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Your ref: Docket No. 52-006
Our ref: DCP/NRC2187

June 30, 2008

Subject: AP1000 Response to Requests for Additional Information (SRP15.3)

Westinghouse is submitting a response to the NRC requests for additional information (RAIs) on SRP Section 15.3. This RAI response is submitted in support of the AP1000 Design Certification Amendment Application (Docket No. 52-006). The information included in the response is generic and is expected to apply to all COL applications referencing the AP1000 Design Certification and the AP1000 Design Certification Amendment Application.

A response is provided for RAI-SRP15.3-RSAC-01 through -17, as sent in an email from Phyllis Clark to Sam Adams dated April 28, 2008. This response completes all requests received to date for SRP Section 15.3.

Questions or requests for additional information related to the content and preparation of this response should be directed to Westinghouse. Please send copies of such questions or requests to the prospective applicants for combined licenses referencing the AP1000 Design Certification. A representative for each applicant is included on the cc: list of this letter.

Very truly yours,

Robert Sisk, Manager
Licensing and Customer Interface
Regulatory Affairs and Standardization

/Enclosure

1. Response to Requests for Additional Information on SRP Section 15.3

D063
NRO

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ENCLOSURE 1

Response to Requests for Additional Information on SRP Section 15.3

AP1000 TECHNICAL REPORT REVIEW

Response to Request For Additional Information (RAI)

RAI Response Number: RAI-SRP15.3-RSAC-01
Revision: 0

Question:

A) In Sections 3.2 and 4.10 of APP-SSAR-GSC-642, Revision 0, "Assessment of Basis for Aerosol Plugging in AP1000 Containment Leak Paths for Radiological Design Basis Accidents" (Document 2), you referenced the Morewitz model for aerosol plugging of containment cracks. However, you did not recognize Novick's critique (Reference 1) of the Morewitz model. The document also does not show that the aerosols and conditions of interest fall within the range of applicability of the Morewitz correlation.

B) Figure 13 in Agarwal and Liu (Document 6) shows aerosol sampling regimes as a function of Stokes number and relative settling. Plugging would occur outside the good sampling region. The staff finds that aerosol leak rate velocity at 0.1% per day leak from the AP1000 containment with Stokes Number of 1.5 you assumed may not fall within the range of plugging regime as shown in the diagram.

C) Furthermore, you did not note that many of the data used to construct the Morewitz correlation were for aerosol produced in sodium fires and involved concentrations and particle sizes well outside the range of interest for those in AP1000 LOCA analyses. Some of the tests involved concentrations up to 800 g/m3. Aerosol particle sizes were measured in few of the tests since concentrations were so high that it was challenging to obtain measurements without overloading the sampling device. Please show the Morewitz model is applicable to conclude that deposition will attenuate aerosol leakage in AP1000 containment leak pathways.

Westinghouse Response:

A) In Reference 2 of the RAI, Novick explicitly showed (see Table 1 in Reference 2) that whenever Davies' criterion (Reference 3) was violated (i.e., STK > 0.032), plugging occurred and whenever Davies' criterion was not violated (STK < 0.032), plugging did not occur. Novick explained in his conclusion that "Particles with high inertia have large Stokes numbers. These particles will impact on the inner walls on entering the passageway forming a deposit and eventually plug the passage. The value of the Stokes number defining the separation between impacting and transported aerosols for sharp-edged passages is approximately given by Davies' inertial criterion in Equation (4)[1]. Finally, if the particles being sampled or transported through a sharp-edged passage have Stokes numbers greater than the value given in Equation (4), the passageway will plug according to Equation (1)[2]."

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[1] Equation (4): $STK = \frac{\rho C D_p^2 V}{9 \mu D} < 0.032$

[2] Equation (1): $M = KD^3$

This evidently makes sense. Davies' criterion is a size criterion for particles. Particles that meet the Davies criterion are small enough to follow the flow streamline and penetrate leak path. Particles that violate the criterion are large particles with inertia too high to follow the streamline. In case of the AP1000 application, STK = 1.5 >> 0.032 so Davies' criterion is significantly violated. Therefore, AP1000 definitely falls within the range of applicability of the Morewitz model.

B) Please note that Westinghouse does not credit complete leak path plugging but does credit attenuation of aerosol releases passing though the leak corresponding to a conservative decontamination factor (DF) of 5. With regard to the work of Agarwal and Liu in Reference 4, "sampled" does not mean "penetrated." The staff did not note that the Agarwal and Liu explicitly stated "It should be emphasized that this investigation is concerned with the entrance of particles into aerosol inlets only. All particles that have entered the inlet are considered to have been sampled. If the particle impacts on the inside surface of the inlet tube, it is not considered lost. The results of this investigation, therefore, should be used with caution, since for such instruments as the optical particle counter, etc., the loss of particles within the sampling tube itself must also be taken into account in assessing the overall sampling efficiency of the device." Therefore, Figure 13 is not applicable to the inertial impaction of the aerosols on the capillary walls. In fact, the aerosols failing to enter the inlet due to settling and inertial impaction effects is an additional contribution to the crack DF and ignoring it is conservative since it would further under-estimate the crack DF of aerosols.

C) Morewitz model has a wide applicability, especially to the aerosol leakage from reactor containment building (RCB) in the events of reactor accidents which was the main purpose of Morewitz's work. We quote Morewitz's Summary and Conclusion section (Reference 1) below as the evidence. In summary, a large number of experiments were examined by Morewitz that covered wide ranges of duct diameters (from 100μm to 30 cm), particle sizes (from submicron to as high as 12 microns), and pressure differentials (from low to as high as 0.7 MPa), and a variety of aerosol materials (e.g., Na2Ox, UO2, PuO2, polystyrene, etc.) and particle sizes. With respect to particle size, for example, Morewitz examined the results from a large number of experiments in which the size of particle ranged from 0.004 to 4+ μm (MMD). For AP1000, particle size ranges roughly from 1.1 to 2.3 μm (MMD). The ranges of all these parameters covered the corresponding values for AP1000, therefore clearly indicating that the Morewitz model is applicable to the AP1000 containment case.

We should also point out that it is true that many factors affect aerosol plugging of containment cracks including crack size, pressure differential, particle characteristics, aerosol concentration and humidity in the containment. But Vaughan (Reference 5) and Morewitz (Reference 1) demonstrated that the primary factor for aerosol plugging of a duct is the duct size, D, the diameter of the duct. The rest of factors could be lumped into a coefficient, K. By assuming the most conservative K and a single and maximum crack diameter for AP1000, it is hard to argue that the Morewitz model is not applicable to AP1000 case.

Quote from Reference 1:

5. SUMMARY AND CONCLUSION

A simple model of the plugging of ducts by aerosol deposits has been used to correlate a number of experiments with a variety of aerosol materials over a wide range of duct diameters. The model predicts that the mass passing into the duct prior to plugging will be proportional to the cube of the duct diameter. The data (Fig 5) show that when 10-70 mg of aerosol has entered a 1-mm-diameter capillary, it will plug. (Such a clean capillary can leak gas at the entire design leak rate of 0.1% per day from a RCB.) Further, the experiments indicate the size distribution of an exiting aerosols is shifted to a larger size by agglomeration within the capillary so that <1 mg is transmitted as respirable size aerosols even through a short-length 1-mm-diameter capillary. However, real leak paths through the concrete walls have rough surface (which is also true for that through the steel shell – added by Westinghouse) so that additional aerosol removal phenomena, such as impaction at bends, are operative and reduce the transmitted aerosol mass even further. Thus, the mass of respirable aerosol leaked at the design pressure from an intact RCB will be < 1mg total rather than the 10 g to 600 g per day (depending on aerosol concentration in the RCB) which will leak if the aerosol is assumed to leak as a gas.

