ENCLOSURE 4

Westinghouse Non-Proprietary Class 3

APP-SSAR-GSC-642, Rev. 0

"Assessment of Basis for Aerosol Plugging in AP1000 Containment Leak Paths for Radiological Design Bases Accidents"

(Non-Proprietary)

AP1000 CALCULATION NOTE COVER SHEET

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AP1000 CALCULATION NOTE NUMBER	REVISION NO.	PAGE	OPEN ITEMS (Y/N)
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Record of Revisions

Rev	Date	Revision Description[1]
0	See EDMS	Original Issue

Note (1) Significant changes are briefly described in this table. In the rest of the calc note, each row that has been changed is marked using a revision bar in the margin of the page. This approach satisfies the change identification requirements in WP 4.5 Section 7.4.

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Polestar Applied Technology, Inc.

AFFIDAVIT

I, David E.W. Leaver, being duly sworn, depose and state as follows:

(1) I am a Principal and an Officer of Polestar Applied Technology, Inc. ("Polestar") and am responsible for the function of reviewing the information described in paragraphs (2) and (8) which is sought to be withheld, and have been authorized to apply for its withholding.

(2) The information sought to be withheld is contained in portions of Polestar-prepared report PSAT 3023CT.QA.01.05 (see paragraph (8)). This report has been prepared for Westinghouse Electric Co. LLC (Westinghouse) in support of AP1000 containment fission product aerosol mitigation. The Polestar report addresses radiological design basis accident fission product aerosol plugging in AP1000 containment leak paths.

(3) In making this application for withholding of proprietary information of which it is the owner, Polestar relies upon the exemption from disclosure set forth in the NRC regulations 10 CFR 9.17(a)(4), 2.390(a)(4), and 2.390(b)(1) for "trade secrets and commercial or financial information obtained from a person and privileged or confidential" (Exemption 2.390(a)(4)). The material for which exemption from disclosure is here sought is all "confidential commercial information".

(4) Some examples of categories of information which fit into the definition of proprietary information are:

a. Information that discloses a process or method, including supporting data, analyses, and design insights based on integration of the data and analyses, to where prevention of its use by Polestar's competitors without license from Polestar constitutes a competitive economic advantage over other companies.

b. Information which, if used by a competitor, would significantly reduce his expenditure of resources or improve his competitive position in the analysis, design, assurance of quality, or licensing of a similar product;

c. Information which reveals cost or price information, production capacities, budget levels, or commercial strategies of Polestar, its customers, or its suppliers;

d. Information which reveals aspects of past, present, or future Polestar customer-funded development plans and programs, of potential commercial value to Polestar;

e. Information which discloses patentable subject matter for which it may be desirable to obtain patent protection.

The information sought to be withheld is considered to be proprietary for the reasons set forth in both paragraphs (4)a and (4)b, above.

(5) The information sought to be withheld was submitted to Westinghouse (and, we trust, to NRC) in confidence. The information is of a sort customarily held in confidence by Polestar, and is in fact so held. The information sought to be withheld has, to the best of my knowledge and belief, consistently been held in confidence by Polestar, no public disclosure has been made, and it is not available in public sources. All disclosures to third parties including any required transmittals to NRC, have been made, or must be made, pursuant to regulatory provisions or proprietary agreements which provide for maintenance of the information in confidence. Its initial designation as proprietary information, and the subsequent steps taken to prevent its unauthorized disclosure, are as set forth in paragraphs (6) and (7) following.

(6) Initial approval of proprietary treatment of a document is made by the manager of the originating component, the person most likely to be acquainted with the value and sensitivity of the information in relation to industry knowledge. Distribution of such documents within Polestar is limited to those with a need to know.

(7) The approval of external release of such a document typically requires review by the project manager, and the Polestar Principal closest to the work, for technical content, competitive effect, and determination of the accuracy of the proprietary designation. Disclosures outside Polestar are limited to regulatory bodies, customers, and potential customers, and their agents, suppliers, and licensees, and others with a legitimate need for the information, and then only in accordance with appropriate regulatory provisions or proprietary agreements.

