Revision of Regulatory Guide 1.183 "Alternative Radiological Source Terms for Evaluating Design Basis Accidents at Nuclear Power Reactors"

Focused Meeting on MSIV Leakage Pathway Modeling Methods

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Agenda

- Key Messages
- Background
- Changes from Disposition of Recent DPO Panel Report
- SAND 2008-6601 Method
- Re-evaluation of AEB-98-03 with Multi-group/Numerical Integration Method
- MSIV Leakage Related Changes Under Consideration
- Technical Assessment on Seismic Analysis for Alternative Drain Pathway
- Looking Forward
- Feedback/Discussion
- Comments and input from the public

Key Messages

- The NRC staff has restarted efforts to revise RG 1.183, “Alternative Radiological Source Terms for Evaluating Design Basis Accidents at Nuclear Power Reactors.”
- Meetings discussing potential changes to RG 1.183 were held (November 19, 2020, March 5, 2021).
- This meeting is a focused meeting to present potential changes to the MSIV leakage pathway modeling methods proposed to be endorsed in regulatory positions.
- RG 1.183 Rev. 0 and Rev. 1 will co-exist as a result of SRM-SECY-18-0049, “Management Directive and Handbook 8.4, “Management of Backfitting, Issue Finality, and Information Collection.”

Background

Background

- During the time since initial issuance of RG 1.183, the staff has documented and discussed issues with MSIV leakage pathway modeling in numerous requests for additional information, safety evaluations for BWRs, NRC RIS 2006-04, “Experience with Implementation of Alternative Source Terms,” dated March 7, 2006 (ADAMS Accession No. ML053460347) and in multiple public workshops on RG 1.183.
- Resolution of these issues is based upon a comprehensive effort to determine parameters that can be used to model the MSIV leakage pathway.

Background (cont'd)

- In October 2009, the NRC issued for public comment a proposed revision to RG 1.183 known as DG or Draft Guide 1199.
- DG-1199 included providing additional guidance on BWR MSIV leakage based upon SAND2008-6601 (ML083180196)
- Staff received public comments on this additional guidance that is being considered in the latest draft revision to RG 1.183.
- Based upon these comments, modifications to the regulatory positions on the MSIV leakage pathway will be made and submitted again for public comments.

Changes from Disposition of Recent Differing Professional Opinion (DPO) Panel Report[1]

- Crediting Safety Related Systems with a deterministic fuel melt source term
- Reinstatement of the Maximum Hypothetical Accident (MHA)
- Removing mechanistic explanations for the deterministic source term
- The LOCA will be defined as an event resulting in the loss of the ability to cool the core
- The MHA LOCA will be defined as an unspecified event resulting in substantial meltdown of the core with subsequent release into the containment of appreciable quantities of fission products
- Appendix A will describe acceptable assumptions for the evaluation of the MHA LOCA
- Elimination of the assumption of a 2-hour delay in the distribution of the fuel melt source term into the containment and the elimination of the R-Factors in the Sandia Method

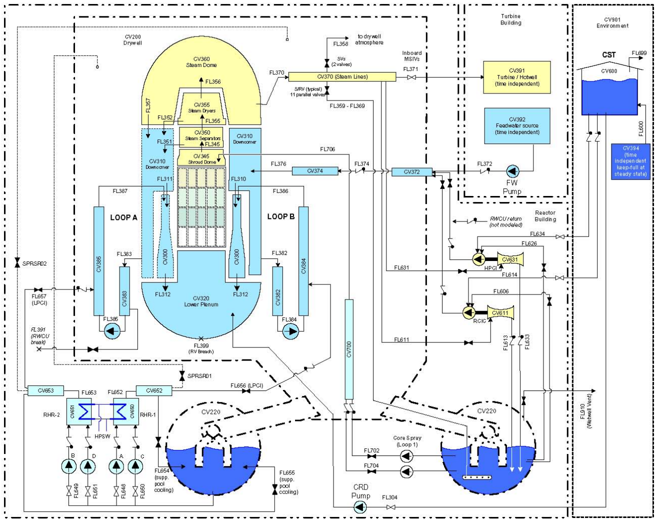
[1] For more information see the DPO Case File for DPO-2020-002 (ML21067A645).

