staff will complete its evaluation of the bounding accident sequence and the aerosol behavior and removal rates corresponding to the selected bounding accident sequence in the containment following a DBA. This is Open Item 15.3-1.

Westinghouse Response:

The Westinghouse responses to RAI 470.009 transmitted by Westinghouse letter DCP/NRC1535, November 26, 2002 and RAI 470.011 Rev. 1 transmitted by Westinghouse letter DCP/NRC1571, April 11, 2003 address previous NRC comments related to this issue.

NRC Additional Comments (Nov 6, 2003 telecon):

- a) Clarify the use of shape factor described in section 15B.2.1.1 of the DCD.
- b) Discuss the sensitivity of aerosol removal to aerosol void fraction identified in section 15B.4.2.3.

Westinghouse Response to NRC Additional Comments (Nov 6, 2003 telecon):

- a) Section 15B.2.1.1 and 15B.3 of the DCD will be revised as shown below.
- b) Section 15B.2.4.3 of the DCD will be revised as shown below.

NRC Additional Comments (March 10, 15 and 16, 2004 telecons):

- a) Provide additional justification for aerosol removal by thermophoresis. In particular, address how the heat transfer rate from the air to the containment wall is calculated and applied in the determination of aerosol removal by thermophoresis.
- b) The particle density fraction (0.8) and void content (water) used by Westinghouse are not sufficiently conservative; NRC would agree with particle density fraction of 0.6 and void content of air.

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- c) The core inventory of Iodine and Cesium used in the AP1000 analysis seems high compared to these values for cores that NRC has reviewed for operating plants.

NRC Additional Comments (March 30 and 31, 2004 telecons):

Only convection heat transfer should be used in determining the lambda due to thermophoresis.

Explain the effect of the revised lambda and atmospheric dispersion factors on accidents other than LOCA.

Explain the long term trend of the overall lambda for AP1000 as compared to that for AP600.

NRC Additional Comments (April 13, 2004 meeting):

Timing of the onset of gap release could be later than assumed in the STARNAUA analysis.

Provide a description of how reflooding into the vessel occurs during the severe accident scenario used for aerosol removal analysis.

Provide a breakdown of contributions to aerosol removal as a function of time, and provide the total aerosol concentration as a function of time.

Tracer gas testing for inleakage to the main control room during VBS operation should be specified in the DCD.

Westinghouse Response (Rev 5) to NRC Additional Comments (March 10, 15, 16, 30 and 31, 2004 telecons, and April 13, 2004 meeting):

Revision 4 of this response provided a revised version of the following discussion to address the NRC additional comments from the April 13, 2004 meeting. In particular, the STARNAUA analysis now assumes onset of gap release at 3300 seconds after the break (MAAP4 time when peak clad temperature reaches 2200 F). A description of the vessel reflooding process is provided and additional data from STARNAUA results is provided. DCD Revision 11 added tracer gas testing for main control room inleakage during VBS operation.

Revision 5 of this response updates the STARNAUA analysis to correct an input error, provides revised dose analysis results using the corrected STARNAUA results, and provides the corresponding DCD revisions to be incorporated in DCD Revision 12.

The STARNAUA analysis of aerosol removal uses only the convective heat transfer at the containment wall as calculated by MAAP4. Explanations are provided regarding accidents other than LOCA, and regarding the long term trend of the AP1000 overall lambda. The control room dose analysis assumption regarding unfiltered air inleakage for the case when the active ventilation system is assumed operable is reduced from 140 cfm to 90 cfm. The lower value is still conservative with respect to what has been achievable in operating plants. Tracer gas testing for unfiltered air inleakage will be conducted to confirm the assumed inleakage.

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- a) The aerosol removal analysis in DCD Revision 11 was found to have an incorrect input; the containment gas space temperature was input in °C whereas the thermophoresis equation in STARNAUA is based on temperature in °K. The result was greater aerosol removal by thermophoresis than is appropriate. The STARNAUA analysis has now been performed using correct input. The following discussion provides the results of the new STARNAUA analysis and the results of new dose calculations using the aerosol removal rates from the new STARNAUA analysis.

Definition of thermophoresis

If a temperature gradient exists in an air volume, a particle in that volume tends to migrate towards the cooler region. The motion is the result of gas molecules on the warm side striking the particle with a greater average momentum than those on the cooler side. This phenomena is defined as thermophoresis. Thermophoresis will exist when there is a temperature gradient in the gas regardless of whether the gradient is caused by conduction or by natural and/or forced convection.

Determination of temperature gradient

Boundary layer theory for convective flow and heat transfer in a gas at a solid surface indicates that the heat transfer rate is ultimately determined by the thermal conduction in the sublayer at the heat transfer surface, which is given by:

$$q = -k_{\text{air}} \cdot A \cdot \frac{dT}{dy}$$

where q is the heat transfer rate, k_{air} is the thermal conductivity of air and dT/dy is the temperature gradient at the heat transfer surface (i.e., $y=0$). However, in engineering applications, convective heat transfer problems are solved not by the equation above, but by:

$$q = h \cdot A \cdot (T_a - T_s)$$

where h is the heat transfer coefficient, T_a is the ambient temperature and T_s is the temperature of heat transfer surface. The reason is that dT/dy at the surface is unknown and is hard to determine in tests. On the other hand, the unknown h can be calculated easily by many empirical or semi-empirical correlations. Once q is calculated using second equation above, it can be substituted into the first equation to calculate the temperature gradient at the wall, i.e.,

$$\left| \frac{dT}{dy} \right| = \frac{q}{k_{\text{air}} \cdot A}$$

Detailed development of this relationship can be found in heat transfer

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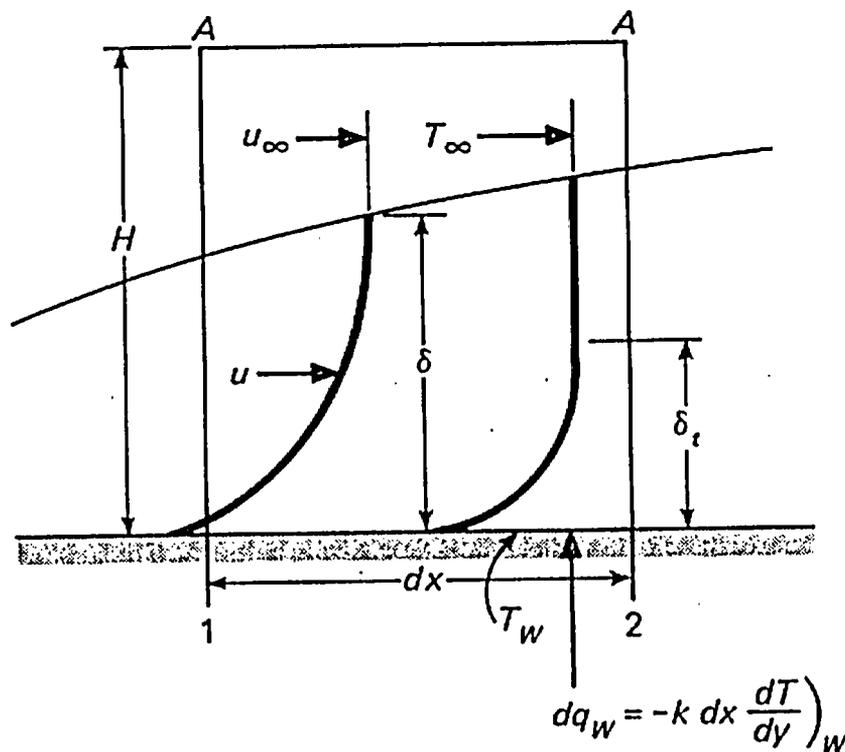
textbooks (e.g., Heat Transfer, J.P. Holman, 4th edition, 1976, McGraw Hill).

Value for a realistic temperature gradient

A high temperature gradient at the wall is not unreasonable even for natural convection situations; on pages 248-250 of the Holman textbook cited above is an example for natural convection of air on a heated vertical surface. The heat flux in this example is 800 W/m^2 and the conductivity of air is given as $0.032 \text{ W/m}^\circ\text{C}$. This results in a temperature gradient at the wall of $25 \text{ }^\circ\text{C/mm}$.

The natural convection heat transfer for the AP1000 severe accident scenario is this same order of magnitude (few hundred W/m^2), so the temperature gradient is also the same order of magnitude as in the textbook example.

The figure below from the Holman textbook illustrates the thermal and momentum boundary layers.



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Calculation of heat transfer from containment air to the wall

The convective heat transfer to the containment shell was determined from the MAAP4 simulation of sequence 3BE-01. The containment gas temperature and the film temperature on the wall are shown in Figure 1 for this sequence. Figure 2 shows the temperature difference between the gas and the film which is the driving mechanism for heat transfer. Figure 3 shows the MAAP4 calculated convective heat transfer to the film on the containment inner surface.

References

1. Holman, J.P., Heat Transfer, McGraw Hill, 4th Ed, 1976.

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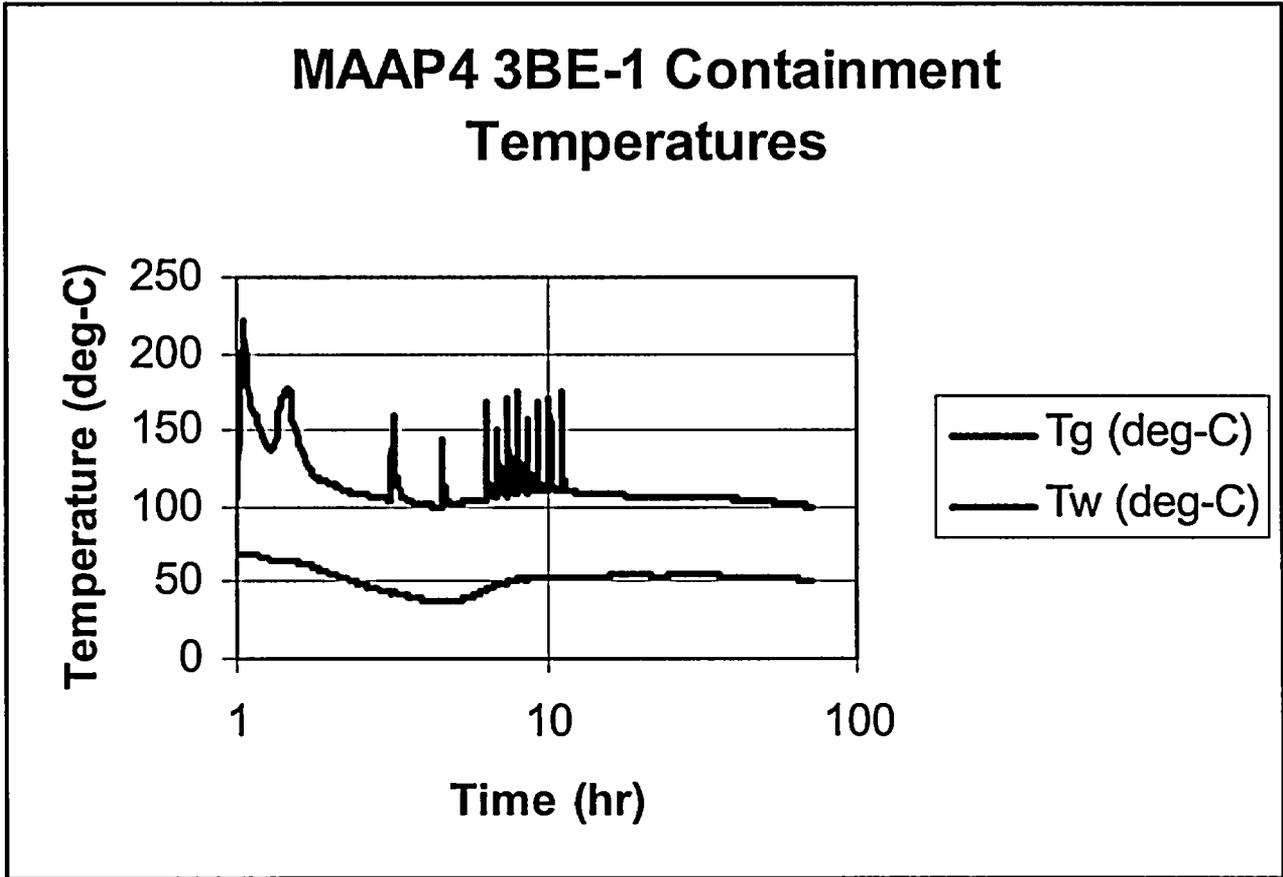