(8) The information identified in paragraph (2), above, is classified as proprietary because it contains detailed information on and results from trade secret methodologies developed by Polestar and applied under the Polestar 10 CFR 50, Appendix B Quality Assurance Program. The trade secret information is identified in [[double bold brackets]] in the calculation. Specifically:

Page 4 – discusses key aspects of the plugging phenomenon to be applied in the calculation based on Polestar's accumulated knowledge and insights on aerosol phenomena

Pages 5, 6, and 7 – a discussion of insights derived from experimental information based on Polestar's accumulated knowledge and insights on aerosol phenomena

Pages 9, 10, and 11 – key aspects of theoretical basis for plugging based on Polestar's accumulated knowledge and insights on aerosol phenomena

Page 11 – key assumptions on the AP1000 problem based on Polestar's accumulated knowledge and insights on aerosol phenomena

Pages 15 – 18 – details on decontamination factor calculation and results based on Polestar's accumulated knowledge and insights on aerosol phenomena

The trade secrets used in this AP1000 work are several of a number of Polestar developed methods, models, and codes. Development of these methods, models, and codes was achieved at a significant cost to Polestar, well over $200,000, which is a significant fraction of internal research and development resources available to a company the size of Polestar.

The development of the methods, models and codes, along with the interpretation and application of the results, is derived from the extensive experience database that constitutes a major Polestar asset.

(9) Public disclosure of the information sought to be withheld is likely to cause substantial harm to Polestar's competitive position and foreclose or reduce the availability of profit-making opportunities. The information is part of Polestar's comprehensive technology base on application of the alternative source term (AST) to operating plants and advanced light water reactors, and its commercial value extends beyond the original development cost. The value of the technology base goes beyond the extensive physical database and analytical methodology and includes development of the expertise to determine and apply the appropriate evaluation process. In addition, the technology base includes the value derived from providing analyses done with methods which have been developed and are being maintained in accordance with 10 CFR 50, Appendix B requirements.

The research, development, engineering, analytical and review costs comprise a substantial investment of time and money by Polestar.

The precise value of the expertise to devise an evaluation process and apply the correct analytical methodology is difficult to quantify, but it clearly is substantial.

Polestar's competitive advantage will be lost if its competitors are able to use the results of the Polestar experience to normalize or verify their own process or if they are able to claim an equivalent understanding by demonstrating that they can arrive at the same or similar conclusions.

The value of this information to Polestar would be lost if the information were disclosed to the public. Making such information available to competitors without their having been required to undertake a similar expenditure of resources would unfairly provide competitors with a windfall, and deprive Polestar of the opportunity to exercise its competitive advantage to seek an adequate return on its relatively large investment in developing these very valuable analytical tools.

STATE OF CALIFORNIA)
) ss:
COUNTY OF SANTA CLARA)

David E.W. Leaver, is being duly sworn, deposes and says:

That he has read the foregoing affidavit and the matters stated therein are true and correct to the best of his knowledge, information, and belief.

Executed at Los Altos, California, this 9th day of October 2007.

David E.W. Leaver
Polestar Applied Technology, Inc.

Subscribed and sworn before me this 9th day of October 2007.

RUTH TUBBS
Commission # 1767312
Notary Public - California
Santa Clara County
My Comm. Expires Oct 8, 2011

Notary Public, State of California

CALCULATION TITLE PAGE

CALCULATION NUMBER: PSAT 3023CT.QA.01.05

CALCULATION TITLE: Assessment of Basis for Aerosol Plugging in AP1000 Containment Leak Paths for Radiological Design Bases Accidents

		ORIGINATOR		CHECKER		IND REVIEWER	
		Print/Sign	Date	Print/Sign	Date	Print/Sign	Date
REV:	0	Jun Li	5/18/07	J. Metcalf	5/22/07	J. Metcalf	5/22/07
	1	Jun Li	7/11/07	D. Leaver		D. Leaver	

REASON FOR REVISION:	Nonconformance Rpt
0 - Initial Issue	N/A
1	N/A

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List of changes for revision 1

No	Description
1	Correction of typo error in Equation (8) on Page 15, i.e., the power 2 should be placed outside the curly bracket instead of inside.
2	Global change of headers (PSAT 206CT.QA.01.05 to PSAT 3023CT.QA.01.05); double bold brackets added to denote proprietary portions of calc.