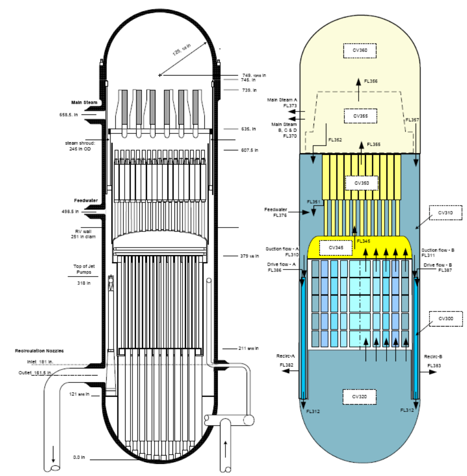
SAND2008-6601 Method

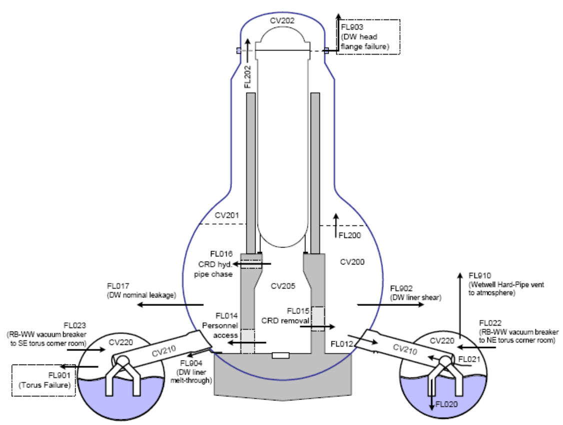
SAND 2008-6601 Method

- A MELCOR main steam line model was developed based upon the range of physical parameters (steam line configurations and designs) and aerosol physics parameters to determine the aerosol deposition in the steam line and condenser.
- MELCOR is well vetted, benchmarked state-of-the-art computer code.
- Considers the effects of reflood holistically, utilizing best estimate models
- The model considers deposition mechanisms other than gravitational aerosol settling (diffusiophoresis, thermophoresis, Brownian motion)
- The model also considers agglomeration, condensation and hygroscopicity.