Figure 1: MAAP4 Containment Temperature for Sequence 3BE-1

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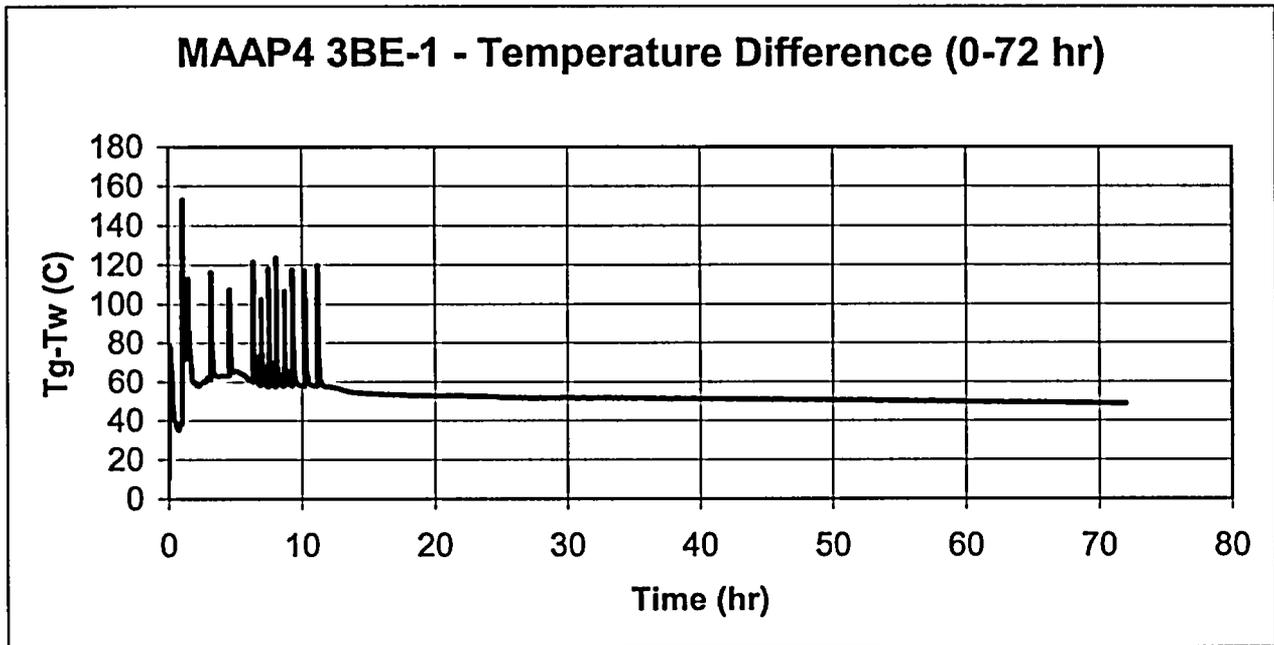


Figure 2: MAAP4 Temperature Difference Between Containment Atmosphere and Liquid Film at the Wall (0 – 72 hours)

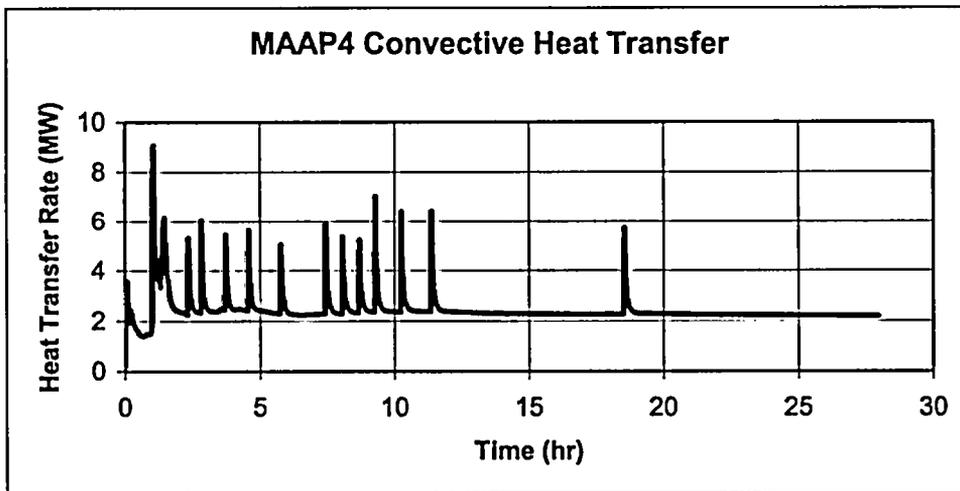


Figure 3: MAAP4 Convective Heat Transfer Between Containment Atmosphere and Liquid Film at the Wall (0 – 28 hours)

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The convective heat flux from MAAP4 is used in the STARNAUA analysis determination of thermophoretic aerosol removal. The heat transfer rate is converted to heat flux by dividing by the containment wall area. The temperature gradient in the air near the containment shell is calculated by dividing the heat flux by conductivity of the air. This is a direct determination of the temperature gradient and can be quite large even for modest heat transfer coefficients and temperature differences, as shown above.

This temperature gradient is used in the Thermophoresis correlation to get thermophoretic deposition velocity. STARNAUA applies this deposition velocity to determine the rate at which aerosol particles are deposited on the water film surface at the wall by multiplying the thermophoretic deposition velocity by the particle concentration and wall surface area. The particle concentration used here is based on a well mixed containment atmosphere. Mixing in the bulk containment is driven by the convective forces resulting from steaming into containment and heat transfer at the boundaries of the containment atmosphere. Even with a high thermophoretic deposition of particles near the wall, the particles in the bulk space will travel fast enough to the region near the wall to maintain a continuous deposition. One can easily derive that the thermophoretic velocity of particles is on the order of a fraction of cm per second. It is very small when compared to particle movement in the bulk space, which is on the order of meters per second or higher. Therefore, thermophoresis will not cause a particle free zone near the surface.

Evaluation of Mixing and Stratification in the AP1000 Containment

As part of the AP600 Design Certification process, a test facility was constructed to characterize the passive containment cooling system. The Large Scale Test facility (Ref: M.D. Kennedy, et al, "Westinghouse-GOTHIC Comparisons with Passive Containment Cooling Tests Using a One-to-Ten Scale Test Facility", Nuclear Technology, Vol. 113, January 1996) was constructed to test a range of containment designs from the Heavy Water Reactor Facility which was a 1:10 scale, to the AP600 which was a 1:8 scale. The vessel was designed with a prototypic height to diameter ratio. The facility was equipped with a water film distribution system on the outside of the shell, and a steam injection system to simulate the mass and energy releases during a large pipe break inside containment. Several tests were performed including steady-state tests to determine the heat and mass transfer characteristics inside and outside the containment shell, transient simulations to determine the containment pressure response to simulated releases, and releases of non-condensable gas along with the steam to determine the degree of mixing and stratification inside the containment.

For the steam-only tests, it was determined that the volume above the operating deck was typically well mixed with somewhat higher temperature above the steam release point along the centerline of the vessel, and lower temperatures along the walls. Flow patterns were observed to be upflow along the centerline and downflow along the walls. The volumes below the operating deck were stagnant, air-rich, and generally much colder than the volume above the deck. Gas velocities were found to be related to the velocity and orientation of the steam jet, but were generally found to be on the order of ~1 m/s.

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For the non-condensable gas injection tests, helium was used to simulate hydrogen that would be evolved during a severe accident. For these tests, helium was injected along with the steam jet. Gas samples were taken at various points in the containment. For all these tests, the gases were found to be well-mixed above the operating deck. Once again, the volume below the operating deck was air-rich and colder. Very little helium was observed in this volume.

It is expected that any aerosol particles suspended in the containment atmosphere would follow the flow patterns observed in these tests, at similar velocities. Since the bulk flow velocity is much higher than the thermophoretic velocity which is on the order of fractions of cm/sec, the containment will be well-mixed with regard to the distribution of aerosol particles. The results of these tests are applicable to the AP1000 since the scaled parameters and test conditions cover the ranges expected for the AP1000 containment under accident conditions. These tests form the basis of the WGOTHIC and MAAP4 code validation for AP1000 containment analysis.

Accident Class 3BE-1 Sequence Details

The initiating event for the 3BE-1 sequence is a double-ended break of a direct vessel injection (DVI) line. The break is modeled as a 4-inch diameter (area = 0.00811 m²) break (DVI venturi throat diameter). The center line elevation of the break is at reference elevation 99'-7" or 7.56 m above the inside bottom of the reactor vessel. The break is assumed to occur in the larger of the two PXS compartments of the containment 4.6 m above the floor of the PXS-B compartment. The larger PXS-B compartment location is conservative since more water is lost to the PXS compartment and it takes longer to flood the containment and refill the vessel.

The initiating event results in the loss of one accumulator, which spills immediately into the break compartment. The CMT in the faulted line will also spill to the PXS-B compartment when the CMT discharge valves are opened on the S-Signal (25 seconds). One CMT and one accumulator (in the intact DVI train) remain available to inject into the reactor vessel through the intact DVI train prior to core uncover.

ADS stage 1 is initiated at 617 seconds (0.17 hr) on low CMT level with a time delay. Stages 2 and 3 are initiated on a time delay from stage 1 at 737 seconds (0.20 hr) and 857 seconds (0.34 hr) respectively. Stages 1, 2 and 3 relieve to the spargers under the water in the IRWST. Stage 4 ADS is initiated on low-low CMT level and RCS low pressure interlock at 1588 seconds (0.44 hr). Stage 4 ADS relieves directly to the containment atmosphere above the water level in the steam generator compartments. The reactor coolant system is fully depressurized (in equilibrium with the containment pressure) by 0.5 hours.

The accident sequence as modeled with MAAP4 initiates ADS on the intact CMT level. The CMT in the faulted DVI train would initiate ADS stage 1 at approximately 120 seconds after the CMT blows down starting at the S-signal. Initiating ADS from the intact CMT conservatively delays the time of core uncover until later in the transient when the condensation rate in the containment is less.

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The squib valves in the gravity injection line in the intact DVI train fail to open when the stage 4 ADS signal is generated at 1588 seconds (0.44 hr), so the accident progresses to core uncover and core damage. The squib valves in the faulted line open on the ADS-4 signal and drain the IRWST into the PXS-B compartment through the faulted DVI line. The PXS-B compartment begins to fill with water. There is a small drain in the PXS compartment that drains water to the containment sump.

After the core uncovers at 2480 seconds (0.69 hr) and the core heats up until the core exit gas temperature reaches 1200°F (0.85 hr). At this signal, the operator successfully executes the procedure to flood the reactor cavity by opening the gravity recirculation valves after a 0.1 hour assumed time delay. The IRWST water then drains to the cavity through one of the two recirculation lines. At 3275 seconds (0.91 hrs) the peak cladding temperature reaches 2200°F marking the onset of rapid core oxidation. Core uncover and the onset of rapid oxidation represent reasonable early and late time points to assume initiation of the gap release.

At approximately 1 hour, the water level in the PXS-B compartment is sufficient to spill water into the RCS through the break and begin refilling the reactor vessel. The water level in the reactor vessel reaches the elevation of the top of the original core configuration at approximately 1.6 hours. The in-vessel core debris remains covered throughout the remainder of the transient. Steaming from the core debris is vented through ADS stage 4 to the containment.

The decay heat from the core debris is released from the RCS as steam venting through the ADS stage 4 and as heat transfer through the lower vessel head into the flooded cavity. After the water in the cavity reaches the saturation temperature at the containment pressure, all decay heat from the core debris is released to the containment atmosphere in the form of steam. This steam is condensed on the containment shell and heat is transferred to the environment via the passive containment cooling system. Thus, a significant fraction of the decay heat is removed via condensation after the vessel is reflooded, and an even larger fraction is removed via condensation once the water in the reactor cavity becomes saturated.

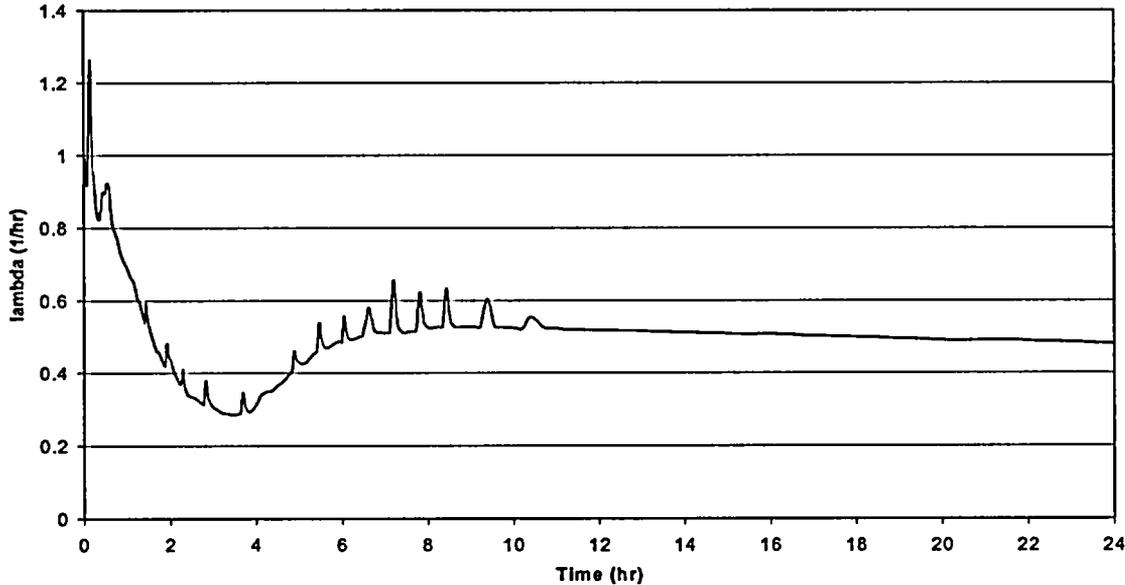
Revised STARNAUA Analysis Results

The overall aerosol removal coefficients (λ) calculated by STARNAUA are shown in the figure below. These removal coefficients are used in the LOCA dose analysis to determine the offsite and control room doses.

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AP1000 Lambda for Sequence 3BE-1
(release at 3300 seconds after event initiation)



It is noted that the AP1000 overall lambda decreases only slightly after about 7 hours out to 24 hours. For AP600 the overall lambda decreased about 10% over this time period. This difference is assessed as follows.

The removal lambda (or decay lambda) for containment aerosols during the phase when the source is terminated is defined by the following equation:

$$\lambda = -(1/n) (dn/dt) - L \quad (1)$$

where n is aerosol mass concentration and L is fractional containment leak rate. Equation (1) is used in STARNAUA to calculate overall aerosol removal λ .

The consideration of aerosol mass conservation yields:

$$V(dn/dt) = -(v_s A_s + v_t A_t + v_d A_d)n - L \cdot V \cdot n \quad (2)$$

where V is the containment volume, v and A are removal velocities of aerosols and the corresponding receiving surface areas, respectively. The subscripts s , t , and d stand for sedimentation, thermophoresis and diffusiophoresis, respectively.