1. Introduction and Background

The purpose of this note is to assess the basis for aerosol plugging, and the resulting decontamination factor, in AP1000 containment leak paths for radiological design bases accidents (DBA).

There is a very good description of the plugging phenomenon given by M. M. R. Williams in Reference [Williams 1994].

"As we have noted above, as particulate matter passes through capillaries or cracks, it will deposit on the surface thereby, over time, changing the internal geometry of the flow area. Eventually, the thickness of deposit leads to complete obstruction and flow ceases. In practice, there are other possibilities. For example, although plugging occurs, the porous nature of the plug may still allow radioactive gas to pass through. There is also the possibility that, at some stage in the deposition process, pieces of deposit will break off from the wall. This could happen under steady flow conditions if the protuberance were sufficiently high for the gas flow to exert a turning moment on it which was great enough to overcome the adhesive forces at the wall. Under unsteady flow conditions, sudden changes in pressure may also dislodge particulate. The fate of the dislodged matter, i.e. the re-entrained material, is also of interest, especially as far as its size is concerned. For example, the size of aerosol particles depositing on the surface initially will be in the range 0.1 to 5 μm. However, the re-entrained 'chunks' may well be of 10 - 100 μm in size. Such chunks could, in a fine capillary, cause immediate blocking if they are wedged at a particular angle. This aspect of the problem involves a strongly stochastic element which has been observed in experiments: we refer to it as mechanical re-suspension."

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Like other natural aerosol phenomena, such as sedimentation, diffusiophoresis and thermophoresis, aerosol plugging in cracks as the aerosol passes through the cracks is well-understood. Much research has been done on this phenomenon, both theoretically and experimentally. [[

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Aerosol plugging has also been credited by NRC for the radiological DBA at an operating nuclear plant [NRC 2007], [Polestar 2007].

2. Experimental Basis for Plugging

2.1 Plugging Tests

A series US Atomic Energy Commission-sponsored aerosol leakage tests was performed during the 1960s at the Containment System Experiment (CSE) facility (a one-fifth linear scale model of a typical 1000 MWe PWR) at Battelle Memorial Institute in Richland, Washington to evaluate the decontamination factors for fission products (Iodine and Cesium) escaping through the vessel penetrations. [[

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More recently, a series of aerosol leakage tests was performed by the Nuclear Power Engineering Corporation (NUPEC) and Nuclear Engineering Laboratory, Toshiba Corporation in Japan with a full-scale BWR Containment and CsI as a representative fission product aerosol [Watanabe 1998]. Test conditions were as follows:

- Containment aerosol concentration and diameter were about 100 mg/m3 and 1μm AMMD respectively;
- Containment atmosphere was dry with temperature less than 200 C and pressure from 1.1 to 5.5 atm.

The DF values for a low-voltage penetration module ranged from 10 to 1000 while that for a hatch flange gasket ranged from 10-30.

Morton and Mitchell performed similar tests to study the influence of pressure on aerosol penetration through capillaries and leaks in early 1990s [Morton and Mitchell 1995]. In those tests, glass spheres in the size range from approximately 2-20 μm volume equivalent diameter and concentration range from 1 to 3 gm/m3 were used. The pressure differential varied from 20 kPa to 100 kPa. A sudden increase or decrease in pressure differential was administrated during some tests to study the influence of pressure change on aerosol plugging behavior. It was observed that a high pressure surge could initiate the breakdown of partly or fully formed plug-like deposits causing deposits to re-suspend. "In some instances, plugging may not occur if re-suspension processes dominate to prevent the accumulation of deposited particles. ... However, any increase in particle emission from the cleared leak-path was temporary, and plug formation continued at the new conditions."

Williams also had an observation on particle re-suspension [Williams 1994]. "It was also noticed that particles which did penetrate the capillaries were much larger than the 3 - 5 μm particles in the source; micrographs indicate particles of sizes 50 μm to 1350 μm. These values are curiously large and can only have been formed by some form of re-suspension; it seems unlikely that particles of such size could be formed by coagulation since there are no obvious processes available in the tube. Also the transit time is much shorter than most coagulation "half-lives"."