References:

1. H.A. Morewitz, "Leakage of Aerosol from Containment buildings," Health Physics, Vol. 42, Page 195-207, 1982
2. V.J. Novick, "Plugging Passages with Particles: Refining the Morewitz Criteria," Aerosol Science and Technology, 21 (1994), 219-222.
3. C.N. Davies, "The Entry of Aerosol into Sampling Tubes and Heads," Applied Physics, Journal of Physics D, 1 (1968), 921-932.
4. J.K. Agarwal and B.Y.H. Liu, "A Criterion for Accurate Sampling in Calm Air,"American Industrial Hygiene Association Journal, 41 (1980), 191-197.
5. N.P. Vaughan, et. al., "Penetration of 1.5 – 9.0 μm Diameter Mono-Disperse Particles through Leaks into Respirators," Annals of Occupational Hygiene, Vol. 38, No. 6 pp 879-893, 1994.

Design Control Document (DCD) Revision:
None

PRA Revision:
None

Technical Report (TR) Revision:
None

AP1000 TECHNICAL REPORT REVIEW

Response to Request For Additional Information (RAI)

RAI Response Number: RAI-SRP15.3-RSAC-02
Revision: 0

Question:

A) You asserted in APP-GW-GLN-122, Revision 0, "Offsite and Control Room Dose Changes," Technical Report 122 (Document 1) that aerosol particles will impact on the walls of a leak pathway and listed a variety of mechanisms for the deposition. You further stated that only the inertial impaction of particles on the walls of the leak pathway is pertinent to the AP1000 containment leak paths.

B) No geometrical information about the leak paths is provided other than a path height of 0.155 cm, crack size of 4.45 cm, and 1.75 inch crack depth. The staff believes that many of the hypothesized leak paths would be better approximated as orifices rather than passageways. The staff also finds that no sufficient geometrical information is provided to evaluate if leak paths are orifices, capillaries or straight channels. Treated as orifices, there would be no "walls" for the hypothesized inertial impaction of aerosols as you assumed. Please describe geometrical information about the leak paths in more detail with justification.

Westinghouse Response:

A) As discussed in Section 3 of APP-SSAR-GSC-642, there are many particle deposition mechanisms in a containment leak path that contribute to plugging, which makes a decontamination factor (DF) calculation based only on the impaction model more robust. Whether or not impaction is the primary deposition mechanism in the leak path depends on the Stokes number which in turn is governed mainly by flow velocity. Impaction is emphasized in the AP1000 DF calculation partly because it is believed to be the primary deposition mechanism for the AP1000 due to high flow velocity and partly because it is easy to model mathematically. The other mechanisms are more difficult to model since the cross-section area of the leak path changes with time and distance as deposition takes place in the crack. Therefore, neglecting other mechanisms is conservative.

Saying that the impaction is primary deposition mechanism does not mean that other mechanisms don't exist or are negligible entirely. Interception, for example, can be important too, especially as deposits build up in the crack. Turbulent deposition can be important when Reynolds number is high and crack size is small.

B) A description of potential containment leak pathways, their geometries and their discharge locations is provided on page 9 of APP-GW-GLN-122. The list of potential leak paths from that discussion is provided in Table 1. The most likely containment leakage occurs through multiple parallel pathways at penetrations and hatch seals (Figures 1 and 2 from DCD Chapter 3.8.2), which discharge to the auxiliary building and would be subjected to additional deposition before being released to the environment. Through-wall cracks in multi-pass butt welds in the containment shell are more unlikely and discharge to the passive containment cooling system (PCS) annulus.

To be conservative, Westinghouse models the leakage from the containment as a single round hole through the containment shell to the PCS annulus. The flow path is considered to be a smooth capillary, which is conservative as outlined below. The diameter of the hole, 1.55 mm, is determined by the design leak rate, which is the maximum diameter for postulated leak path. The length of the hole is determined by the straight-through thickness of the containment shell, which is 1.75 inches. The single hole modeled in AP1000 containment shell has a length to diameter ratio (L/D) that is, at a minimum, 28.6. According to Sutter (Reference 1) an orifice is an opening in which the length is smaller than or equal to the diameter of the opening. It is inappropriate to treat the hole in the AP1000 containment shell as an orifice.

The modeling of the AP1000 leak path to the environment has significant conservatism:

- The leakage is modeled as being through a single leak path with a constant diameter based on the maximum leak rate. Given a constant leak rate, multiple leak paths would each have a smaller diameter, which increases the Stokes number for a given particle size and therefore decreases the number of particles that penetrate the path.
- The leak path is considered to be a smooth, straight capillary. Other geometries such as slots have more surface area for a given flow area for impaction to occur within the leak path. Mechanistically considering a torturous crack through the wall would also enhance deposition.

  The single round hole model was recognized by Morton and Mitchell (Reference 2) as being a conservative model for aerosol release from the containment: "Other assumptions are also made when assessing and quantifying particle leakage across a damaged container seal. For instance, the total leakage is attributed to a single pathway, which is assumed to have a circular profile. ... This conservative approach almost certainly results in gross over-estimates of the quantities of radioactive aerosol that would be released into the environment under accident conditions."
- The release is assumed to be discharged to the PCS annulus air which is flowing to the environment. The discharge is not considered to be the auxiliary building. Aerosols released to the auxiliary building would be subjected to gravitational and phoretic deposition with reasonably long residence times before reaching the environment.
- The releases do not consider the water film at the entrance or exit of the leak path or the effect of condensation within the leak path. Given the cooling by the PCS, there would be a water film at least on the inside surface of the shell, even if the outer surface were dry. The effect of cool walls was recognized by Novick (Reference 3) as enhancing deposition when he notes that his criticism of the Morewitz criteria is not applicable to situations where there is a large thermal gradient: "In general, large temperature gradients (i.e., a hot gas with cool walls) with cause condensable vapors to deposit onto the passage walls or onto existing particles, thereby increasing their Stokes number and deposition probability."
- The discharge of the PCS is at 228 feet above ground level, but the release to the environment is considered to be at ground level.

Table 1
Potential Leak Paths and Characteristics for AP1000

Leak Path	Location Relative to Operating Deck	Geometry	Wet Inside?	Wet Outside?	Discharges to:
Crack in containment shell weld	Above	1 rough slit 1.75" in length	Yes	Yes	PCS annulus
Leak past equipment hatch gasket	Above or below	2 smooth short slits in series	Yes	No	Aux Building
Crack in penetration weld	Below	1 rough slit 1.75" in length	Yes	No	Aux Building
Leak through containment isolation valves	Below	2 smooth short slits in series	Yes	No	Aux Building
Leak through electrical penetrations	Below	2 smooth short slits in series	Yes	No	Aux Building

References:

1. S.L. Sutter, et al., "Depleted Uranium Dioxide Powder Flow through Very Small Openings," NUREG-1099, PNL-3177, Pacific Northwest National Laboratory, Richland WA., February 1980.
2. D.A.V. Morton and J.P. Mitchell, "Aerosol Penetration through Capillaries and Leaks: Experimental studies an the Influence of Pressure," Journal of Aerosol Science, Vol. 26, No. 3, pp. 353-367, 1995.
3. V.J. Novick, "Plugging Passages with Particles: Refining the Morewitz Criteria," Aerosol Science and Technology, 21 (1994), 219-222.