The combination of Equations (1) and (2) yields an equivalent expression for λ , i. e.,

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$$\lambda = v_s(A_s/V) + v_i(A_i/V) + v_d(A_d/V) \quad (3)$$

Examining Equation (3), we can conclude that λ changes with the sum of all three removal velocities since all three area to volume ratios are constant.

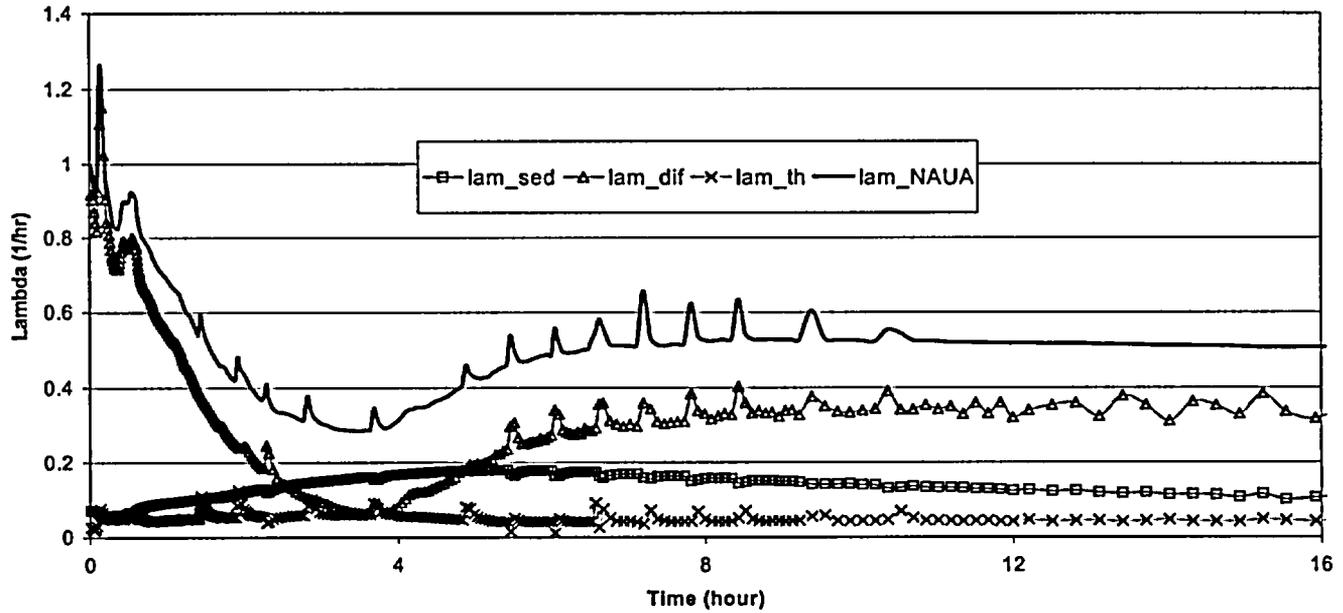
The expressions for the three aerosol removal velocities are given in DCD Sections 15B.2.1.1, 15B.2.1.2 and 15B.2.1.3, respectively. According to the expressions, sedimentational velocity is particle size dependent. Diffusiophoretic velocity, however, is not size dependent, but proportional to the condensation rate. Thermophoretic velocity is somewhat size dependent (much smaller dependency than sedimentation) and proportional to the convective heat transfer rate. As a result, the sedimentational velocity is expected to decrease as larger particles settle out in time. For both AP600 and AP1000 the thermal hydraulic conditions for thermophoresis and for diffusiophoresis are nearly constant in this time period. Because sedimentation is a larger contributor to the overall λ for AP600 (~1/3) as compared to AP1000 (~1/5) the result is the larger decrease in overall lambda observed for AP600 during this time period. Also, in the dose analysis, aerosol removal is only credited until a DF of 1000 is achieved; for the AP1000 analysis reported below this occurs at 15.5 hours.

The following two figures provide STARNAUA results for lambda elements and for aerosol particle concentration in containment atmosphere.

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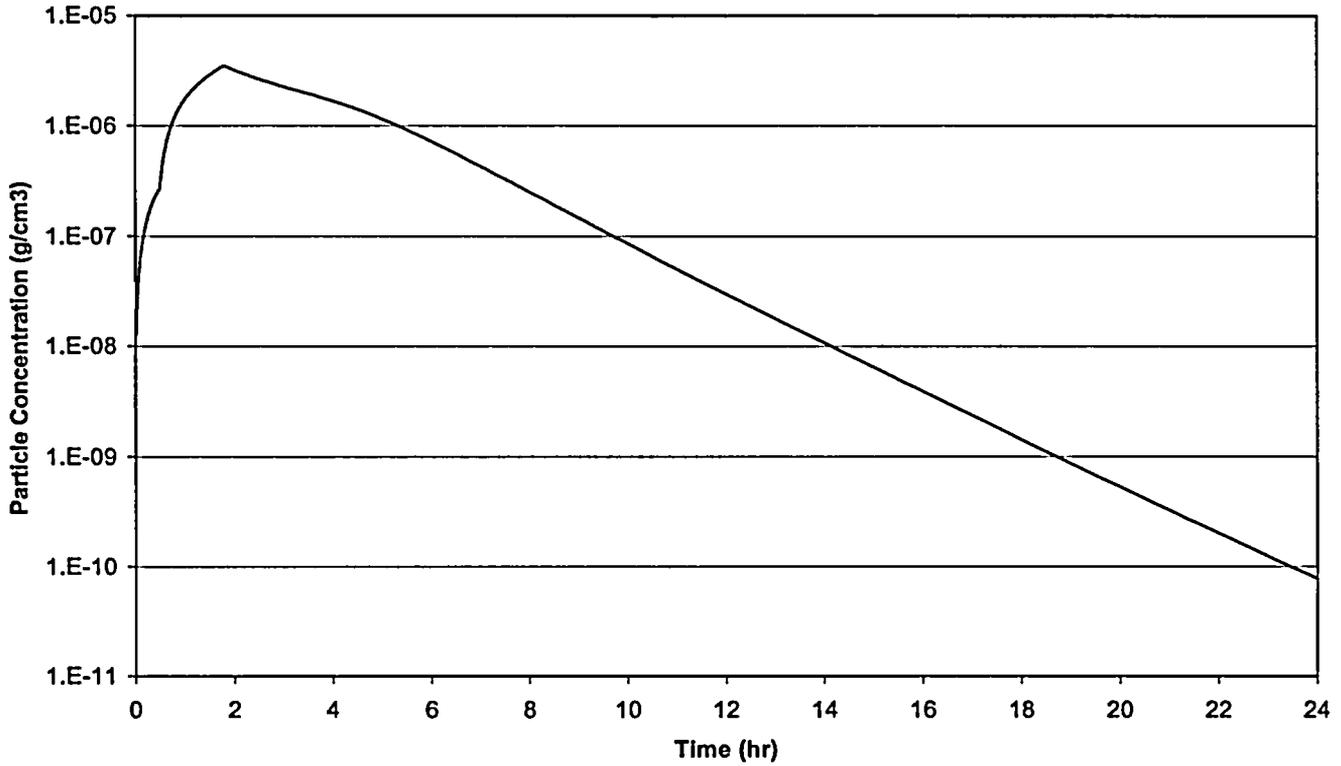
Lambda Breakdowns for the Case In Which Gap Release Starts 3300 Seconds



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Particle Concentration for the Case in Which Gap Release Starts 3300 Seconds



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Revised Dose Analyses

The radiological consequences of the LOCA have been recalculated taking into account the revised aerosol removal coefficients. In order to continue to obtain doses that are within the dose acceptance limits, the atmospheric dispersion factors have been redefined for the Site Boundary, the Low Population Zone outer boundary, and the Control Room. These revised atmospheric dispersion factors are provided below:

Site Boundary 5.1E-4 sec/m³ (5.8E-4 was the previous value)

Low Population Zone

0 – 8 hours 2.2E-4 sec/m³ (2.7E-4 was the previous value)
 8 – 24 hours 1.6E-4 sec/m³ (2.0E-4 was the previous value)
 24 – 96 hours 1.0E-4 sec/m³ (this value was not changed)
 96 – 720 hours 8.0E-5 sec/m³ (this value was not changed)

Control Room

Atmospheric Dispersion Factors at HVAC Intake (sec/m ³)				
	Plant Vent or PCS Air Diffuser as Release Point		Ground Level Containment Release Points	
	New Value	Old Value	New Value	Old Value
0 -2 hr	2.2E-3	2.45E-3	2.2E-3	2.45E-3
2-8 hr	1.4E-3	1.65E-3	1.4E-3	1.65E-3
8-24 hr	6.0E-4	6.6E-4	6.0E-4	6.6E-4
24-96 hr	4.5E-4	5.0E-4	4.5E-4	5.0E-4
96-720 hr	3.6E-4	4.0E-4	3.6E-4	4.0E-4

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Atmospheric Dispersion Factors at Control Room Door (sec/m ³)				
	Plant Vent or PCS Air Diffuser as Release Point		Ground Level Containment Release Points	
	New Value	Old Value	New Value	Old Value
0 -2 hr	6.6E-4	8.0E-4	6.6E-4	8.0E-4
2-8 hr	4.8E-4	6.0E-4	4.8E-4	6.0E-4
8-24 hr	2.1E-4	3.0E-4	2.1E-4	3.0E-4
24-96 hr	1.5E-4	2.0E-4	1.5E-4	2.0E-4
96-720 hr	1.3E-4	1.5E-4	1.3E-4	1.5E-4

Additionally, the unfiltered inleakage to the Control Room when the HVAC is assumed to be in operation was reduced from 140 cfm to 90cfm.

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The LOCA doses resulting from leakage of activity from the containment are recalculated to be:

Site Boundary	24.6 rem TEDE
Low Population Zone	23.8 rem TEDE
Control Room	4.77 rem TEDE (with Emergency Habitability System in service, including direct dose)
Control Room	4.54 rem TEDE (with HVAC in service, including direct dose)

The radiological consequences analyses performed for all other accidents have used the previously defined offsite atmospheric dispersion factors. Also, certain other accidents (e.g., the Rod Ejection Accident) have used the previously defined atmospheric dispersion factors for the Control Room. Since the atmospheric dispersion factor changes identified above are all more restrictive than the previously assumed values, the doses calculated for these events are conservative and would only be reduced if the above changes in dispersion factors were incorporated in the analyses.

Similarly, while the revised LOCA analysis assumes an unfiltered inleakage to the control room of 90 cfm for the case in which the active ventilation system is operable, the assumed inleakage for the other accident analyses is 140 cfm. Thus, these other dose analyses are conservative and the calculated doses would decrease if the reduction in unfiltered inleakage is taken into account.

- b) Westinghouse believes that the use of a particle density fraction of 0.8 is consistent with empirical data. While the 0.8 particle density fraction together with the assumption that the aerosol void are water-filled are believed to be appropriate for the AP1000 post-LOCA containment environment, this analysis of aerosol removal has been performed using a reduced particle density fraction of 0.6 combined with the assumption that the voids are air-filled.
- c) Core nuclide inventories vary with both power and burnup. For nuclides with relatively short half-lives (e.g., I-131 and I-133), the inventory in the core is dependent primarily on power level with core burnup having little impact. However, for nuclides that have long half-lives (e.g., I-129, Cs-134, and Cs-137) or are stable (e.g., I-127), both the core power level and core burnup will strongly affect the nuclide inventory in the core. The AP1000 power level is comparable to currently operating Westinghouse four-loop plants and is designed to operate with an 18-month fuel cycle. If this is compared with a Westinghouse three-loop plant operating with an annual fuel cycle, the short-lived nuclides will be found to be roughly proportional to power level but the long-lived and stable nuclides will be significantly greater for the AP1000 because of the longer operating time over which these nuclides are created.

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Design Control Document (DCD) Revision:

Revisions will be made to Tier 1 Table 5.0-1, Tier 2 Table 2-1, Section 6.4.4, , Table 9.4.1-1, , Section 15.6.5.3.8, Table 15.6.5-2, Table 15.6.5-3, Table 15A-5, Table 15A-6, and Appendix 15B, as shown on the following pages.