Two tables below provide some perspective for the crack retention of aerosols experiments in light of AP1000.

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Table 1. Comparison of the test conditions and typical AP1000 accident conditions

Table 2. Particle sedimentation velocity vs. particle diameter

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2.2 LACE Tests

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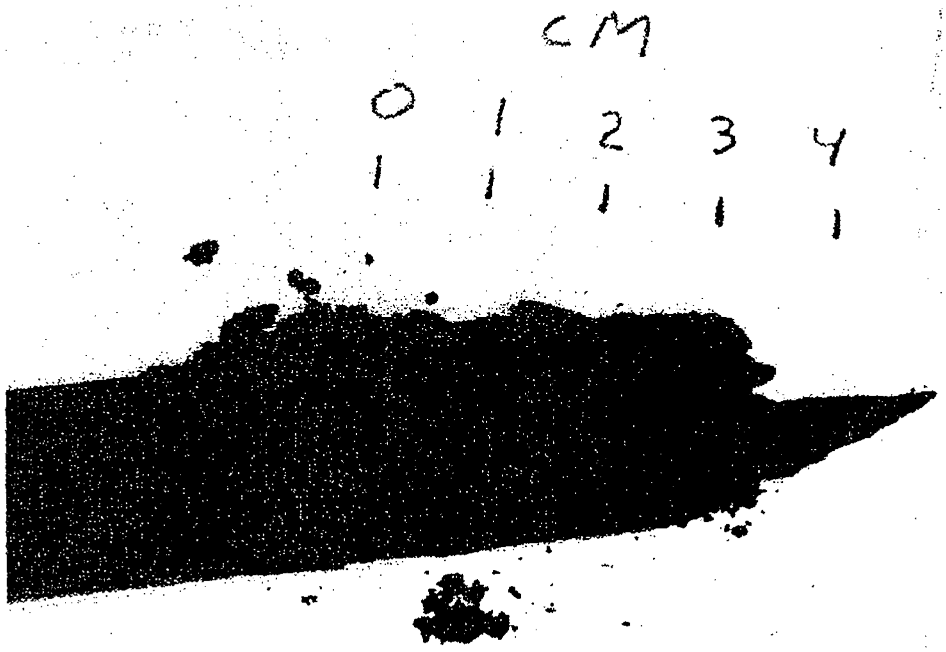
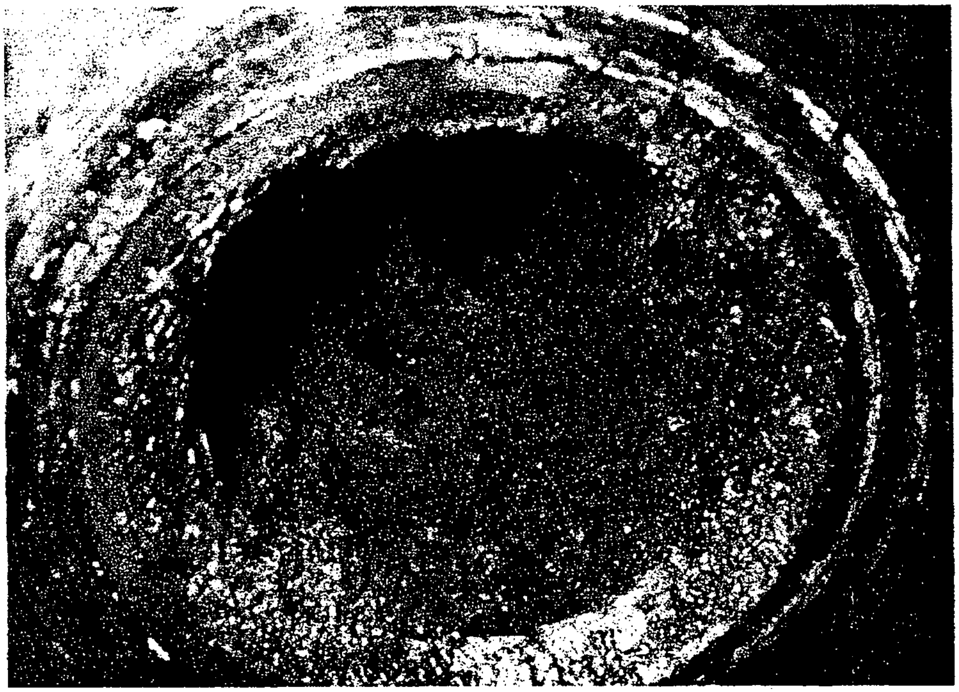
Take Test LA3 [LACE TR-011] for example. Test LA3 was a large-scale experiment in which aerosol behavior in pipe flow under simulated containment bypass conditions was studied. The test consisted of three subtests, namely, LA3A, LA3B and LA3C. Each subtest was performed with a different pair of values of two key parameters: gas velocity and aerosol composition. All subtests involved the flow of superheated steam, gas and aerosol through a long test pipe (29-m in length) of 63 mm inner diameter with six 90-degree bends. The test aerosol consisted of soluble CsOH and insoluble MnO. The gas carrying the aerosol through the test pipe was a mixture of 50% steam and 50% nitrogen by volume at ~300 °C.