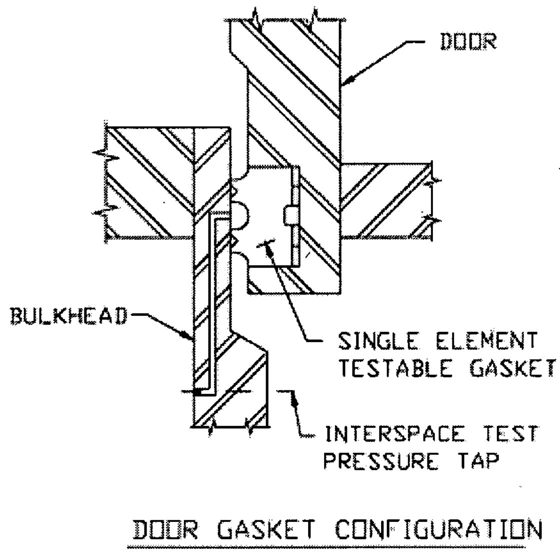

Figure 1
Hatch Gasket Configuration

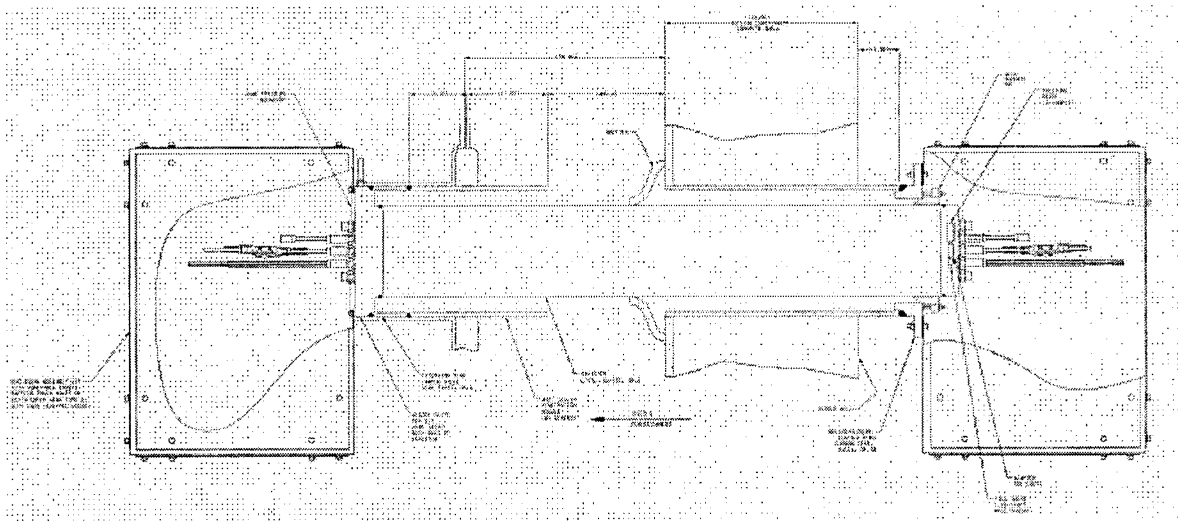

Figure 2
Typical Electrical Penetration

Design Control Document (DCD) Revision:
None

PRA Revision:
None

Technical Report (TR) Revision:
None

AP1000 TECHNICAL REPORT REVIEW

Response to Request For Additional Information (RAI)

RAI Response Number: RAI-SRP15.3-RSAC-03
Revision: 0

Question:

You hypothesized in Document 1 that aerosol particles impact and adhere to the walls despite the relatively high flow velocities needed to meet the AP1000 containment leak rate of 0.1% per day. The staff believes that large particles will bounce on high velocity impact with walls and be re-entrained in the overall flow. Please address (1) particles bouncing on high velocity impact with walls, (2) re-entrainment of particles into the overall flow, and (3) de-agglomeration of aerosol particles, especially larger composite particles such as are expected in the AP1000 LOCA.

Westinghouse Response:

We have addressed particle re-suspension and re-entrainment in APP-SSAR-GSC-642 using the results of the Williams study (Reference 1), that of Morton and Mitchell (Reference 2) and that of Morewitz (Reference 3). As we know, there are several mechanisms for particle re-suspension in the leak path. Bouncing off is assumed to be one of them. Mechanical re-suspension in the form of dislodged deposited particles is another. With those phenomena occurring, the size of re-entrained particles exiting the leak path was observed to be much larger (with the MMD from tens to over a thousand microns) than the particles entering the leak path (with the MMD from 1 to 5 microns) in the experiments (References 1, 2 and 3). Any re-suspension, de-agglomoration, and/or re-entrainment in the experiments, are reflected in the observations. Most of those tests in References 1, 2 and 3 were conducted at high pressure differentials in order to generate leak rates of interest to the researchers for the capillaries of such small sizes. They are comparable to the AP1000 case as far as the bouncing off, re-suspension and de-agglomeration are considered and their results for the sizes of exiting aerosols are applicable to the AP1000 case.

As a result of the larger size of re-entrained particles, if they escape the crack they are most likely to be retained in the passive containment cooling system (PCS) annulus either by sedimentation (for which one can get a sense of the settling velocity from Table 2 of APP-SSAR-GSC-642) or by impaction on the PCS baffle surface opposite to the containment steel shell, which is 1 ft away.

Since the AP1000 leak path will more likely be rough and torturous, the AP1000 thermal hydraulic condition will be humid, the particle bouncing off, re-suspension and de-agglomeration will be even less likely to occur.

In summary, our approach was to ignore the actual mechanisms of re-suspension, de-agglomeration, and re-entrainment, but to apply the final results of those mechanisms, i.e., any re-entrained particles which escape the crack are included in the aerosol mass that exited the leak path in the experiments, the results of which have been translated into decontamination factors for our purposes. As stated in APP-SSAR-GSC-642, the experimental DFs range from 10 to 1000. A conservative DF of 5 is applied to the AP1000 containment leakage.

Reference(s):

1. Williams, M. M. R., "Particle deposition and plugging in tubes and cracks (with special reference to fission product retention)," Progress in Nuclear Energy, Vol. 28, No. 1, pp. 1-60, 1994.
2. Morton, D. A. V., and J. P. Mitchell, "Aerosol Penetration through Capillaries and Leaks: Experimental Studies on the Influence of Pressure," Journal of Aerosol Science, Vol. 26, No. 3, pp. 353-367, 1995.
3. Morewitz, H. A., "Leakage of Aerosols from Containment Buildings," Health Physics, Vol. 42, pp. 195 – 207, 1982.

DCD Revision:
None

PRA Revision:
None

Technical Report (TR) Revision:
None

AP1000 TECHNICAL REPORT REVIEW

Response to Request For Additional Information (RAI)

RAI Response Number: RAI-SRP15.3-RSAC-04
Revision: 0

Question:

A) You hypothesized in Document 1 that particles depositing on the "walls" will form a plug. Without geometrical information on the leakage pathways, it is not readily apparent what "walls" are available for plug formation.
B) You also asserted that should any plug re-suspend, it will simply redeposit without any de-agglomeration which is quite different from what has been seen in many re-suspension experiments and what was seen in the ARTIST tests (Reference 3) with aerosol flow through a steam generator tube. Please address "saltation" of deposited aerosol that would be associated with the impact of the large re-suspended "plugs" on the "walls".

Westinghouse Response:

A) The details of the leakage pathway are presented in the response to RAI-SRP15.3-RSAC-02.
B) We do not assume that there is no de-agglomeration or no saltation. Instead, we believe that if de-agglomeration or saltation occurred, it would have been accounted for in the experimental results for the sizes and mass of penetrated particles since de-agglomeration and saltation could only occur before the penetrated particles were measured or observed. As stated in APP-SSAR-GSC-642, the experimental decontamination factors range from 10 to 1000. A conservative DF of 5 is applied to the AP1000 containment leakage.