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Table 5.0-1 (cont.) Site Parameters	
Soil Average Allowable Static Soil Bearing Capacity Maximum Allowable Dynamic Bearing Capacity for Normal Plus Safe Shutdown Earthquake (SSE) Shear Wave Velocity Liquefaction Potential	Greater than or equal to 8,600 lb/ft ² over the footprint of the nuclear island at its excavation depth Greater than or equal to 120,000 lb/ft ² at the edge of the nuclear island at its excavation depth Greater than or equal to 8000 ft/sec based on low-strain, best-estimate soil properties over the footprint of the nuclear island at its excavation depth None
Seismic SSE Fault Displacement Potential	SSE free field peak ground acceleration of 0.30 g at foundation level of nuclear island with modified Regulatory Guide 1.60 response spectra (See Figures 5.0-1 and 5.0-2.) None
Atmospheric Dispersion Factors (X/Q) Site Boundary (0-2 hr) Site Boundary (annual average) Low Population Zone Boundary 0 - 8 hr 8 - 24 hr 24 - 96 hr 96 - 720 hr	$\leq 5.1 \times 10^{-4} \text{ sec/m}^3$ $\leq 2.0 \times 10^{-5} \text{ sec/m}^3$ $\leq 2.2 \times 10^{-4} \text{ sec/m}^3$ $\leq 1.6 \times 10^{-4} \text{ sec/m}^3$ $\leq 1.0 \times 10^{-4} \text{ sec/m}^3$ $\leq 8.0 \times 10^{-5} \text{ sec/m}^3$

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Table 5.0-1 (cont.) Site Parameters	
Soil Average Allowable Static Soil Bearing Capacity Maximum Allowable Dynamic Bearing Capacity for Normal Plus Safe Shutdown Earthquake (SSE) Shear Wave Velocity Liquefaction Potential	Greater than or equal to 8,600 lb/ft ² over the footprint of the nuclear island at its excavation depth Greater than or equal to 120,000 lb/ft ² at the edge of the nuclear island at its excavation depth Greater than or equal to 8000 ft/sec based on low-strain, best-estimate soil properties over the footprint of the nuclear island at its excavation depth None
Seismic SSE Fault Displacement Potential	SSE free field peak ground acceleration of 0.30 g at foundation level of nuclear island with modified Regulatory Guide 1.60 response spectra (See Figures 5.0-1 and 5.0-2.) None
Atmospheric Dispersion Factors (X/Q) Site Boundary (0-2 hr) Site Boundary (annual average) Low Population Zone Boundary 0 - 8 hr 8 - 24 hr 24 - 96 hr 96 - 720 hr	$\leq 5.158 \times 10^{-4} \text{ sec/m}^3$ $\leq 2.0 \times 10^{-5} \text{ sec/m}^3$ $\leq 2.227 \times 10^{-4} \text{ sec/m}^3$ $\leq 1.620 \times 10^{-4} \text{ sec/m}^3$ $\leq 1.0 \times 10^{-4} \text{ sec/m}^3$ $\leq 8.0 \times 10^{-5} \text{ sec/m}^3$

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Table 5.0-1 (cont.) Site Parameters					
Table 5.0-1 (cont.) Site Parameters					
Control Room Atmospheric Dispersion Factors (χ/Q) for Accident Dose Analysis					
χ/Q (s/m ³) at HVAC Intake for the Identified Release Points ⁽¹⁾					
	Plant Vent or PCS Air Diffuser ⁽³⁾	Ground Level Containment Release Points ⁽⁴⁾	PORV and Safety Valve Releases ⁽⁵⁾	Steam Line Break Releases	Fuel Handling Area ⁽⁶⁾
0 - 2 hours	2.22-45E-3	2.2E-32-45E-3	2.0E-2	2.4E-2	6.0E-3
2 - 8 hours	1.41-65E-3	1.4E-31-65E-3	1.8E-2	2.0E-2	4.0E-3
8 - 24 hours	6.06-6E-4	6.0E-46-6E-4	7.0E-3	7.5E-3	2.0E-3
1 - 4 days	4.55-0E-4	4.5E-45-0E-4	5.0E-3	5.5E-3	1.5E-3
4 - 30 days	3.64-0E-4	3.6E-44-0E-4	4.5E-3	5.0E-3	1.0E-3
χ/Q (s/m ³) at Control Room Door for the Identified Release Points ⁽²⁾					
0 - 2 hours	6.68-0E-4	6.6E-48-0E-4	4.0E-3	4.0E-3	6.0E-3
2 - 8 hours	4.86-0E-4	4.8E-46-0E-4	3.2E-3	3.2E-3	4.0E-3
8 - 24 hours	2.13-0E-4	2.1E-43-0E-4	1.2E-3	1.2E-3	2.0E-3
1 - 4 days	1.52-0E-4	1.5E-42-0E-4	1.0E-3	1.0E-3	1.5E-3
4 - 30 days	1.31-5E-4	1.3E-41-5E-4	8.0E-4	8.0E-4	1.0E-3

Notes:

1. These dispersion factors are to be used 1) for the time period preceding the isolation of the main control room and actuation of the emergency habitability system, 2) for the time after 72 hours when the compressed air supply in the emergency habitability system would be exhausted and outside air would be drawn into the main control room, and 3) for the determination of control room doses when the nonsafety ventilation system is assumed to remain operable such that the emergency habitability system is not actuated.
2. These dispersion factors are to be used when the emergency habitability system is in operation and the only path for outside air to enter the main control room is that due to ingress/egress.
3. These dispersion factors are used for analysis of the doses due to a postulated small line break outside of containment. The plant vent and PCS air diffuser are potential release paths for other postulated events (loss-of-coolant accident, rod ejection accident, and fuel handling accident inside the containment); however, the values are bounded by the dispersion factors for ground level releases.
4. The listed values represent modeling the containment shell as a diffuse area source, and are used for evaluating the doses in the main control room for a loss-of-coolant accident, for the containment leakage of activity following a rod ejection accident, and for a fuel handling accident occurring inside the containment.
5. The listed values bound the dispersion factors for releases from the steam line safety and power-operated relief valves, and the condenser air removal stack. These dispersion factors would be used for evaluating the doses in the main control room for a steam generator tube rupture, a main steam line break, a locked reactor coolant pump rotor, and the secondary side release from a rod ejection accident. Additionally, these dispersion coefficients are conservative for the small line break outside containment.
6. The listed values bound the dispersion factors for releases from the fuel storage and handling area. The listed values also bound the dispersion factors for releases from the fuel storage area in the event that spent

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**Table 5.0-1 (cont.)
Site Parameters**

fuel boiling occurs and the fuel building relief panel opens on high temperature. These dispersion factors are used for the fuel handling accident occurring outside containment and for evaluating the impact of releases associated with spent fuel pool boiling.

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Table 2-1 (Sheet 2 of 3)	
SITE PARAMETERS	
Plant Grade Elevation	Less than plant elevation 100' except for portion at a higher elevation adjacent to the annex building
Precipitation	
Rain	19.4 in./hr (6.3 in./5 min)
Snow/Ice	75 pounds per square foot on ground with exposure factor of 1.0 and importance factors of 1.2 (safety) and 1.0 (non-safety)
Atmospheric Dispersion Values - $\chi/Q^{(e)}$	
Site boundary (0-2 hr)	$\leq 5.15\text{-}8 \times 10^{-4} \text{ sec/m}^3$
Site boundary (annual average)	$\leq 2.0 \times 10^{-5} \text{ sec/m}^3$
Low population zone boundary	
0 - 8 hr	$\leq 2.22\text{-}7 \times 10^{-4} \text{ sec/m}^3$
8 - 24 hr	$\leq 1.62\text{-}0 \times 10^{-4} \text{ sec/m}^3$
24 - 96 hr	$\leq 1.0 \times 10^{-4} \text{ sec/m}^3$
96 - 720 hr	$\leq 8.0 \times 10^{-5} \text{ sec/m}^3$
Population Distribution	
Exclusion area (site)	0.5 mi

Notes:

- (a) Maximum and minimum safety values are based on historical data and exclude peaks of less than 2 hours duration.
- (b) Maximum and minimum normal values are the 1 percent exceedance magnitudes.
- (c) With ground response spectra (at foundation level of nuclear island) as given in Figures 3.7.1-1 and 3.7.1-2.
- (d) The noncoincident wet bulb temperature is applicable to the cooling tower only.
- (e) For AP1000, the terms "site boundary" and "exclusion area boundary" are used interchangeably. Thus, the χ/Q specified for the site boundary applies whenever a discussion refers to the exclusion area boundary.

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Table 2-1 (Sheet 3 of 3)					
SITE PARAMETERS					
Control Room Atmospheric Dispersion Factors (χ/Q) for Accident Dose Analysis					
χ/Q (s/m ³) at HVAC Intake for the Identified Release Points ⁽¹⁾					
	Plant Vent or PCS Air Diffuser ⁽³⁾	Ground Level Containment Release Points ⁽⁴⁾	PORV and Safety Valve Releases ⁽⁵⁾	Steam Line Break Releases	Fuel Handling Area ⁽⁶⁾
0 - 2 hours	2.2E-32.45E-3	2.2E-32.45E-3	2.0E-2	2.4E-2	6.0E-3
2 - 8 hours	1.4E-31.65E-3	1.4E-31.65E-3	1.8E-2	2.0E-2	4.0E-3
8 - 24 hours	6.0E-46.6E-4	6.0E-46.6E-4	7.0E-3	7.5E-3	2.0E-3
1 - 4 days	4.5E-45.0E-4	4.5E-45.0E-4	5.0E-3	5.5E-3	1.5E-3
4 - 30 days	3.6E-44.0E-4	3.6E-44.0E-4	4.5E-3	5.0E-3	1.0E-3
χ/Q (s/m ³) at Control Room Door for the Identified Release Points ⁽²⁾					
	Plant Vent or PCS Air Diffuser ⁽³⁾	Ground Level Containment Release Points ⁽⁴⁾	PORV and Safety Valve Releases ⁽⁵⁾	Steam Line Break Releases	Fuel Handling Area ⁽⁶⁾
0 - 2 hours	6.6E-48.0E-4	6.6E-48.0E-4	4.0E-3	4.0E-3	6.0E-3
2 - 8 hours	4.8E-46.0E-4	4.8E-46.0E-4	3.2E-3	3.2E-3	4.0E-3
8 - 24 hours	2.1E-43.0E-4	2.1E-43.0E-4	1.2E-3	1.2E-3	2.0E-3
1 - 4 days	1.5E-42.0E-4	1.5E-42.0E-4	1.0E-3	1.0E-3	1.5E-3
4 - 30 days	1.3E-41.5E-4	1.3E-41.5E-4	8.0E-4	8.0E-4	1.0E-3

Notes:

1. These dispersion factors are to be used 1) for the time period preceding the isolation of the main control room and actuation of the emergency habitability system, 2) for the time after 72 hours when the compressed air supply in the emergency habitability system would be exhausted and outside air would be drawn into the main control room, and 3) for the determination of control room doses when the non-safety ventilation system is assumed to remain operable such that the emergency habitability system is not actuated.
2. These dispersion factors are to be used when the emergency habitability system is in operation and the only path for outside air to enter the main control room is that due to ingress/egress.
3. These dispersion factors are used for analysis of the doses due to a postulated small line break outside of containment. The plant vent and PCS air diffuser are potential release paths for other postulated events (loss-of-coolant accident, rod ejection accident, and fuel handling accident inside the containment); however, the values are bounded by the dispersion factors for ground level releases.

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4. The listed values represent modeling the containment shell as a diffuse area source, and are used for evaluating the doses in the main control room for a loss-of-coolant accident, for the containment leakage of activity following a rod ejection accident, and for a fuel handling accident occurring inside the containment.
5. The listed values bound the dispersion factors for releases from the steam line safety & power-operated relief valves and the condenser air removal stack. These dispersion factors would be used for evaluating the doses in the main control room for a steam generator tube rupture, a main steam line break, a locked reactor coolant pump rotor, and for the secondary side release from a rod ejection accident. Additionally, these dispersion coefficients are conservative for the small line break outside containment.
6. The listed values bound the dispersion factors for releases from the fuel storage and handling area. The listed values also bound the dispersion factors for releases from the fuel storage area in the event that spent fuel boiling occurs and the fuel building relief panel opens on high temperature. These dispersion factors are used for the fuel handling accident occurring outside containment and for evaluating the impact of releases associated with spent fuel pool boiling.

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6.4.4 System Safety Evaluation

Doses to main control room personnel were calculated for both the situation in which the emergency habitability system (VES) is relied upon to limit the amount of activity the personnel are exposed to and the situation in which the nuclear island nonradioactive ventilation system (VBS) is available to pressurize the main control room with filtered air and provide recirculation cleanup. Doses were calculated for the following accidents:

	<u>VES Operating</u>	<u>VBS Operating</u>
Large Break LOCA TEDE	4.8 rem TEDE	4.54.95—rem
Fuel Handling Accident	4.5 rem TEDE	2.4 rem TEDE
Steam Generator Tube Rupture (Pre-existing iodine spike)	4.8 rem TEDE	3.4 rem TEDE
(Accident-initiated iodine spike)	2.1 rem TEDE	1.8 rem TEDE
Steam Line Break (Pre-existing iodine spike)	3.4 rem TEDE	2.1 rem TEDE
(Accident-initiated iodine spike)	3.7 rem TEDE	4.9 rem TEDE
Rod Ejection Accident	2.1 rem TEDE	1.3 rem TEDE
Locked Rotor Accident (Accident without feedwater available)	0.9 rem TEDE	0.9 rem TEDE
(Accident with feedwater available)	0.7 rem TEDE	1.6 rem TEDE
Small Line Break Outside Containment	1.2 rem TEDE	0.3 rem TEDE

For all events the dose are within the dose acceptance limit of 5.0 rem TEDE. The details of analysis assumptions for modeling the doses to the main control room personnel are delineated in the LOCA dose analysis discussion in subsection 15.6.5.3.

No radioactive materials are stored or transported near the main control room pressure boundary. As discussed and evaluated in subsection 9.5.1, the use of noncombustible construction and heat and flame resistant materials throughout the plant reduces the likelihood of fire and consequential impact on the main control room atmosphere. Operation of the nuclear island nonradioactive ventilation system in the event of a fire is discussed in subsection 9.4.1.

The exhaust stacks of the onsite standby power diesel generators are located in excess of 150 feet away from the fresh air intakes of the main control room. The onsite standby power system fuel oil storage tanks are located in excess of 300 feet from the main control room fresh air intakes. These separation distances reduce the possibility that combustion fumes or smoke from an oil fire would be drawn into the main control room.

The protection of the operators in the main control room from offsite toxic gas releases is discussed in Section 2.2. The sources of onsite chemicals are described in Table 6.4-1, and their locations are shown on Figure 1.2-2. Analysis of these sources is in accordance with Regulatory Guide 1.78 (Reference 5) and the methodology in NUREG-0570, "Toxic Vapor Concentrations in the Control Room Following a Postulated Accidental Release" (Reference 6), and the analysis shows that these sources do not represent a toxic hazard to control room personnel.