The photos below were taken after the tests and show the paste-like deposited aerosols left in or collected from the test pipes:

LA3A



LA3B



LA3C

3. Theoretical Basis for Plugging

The mechanisms of particle deposition in containment cracks include impaction, interception, laminar/turbulent diffusion, thermophoresis, diffusiophoresis, sedimentation, etc. Of these mechanisms, impaction is believed to be the primary mechanism of aerosol deposition in cracks, [[

3.1 Impaction Model

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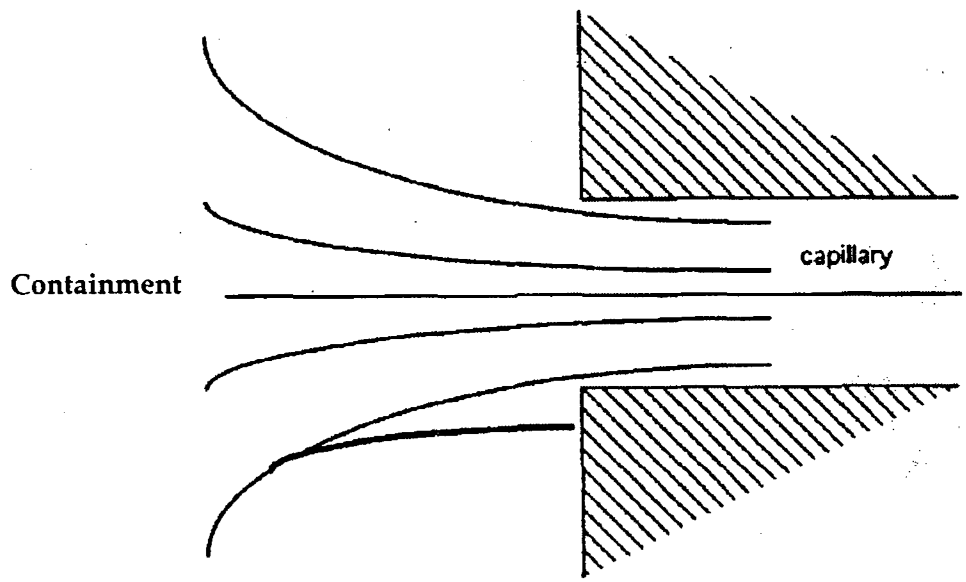

Figure 1. Schematics of Impaction Model

All textbooks, e.g. [Friedlander 1977], state that particle impaction is governed by Stokes number, St, where

$$St = \frac{\left(d_p^2 \rho_p U / 18\mu\right)}{D} \qquad (1)$$

In Equation (1) d_p is the particle diameter, ρ_p the particle density, μ the coefficient of viscosity (or the dynamic viscosity) of the gas, U the flow velocity within the crack and

D the width of the crack. Note that the numerator is so-called "stop distance" defined as the distance the particle of interest traveling in certain direction will travel before it loses its velocity in that direction. The denominator, on the other hand, is the characteristic length scale of the crack. [[

3.2 Morewitz Model

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If one assumes conservatively that all aerosols entering the duct before the duct is plugged leak without any deposition (which over-estimates the leaked mass), the DF is given by the following expression:

$$DF = \frac{M_{tot}}{M} \tag{5}$$

where M_{tot} is the total leaked mass over the entire leaking period of interest without any retention in the crack and M is determined by Equation (4).