   The de-agglomeration studied in ARTIST project is not applicable to AP1000 or any similar crack plugging cases. In the ARTIST program, de-agglomeration takes place when fresh (not "backed") powder passing through a sonic front. As the fresh powder passes through the sonic front created using a specially designed cone, the shear force due to the pressure drop across the sonic front will cause particles to de-agglomerate. Such de-agglomeration is not expected for fission product particles generated by vapor condensation as in the AP1000 case (Reference 1). Additionally, it is practically impossible to have a capillary geometry that would lead to a shock wave or sonic front.

Reference(s):

1. SUMMARY RECORD of the 3rd Meeting of the ARTIST Project Review Committee (PRC), Paul Scherrer Institute, 20-22 June 2005

DCD Revision:
None

PRA Revision:
None

Technical Report (TR) Revision:
None

AP1000 TECHNICAL REPORT REVIEW

Response to Request For Additional Information (RAI)

RAI Response Number: RAI-SRP15.3-RSAC-05
Revision: 0

Question:

You referenced, in Documents 1 and 2, the CSE experiments and observed aerosol deposition without noting that the deposition observed in these experiments was not associated with inertial impaction you assumed and that the aerosol was not similar to the types of aerosol expected in AP1000 DBA LOCA. You further stated that aerosols used in the EPRI-LACE tests were prototypic, which they are now known not to be. The aerosol used in these tests was deliberately chosen to emphasize hygroscopic effects that depend on chemical speciation of the aerosol that is not observed in the more prototypic tests involving irradiated materials. Please justify the applicability of the CSE experiments and EPRI-LACE tests to the aerosol plugging and impaction for the AP1000 containment leak pathways.

Westinghouse Response:

According to Hilliard (Reference 1), the CSE tests were conducted at typically high pressure (i.e., ~50 psia). One can conclude that the leak flow would be choked, which means the leak flow velocity would be sonic and inertial impaction would be an important aerosol deposition mechanism. Based on the information presented in Table IX of Reference 1, the fission product attenuation within the leak paths provided DFs of 13.2 for iodine and 90.9 for cesium averaged over the first 2 hours, and DFs of 17.8 for iodine and 100 for cesium averaged over 24 hours. AP1000 credits a DF of 5 for aerosol attenuation in the leak path.

Also according to Hilliard, iodine, cesium, and UO2 were used in all CSE tests. Tellurium, barium, ruthenium, and xenon were used in selected tests. Those types of aerosols are typical for design basis accidents according to NUREG-1465.

The LACE tests (Reference 2), which are similar to CSE tests, were intended to simulate severe reactor accidents also. Soluble aerosol material (e.g., CsOH) was used to study hygroscopic effect. However, insoluble aerosol material (MnO) was also used to study non-hygroscopic effect. The LACE tests were not biased toward either effect. Nevertheless, the LACE test results were shown in our report simply to provide a visual illustration of aerosol deposition on a flow surface.

Reference(s):

1. Hilliard R. K. & A. K. Postma, "Large-Scale Fission Product Containment Tests," Nuclear Technology, Vol. 53, No. 2, 163-175, May 1981.
2. Dickinson D.R., et al, "Aerosol Behavior in LWR Containment bypass Piping-Results of LACE Test LA3," LACE TR-011, 1987.

DCD Revision:
None

PRA Revision:
None

Technical Report (TR) Revision:
None

AP1000 TECHNICAL REPORT REVIEW

Response to Request For Additional Information (RAI)

RAI Response Number: RAI-SRP15.3-RSAC-06
Revision: 0

Question:

You referenced, in Documents 1 and 2, Toshiba integral tests (Reference 1) and the observed penetration of seals and electrical penetrations. You did not note that leak pathways were growing in these tests as a function of time above critical temperature and pressure thresholds. Again, the aerosol deposition observed in these experiments may not have been the inertial impaction you hypothesized in the documents to be the creditable mechanism. Please justify the applicability of the Toshiba experiments to the aerosol plugging and impaction for the AP1000 containment leak pathways.

Westinghouse Response:

There is no information presented in the Toshiba test summary paper (Reference 1) regarding growing leak pathways during the aerosol releases. The "Failure Criteria" tests created prototypical leak paths in actual electrical penetrations and hatch gaskets by pressurizing and heating the test assembly well beyond the severe accident conditions expected for AP1000. After leak paths were created in the test pieces, aerosol trapping tests were performed on the damaged penetrations and hatch gaskets to determine the decontamination factors.

The Toshiba tests were performed to study the retention of aerosols by containment leak paths in reactor accidents. In the tests, pressure differentials ranged from 0.1 to 4.5 atms. The flow velocity ranges from slow to sonic. The measured flow rates through the test pieces for the 170 kPa test presented in Figure 5 of Reference 1 varies from greater than 150 N-liters/min to less than 50 N-liters/min. The tests were performed under dry conditions at temperatures less than 200°C to eliminate the effects of steam concentration. The AP1000 accident pressure differential is ~150 kPa and the temperature is less than 200°C with a significant steam partial pressure. The 170 kPa test presented in Reference 1 creates a flow rate that is greater than the maximum AP1000 leakage, which is 1.36 cfm or 38.5 liters/min at the containment conditions. The Toshiba test conditions are very similar to that of the AP1000 accident conditions and the tests are applicable to AP1000. The leak rate from the test bounds the maximum leak rate expected from the AP1000 containment.

With the aforementioned test conditions, the primary particle deposition mechanism would vary from test to test. It is important is to note that the final DF from all these tests range from 10 to 1000, which includes DF primarily contributed by inertial impaction.

Reference(s):

1. Watanabe, A., et al, "Fission Product Aerosol Trapping Effects in the Leakage Path of Containment Penetration under Severe Accident Conditions," Session IV Aerosol Growth, Transport and Deposition in the Containment, Third OECD Specialist Meeting on Nuclear Aerosols in Reactor Safety, Germany, 1998.

DCD Revision:
None

PRA Revision:
None

Technical Report (TR) Revision:
None

AP1000 TECHNICAL REPORT REVIEW

Response to Request For Additional Information (RAI)

RAI Response Number: RAI-SRP15.3-RSAC-07
Revision: 0

Question:

You provided, in Document 2, Section 1, "Introduction and Background," a quote from Williams' Progress in Nuclear Energy article and highlighted comments on formation of plugs and re-suspension. Please examine and provide criteria used by Williams for plugging and the substantial literature on re-suspension of deposited aerosol and describe how the referenced material is applicable to the AP1000. Williams did not address the deposition mechanism emphasized in either Document 2 or TR-122. You noted that aerosol deposition is used to seal leaks in ductwork, but you did not note that typically such methods employ rather larger particles than those in question for reactor accident analyses.

Westinghouse Response:

We quoted the description of plugging phenomena (including re-suspension phenomena) given by Williams (Reference 1) in his introduction to plugging theory as our introduction to the phenomena associated with plugging and re-suspension. It is merely a description of the general plugging and re-suspension phenomena. Williams addresses a complete set of aerosol deposition mechanisms in Reference 1 including inertial impaction, interception, diffusion, thermophoresis, and diffusiophoresis. We do not understand the staff's statement that "Williams did not address the deposition mechanism emphasized in either Document 2 or TR-122" (meaning that Williams did not address inertial impaction).

Sealing leaks in ductwork with aerosol was mentioned in our introduction merely to state that this phenomenon is well understood is used in normal everyday applications. If "typically such methods employ rather larger particles than those in question for reactor accident analyses" it only means that the Davies criterion (Reference 2) can be violated at lower velocities, which is typically the case for ductwork sealing, i.e., STK > 0.032, so that Morewitz model (Reference 3) is applicable. Once Davies criterion is violated, it is the effective diameter of the leak path (as opposed to the particle size) that is the key parameter that governs plugging, according to the Morewitz model.