A supply of protective clothing, respirators, and self-contained breathing apparatus adequate for 11 persons is stored within the main control room pressure boundary.

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The main control room emergency habitability system components discussed in subsection 6.4.2.3 are arranged as shown in Figure 6.4-2. The location of components and piping within the main control room pressure boundary provides the required supply of compressed air to the main control room pressure boundary, as shown in Figure 6.4-1.

During emergency operation, the main control room emergency habitability system passive heat sinks are designed to limit the temperature inside the main control room to remain within limits for reliable human performance (References 2 and 3) over 72 hours. The passive heat sinks limit the air temperature inside the instrumentation and control rooms to 120°F and dc equipment rooms to 120°F. The walls and ceilings that act as the passive heat sinks contain sufficient thermal mass to accommodate the heat sources from equipment, personnel, and lighting for 72 hours.

The main control room emergency habitability system nominally provides 65 scfm of ventilation air to the main control room from the compressed air storage tanks. Sixty scfm of ventilation flow is sufficient to pressurize the control room to at least positive 1/8-inch water gauge differential pressure with respect to the surrounding areas in addition to limiting the carbon dioxide concentration below one-half percent by volume for a maximum occupancy of 11 persons and maintaining air quality within the guidelines of Table 1 and Appendix C, Table C-1, of Reference 1.

Automatic transfer of habitability system functions from the main control room/technical support center HVAC subsystem of the nuclear island nonradioactive ventilation system to the main control room emergency habitability system is initiated by either the following conditions:

- “High-high” particulate or iodine radioactivity in MCR air supply duct
- Loss of ac power for more than 10 minutes

The airborne fission product source term in the reactor containment following the postulated LOCA is assumed to leak from the containment and airborne fission products are assumed to result from spent fuel pool steaming. The concentration of radioactivity, which is assumed to surround the main control room, after the postulated accident, is evaluated as a function of the fission product decay constants, the containment leak rate, and the meteorological conditions assumed. The assessment of the amount of radioactivity within the main control room takes into consideration the radiological decay of fission products and the infiltration/exfiltration rates to and from the main control room pressure boundary.

A single active failure of a component of the main control room emergency habitability system or nuclear island nonradioactive ventilation system does not impair the capability of the systems to accomplish their intended functions. The Class 1E components of the main control room emergency habitability system are connected to independent Class 1E power supplies. Both the main control room emergency habitability system and the portions of the nuclear island nonradioactive ventilation system which isolates the main control room are designed to remain functional during an SSE or design-basis tornado.

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Table 9.4.1-1 (Sheet 2 of 2)

COMPONENT DATA – NUCLEAR ISLAND NONRADIOACTIVE VENTILATION SYSTEM

MCR/TSC HVAC Subsystem (Nominal Values)

Supplemental Air Filtration Subsystem			
Quantity		2	
System capacity per unit (%)		100	
Fan Requirements			
Type		Centrifugal	
Design airflow (scfm)		4,000	
Fan static pressure (in. wg)		14	
Heating Coil Requirements			
Type		Electric	
Capacity (kw)		20	
Filter Requirements			
High efficiency filter, minimum ASHRAE efficiency (%)		80	
HEPA filter, DOP efficiency (%)		99.97	
Post filter, DOP efficiency (%)		95	
Charcoal Adsorber Requirements			
Bed depth (in.)		4.0	
Decontamination efficiency (%)		90	
Air residence time (sec.)		0.5	
MCR Envelope Leakage Rates			
Leakage	Inleakage Rate at 1/8 in. wg (scfm)	Outleakage Rate at 1/8 in. wg (scfm)	
MCR access doors	10	--	
TSC access doors	10	--	
MCR structure	--	20	
TSC structure	--	500	
MCR/TSC HVAC equipment & ductwork (operating)	9970	480	

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15.6.5.3.8 LOCA Doses

15.6.5.3.8.1 Offsite Doses

The doses calculated for the exclusion area boundary and the low population zone boundary are listed in Table 15.6.5-3. The doses are within the 10 CFR 50.34 dose guideline of 25 rem TEDE.

The reported exclusion area boundary doses are for the time period of ~~1.2 to 2.2~~ 1.4 to 3.4 hours. This is the 2-hour interval that has the highest calculated doses. The dose that would be incurred over the first 2 hours of the accident is well below the reported dose.

At the time the LOCA occurs, there is the potential for a coincident loss of spent fuel pool cooling with the result that the pool could reach boiling and a portion of the radioactive iodine in the spent fuel pool could be released to the environment. The loss of spent fuel pool cooling has been evaluated for a duration of 30 days. There is no contribution to the 2-hour site boundary dose because pool boiling would not occur until after 8 hours. The 30-day contribution to the dose at the low population zone boundary is less than 0.01 rem TEDE and, when this is added to the dose calculated for the LOCA, the resulting total dose remains less than that reported in Table 15.6.5-3.

15.6.5.3.8.2 Doses to Operators in the Main Control Room

The doses calculated for the main control room personnel due to airborne activity entering the main control room are listed in Table 15.6.5-3. Also listed on Table 15.6.5-3 are the doses due to direct shine from the activity in the adjacent buildings and sky-shine from the radiation that streams out the top of the containment shield building and is reflected back down by air-scattering. The total of the three dose paths is within the dose criteria of 5 rem TEDE as defined in GDC 19.

As discussed above for the offsite doses, there is the potential for a dose to the operators in the main control room due to iodine releases from postulated spent fuel boiling. The calculated dose from this source is less than 0.01 rem TEDE and, when this is added to the dose calculated for the LOCA, the resulting total dose remains less than that reported in Table 15.6.5-3.

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Table 15.6.5-2 (Sheet 3 of 3)

ASSUMPTIONS AND PARAMETERS USED IN CALCULATING RADIOLOGICAL CONSEQUENCES OF A LOSS-OF-COOLANT ACCIDENT

Miscellaneous assumptions and parameters	
- Unfiltered air inleakage (cfm)	90440
- Offsite power	Not applicable
- Atmospheric dispersion factors (offsite)	See Table 15A-5
- Nuclide dose conversion factors	See Table 15A-4
- Nuclide decay constants	See Table 15A-4
- Offsite breathing rate (m ³ /sec)	
0 - 8 hr	3.5 E-04
8 - 24 hr	1.8 E-04
24 - 720 hr	2.3 E-04

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Table 15.6.5-3	
RADIOLOGICAL CONSEQUENCES OF A LOSS-OF-COOLANT ACCIDENT WITH CORE MELT	
	TEDE Dose (rem)
Exclusion zone boundary dose (1.2—3.21.4 - 3.4 hr) ⁽¹⁾	24,724.6
Low population zone boundary dose (0 - 30 days)	22,823.8
Main control room dose (emergency habitability system in operation)	
- Airborne activity entering the main control room	4,644.61 rem
- Direct radiation from adjacent structures	0.15 rem
- Sky-shine	0.01 rem
- Total	4,804.77 rem
Main control room dose (normal HVAC operating in the supplemental filtration mode)	
- Airborne activity entering the main control room	4,794.38 rem
- Direct radiation from adjacent structures	0.15 rem
- Sky-shine	0.01 rem
- Total	4,954.54 rem

Note:

1. This is the 2-hour period having the highest dose.

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Site boundary χ/Q (s/m^3) 0 - 2 hours ⁽¹⁾	5.15-8x10 ⁻⁴
Low population zone χ/Q (s/m^3) 0 - 8 hours	2.22-7x10 ⁻⁴
8 - 24 hours	1.62-0x10 ⁻⁴
24 - 96 hours	1.0x10 ⁻⁴
96 - 720 hours	8.0x10 ⁻⁵

Note:

1. Nominally defined as the 0- to 2-hour interval but is applied to the 2-hour interval having the highest activity releases in order to address 10 CFR Part 50.34 requirements.

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Table 15A-6					
CONTROL ROOM ATMOSPHERIC DISPERSION FACTORS (χ/Q) FOR ACCIDENT DOSE ANALYSIS					
χ/Q (s/m ³) at HVAC Intake for the Identified Release Points ⁽¹⁾					
	Plant Vent or PCS Air Diffuser ⁽³⁾	Ground Level Containment Release Points ⁽⁴⁾	PORV and Safety Valve Releases ⁽⁵⁾	Steam Line Break Releases	Fuel Handling Area ⁽⁶⁾
0 - 2 hours	2.2E-32.45E-3	2.2E-32.45E-3	2.0E-2	2.4E-2	6.0E-3
2 - 8 hours	1.4E-31.65E-3	1.4E-31.65E-3	1.8E-2	2.0E-2	4.0E-3
8 - 24 hours	6.0E-46.6E-4	6.0E-46.6E-4	7.0E-3	7.5E-3	2.0E-3
1 - 4 days	4.5E-45.0E-4	4.5E-45.0E-4	5.0E-3	5.5E-3	1.5E-3
4 - 30 days	3.6E-44.0E-4	3.6E-44.0E-4	4.5E-3	5.0E-3	1.0E-3
χ/Q (s/m ³) at Control Room Door for the Identified Release Points ⁽²⁾					
	Plant Vent or PCS Air Diffuser ⁽³⁾	Ground Level Containment Release Points ⁽⁴⁾	PORV and Safety Valve Releases ⁽⁵⁾	Steam Line Break Releases	Fuel Handling Area ⁽⁶⁾
0 - 2 hours	6.6E-48.0E-4	6.6E-48.0E-4	4.0E-3	4.0E-3	6.0E-3
2 - 8 hours	4.8E-46.0E-4	4.8E-46.0E-4	3.2E-3	3.2E-3	4.0E-3
8 - 24 hours	2.1E-43.0E-4	2.1E-43.0E-4	1.2E-3	1.2E-3	2.0E-3
1 - 4 days	1.5E-42.0E-4	1.5E-42.0E-4	1.0E-3	1.0E-3	1.5E-3
4 - 30 days	1.3E-41.5E-4	1.3E-41.5E-4	8.0E-4	8.0E-4	1.0E-3

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Notes:

1. These dispersion factors are to be used 1) for the time period preceding the isolation of the main control room and actuation of the emergency habitability system, 2) for the time after 72 hours when the compressed air supply in the emergency habitability system would be exhausted and outside air would be drawn into the main control room, and 3) for the determination of control room doses when the non-safety ventilation system is assumed to remain operable such that the emergency habitability system is not actuated.
2. These dispersion factors are to be used when the emergency habitability system is in operation and the only path for outside air to enter the main control room is that due to ingress/egress.
3. These dispersion factors are used for analysis of the doses due to a postulated small line break outside of containment. The plant vent and PCS air diffuser are potential release paths for other postulated events (loss-of-coolant accident, rod ejection accident, and fuel handling accident inside the containment); however, the values are bounded by the dispersion factors for ground level releases.
4. The listed values represent modeling the containment shell as a diffuse area source, and are used for evaluating the doses in the main control room for a loss-of-coolant accident, for the containment leakage of activity following a rod ejection accident, and for a fuel handling accident occurring inside the containment.
5. The listed values bound the dispersion factors for releases from the steam line safety & power-operated relief valves and the condenser air removal stack. These dispersion factors would be used for evaluating the doses in the main control room for a steam generator tube rupture, a main steam line break, a locked reactor coolant pump rotor, and for the secondary side release from a rod ejection accident. Additionally, these dispersion coefficients are conservative for the small line break outside containment.
6. The listed values bound the dispersion factors for releases from the fuel storage and handling area. The listed values also bound the dispersion factors for releases from the fuel storage area in the event that spent fuel boiling occurs and the fuel building relief panel opens on high temperature. These dispersion factors are used for the fuel handling accident occurring outside containment and for evaluating the impact of releases associated with spent fuel pool boiling.

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APPENDIX 15B

REMOVAL OF AIRBORNE ACTIVITY FROM THE CONTAINMENT ATMOSPHERE FOLLOWING A LOCA

The AP1000 design does not depend on active systems to remove airborne particulates or elemental iodine from the containment atmosphere following a postulated loss-of-coolant accident (LOCA) with core melt. Naturally occurring passive removal processes provide significant removal capability such that airborne elemental iodine is reduced to very low levels within a few hours and the airborne particulates are reduced to extremely low levels within 12 hours.

15B.1 Elemental Iodine Removal

Elemental iodine is removed by deposition onto the structural surfaces inside the containment. The removal of elemental iodine is modeled using the equation from the Standard Review Plan (Reference 1):

$$\lambda_d = \frac{K_w A}{V}$$

where:

- λ_d = first order removal coefficient by surface deposition
- K_w = mass transfer coefficient (specified in Reference 1 as 4.9 m/hr)
- A = surface area available for deposition
- V = containment building volume

The available deposition surface is 219,000 ft², and the containment building net free volume is 2.06 x 10⁶ ft³. From these inputs, the elemental iodine removal coefficient is 1.7 hr⁻¹.

Consistent with the guidance of Reference 1, credit for elemental iodine removal is assumed to continue until a decontamination factor (DF) of 200 is reached in the containment atmosphere. Because the source term for the LOCA (defined in subsection 15.6.5.3) is modeled as a gradual release of activity into the containment, the determination of the time at which the DF of 200 is reached needs to be based on the amount of elemental iodine that enters the containment atmosphere over the duration of core activity release.

15B.2 Aerosol Removal

The deposition removal of aerosols from the containment atmosphere is accomplished by a number of processes including sedimentation, diffusiophoresis, and thermophoresis. All three of the deposition processes are significant contributors to the overall removal process in the AP1000. The large contributions from diffusiophoresis and thermophoresis to the total removal are a direct consequence of the high heat transfer rates from the containment atmosphere to the containment wall that characterize the passive containment cooling system.