MELCOR Analysis of Full Plant DBA

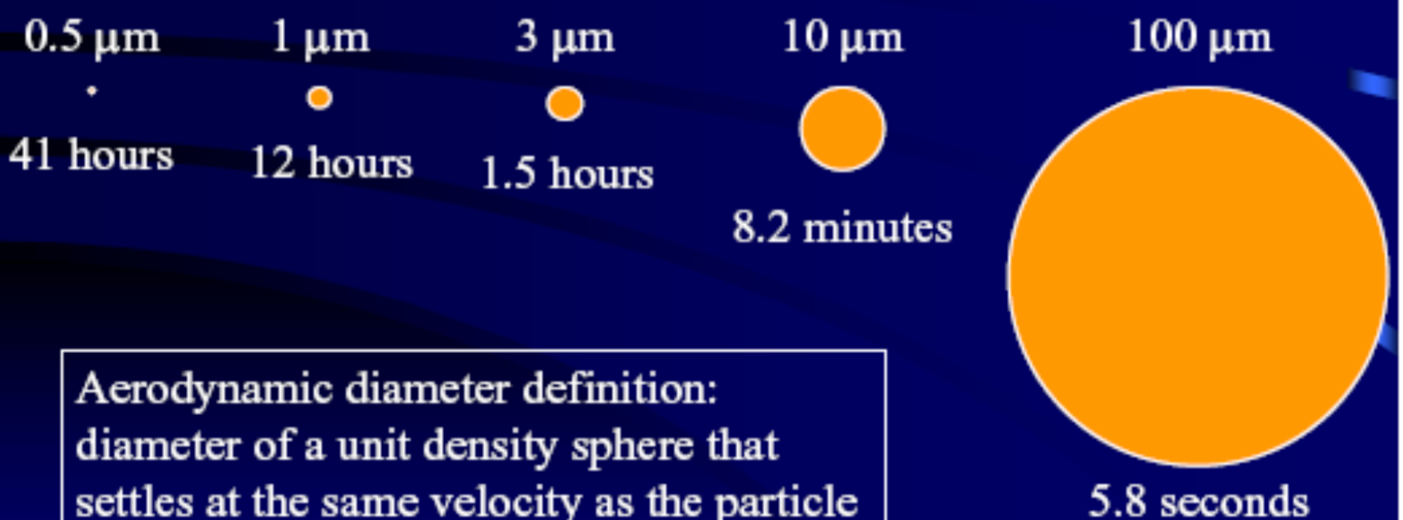






Particle Settling in Still Air

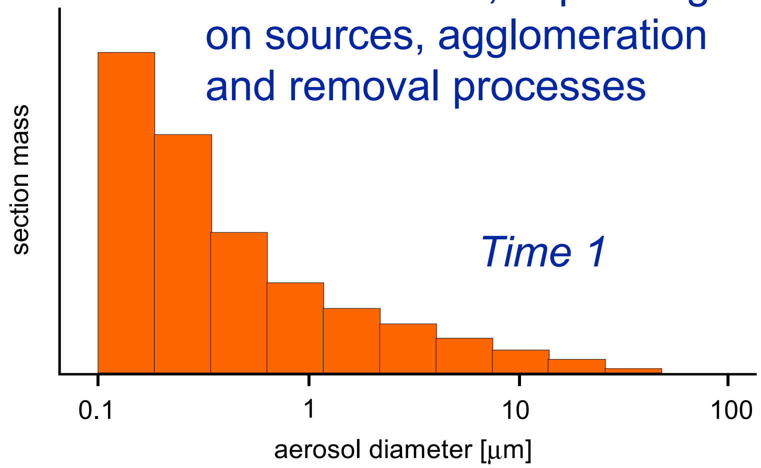
Time to settle 5 feet by unit density spheres

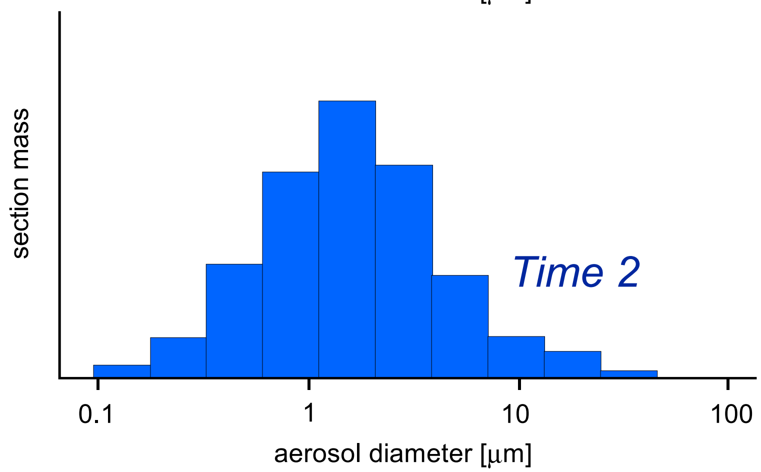


Aerodynamic diameter definition: diameter of a unit density sphere that settles at the same velocity as the particle in question

SAND 2008-6601 Method (cont'd)

Aerosol size distribution evolves in time, depending on sources, agglomeration and removal processes