Reference(s):

1. M. R. Williams, "Particle Deposition and Plugging in Tubes and Cracks," Progress in Nuclear Energy, Vol. 28, No. 1, pp. 1-60, 1994.
2. C.N. Davies, "The Entry of Aerosol into Sampling Tubes and Heads," Applied Physics, Journal of Physics D, 1 (1968), 921-932.
3. H.A. Morewitz, "Leakage of Aerosol from Containment buildings," Health Physics, Vol. 42, Page 195-207, 1982

DCD Revision:
None

PRA Revision:
None

Technical Report (TR) Revision:
None

AP1000 TECHNICAL REPORT REVIEW

Response to Request For Additional Information (RAI)

RAI Response Number: RAI-SRP15.3-RSAC-08
Revision: 0

Question:

You referenced in Document 2, Section 2, "Experimental Basis for Plugging," the work by Mitchell and coworkers (Reference 1) on capillary flow tests which did not at all address the inertial deposition mechanism except to show that it was not especially important for the quiescent sampling done for the tests. The staff noted that the experiments did encounter circumstances where no plugging was observed for even as small as 30 μm capillaries and that at high differential pressures, such as is calculated to occur in the AP1000 containment following a LOCA, plugging took over an hour to occur if it occurred at all. The staff further noted that the plugging was created by aerosol deposition mechanisms other than inertial impaction. Please justify the applicability of the work performed by Mitchell to the aerosol plugging and impaction for the AP1000 containment leak pathways.

Westinghouse Response:

In the abstract of Reference 1, Morton and Mitchell wrote "The present work has demonstrated the importance of pressure in regulating the rate at which the leak-path is plugged by deposited particles. Much of this deposition appears to take place at the entrances of the capillaries where the air-flow converges." Saying that aerosols deposit where air-flow converges is equivalent to saying that aerosols deposit by inertial impaction when the particles cannot follow the converging streamlines. It is true that inertial impaction is not especially important for low flow velocity situations (if that is what is referred to as "quiescent). But for the AP1000 analysis, the flow velocity is not low since the leak rate is 0.1% per day. If the leak rate is assumed to be substantially lower so as to not include impaction, then there will be a benefit from the lower rate of activity release, not to mention other aerosol deposition mechanisms (e.g., phoretic deposition), which will become more important with increased residence times inside the containment cracks.

In conclusion (a) of Reference 1, Morton and Mitchell state: "At relatively high pressure differentials across the capillary on test ($\geq$ 80 kPa), there was little evidence that particle deposition occurred to an extent that resulted in significant blockage of the leak-path." In APP-SSAR-GSC-642 and in APP-GW-GLN-122, Westinghouse does not credit complete plugging of the containment leak path, only an aerosol decontamination factor (DF) of 5. In conclusion (d) of Reference 1, Morton and Mitchell also state that "... in the early stages of deposit formation, there was little (if any) reduction of the air leakage rate, despite evidence from the APS33B-measured penetration rates that significant aerosol attenuation had occurred during exposure." Significant aerosol deposition occurred in the tests even while there was little or no plugging of the gas flow through the leak path, which was also observed and discussed by Sutter in Reference 2.

Morton and Mitchell recognized deposition as a real phenomenon that could be used to attenuate the particulate releases in the analysis of containment leakage. In the introduction of

Reference 1, they wrote "In assessments of particle leakage, the conservative assumption is usually made that the particles will penetrate the leak-path if the assessed size distribution includes a significant proportion of particles with diameters less than the maximum hole size. ... Other assumptions are also made when assessing and quantifying particle leakage across a damaged container seal. For instance, the total leakage is attributed to a single pathway, which is assumed to have a circular profile. ... This conservative approach almost certainly results in gross over-estimates of the quantities of radioactive aerosol that would be released into the environment under accident conditions."

Reference(s):

1. D. A. V. Morton and J. P. Mitchell, "Aerosol Penetration through Capillaries and Leaks: Experimental Studies on the Influence of Pressure," Journal of Aerosol Science, Vol. 26, No. 3, pp. 353-367, 1995.
2. S.L. Sutter, et al., "Depleted Uranium Dioxide Powder Flow through Very Small Openings," NUREG-1099, PNL-3177, Pacific Northwest National Laboratory, Richland WA., February 1980.

DCD Revision:
None

PRA Revision:
None

Technical Report (TR) Revision:
None

AP1000 TECHNICAL REPORT REVIEW

Response to Request For Additional Information (RAI)

RAI Response Number: RAI-SRP15.3-RSAC-09
Revision: 0

Question:

A) You compared experimental conditions with typical AP1000 LOCA conditions in Table 1, in Document 2, Section 2. Please state what experiments were considered in this table. The extent data base covers a much wider range than what is implied.

B) Williams as referenced by you analyzed several experiments and noted several cases where no plugging occurred. His analysis was for aerosol deposition other than inertial impaction from the aerosol sampling. Please elaborate in more detail the intent of this comparison.

Westinghouse Response:

A) Table 1 presents the test conditions (References 1 through 3) with respect to the AP1000 accident conditions

Table 1 – Comparisons of the test conditions and typical AP1000 accident conditions

	Toshiba Test	CSE Test	Morewitz(1)	AP1000(2)
Crack Size	> 1.55 mm(3)	~0.25mm(4)	0.1 - 300 mm	< 1.55 mm
Pressure Differential	10 – 450 kPa	~244 kPa	Low to 1000 psi	20 – 150 kPa
Temperature	<200 °C	~121 °C	did not mention	< 200 °C
Particle Concentration	~0.1 g/m³	~0.1-0.15 g/m³	Typ for severe accident	0-3.3 g/m³
Particle Size (AMMD)	~1 μm	~1 μm	0.004 – 12 μm (AED)	2.3-4.6 μm
Decontamination Factor	10 - 1000	13 - 100	10,000	5

(1)Tests examined by Morewitz
(2)See derivation in Section 4 of APP-SSAR-GSC-642
(3)Crack size should be bigger since leak rate is greater than AP1000 leak rate
(4)Estiamte based on 0.17% per day leak rate and sonic flow assumption indicated in the reference for the tests

B) We did not use test data from Williams (Reference 4) since there were no details given for these tests. However, we used Williams' observations to introduce the topics of plugging and re-suspension phenomena from the tests in our introduction section.

As stated in the response to RAI RAI-SRP15.3-RSAC-08, Westinghouse does not credit complete plugging of the leak path, only a decontamination factor of 5.

Reference(s):

1. A.Watanabe, et al, "Fission Product Aerosol Trapping Effects in the Leakage Paths of Containment Penetration under Severe Accident Conditions," Session IV Aerosol Growth, Transport, and Deposition in the Containment, Third OECD Specialist Meeting on Nuclear Aerosols in Reactor Safety, Germany, 1998.
2. R.K. Hilliard and A.K.Postma, "Large-Scale Fission Product Containment Tests," Nuclear Technology, Vol. 53, No. 2, 163-175, May 1981.
3. H.A. Morewitz, "Leakage of Aerosol from Containment buildings," Health Physics, Vol. 42, Page 195-207, 1982.
4. M.R.Williams, "Particle Deposition and Plugging in Tubes and Cracks," Progress in Nuclear Energy, Vol. 28, No. 1, pp. 1-60, 1994.