4. AP1000 Decontamination Factor (DF) Calculation

4.1 Assumptions

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4.2 AP1000 Crack Location

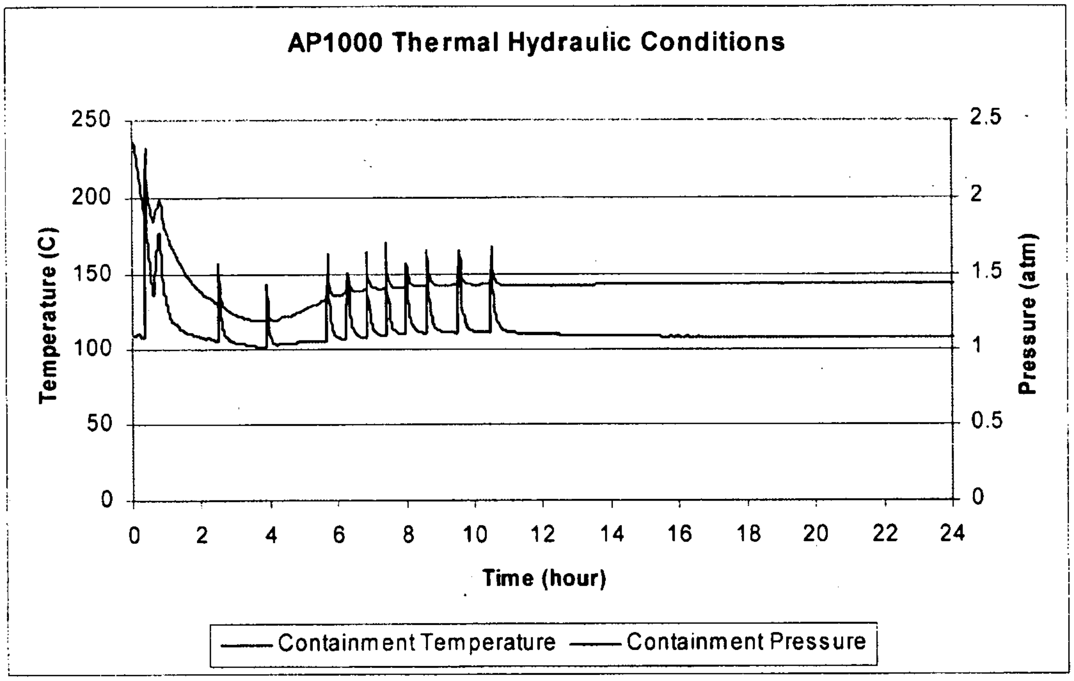
In this analysis, aerosol removal and/or holdup after the leakage leaves the cracks will be not credited for the sake of conservatism. Therefore, it is not necessary to identify the actual crack locations. But, it should be pointed out that cracks on the PCCS steel shell are most likely to occur in the areas where the penetrations are located, such as the hatches and the cable penetrations. In AP1000 design, those penetrations lead to either auxiliary buildings or volumes where the holdup and further aerosol removal are likely to take place.

Assuming that crack can occur anywhere in the PCCS shell, one may think that the worst location for the cracks in terms of maximizing the activity release is at the top of the PCCS dome since it is point of PCCS closest to the opening at the top of the containment so that the additional activity reduction will be minimized. But this is not true since there is a basket sitting right on the top of the PCCS dome which will be filled with water from PCCS water storage tank during accidents so that the leakage from cracks at that location is likely to be scrubbed.

The areas around the basket are also likely to have running water during accidents as the water spilt over from the basket is guided away uniformly to maximize the coverage of the PCCS shell for most efficient heat removal. So, the worst crack location is likely to be somewhat far away from the containment opening.