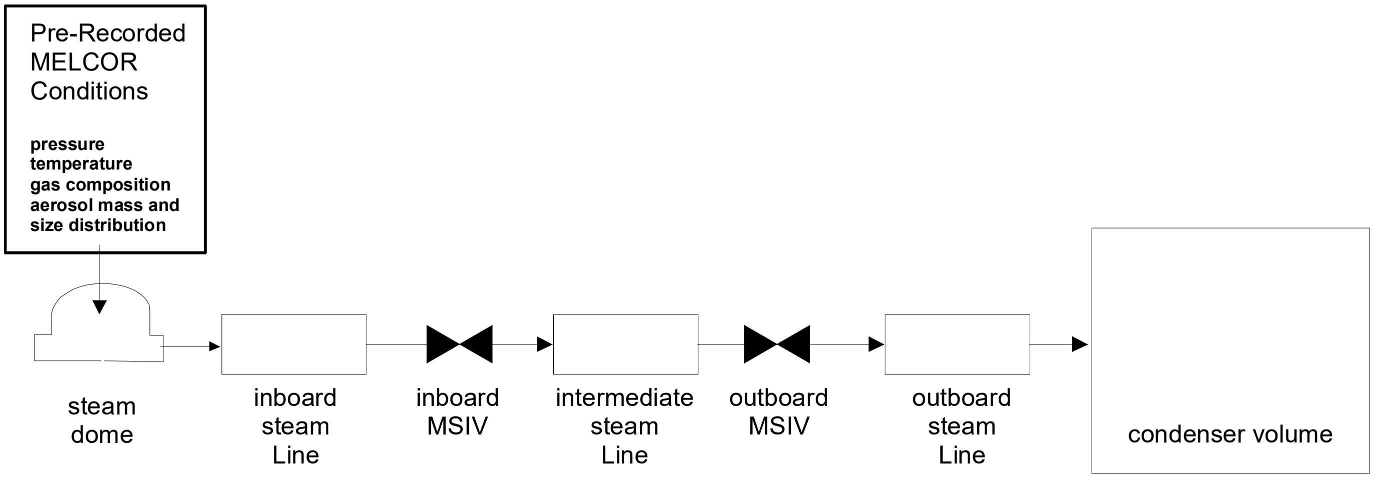


- MAEROS sectional model of Gelbard
- Particles grow in size
  - Agglomeration
  - Water condensation
- Particle fallout by gravitational settling
- Particle deposition processes
  - Thermophoresis
  - Diffusiophoresis
  - Brownian motion
- Cs chemisorption in RCS modeled
  - Iodine from CsI re-volatilizes when reheated

Validation Experiments

PANDA, DEHBI, CVTR, FALCON, LACE-LA4, ABCOVE, Wisconsin flat plate

SAND 2008-6601 Method (cont'd)



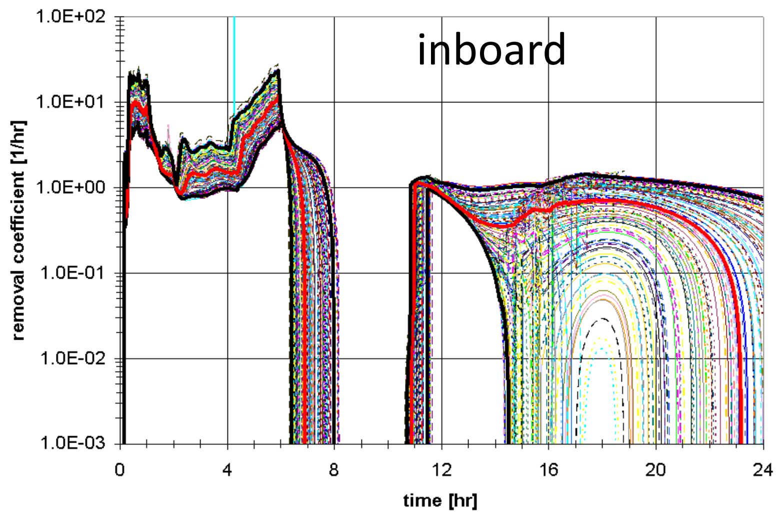
- Reduced nodalization
- Boundary conditions from full-plant MELCOR analysis
- Monte Carlo sampling used to derive distributions

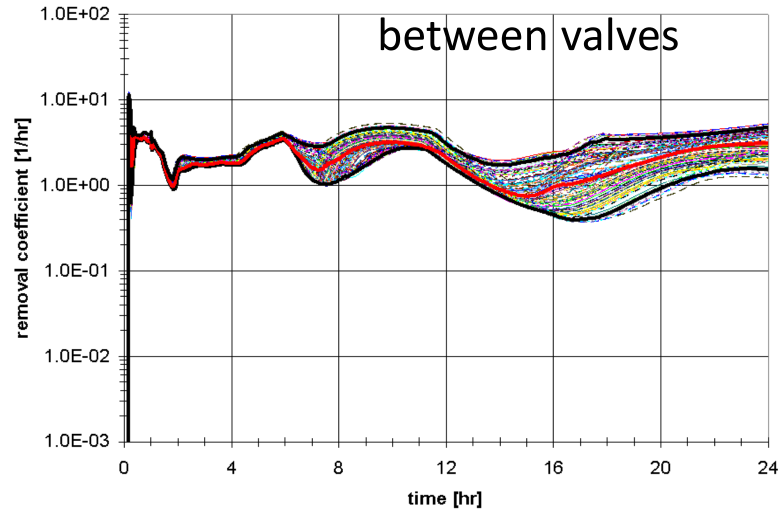
SAND 2008-6601 Method (cont'd)