DCD Revision:
None

PRA Revision:
None

Technical Report (TR) Revision:
None

AP1000 TECHNICAL REPORT REVIEW

Response to Request For Additional Information (RAI)

RAI Response Number: RAI-SRP15.3-RSAC-10
Revision: 0

Question:

You showed in Table 2, in Document 2, Section 2, the settling velocity for fully dense spherical particles 10 to 500 μm in size. However, Table 1 indicates that the particles of interest for analysis of the AP1000 DBA LOCA are much smaller (2.3 to 4.6 μm in diameter) and they are not fully dense spheres. The text of Table 2 seems to imply that the settling velocities are applicable to re-suspended deposits which are inconsistent with Williams' notion of deposits which are highly porous. They would be susceptible to bounce and de-agglomeration as they flow along a passage way. They could cause saltation of other deposited particles that they impact. None of this is mentioned in the document. Please elaborate in more detail the purpose of this table.

Westinghouse Response:

The purpose of APP-SSAR-GWC-642, Table 2 is to provide a sense of the settling speed of re-suspended particles as a function of diameter, as we explicitly stated in the paragraph above the table. According to the observations in many experiments as discussed in RAI-SRP15.3-RSAC-03, the re-suspended particles are large in size (seemingly from 10 to 1000 μm). The particles sizes indicated in Table 1 are the particle sizes distributed in the containment atmosphere before entering the leak path.

Per Stokes Law, for particles in the size range of the AP1000 containment problem settling velocity is proportional to the particle diameter squared while it is linearly proportional to the particle density. Thus, the porosity effect on settling is less than the size effect. In addition, staff seems to have added the word "highly" to Williams' notion of deposits. What Williams said in Reference 1 was "although plugging occurs, the porous nature of the plug may still allow radioactive gas to pass through." Considering the sizes of gas molecules, the deposits are not "highly" porous. Furthermore, as described in Assumption 6 of Reference 2, fission product aerosols will be in liquid form as they move out of the RCS into containment, and the packing fraction of the aerosols after cooling and solidification will be low (i.e., equivalent to low porosity). Finally, AP1000 conditions are typically wet with condensate film running on the inside and water on the outside, which are not favorable conditions for high porosity.

Reference(s):

1. M. M. R. Williams, "Particle deposition and plugging in tubes and cracks (with special reference to fission product retention)," Progress in Nuclear Energy, Vol. 28, No. 1, pp.1-60, 1994.
2. APP-SSAR-GSC-615, Revision 1, "AP1000 Containment Lambda," August 23, 2004.

AP1000 TECHNICAL REPORT REVIEW

Response to Request For Additional Information (RAI)

DCD Revision:
None

PRA Revision:
None

Technical Report (TR) Revision:
None

AP1000 TECHNICAL REPORT REVIEW

Response to Request For Additional Information (RAI)

RAI Response Number: RAI-SRP15.3-RSAC-11
Revision: 0

Question:

In Section 2.2 of Document 2, you provided photographs of the results of the LACE tests with aerosols which are not representative of aerosol expected in the postulated AP1000 LOCA. The 29 meter length of the pipe system used in the tests is inconsistent with leak pathways of AP1000 containment. Please justify the applicability of the LACE tests to the aerosol plugging and impaction for the AP1000 containment leak pathways.

Westinghouse Response:

This has been discussed previously in the response to RAI-SRP15.3-RSAC-05.

DCD Revision:
None

PRA Revision:
None

Technical Report (TR) Revision:
None

RAI Response Number: RAI-SRP15.3-RSAC-12
Revision: 0

Question:

You described, in Document 2, an impaction model that does not draw upon the well-known work for sampling efficiency from a quiescent gas phase by Davies (Reference 1) or on the work of Carrié and Modera for sampling from a flowing gas (References 2 and 3). Carrié and Modera did their experiments to see if aerosol deposition could be used to plug leaks in ducts. It is unclear if you defined a Stokes number with corrections for slip or shape factor. If not, please do so. You concluded that a critical Stokes number is 1.5, based on respirator leakage studies which did not include sonic flow. Novick's paper (Reference 4) does not support the contention that 1.5 is a critical stokes number with regard to plugging of cracks, especially if the system is not in the plugging regime. Please use any of the well-known correlations of penetration efficiency as a function of Stokes number instead of relying on an analysis for leakage around respirators. Please address the fact that deposition is not solely dependent on Stokes number. Please consider that regardless of the Stokes number, there must be time for particles to move from the gas phase to the surface.

Westinghouse Response:

The problem of interest to us is the equivalent of suction of aerosols in calm air. Davies' work on sampling (reference 1) is applicable to AP1000 conditions while the works of Carrié and Modera (References 2 and 3), which were performed to study duct leak sealing by aerosols in transverse flows, are not.

The results of Davies' work for calm air condition are given in Table 1 (i.e., Table 1, Permissible radii of tubes (cm) for sampling aerosols in calm conditions). According to Davies, the radii of tubes (cm) for sampling aerosols of unit density (1 g/cm3) in calm conditions that will lead to negligible aerosol deposition by inertial impaction and sedimentation are functions of aerosol diameter (μm) and flow rate of suction (cm3/s). The suction (leak) rate for AP1000 is 642 cm3/s. From Table 1, the minimum tube (leak path) radius for 1 micron particle of unit density is greater than 0.284 cm, which is 3.7 times the AP1000 crack radius of 0.0775 cm. It means that significant inertial impaction would occur. It agrees with the conclusion in the response to RAI-SRP15.3-RSAC-01 that Davies' criterion is violated.

The slip correction factor and shape factor were not considered in our Stokes number calculation since they are secondary parameters that have limited impact on the particles of most interest to us, i.e., the larger ones in the distribution (e.g., the particle diameter > 0.74 μm). It was our belief that they were not significant enough to change our conclusions given the large margin for the DF and the conservatisms in our assumptions.

There is nothing special about sonic flow in non-dimensionalized space (e.g., the spaces governed by non-dimensional parameters like Stokes and Reynolds numbers). As we know, the purpose of non-dimensional analysis is to derive the non-dimensional parameters, such as the

Stokes number, the Reynolds number, etc, that govern the physical phenomena. In inertia impaction, the governing parameter is Stokes number, which includes the effect of particle velocity, regardless if it is sonic or not.

Novick's paper (Reference 4) suggests that when Davies' criterion is violated (Stokes number is greater than 0.032), the measurement of aerosol concentration by sampling device will not be accurate since the particle deposition from inertial impaction will be significant enough to yield a significant error in the measurement. Novick paper does not say that as soon as the Stokes number exceeds 0.032, the sampling tube will be plugged. According to Vaughan's study (Reference 5), particle deposition due to inertial impaction becomes almost complete when Stokes number equals 1.5, which is about 50 times greater than Davies' criterion. It clearly makes sense for any leakage whether it's for a respirator or a containment leak path.

The most well-known penetration correlation in the field of aerosol penetration is the Morewitz correlation and we applied this correlation in our study as presented in Section 3.2 of APP-SSAR-GSC-642.

Inertial impaction (governed by Stokes number) is not the only mechanism for aerosol deposition. We merely stated that we are considering inertial impaction for calculation of a DF to use for AP1000 as it is a dominant mechanism in our case (large Stokes number) and is mathematically convenient to model. It is conservative to neglect deposition mechanisms not dependent on Stokes number, e.g., phoretic deposition, since they only enhance the DF in the leak path.

It is true that "there must be time for particles to move from the gas phase to the surface". However, that time is short for particles with high Stokes number (Davies criterion), which is why most of the particle deposition occurs near the entrance of the leak path as observed in all of the experiments.