4.3 AP1000 Thermal Hydraulic Conditions

The AP1000 thermal hydraulic conditions during the accidents are shown in figure below, i.e., T varies from 100 to 220 °C while P varies from 1.2 to 2.4 atm [Polestar 2004].



4.4 Sonic Velocity

Sonic velocity (U) for ideal gas is given by the following expression:

$$U = \sqrt{\frac{\gamma \Re T}{M_w}} \tag{6}$$

where γ is the ratio of specific heat capacities, $\Re$ is the universal gas constant (= 8.3145 J/mole•K), M_w is the molecular weight in gram/mole and T is the temperature in Kelvin. Given that the primary gases in the containment are air and steam, the properties for air and steam are provided in the table below:

Table 3. Properties for air and steam

	Air	**Steam**
Molecular weight	29 g/mole	18 g/mole
Ratio of heat capacities		
20 °C	1.40	
100 °C	1.401	1.324
200 °C	1.398	1.310

From Equation (6) and the properties provided in Table 3, we obtain the sonic velocity in air or steam as a function of temperature as shown in Figure 2 below:

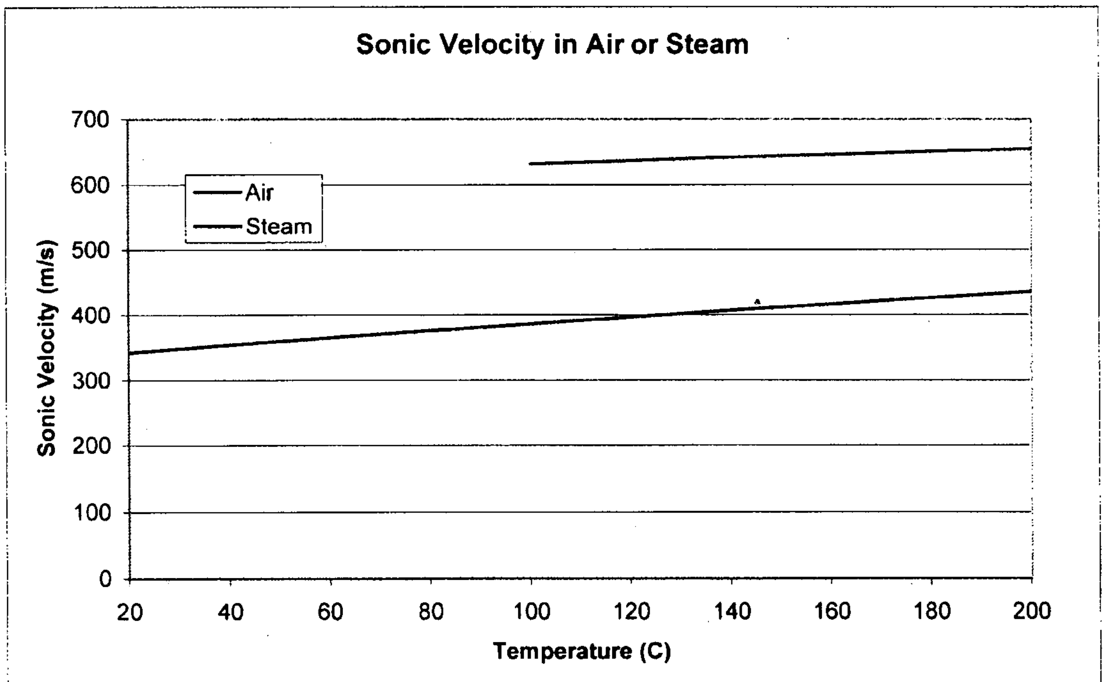


Figure 2. Sonic velocity in air or steam as a function of temperature

Note that the minimum sonic velocity of interest here is 340 m/s.

4.5 Gas Viscosity

From an EPA website[2] we can obtain the values of air viscosity as a function of temperature in Table 4. Bear in mind that steam viscosity is somewhat smaller than air viscosity at the same temperature. It implies that Stokes number is greater in steam than that in air, with everything else remaining the same.