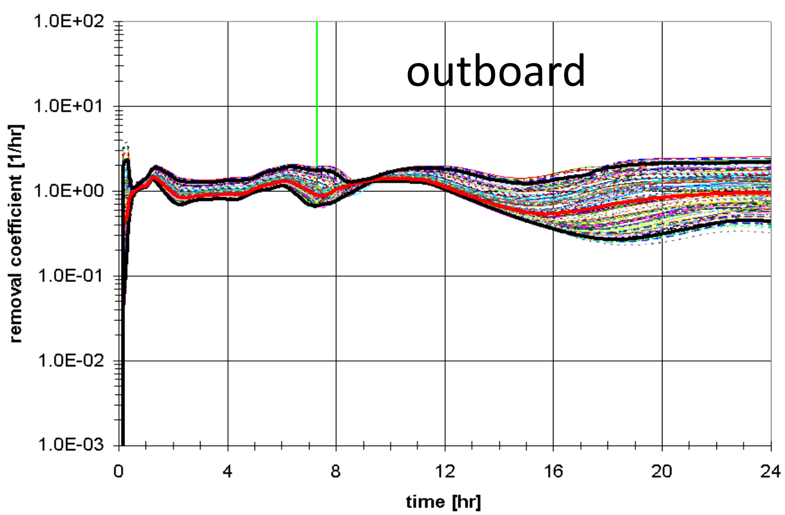
- The method used is very similar to those currently endorsed in RG 1.183 for modeling containment aerosol removal by natural processes and by sprays (See Regulatory Positions A-3.2 and A-3.3).

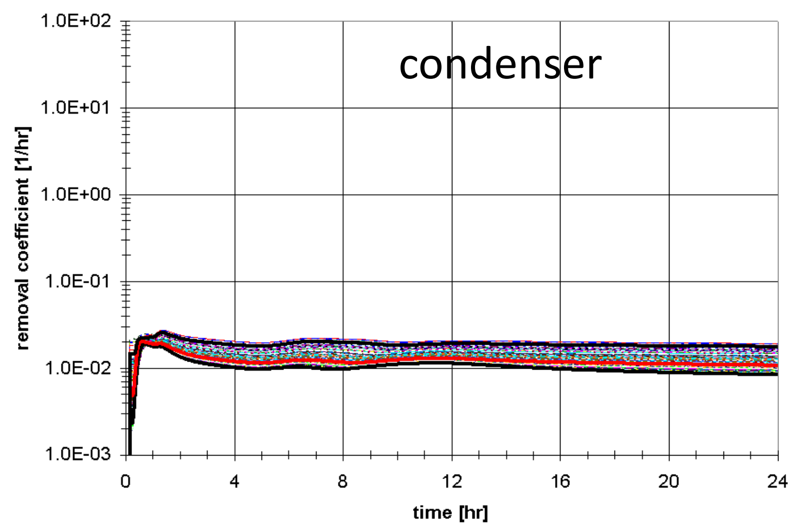
- The aerosol deposition vs. time and the location in the steamline and the condenser were calculated considering the uncertainty in parameters that impact deposition.