Reference(s):

1. C.N. Davies, "The Entry of Aerosol into Sampling Tubes and Heads," Applied Physics, Journal of Physics D, 1 (1968), 921-932.
2. F.R. Carrie and M.P. Modera, "Particle Deposition in a Two-Dimensional Slotfrom a Transverse Stream," Aerosol Science and Technology, 28 (1998), 235-246.
3. F.R. Carrie and M.P. Modera, "Experimental Investigation of Aerosol Deposition on Slot and Joint Type Leaks," Journal of Aerosol Science, 33 (2002), 1447-1462.
4. V.J. Novick, "Plugging Passages with Particles: Refining the Morewitz Criteria,"Aerosol Science and Technology, 21 (1994), 219-222.
5. N. P. Vaughan et al, "Penetration of 1.5 – 9.0 µm Diameter Mono-disperse Particles through Leaks into Respirators," Annals of Occupational Hygiene, Vol. 38, No 6, pp 879-893, 1994.

DCD Revision:
None

PRA Revision:
None

Technical Report (TR) Revision:
None

AP1000 TECHNICAL REPORT REVIEW

Response to Request For Additional Information (RAI)

RAI Response Number: RAI-SRP15.3-RSAC-13
Revision: 0

Question:

The AP1000 LOCA analysis used an aerosol particle size narrowly distributed lognormally around a mean of 0.22 μm. It assumes that sonic velocities prevail in the leak path which immediately puts the aerosol outside the range of applicability of the Morewitz model. Without details of the geometry, the staff is unable to assure that the Stokes number is such that other criteria for sampling are satisfied. Temperatures and pressures are noted in the documents but please address pressure spikes that could lead to re-suspension of deposited particles are not emphasized.

Westinghouse Response:

To formulate his correlation for aerosol plugging, Morewitz examined the results from a large number of experiments in which the size of particle (MMD) ranged from as small as 0.004 μm or as high as 12 μm (AED) and pressure differential ranged from low to as high as 1000 psi (Reference 1). Note that it takes less than 15 psid to create sonic flow, so we do not understand the staff's position that sonic flow is outside the range of the Morewitz model. For AP1000, particle size ranges roughly from 1.1 to 2.3 μm (MMD, assuming the particle density being 4 g/cm3) and pressure differential ranged from 3 to 20 psi. AP1000 is well within the range of applicability of the Morewitz correlation.

Re-suspension of particles is discussed in the response to RAI-SRP15.3-RSAC-03.

Reference(s):

1. H. A. Morewitz, "Leakage of Aerosols from Containment Buildings," Health Physics, Vol. 42, pp195–207, 1982

DCD Revision:
None

PRA Revision:
None

Technical Report (TR) Revision:
None

AP1000 TECHNICAL REPORT REVIEW

Response to Request For Additional Information (RAI)

RAI Response Number: RAI-SRP15.3-RSAC-14
Revision: 0

Question:

In document 2, you calculated the size of leak needed to produce a leak rate of 0.1% per day assuming isothermal flow through a capillary. Please justify the isothermal assumption.

Westinghouse Response:

In our view, the DF calculation is not sensitive to the velocity variation due to change of thermal hydraulic conditions along the leak path. Particles deposition takes place near the entrance of the leak path so it is sufficient to know the velocity near the entrance. Secondly, at sonic velocity, the change in gas temperature will be small due to short residence time and therefore the change in speed is not significant. Finally, the thermal hydraulic condition inside the leak path will not drop to below 20 °C which is the temperature used to calculate sonic velocity in document 2 for conservatism. With enough margin of conservatism in sonic velocity aforementioned, there is no need to get too detailed about leak path thermal hydraulic conditions.

Additionally, consideration of the cooling within the flow path will produce condensation, which would only increase deposition. Condensation was conservatively neglected in the consideration of the decontamination factor.

DCD Revision:
None

PRA Revision:
None

Technical Report (TR) Revision:
None

AP1000 TECHNICAL REPORT REVIEW

Response to Request For Additional Information (RAI)

RAI Response Number: RAI-SRP15.3-RSAC-15
Revision: 0

Question:

You stated, in Document 2 (page 22) that the aerosol concentration is 4000 g/m3. This is unlikely since it would imply about 220 tons of aerosols in the containment atmosphere. Such high concentrations would obviate all the hydraulic analyses shown in the document since at these concentrations the motions of the aerosol and the gas phase are tightly coupled. On a mass basis, there would be about 4 times as much aerosol as there is gas. Since the aerosol is generating heat by radioactive decay, even sedimentation calculations are challenging to do at such astronomical particle concentrations. Please justify the aerosol concentration assumed.

Westinghouse Response:

On page 22 of APP-SSAR-GSC-642, Revision 0, Section 4.7, Particle Density, the following statement is made:

> "[[According to [Polestar 2004], the average particle density of AP1000 containment aerosols is estimated to be about 4 kg/m^3."

The 4 kg/m^3 is the particle density and not the aerosol concentration.

The particle density value of 4 kg/m^3, however, is incorrect due to a typographical error. The correct number for the particle density is 4000 kg/m^3 or 4 g/cm^3.

Aerosol concentration is provided in APP-SSAR-GSC-642, Revision 0, Figure 5. Aerosol Concentration peaks at 3.3 g/m^3 at 1.8 hours during the release from the fuel and falls to less than 0.1 g/m^3 at 12 hours. Therefore, the airborne mass of aerosol that can leak to the environment is reduced relatively quickly and will be less than 1% of the initial mass at 24 hours.

DCD Revision:
None

PRA Revision:
None

Technical Report (TR) Revision:
None

AP1000 TECHNICAL REPORT REVIEW

Response to Request For Additional Information (RAI)

RAI Response Number: RAI-SRP15.3-RSAC-16
Revision: 0

Question:

Neglecting the complications of aerosol coupling to gas motions implied by the assumed high aerosol concentrations, you concluded that particles larger than 0.74 μm will not penetrate a leak path regardless of path length. The staff believes that this is very much depends on the leak geometry and the adequacy of the Stokes number model. The staff further believes that the geometries appear to be more like orifices than tubes and the staff has experimental data for particles larger than 0.74 μm penetrating orifices much smaller than the assumed 1500 μm pathways. Data by Sutter et al. (Reference 1) involved tests with aerosol having a minimum diameter of 1 μm. Mitchell's experiments with orifices (Reference 2) also involved penetration of smaller flow pathways by larger particles. Even if the tube geometry is accepted as appropriate for the leak pathways, there are ample experimental data showing fairly efficient penetration by larger particles. Accepting the sonic flow arguments made in the document, then aerosol particles with Stokes number well in excess of the value 1.5 will be efficiently sampled according to work by Davies (Reference 3) and by Agarwal and Liu (Reference 4). Justify that particles larger than 0.74 μm will not penetrate a leak path regardless of length.

Westinghouse Response:

We acknowledged in the response to RAI-SRP15.3-RSAC-15 that there was a typo for particle density and that the value is for the particle density is not the aerosol concentration.

The leak geometry is discussed in detail in the response to RAI-SRP15.3-RSAC-02. One of the key points in that response is that whether a leak geometry should be modeled as an orifice or as a capillary depends on the length to diameter ratio. The common definition of an orifice is a leak with the length to diameter ratio less than or equal to one. The AP1000 leak path, with the length to diameter ratio of about 30 at minimum, should not be considered as an orifice.

It is important to note that Westinghouse has only claimed an aerosol fission product decontamination factor (DF) of 5, not complete leak path plugging. In other words, we did not claim that none of the large particles would penetrate leak path. We claimed that under AP1000 accident conditions, a fraction of particles would penetrate leak path and the rest would be retained as demonstrated in experimental results. The primary mechanism was theorized to be inertial impaction because of the high pressure assumption for design basis accidents and the DF corresponding to inertial impaction was calculated. The inertia impaction model for aerosol deposition in a tube under suction basically says that the particles with Stokes numbers greater than 1.5 (which is equivalent to particles larger than 0.74 μm under the AP1000 conditions) will almost completely deposit in the tube. But it does not mean that particles larger than 0.74 μm cannot penetrate a capillary. We claim a decontamination factor, not complete plugging.