Because of the AP1000 passive containment cooling system design, there are high sensible heat transfer rates (resulting in higher thermophoretic removal of aerosols) when condensational heat transfer is low (and the aerosol removal by diffusiophoresis is also low). The reverse is also true. Thus, there is an

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appreciable deposition removal throughout the accident from either diffusiophoresis or thermophoresis, in addition to the removal by sedimentation.

15B.2.1 Mathematical Models

The models used for the three aerosol removal processes are discussed as follows.

15B.2.1.1 Sedimentation

Gravitational sedimentation is a major mechanism of aerosol removal in a containment. A standard model (Stokes equation with the Cunningham slip correction factor) for this process is used. The Stokes equation (Reference 2) is:

$$v_s = \frac{2\rho_p g r^2 C_n}{9\mu}$$

where:

- v_s = settling velocity of an aerosol particle
- ρ_p = material density of the particle
- g = gravitational acceleration
- r = particle radius
- μ = gas viscosity
- C_n = Cunningham slip correction factor, a function of the Knudsen number (Kn) which is the gas molecular mean free path divided by the particle radius

However, the Stokes equation makes the simplifying assumption that the particles are spherical. The particles are expected to be nonspherical, and it is conventional to address this by introducing a "dynamic shape factor" (Reference 2) in the denominator of the Stokes equation, such that the settling velocity for the nonspherical particle is the same as for a spherical particle of equal volume. The value of the dynamic shape factor (ϕ) thus depends on the shape of the particle and, in general, must be experimentally determined.

The concept of dynamic shape factor can also be applied to a spherical particle consisting of two components, one of which has the density of the particle material, while the other component has a different density (Reference 9). In this manner, the impact of the void fraction in the particle can be modeled. Thus, the revised Stokes equation is:

$$v_s = \frac{2\rho_p g r^2 C_n}{9\mu\phi}$$

The derivation of ϕ follows.

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The two-component particle is considered to have a density ρ_{av} and an effective radius of r_e . Assuming that the second component of the particle is the void volume and letting the void fraction be ϵ , then the average density of the particle is:

$$\rho_{av} = \text{the average density of the particle} = \rho_p (1-\epsilon) + \rho_v \epsilon$$

where:

$$\begin{aligned} \rho_v &= \text{density of the void material (0.0 for gas filled, 1.0 for water filled)} \\ \epsilon &= \text{void fraction} \\ \rho_p &= \text{material density (solid particle with no voids)} \end{aligned}$$

The definition of ϕ is obtained from the Stokes equation and the equation for mass of a sphere:

$$\frac{2\rho_p g r^2 C_n}{9\mu\phi} = \frac{2\rho_{av} g r_e^2 C_n}{9\mu}$$

which reduces to:

$$\rho_p r^2 = \phi \rho_{av} r_e^2$$

and

$$\frac{4\rho_p \pi r_0^3}{3} = \frac{4\rho_{av} \pi r_e^3}{3}$$

which reduces to:

$$\rho_p r_0^3 = \rho_{av} r_e^3$$

Then:

$$\phi = \frac{\rho_p r^2}{\rho_{av} r_e^2}$$

and

$$r_e = r \left(\frac{\rho_{av}}{\rho_p} \right)^{-1/3}$$

From these two relationships, the dynamic shape factor is given by:

$$\phi = \left(\frac{\rho_{av}}{\rho_p} \right)^{-1/3}$$

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15B.2.1.2 Diffusiophoresis

Diffusiophoresis is the process whereby particles are swept to a surface (for example, containment wall) by the flow set up by a condensing vapor (Stefan flow). The deposition rate is independent of the particle size and is proportional to the steam condensation rate on the surface. The standard equation for this phenomenon is due to Waldmann and Schmitt (Reference 3):

$$v_d = \frac{\sqrt{M_v}}{\sqrt{M_v} + \chi_{a/v} \sqrt{M_a}} \frac{W}{\rho_v}$$

where:

v_d = diffusiophoretic deposition velocity

$\chi_{a/v}$ = ratio of mole fraction of air to mole fraction of steam in the containment atmosphere

M_v = molecular weight of steam

M_a = molecular weight of air

W = steam condensation rate on the wall

ρ_v = mass density of steam in the containment atmosphere

Because of the design of the passive containment cooling system, steam condensation rates are high at certain times in the design basis LOCA; thus at these times, diffusiophoretic deposition rates are significant.

15B.2.1.3 Thermophoresis

Thermophoresis is the process whereby particles drift toward a surface (for example, the containment wall) under the influence of a temperature gradient in the containment atmosphere at the surface. The effect arises because the gas molecules on the hot side of the particles undergo more collisions with the particle than do those on the cold side. Therefore, there is a net momentum transfer to the particle in the hot-to-cold direction. There are several models in the literature for this effect; the one used is the Brock equation in a form due to Talbot et al. (Reference 4). As indicated below, this model is in agreement with experimental data. The thermophoretic deposition rate is somewhat dependent on particle size and is proportional to the temperature gradient at the wall, or equivalently, the sensible heat transfer rate to the wall. The Talbot equation is:

$$v_{th} = \frac{2 C_s C_n (\mu_g / \rho_g) [\alpha + C_T Kn] dT}{[1 + 2(\alpha + C_T Kn)][1 + 3 C_M Kn]} \left(\frac{1}{T} \right) \frac{dT}{dy}$$

where:

v_{th} = thermophoretic deposition velocity

α = k_g/k_p which is the ratio of the thermal conductivities of the gas (evaluated at the gas temperature at each time step) and the aerosol particle (k_p is set

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- equal to the thermal conductivity of water – the results are not sensitive to k_p or α .)
- $Kn =$ Knudsen number (equal to the gas molecular mean free path divided by the particle radius)
- $C_n =$ Cunningham slip correction factor, a function of the Knudsen number
- $\mu_g =$ gas viscosity
- $\rho_g =$ gas density
- $C_s =$ slip accommodation coefficient (Reference 4 gives the best value as 1.17.)
- $C_T =$ thermal accommodation coefficient (Reference 4 gives the best value as 2.18.)
- $C_M =$ momentum accommodation coefficient (Reference 4 gives the best value as 1.14.)

The temperature gradient at the wall, dT/dy , can be evaluated as

$$\frac{dT}{dy} = \frac{\phi_s}{k_g}$$

where ϕ_s is the sensible heat flux to the wall, and k_g is the thermal conductivity of the gas. The sensible heat flux used in the analysis is the convective heat transfer calculated as discussed in subsection 15B.2.4.7.

15B.2.2 Other Removal Mechanisms

In addition to the above mechanisms, there are others that were not considered, including turbulent diffusion and turbulent agglomeration. The neglect of these mechanisms adds further conservatism to the calculation.

15B.2.3 Validation of Removal Mechanisms

The aerosol processes are well established and have been confirmed in many separate effects experiments, which are discussed in standard references (References 2 through 4). The Stokes formula for sedimentation velocity has been well confirmed for particles whose diameters are less than about 50 μm . In the present calculations, these make up basically all of the aerosol.

There are some separate effects validations of the diffusiophoretic effect, but the best confirmation comes from integral experiments such as the LACE tests (Reference 5). Calculations of these and other integral tests accurately predict the integrated mass of plated aerosol material only if diffusiophoresis is taken into account. If it is neglected, the predicted plated mass is about two orders of magnitude too small, compared to the observed plated mass.

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The Talbot equation for the thermophoretic effect has been experimentally confirmed to within about 20 to 50 percent over a wide range of particle sizes (Reference 4). The temperature gradient at the wall, which drives this phenomenon, can be approximated by the temperature difference between the bulk gas and the wall divided by an appropriate length scale obtained from heat transfer correlations. Alternatively, because sensible heat transfer rates to the wall are available, it is easier and more accurate to use these rates directly to infer the temperature gradient.

15B.2.4 Parameters and Assumptions for Calculating Aerosol Removal Coefficients

The parameters and assumptions were selected to conservatively model the environment that would be expected to exist as a result of a LOCA with concurrent core melt.

15B.2.4.1 Containment Geometry

The containment is assumed to be a cylinder with a volume of 55,481 m³ (1,959 x 10⁶ ft³). This volume includes those portions of the containment volume that would be participating in the aerosol transport and mixing; this excludes dead-ended volumes and flooded compartments. The horizontal surface area available for aerosol deposition by sedimentation is 2900 m² (31,200 ft²). This includes projecting areas such as decks in addition to the floor area and excludes areas in dead-ended volumes and areas that would be flooded post-LOCA. The surface area for Brownian diffusive plateout of aerosols is 8008 m² (86,166 ft²).

15B.2.4.2 Source Size Distribution

The aerosol source size distribution is assumed to be lognormal, with a geometric mean radius of 0.22 μm and a geometric standard deviation equal to 1.81. These values are derived from an evaluation of a large number of aerosol distributions measured in a variety of degraded-fuel tests and experiments. The sensitivity of aerosol removal coefficient calculations to these values is small.

15B.2.4.3 Aerosol Void Fraction

Review of scanning electron microscope photographs of deposited aerosol particles from actual core melt and fission product vaporization and aerosolization experiments (the Argonne STEP-4 test and the INEL Power Burst Facility SFD 1-4 test) indicates that the deposited particles are relatively dense, supporting a void fraction of 0.2.

The above-mentioned test results indicate that a void fraction of 0.2 is appropriate for modeling the aerosols resulting from a core melt. As part of the sensitivity study that was performed for the AP600 project, a case was run with a void fraction of 0.9. That analysis showed that the high void fraction resulted in an integrated release of aerosols over a 24-hour period that was less than 14 percent greater than that calculated when using the void fraction of 0.2. Thus, it is clear that the removal of aerosols from the containment atmosphere is not highly sensitive to the value selected for the void fraction. This is largely due to the fact that, while the selected value for void fraction has a significant impact on the calculated sedimentation removal, the impact on thermophoresis and diffusiohoresis removal is slight or none. The impact for AP1000 of using the higher value for void fraction would be less than was determined for the AP600 since sedimentation removal comprises a smaller fraction of the total removal calculated for the AP1000.

For additional conservatism the AP1000 aerosol removal analysis uses a void fraction of 0.4 and assumes the voids are filled with air.

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15B.2.4.4 Fission Product Release Fractions

Core inventories of fission products are from ORIGEN calculations for the AP1000 at end of the fuel cycle. Fractional releases to the containment of the fission products are those specified in subsection 15.6.5.3.

15B.2.4.5 Inert Aerosol Species

The inert species include SnO₂, UO₂, Cd, Ag, and Zr. These act as surrogates for all inert materials forming aerosols. The ratio of the total mass of inert species to fission product species was assumed to be 1.5:1. This value and the partitioning of the total inert mass among its constituents are consistent with results from degraded fuel experiments (Reference 6).

15B.2.4.6 Aerosol Release Timing and Rates

Aerosol release timing is in accordance with the source term defined in subsection 15.6.5.3. Aerosol release takes place in two main phases: a gap release lasting for 0.5 hour, followed by an early in-vessel release of 1.3 hours duration. During each phase, the aerosols are assumed to be released at a constant rate. These rates were obtained for each species by combining its core inventory, release fraction, and times of release. Only cesium and iodine are released during the gap release phase. During the in-vessel release phase, the other fission product and inert species are released as well.

15B.2.4.7 Containment Thermal-hydraulic Data

The thermal-hydraulic parameters used in the aerosol removal calculation are the containment gas temperature, the containment pressure, the steam condensation rate on the wall, the steam mole fraction, and the convective heat transfer rate, all as functions of time. The AP1000-specific parameters were obtained using MAAP4 (Reference 7) for the 3BE-1 severe accident sequence (medium LOCA with failure to inject water from the refueling water storage tank into the reactor vessel). The thermal-hydraulic data are thus consistent with a core melt sequence.

15B.2.5 Aerosol Removal Coefficients

The aerosol removal coefficients are provided in Table 15B-1 starting at the onset of core damage through 24 hours. The removal coefficients for times beyond 24 hours are not of concern because there would be so little aerosol remaining airborne at that time. The values range between 0.440.29 hr⁻¹ and 1.1 hr⁻¹ during the time between the onset of core damage (0.167 hour) and 24 hours.

These removal coefficients conservatively neglect steam condensation on the airborne particles, turbulent diffusion, and turbulent agglomeration. Additionally, the assumed source aerosol size is conservatively small being at the low end of the mass mean aerosol size range of 1.5 to 5.5 μm used in NUREG/CR-5966 (Reference 8). Selection of smaller aerosol size would underestimate sedimentation.

Unlike the case for the elemental iodine removal, there is no limit assumed on the removal of aerosols from the containment atmosphere.