Illustrative Example of Results from Deposition Analysis









SAND 2008-6601 Results
MSL and Condenser Removal Coefficients

MSL section	0 - 10 (hr)	10^{+} (hr)
in-board	0*	0*
between MSIVs	1.8	1.0
out-board	1.0	0.7
condenser	0.015	0.012

Note. removal coefficients are given in 1/hr

* Not credited because of thermal bi-directional flow, turbulence, containment boundary

- Based upon Recommendation 6.4 of SAND 2008-6601 for post-reflood conditions (taken from Table 6.1)
- Lambdas decrease as remaining aerosols becomes smaller

Re-Evaluation of AEB 98-03 with Multi-group /Numerical Integration Method

Topics on Re-evaluated AEB 98-03…

- Provide topical discussion of AEB-98-03 and Regulatory Issues Summary (RIS) RIS 2006-04
- Overview of re-evaluating AEB 98-03's use of Stokes settling velocity equation and use of creditable aerosol physics parameters.
- Evaluation of the industry developed 20-group method, here-in referred to as the "multi-group method," to evaluate the settling velocity distribution.
- Development of a numerical method to directly integrate the settling velocity distribution.
- Takeaways
- Multi-group and Numerical Integration Methods

Background – AEB 98-03 and 20-Group

- RG 1.183 Rev. 0 does not provide a aerosol deposition model within the main steam lines.
  - Instead, some licensees followed the initial analyses supporting the first approved 10 CFR 50.67 AST implementation for the Perry plant, (**AEB-98-03**).
  - AEB-98-03 utilizes the Stokes Setting Velocity Equation, u_s ,and Monte Carlo Methods to sample uncertain distributions.

$$\boxed{u_s\left(\frac{m}{s}\right) = \frac{\rho d_e^2 g C_s}{18\mu\kappa}}$$

ρ = aerosol density
d_e = aerosol diameter
g = gravitational acceleration

C_s = Cunningham slip factor
μ = viscosity
κ = shape factor

- RIS 2006-04 found AEB-98-03 settling velocity method to be acceptable with certain conditions…
  1. Aerosol physics parameters to compute settling velocities needed correction.
  2. Use of only the median, 50^{th}, settling velocity which does not account for the tail-ends of the settling velocity distribution or its “shift” through sequential control volumes.

Background – AEB 98-03 and 20-Group (cont'd)

- To address these concerns, licensees would:
  1. Take more conservative AEB-98-03 settling velocities (~3rd to 10th percentiles instead of 50th).
  2. "**20-Group Method**" developed to account for the entire settling velocity distribution.

- To date:
  - A partial review of BWR FSARs found that a considerable number of facilities have utilized some form of AEB-98-03.
  - Several sites have utilized the 20-Group Method.

Re-evaluation of AEB-98-03

– Utilized the aerodynamic mass median diameter (AMMD) which has the benefit of:
  - Being directly measured through experiments where other aerosol parameters (density and shape) are not needed to evaluate settling rates once the aerodynamic distribution is known.
  - Simplifies AEB-98-03's model to just one known distribution (i.e., AMMD) which can be re-written in terms of the aerodynamic diameter, d_a, to be:

$$u_s = \frac{\rho_0 \cdot d_a^2 \cdot g \cdot C_s(d_a)}{18\mu},$$

where:

ρ_0 = aerosol unit density = 1.0 g/cm^3
d_a = aerosol aerodynamic diameter
$C_s(d_a)$ = Cunningham slip factor as a function of d_a
μ = viscosity

  - Measured distributions are directly representative of the aerosol physics behaviors and processes not captured with original AEB-98-03 such as agglomeration, re-vaporization, condensation, hygroscopicity.

Re-evaluation of AEB-98-03 (Cont'd)

- The European State of the Art Report on Nuclear Aerosols (SOAR) evaluated the results of the PHEBUS-FP experiments and gave recommended aerodynamic size distributions.[1]
  - Experimental results range between AMMDs of 1- and 4 µm with a log-normal distribution and geometric standard deviation (GSD) of 2.0.

- Staff evaluated the SOAR and other reports and find it reasonable to select a value of 2 µm AMMD with a log-normal distribution and GSD of 2.0 for the purposes of stylized design-basis accident dose calculations.

- This approach greatly simplifies the analysis, is defensible, easy to perform and computes similar results to high-order codes, such as MELCOR.

1 – Allelein, et. al., "State-of-the-Art Report on Nuclear Aerosols," (SOAR report), NEA/CSNI/R(2009)5

Multi-group Method

- <u>Description</u>: statistical treatment of assessing the first-order removal processes of gravitational settling from a settling velocity distribution within control volumes.

- <u>Purpose</u>: develop a representative “effective” removal constant for the purposes of assessing DBA radiological consequences.