Morton and Mitchell's work (Reference 2) was discussed in detail in the response to RAI-SRP15.3-RSAC-08. Sutter (Reference 1) provides another great example of significant decontamination factor in the leak path.

It is not possible to directly extract leak path DF from the test results in Sutter since the particle concentration in the container before entering the leak were not measured in the tests. But we can indirectly estimate the DF for the cases Sutter refers to as "Extended Time Runs" as follows:

First we need to know that in Sutter's tests, the powder in the container was aerosolized by a compressed air jet (referred to as agitation airflow) "through a probe at the bottom of the container about 7.6 cm below the power level" (Page 23).

Then we turn to Sutter's description of "Extended Time Runs" in which the nominal 110-µm orifice at 100 psig upstream pressure was used. Some of the runs were aborted since the orifice became so plugged that "adequate airflow could not be achieved; flows were 50 and 100 cc/min (~700 cc/min was desired)." For the successful tests, the airflow either decreased first (due to plugging) but restored to the desired rate (probably due to dislodge of deposits) or was maintained constant through the entire run with no evidence of plugging.

The following observations were made by Sutter et al. (Reference 1): "The total DUO (Depleted Uranium Oxide) transmitted in the extended time runs and shorter time experiments are compared in the plots in Figure 23. The DUO collected from the run exhibiting plugging and subsequent release of the plug showed the highest result for 24 hr, 305 µg. The 105 µg collected in the second 24-hr run is comparable to the highest collection from individual runs for shorter time periods, and therefore, it appears that maximum powder leakage occurred early in any run. The average leakage during a 1-min pressurization / depressurization time was 30 µg. If this leakage had persisted for 24 hr, 5.5×10^4 µg DUO would have leaked, contrasted to the actual 305 and 105 µg."

If we estimate the orifice DF for the extended time runs, the average 24 hour DF would be 180 to 520 (i.e., 5.5×10^4 µg /305 µg to 5.5×10^4 µg /105 µg). This is a perfect example to show the relationship between plugging and crack retention of aerosols. It does not require plugging to yield high DF.

The staff has to show which work by Davies would indicate that "aerosol particles with Stokes number well in excess of the value 1.5 will be efficiently sampled." We cannot draw that conclusion from Reference 3.

With regard to the work of Agarwal and Liu in Reference 4, "sampled" does not mean "penetrated." The staff did not note that the Agarwal and Liu explicitly stated "It should be emphasized that this investigation is concerned with the entrance of particles into aerosol inlets only. All particles that have entered the inlet are considered to have been sampled. If the particle impacts on the inside surface of the inlet tube, it is not considered lost. The results of this investigation, therefore, should be used with caution, since for such instruments as the optical particle counter, etc., the loss of particles within the sampling tube itself must also be taken into account in assessing the overall sampling efficiency of the device."

In applying the Morewitz model (Reference 5), the impaction model in our report, we neglect the fact that some particles did not make it into the leak path due to settling and inertial effects as discussed by Agarwal and Liu, which would be an additional contribution to the DF for the leak path. By only considering the retention of aerosols impacting the walls inside the leak path, the DF was conservatively underestimated.

We should also point out that in the work by Agarwal and Liu the opening was facing upward instead of facing sideway as it would be in AP1000 cases. The upward facing opening would improve the sampling efficiencies, according to Davies.

Reference(s):

1. S.L. Sutter, et al., "Depleted Uranium Dioxide Powder Flow through Very Small Openings," NUREG-1099, PNL-3177, Pacific Northwest National Laboratory, Richland WA., February 1980.
2. D.A.V. Morton and J.P. Mitchell, "Aerosol Penetration through Capillaries and Leaks: Experimental studies an the Influence of Pressure," Journal of Aerosol Science, Vol. 26, No. 3, pp. 353-367, 1995.
3. C.N. Davies, "The Entry of Aerosol into Sampling Tubes and Heads," Applied Physics, Journal of Physics D, 1 (1968), 921-932.
4. J.K. Agarwal and B.Y.H. Liu, "A Criterion for Accurate Sampling in Calm Air," American Industrial Hygiene Association Journal, 41 (1980), 191-197.
5. H.A. Morewitz, "Leakage of Aerosol from Containment buildings," Health Physics, Vol. 42, Page 195-207, 1982.

DCD Revision:
None

PRA Revision:
None

Technical Report (TR) Revision:
None

AP1000 TECHNICAL REPORT REVIEW

Response to Request For Additional Information (RAI)

RAI Response Number: RAI-SRP15.3-RSAC-17
Revision: 0

Question:

Please consider a leak pathway that develops later in an accident (e.g., 1 hour later), much as observed in the Toshiba experiments (Reference 1). At this later time, much of the aerosol would have been removed by the combination of diffusiophoresis and gravitational sedimentation so that residual aerosol would have a much larger fraction of mass in the smaller size particles. Then, even adopting your analysis as presented, large amounts of radioactive material could be leaked prior to plugging of the emergent leak pathway. Indeed, one could well imagine that as a leak pathway plugs others emerge as the effects of the accident progress. Please provide expected particle size distribution in leak pathways as a function of time up to 30 days.

Westinghouse Response:

Considering a leak path that develops later in the accident or leak paths that open as others close would not change the conclusions of our analysis for the following reasons:

- Westinghouse does not credit complete plugging of the leak path, only an aerosol decontamination factor (DF) of 5 (see the response to RAI-SRP15.3-RSAC-16).
- Attenuation of the aerosol releases due to inertial impaction occurs in the leak path from the time it opens, supported in theory by the Morewitz correlation and noted in the experiment by Morton and Mitchell (Reference 2) conclusion (d) (see response to RAI-SRP15.3-RSAC-08). Attenuation of the aerosols would increase as the leak path plugged and its effective diameter shrank, but Westinghouse is not crediting plugging of the leak path to be conservative.
- The DF calculation is based on the initial aerosol size distribution at time zero (before agglomeration). APP-SSAR-GSC-642, Figure 4 shows transient airborne aerosol size as a ratio of the transient mean diameter to the initial mean diameter as a function of time. The ratio peaks at 2.1 at 6 hours and falls slowly to 1.5 at 24 hours. Therefore, the airborne size distribution in the containment atmosphere grows significantly and doesn't decrease very quickly. In the first 24 hours, the transient aerosol size is always larger than the initial size distribution that was used to calculate the DF. Thus, if we were to assume that the leak path develops later in an accident, we would use a larger particle size to calculate the DF and would obtain a greater value.
- APP-SSAR-GSC-642, Figure 5, Aerosol Concentration peaks at 3.3 g/m^3 at 1.8 hours during the release from the fuel and falls to less than 0.1 g/m^3 at 12 hours. Therefore, the airborne mass of aerosol that can leak to the environment is reduced relatively quickly and will be almost zero at 24 hours. The size distribution out to 30 days is immaterial.

Reference(s):

1. A.Watanabe, et al, "Fission Product Aerosol Trapping Effects in the Leakage Paths of Containment Penetration under Severe Accident Conditions," Session IV Aerosol Growth, Transport, and Deposition in the Containment, Third OECD Specialist Meeting on Nuclear Aerosols in Reactor Safety, Germany, 1998.
2. D. A. V. Morton and J. P. Mitchell, "Aerosol Penetration through Capillaries and Leaks: Experimental Studies on the Influence of Pressure," Journal of Aerosol Science, Vol. 26, No. 3, pp. 353-367, 1995.

DCD Revision:
None

PRA Revision:
None

Technical Report (TR) Revision:
None