Table 4. Absolute Gas Viscosities

Temperature °C	Gas Viscosity gm/cm-sec	Temperature °F	Gas Viscosity gm/cm-sec
0	1.72×10^{-4}	32	1.72×10^{-4}
20	1.81×10^{-4}	60	1.79×10^{-4}
25	1.82×10^{-4}	68	1.81×10^{-4}
40	1.89×10^{-4}	80	1.83×10^{-4}
60	1.99×10^{-4}	90	1.85×10^{-4}
80	2.08×10^{-4}	100	1.88×10^{-4}
100	2.17×10^{-4}	120	1.93×10^{-4}
120	2.26×10^{-4}	140	1.98×10^{-4}
140	2.34×10^{-4}	160	2.03×10^{-4}
160	2.43×10^{-4}	180	2.08×10^{-4}
180	2.52×10^{-4}	200	2.13×10^{-4}
200	2.60×10^{-4}	250	2.26×10^{-4}
220	2.68×10^{-4}	300	2.40×10^{-4}
240	2.77×10^{-4}	350	2.50×10^{-4}
260	2.85×10^{-4}	400	2.60×10^{-4}
280	2.93×10^{-4}	450	2.73×10^{-4}
300	3.01×10^{-4}	500	2.85×10^{-4}

Note: Celsius and Fahrenheit temperature scales are not intended to be identical or parallel.

4.6 Maximum Crack Size

According to [Polestar 2004], the AP1000 containment has a volume of 55,481 m^3 that is about two million cubic feet; the maximum leak rate allowed (L) is 0.1 % per day that is about 1.36 cfm or 6.421×10^{-4} m^3/s. Under test pressure, the air leakage flow velocity is going to be sonic. The diameter of the leak-path, assuming it is tube-shaped, is given by the following equation:

$$D = 2\sqrt{\frac{L}{\pi U}} \tag{7}$$

[2] http://www.epa.gov/eogapti1/module2/viscosity/viscosity.htm

Note that the greater the sonic velocity, the smaller the leak-path diameter. For minimum sonic velocity, i.e., 340 m/s, the maximum diameter of the leak-path is 1.55 mm.

4.7 Particle Density

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4.8 DF Based on Impaction Model

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Figure 3. Particle radius that corresponds to 1.5 Stokes number as a function of temperature

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Figure 4. Ratio of temporary AMMD for AP1000 aerosols

4.9 AP1000 Aerosol Conditions

4.10 DF Based on Morewitz Model

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Figure 5. Containment aerosol concentration and leakage.]]

4.11 Summary

The results of calculations are summarized as follows:

1. The DF due to retention of aerosols in the crack by impaction alone is at least 5.4 with very conservative assumptions, i.e., no impaction is considered for particles whose Stokes number is smaller than 1.5 and the aerosols deposited in the crack earlier do not affect the later deposition.

2. The DF based on Morewitz model is estimated to be in the range from 100 to 700, corresponding to the range of the coefficient, *k*, in the model that varies from 10 to 50 g/cm^3.

5. Conclusions

It can be concluded that

1. For the anticipated AP1000 accident conditions, it is highly likely that plugging will occur with significant DFs, i.e., DFs greater than 10.

Note that there are a number of AP1000 conditions that will have a positive effect on plugging, such as:

- The PCCS atmosphere is humid (instead of dry), with a water film running on both sides of the PCCS shell.
- The crack is unlikely to be tube-like with a smooth surface but rather slit-like with a rough surface, a torturous path, and a sharp entrance (instead of rounded one).
- The size of the crack is likely to be smaller than the 1.55 mm calculated here since the actual leak rate is expected to be less than 0.1% per day and is likely to be the result of multiple cracks.

2. Humid condition for AP1000 makes re-suspension more difficult to occur. If re-suspension occurs, the re-suspended aerosols are judged not likely to be transported to the environment since:

   - If re-suspended, such aerosol particles are significantly larger and may be retained in the crack downstream.
   - If these large particles make their way out of the crack, they will either quickly settle or impinge on the wall opposite the steel shell (~ 1 ft away) and re-deposit.

6. References

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