- <u>What it does</u>:
  - Monte Carlo integration to sample within settling velocity distribution, creating a data-set.
  - Discretizes the settling velocity data-set into ‘groups’ or ‘bins’ representing ranges of settling velocities.
  - Each group is assigned probabilities to compute “probability-weighted settling velocities.”
  - Sum the probability-weighted settling velocities to compute representative “total effective aerosol removal efficiencies” (TEAREs) and lambdas (hr-1).

- <u>How it is used</u>: Model's plant-specific piping sizes and flow rates to compute removal constants which describe the aerosol transfer between compartments and elimination of aerosol concentration due to gravitational settling.

Numerical Integration Method

- Description: directly integrate the settling velocity distribution within control volumes for assessing the first-order removal processes of gravitational settling.

- Purpose: develop a representative “effective” removal constant for the purposes of assessing DBA radiological consequences.

Numerical Integration Method (cont'd)

- What it does:
  - Utilizes the equation for a normalized number distribution ($n(d_a)$) of particles of aerodynamic diameter, (d_a), given (Williams, 91)[1] as:

$$n(d_a) = \frac{1}{d_a\sqrt{2\pi}\,\ln(\sigma_g)} Exp\left[-\frac{\ln\left(\frac{d_a}{d_g}\right)^2}{2\ln(\sigma_g)^2}\right]$$

where:

σ_g=geometric standard deviation

d_g=geometric mean (which, for a log-normal distribution, is the same as the median diameter)

  - According to the Hatch-Choate equations, the aerodynamic mass median diameter (AMMD) is related to the median diameter (d_g) by the relation:

$$\mathrm{d_g} = AMMD\ Exp[-3\ln(\sigma_g)^2]$$

[1] Williams, M.M.R. (1991). *Aerosol Science Theory and Practice*, New York: Pergamon Press.

Numerical Integration Method (cont'd)

- How it is used: Model's plant-specific piping sizes and flow rates to compute removal constants which describe the aerosol transfer between compartments and elimination of aerosol concentration due to gravitational settling.

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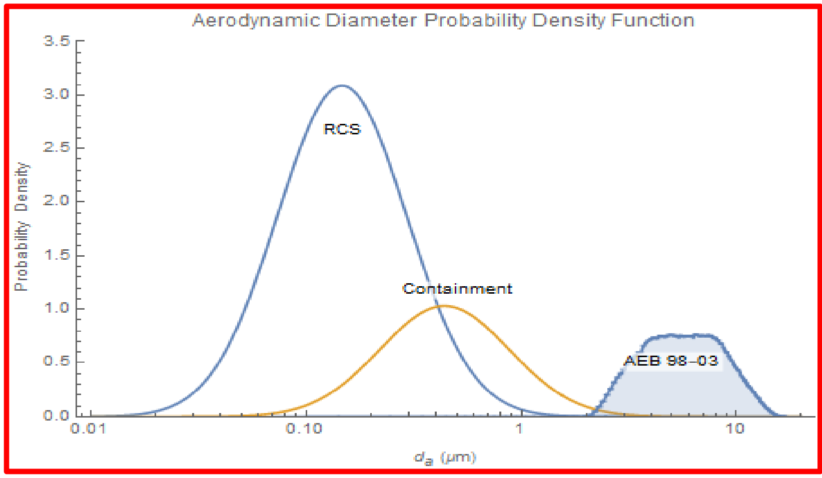
SOAR, Multi-group, and Direct Integration