15B.3 References

1. NUREG-0800, Section 6.5.2, Revision 2, "Containment Spray as a Fission Product Cleanup System."

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8. Powers D. A., and Burson, S. B., "A Simplified Model of Aerosol Removal by Containment Sprays," NUREG/CR-5966, June 1993.
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Table 15B-1

**AEROSOL REMOVAL COEFFICIENTS IN THE AP1000 CONTAINMENT
FOLLOWING A DESIGN BASIS LOCA WITH CORE MELT**

Time Interval (hours)	Removal Coefficient (hr ⁻¹)
0.167 - 0.2	1.147
0.2 - 0.252	1.03
0.252 - 0.293	0.967
0.293 - 0.402	0.928
0.402 - 0.435	0.961
0.435 - 0.617	1.003
0.617 - 0.642	0.947
0.642 - 0.672	0.917
0.672 - 0.73	0.893
0.73 - 0.785	0.872
0.785 - 0.831	0.851
0.831 - 0.877	0.83
0.877 - 0.922	0.816
0.922 - 1.05	0.796
1.05 - 1.15	0.769
1.15 - 1.2	0.751
1.2 - 1.244	0.728
1.244 - 1.318	0.708
1.318 - 1.367	0.686
1.367 - 1.421	0.671
1.421 - 1.486	0.797
1.486 - 1.504	0.719
1.504 - 1.533	0.689
1.533 - 1.561	0.662
1.561 - 1.601	0.638
1.601 - 1.651	0.616
1.651 - 1.765	0.592

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1.765	-	1.907	0.572
1.907	-	1.976	0.75
1.976	-	2.052	0.616
2.052	-	2.173	0.551
2.173	-	2.271	0.517
2.271	-	2.824	0.469
2.824	-	2.874	0.703
2.874	-	2.975	0.528
2.975	-	3.126	0.464
3.126	-	3.683	0.444
3.683	-	3.787	0.502
3.787	-	4.138	0.456
4.138	-	4.729	0.488
4.729	-	4.876	0.514
4.876	-	4.924	0.709
4.924	-	5.021	0.590
5.021	-	5.813	0.552
5.813	-	6.522	0.585
6.522	-	6.61	0.679
6.61	-	7.139	0.606
7.139	-	7.321	0.649
7.321	-	7.757	0.608
7.757	-	7.916	0.566
7.916	-	8.41	0.624
8.41	-	8.578	0.763
8.578	-	9.397	0.625
9.397	-	9.562	0.709
9.562	-	17.641	0.625
17.641	-	18.358	0.659
18.358	-	23.22	0.618
23.22	-	24	0.608

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Table 15B-1

**AEROSOL REMOVAL COEFFICIENTS IN THE AP1000 CONTAINMENT
FOLLOWING A DESIGN BASIS LOCA WITH CORE MELT**

Time Interval (hours)		Removal Coefficient (hr ⁻¹)
0.167	- 0.179	1.141
0.179	- 0.200	1.013
0.200	- 0.251	0.944
0.251	- 0.292	0.882
0.292	- 0.433	0.842
0.433	- 0.631	0.901
0.631	- 0.684	0.821
0.684	- 0.801	0.781
0.801	- 0.893	0.735
0.893	- 1.033	0.699
1.033	- 1.171	0.662
1.171	- 1.233	0.627
1.233	- 1.331	0.594
1.331	- 1.395	0.562
1.395	- 1.429	0.551
1.429	- 1.475	0.576
1.475	- 1.519	0.537
1.519	- 1.579	0.510
1.579	- 1.653	0.483
1.653	- 1.776	0.458
1.776	- 1.903	0.430
1.903	- 1.991	0.462
1.991	- 2.067	0.429
2.067	- 2.176	0.396
2.176	- 2.371	0.380
2.371	- 2.621	0.337
2.621	- 2.822	0.320
2.822	- 2.872	0.357

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2.872	-	2.973	0.327
2.973	-	3.176	0.302
3.176	-	3.684	0.287
3.684	-	3.737	0.328
3.737	-	3.839	0.304
3.839	-	3.990	0.298
3.990	-	4.090	0.317
4.090	-	4.438	0.346
4.438	-	4.684	0.369
4.684	-	4.880	0.396
4.880	-	4.928	0.449
4.928	-	5.362	0.435
5.362	-	5.460	0.459
5.460	-	5.511	0.518
5.511	-	5.608	0.487
5.608	-	6.040	0.479
6.040	-	6.090	0.537
6.090	-	6.615	0.506
6.615	-	6.753	0.567
6.753	-	7.194	0.513
7.194	-	7.285	0.594
7.285	-	7.814	0.518
7.814	-	7.904	0.581
7.904	-	8.431	0.528
8.431	-	8.521	0.589
8.521	-	9.387	0.529
9.387	-	9.553	0.568
9.553	-	11.189	0.530
11.189	-	14.937	0.516
14.937	-	17.610	0.506
17.610	-	24	0.492

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PRA Revision:

None

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DSER Open Item Number: ACRS ISSUE 6 Revision 2

Original RAI Number(s): None

Summary of Issue:

Organic Iodine Production: The acidification of containment water as a result of radiolysis of organic material could give rise to significant airborne fission product iodine in gaseous organic form. We need to review how Westinghouse and the staff have dealt with this potential

Westinghouse Response:

Our understanding of the concern is that the water film on the inside of the containment might become acidic due to the pickup of HNO₃ and HCl which would result in the production of elemental iodine from the cesium iodine in solution. HNO₃ may be produced in the water film during its drain time. HCl may be produced from the radiolytic decomposition of the HYPALON jackets on electrical cables in containment.

In actuality the water film is expected to be neutral or basic because of the following:

1. A representative AP1000 core melt sequence was selected, i.e. 3BE-1, which is a DVI LOCA with failure of more than one ADS stage 4 path. The condensate film thickness and velocity were obtained from the MAAP4 analysis of this sequence and were used to calculate the water film drain time. From the top of cylindrical shell section (>33 meter height) the drain time was determined to vary from about 1 minute at 1 hour to about 2.5 minutes at 10 hours. Note that some water will drain from higher up on the dome and some from lower on the shell. It is only during this limited time frame that acids (HNO₃ and HCl) can be introduced into the water film. It is important to emphasize that the PCS feature results in the continuous generation of 'clean' steam that condenses on the dome and shell and transports the deposited fission products to the water pool in the bottom of the containment. The dome and shell are coated with inorganic zinc not an organic paint. Thus, the coatings on these surfaces would not provide a source of organic material for the generation of organic iodine.
2. CsI and CsOH are released to the containment atmosphere from the reactor as the core melts. Both CsOH and CsI are deposited on the water film on the containment shell. The deposition rate is related to the rate of steam condensation on the containment shell. Both CsOH and CsI are highly soluble chemicals and are rapidly taken up by the water film draining down the shell.
3. The CsOH is a strong base that tends to counteract the acidification of the film by HNO₃ and HCl.
4. The rate of mass transfer of deposited CsOH and CsI into the draining film is quite high. Once deposited on the water film, they quickly drain into the lower containment volumes. Once the release for fission products from the RCS is over, the process of depositing fission products on the water film slows down and stops. The potential of iodine

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- re-evolution from the water film is only an issue for the early part of the sequence when a significant iodide concentration could be produced in the draining water film.
5. The AP1000 design provides sufficient TSP to the containment water pool to account for both HNO₃ and HCl production. In the long term, the fission products are transported to the containment water pool.
 6. Once the fission products are transported to the containment water pool, they will remain there since there is no containment recirculation spray capability and because the process of creating steam (either inside or outside the reactor vessel) will not re-introduce fission products or other chemical species into the containment atmosphere.

As a result, the pH of the containment water film would not be sufficiently acidic while there is iodine present in the film and iodine in the film would not re-evolve as elemental iodine.

The draining film's pH is determined by the potential amount of acidification that could occur during its limited residence time. The amounts of CsOH (a strong base), HNO₃, and HCl (both strong acids) are estimated to assess the film's pH value. Nitric acid production by radiolysis based on radiation absorption by water can be estimated from a radiation G value (0.007 molecules/100 ev). This radiation G-value corresponds to 7.3E-6 gr-mol HNO₃/(L-M rad) (NRC, 1992). The radiation absorbed by the water film is expressed in Megarad (Mrad). The AP1000 dose and dose rates for beta and gamma radiation inside containment for LOCA accidents are provided in the attached figures (Westinghouse, 2004) and are based on the source term as described in NUREG-1465 (NRC, 1995) and Regulatory Guide 1.183 (NRC, 2000). The gap and in-vessel fission product releases are completed by two hours and the maximum dose rates in containment occur at this time. The sum of the beta and gamma dose rates at 2 hours is 7.3E6 rad/hour. The film residence time on the containment shell for the corresponding condensation rate of approximately 7.8 kg/sec is estimated to be 105 seconds. Thus, the integrated dose delivered to the draining film for this residence time is calculated to be 0.22 Mrad. Based on the above G value for nitric acid generation, 1.6E-6 gr-mole HNO₃ will be produced per liter of film. The resulting hydronium ion concentration of 1.6E-6 gr-mole/l would correspond to a pH value of 5.8, which is weakly acidic.

A second potential source of acid generation in containment would be the radiolytic decomposition of the jacket material (HYPALON) on electric cables. In the presence of a radiation field this material evolves hydrochloric acid (HCl) as a gas. Based on a G value of 2.1 molecules HCl/100 ev of absorbed radiation the amount of HCl produced by the irradiation of electrical cable is estimated as 4.6E-4 gr-mole of HCl per pound of insulation per Mrad (NRC, 1992). The amount of HYPALON material in the AP1000 containment is estimated to be 30,000 pounds. The total (beta plus gamma) integrated dose in containment at 2 hours is found to be 10 Mrad from the attached dose figures. This integrated dose would cause 138 gr-mole of HCl gas to be evolved from the cables. The total integrated beta and gamma doses are used in this bounding response to calculate the amount of HCl produced by the radiolytic decomposition of the HYPALON jacket material on the electrical cable within containment. The use of the total integrated beta dose is conservative since the beta radiation only has a limited ability to penetrate thick insulation jackets, stacks of cables in a cable tray, or the covers used on cable trays. Furthermore, the center of the containment was used as the dose point to quantify the integrated doses. Thus, radiation from all sides of that point is incorporated in the integrated

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doses in the attached figures. However, only the cable jacket material with FP directly deposited on it is of interest. All the jacket surface area is not exposed to direct FP deposition. This would reduce the dose delivered to the jacket material inventory by approximately one quarter.

The HCl gas would escape into the containment from the outer surfaces of the cable bundles in uncovered trays and into the spaces between the cables stacked in the cable trays. Covers on cable trays would further inhibit the release of the evolved HCl to the containment gas space. The amount of HCl that resides in the containment free volume will mix with the air and steam. The mass fraction of HCl in the containment gas space could be estimated by assuming homogeneous mixing. As steam is condensed on the containment shell, the concentration of HCl mixed with the steam and air could be transported to the containment shell and some portion of the HCl could dissolve into the draining condensate film. Thus, the HCl evolved from the cables would be partitioned between the cable bundles and trays, the containment free volume, and the draining film. In this assessment it is very conservatively assumed that HCl is delivered to the draining film at the same average rate that it evolves. This overpredicts the HCl delivery rate by one or two orders of magnitude. The bounding average evolution rate for HCl is estimated to be $1.92E-2$ gr-mole HCl/sec based on 138 gr-mole of HCl being evolved over a two hour period. For the 105 second film residence time, 2.02 gr-mole of HCl could be deposited in the film at this delivery rate. Based on the 7.8 kg/sec condensation rate and the AP1000 containment shell dimensions (33.2 m height and 4134 m² area), the film thickness is estimated to be 210 microns and its volume 860 liters. Thus, the concentration of HCl in the draining film is approximately $2.3E-3$ gr-mole HCl per liter. In combination with the estimated HNO₃ generation this could yield a hydronium ion concentration of $2.301E-3$ gr-moles H⁺ per liter that corresponds to a pH value of 2.6. Such a pH value would be sufficiently low to result in the re-evolution of elemental iodine given iodide was simultaneously present in the draining film.

The amount of hydroxyl ion, [OH⁻], and iodide ion, [I⁻], in the draining film can be estimated by assessing the mass transfer rates for the CsOH and CsI deposited on the containment shell. These two chemical species are highly soluble in water and are readily dissolved by the draining condensate film. The solubility limits from the Handbook of Chemistry and Physics (47th Edition) are 395.5 gr of CsOH and 160 gr of CsI per 100 cubic centimeters of water.

Significant amounts of these chemical species are released from the reactor coolant system into the containment. Per the source term definition, 40% of the core halogens (I, Br) and 30% of the core alkali metals (Cs, Rb) are released as aerosols that can simultaneously deposit on the containment surface. The mass transfer coefficient for CsOH and CsI has been estimated to be approximately $5.6E-3$ kg/m²-sec for the containment conditions and condensation rate at 2 hours in this accident sequence. Considering a mass fraction at the interface between the film and deposit that equals each specie's solubility limit and the shell surface area, their mass transfer rates can be calculated. The transfer rates are found to be 4.75 kg/sec for CsOH and 3.7 kg/sec for CsI. Thus, for a 105 sec residence time large amounts of these species could be dissolved, i.e., $3.33E3$ gr-mole of CsOH and $1.5E3$ gr-mole CsI, given the availability of such quantities of these chemical species. If the mass transfer coefficient rate was assumed to be much smaller to check the sensitivity of these results, i.e. 10^{-4} kg/m²-sec, the mass transfer

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rates would be reduced by more than an order of magnitude. They would become 0.33 kg/sec for CsOH and 0.24 kg/sec for CsI. This could lead to 2.31E2 gr-mole of CsOH and 0.97E2 gr-mole of CsI being simultaneously dissolved in the estimated film volume of 860 liter again assuming sufficient inventories of these chemicals are available. The corresponding film concentrations would become 0.27 gr-mole/l for CsOH and 0.11 gr-mole/l for CsI. This much OH⁻ in solution would completely neutralize the film's acidification and result in a pH value of 13.4 which is strongly basic. In fact only approximately 2 gr-mole of OH⁻ in solution in the draining film would neutralize it based on the conservative estimate of HCl deposition. Given that CsOH aerosol is expected to be deposited simultaneously with the CsI aerosol, it is also expected that the draining film will not likely become acidic for those intervals that CsI is present.

Sensitivity Analysis

The design basis source term definition considers that 3% of the elemental iodine that is released from the RCS is converted to organic iodine in containment. The source term considers 95% of the iodine release from RCS as being in aerosol form and 5% of the iodine release as being elemental. A 3% elemental conversion leads to 0.15% of the released iodine as being in organic form. A sensitivity study was performed to investigate the potential impact on the design basis doses of not controlling the containment draining film pH.

The sensitivity study is based on the following:

- The AP1000 containment response for the three 3BE-1 sequence as calculated by MAAP4 is used to obtain the history of the partial pressure of steam in containment.
- The total aerosol deposition coefficient, λ , in reciprocal hours (hr^{-1}) for diffusiophoresis, thermophoresis and sedimentation combined as determined by the STARNAUA code. This is conservative since only the diffusiophoresis and thermophoresis will deposit aerosol fission products on the containment dome and shell.
- The initial core inventory of cesium iodide (49.3 kg) for the AP1000 reactor.
- No cesium hydroxide (CsOH) aerosol is deposited on the condensate film that drains down the inside surface of the containment dome and shell. Since deposition of CsOH would tend to neutralize the acidification of the film and since an acidified film could lead to the evaluation of elemental iodine, it is conservative to ignore CsOH deposition.
- Instantaneous conversion of 100% of the iodide deposited in the draining film to elemental iodine. This maximizes the potential of forming organic iodine.
- Establishment of the equilibrium concentrations of the aqueous and gaseous elemental iodine per the applicable partition coefficient (PC). Although experimental evidence indicates it may take a few hours to reach steady state and since the draining film residence time is only estimated to be a few minutes or less, it is conservative to assume that the maximum concentration of elemental iodine in the gaseous state is obtained.
- Draining film temperature equal to the saturation temperature for the containment's steam partial pressure. This ignores the decreasing temperature across the condensate film between the gas space and the heat sink wall. The mean film temperature will be less than the steam's

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saturation temperature. A higher film temperature yields a lower aqueous to elemental iodine partition coefficient. A lower PC means a larger concentration of gaseous elemental iodine and a corresponding larger amount of organic iodine in containment.

- All gaseous elemental iodine immediately escapes the water film to enter the containment gas space. No credit for any retention of gaseous elemental iodine in the draining film maximizes the potential for organic iodine in containment.
- A problem end time of 10 hours is assumed. At approximately 10 hours the concentration of iodide in the draining film due to aerosol deposition is low enough that conversion to elemental iodine is negligible. This assumption is confirmed by the calculation's results that show essentially complete cesium iodide deposition by 10 hours.

Results

Approximately 4.7% of the iodine aerosol released per the design basis source term definition is estimated to be converted to elemental iodine and released into the containment gas space. With the assumed 3% conversion to the organic form for the elemental iodine released to the containment atmosphere, the impact on the organic iodine source term is to increase it from the amount specified in the regulatory design basis source term (0.15%) to 0.28% of the iodine aerosol released from the RCS.

The impact on the design basis doses of the additional organic iodine for the site boundary, low population zone, and control room has been estimated based on a 0.33% organic iodine fraction. The respective doses have been estimated to increase from 24.7 to 24.71 rem, from 22.8 to 23.16 rem, and from 4.8 to 5.07 rem. These sensitivity study results indicate that sufficient margin exists in the design basis dose assessment to accommodate these postulated consequences of no explicit pH control for the drain condensate films even if no cesium hydroxide deposition is considered.

Responses for NRC Questions Per NRC Audit of Westinghouse AP1000 Organic Iodine Evolution Calculation

Background

In the March 17, 2004 ACRS interim letter on the AP1000 certification, Issue #6 addressed a question regarding severe accidents for this design. Issue #6 is as follows:

The acidification of containment water as a result of radiolysis of organic material could give rise to significant airborne fission product iodine in gaseous organic form. We need to review how Westinghouse and the staff have dealt with this potential.

During the June 3, 2004 Advisory Committee on Reactor Safeguards meeting, the Westinghouse AP1000 response to this issue was presented to the full committee and discussed during that

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presentation. The presentation included a sensitivity study that investigated the potential evolution of organic iodine assuming that no basic (pH) fission product species were deposited on the draining condensate films on the containment inside walls. Westinghouse prepared a calculation to document the sensitivity study.

On June 14, 2004 the NRC audited the calculation that was prepared per the NRC's request to document the sensitivity study performed in response to Issue #6 of the interim letter. The calculation prepared by the Westinghouse AP1000 project was entitled, "Assessment of Potential for Organic Iodine Production in the Draining Condensate Films for the AP1000 Containment" (FAI/04-37, Rev. 0). During the NRC audit Westinghouse was available and provided clarifications as requested by the NRC audit team. The NRC audited the calculation including spot checks of numerical results presented in the document.

A follow-up conference call between the NRC and Westinghouse was held on June 16, 2004 to discuss the outcome of the NRC audit of this calculation. Two additional NRC questions were addressed during the June 16, 2004 conference call. The NRC questions and the Westinghouse responses are documented below.

Question 1: How was the amount of cesium hydroxide required to neutralize the nitric and hydrochloric acid in the draining film determined? The ACRS presentation (June 3, 2004) indicated the pH of the film due to the presence of each acid by itself. However, the film pH would be lower given the simultaneous presence of both acids.

Response 1: The inventories of cesium hydroxide required to neutralize the nitric and hydrochloric acids were calculated individually. This was done by determining the amount of nitric acid generation for the 10-hour interval and estimating the number of gram-moles of hydronium ion that would be produced. The number of grams-moles of hydronium ion produced by deposition of hydrochloric acid on the film during the 10-hour interval was also determined. The corresponding amount of hydroxyl ion required to neutralize the sum of these two hydronium ion inventories was used to calculate the total amount of cesium hydroxide deposition (approximately 270 grams) required to neutralize it. This assessment was not dependent on the pH of the film but rather the total inventory of hydronium ion to be neutralized.

Question 2: A radiation G value was used to estimate the nitric acid production. Did this radiation G value apply to water only?

Response 2: Yes.

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References

NRC, 1992, "Iodine Evolution and pH Control," NUREG/CR-5950, E. C. Behm, et al., December.

NRC, 1995, "Accident Source Terms for Light-Water Nuclear Power Plants – Final Report," NUREG-1465, L. Stoffer, et al., February.

NRC, 2000, "Alternative Radiological Source Terms for Evaluating Design Basis Accidents at Nuclear Power Plants," Regulatory Guide 1.183, July.

Westinghouse, 2004, AP1000 Design Control Document (APP-GW-GL-700), Revision 10.

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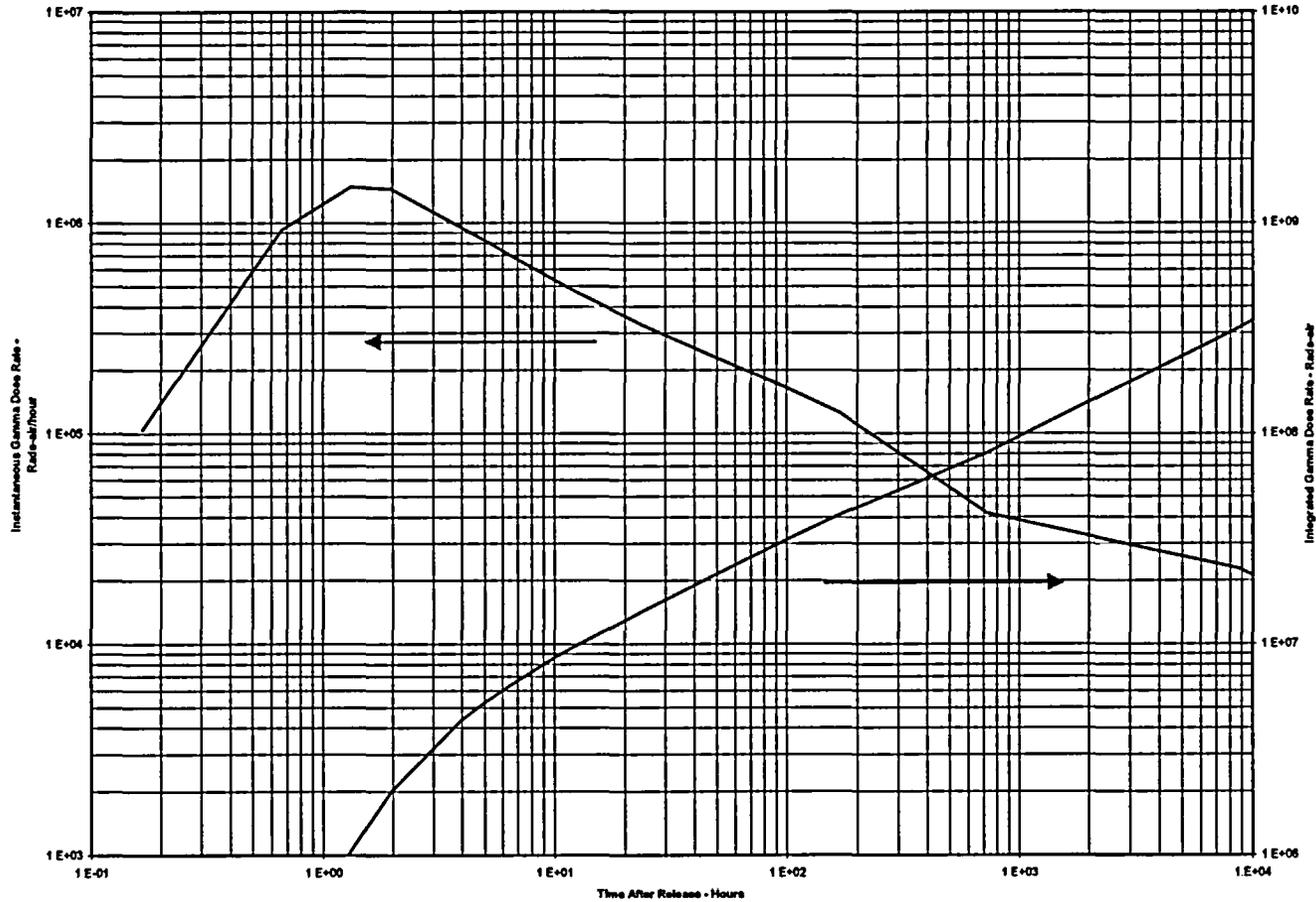


Figure 3D.5-2
Gamma Dose and Dose Rate Inside
Containment After a LOCA

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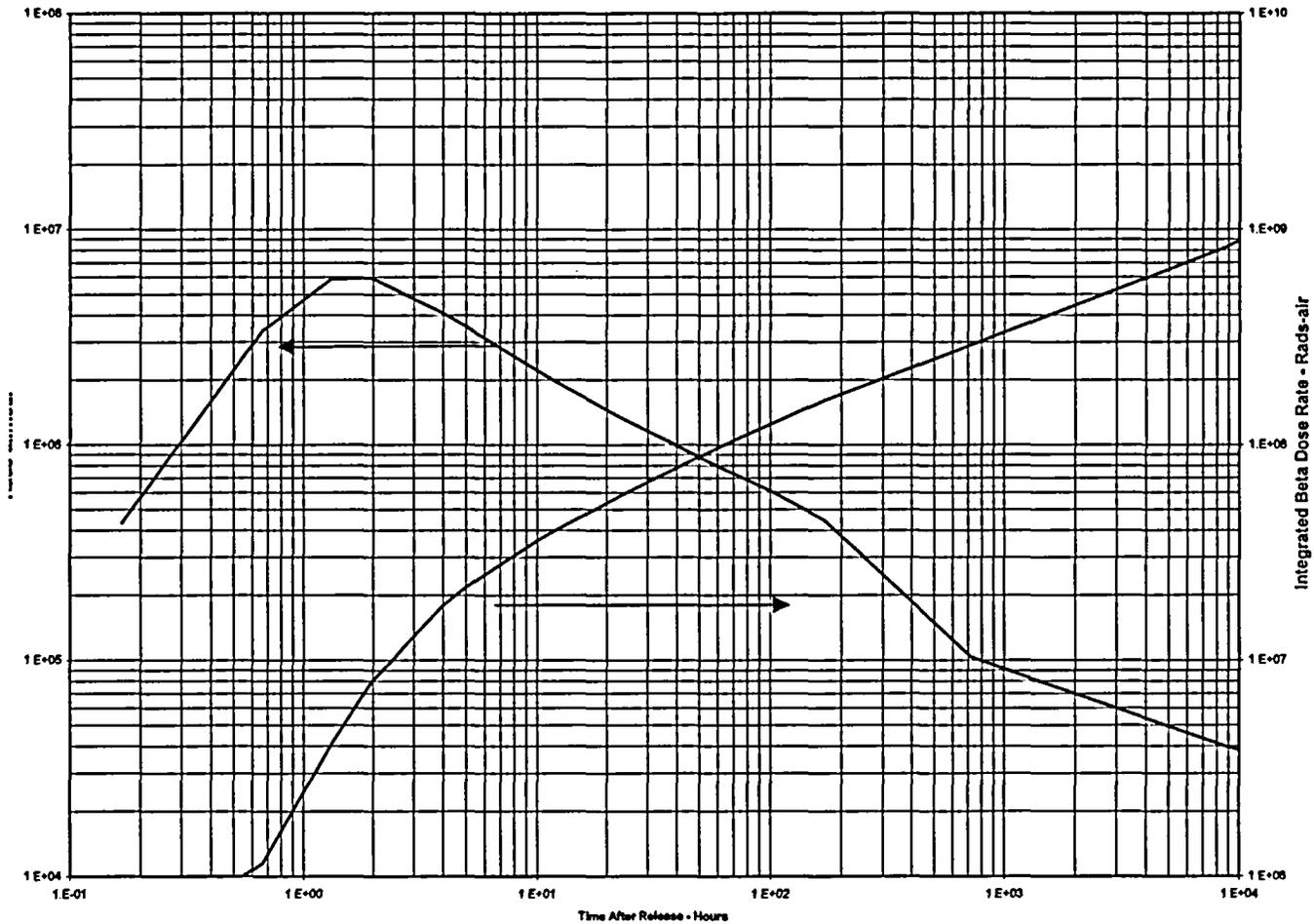


Figure 3D.5-3
Beta Dose and Dose Rate Inside
Containment After a LOCA

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Design Control Document (DCD) Revision:

None

PRA Revision:

None