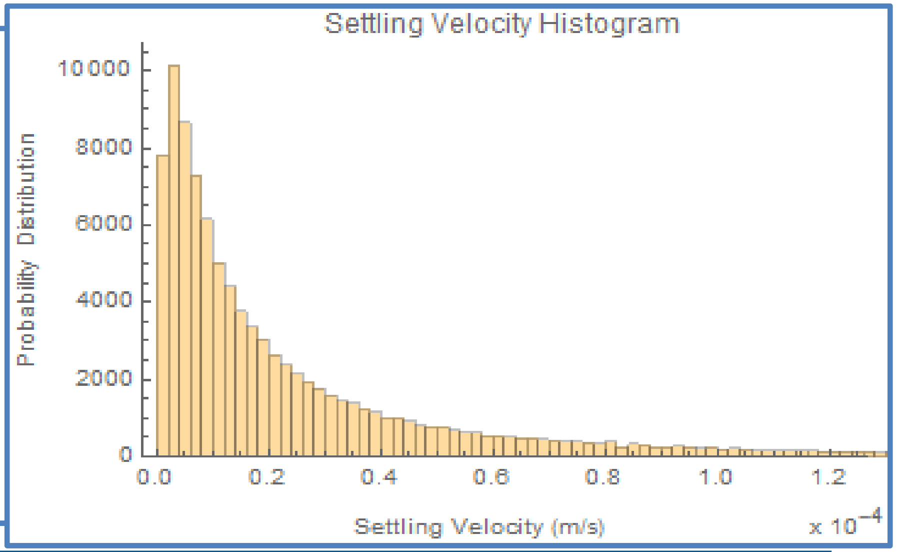
Re-Evaluated AEB-98-03

← Comparisons between aerodynamic diameter probability distributions between SOAR recommendations and AEB-98-03.

→ Both methods discretize settling velocity distribution to integrate it.

Tips for Multi-Group based on LAR reviews…

- Generate 1E5 settling velocity data points.
- Discretize the data into 2000 equal-width groups to convergence results.
- For each group, assign the mid-point as a conservative representative settling velocity.
- To model the changing settling velocity distribution for consecutive volumes, utilize the output from previous volumes as the input for the next.



Takeaways…

- Both Monte Carlo and numerical integration compute the same results, and each is useful for different reasons.
  - Monte Carlo – useful when multiple uncertain parameters are considered.
  - Numerical Integration – greatly simplifies calculation.

- For the multi-group method, around 2000 groups are needed to converge results.

- Updated AEB 98-03 physics assumptions result in settling velocities 2 – 3 orders of magnitude lower than original AEB 98-03 (they settle out much slower).

- Updated models expected to increase accident dose related figures-of-merit results from the original AEB-98-03 model but would be compensated by the credit provided by the alternative drain pathway using the updated seismic analysis.

Multi-Group and Numerical Integration Methods

- Reasonable to adopt a log-normal distribution utilizing a AMMD of 2 μm with a GSD of 2.
- Flexible enough to allow for plant-specific information and could be used for SMR BWR-type designs (not withstanding the source term distribution intended for large-light water reactors).
- Can be used to model aerosol settling within the alternate pathway on a case-by-case basis.
- Reproduceable and easily accessible to perform with Excel or within a few lines of higher-order programming codes.
- Develop calculational aids as reference documents within RG 1.183 Rev. 1.

MSIV Leakage Related Changes Under Consideration

- Consider endorsing all three deposition methods as acceptable in regulatory positions (SAND 2008-6601, Multi-group & numerical integration methods) to be used in conjunction with revised seismic analysis
- Clarifications for BWR MSIV leakage pathway
  - All steam lines are intact, assuming no break.
  - Delete regulatory position crediting containment sprays when crediting aerosol removal within the main steam lines.
  - No credit for holdup or aerosol deposition within the inboard main steam line.

Technical Assessment on Seismic Analysis for Alternative Drain Pathway

Alternate Pathway Holdup in Rev. 1

- Pathway identification and availability guidance same as Regulatory Position A-6.5 in Rev. 0
- Streamlined information needs for seismic capacity of SSCs in pathway

Elements of Technical Assessment

Fragility Data
- Compilation (e.g., NUREGs, EPRI reports, archival publications)
- Recent seismic probabilistic risk assessments (PRAs)

Operating Experience - Walkdowns
- North Anna
- Kashiwazaki-Kariwa
- The Great Tohoku Earthquake of 2011

Representative Risk
- Hazard and fragility convolution

Lower Bound Median Fragility Parameters to Encompass Seismic Failure Modes

Streamlined Information Needs - Development Approach

- Justification that plant is not outlier to technical assessment
- Reliability of pathway commensurate with safety significance
- Consideration of tiered approach based on plant-specific ground motion response spectrum (GMRS)

Streamlined Information Needs - Development Considerations

- Margin in code of record of SSCs in alternate pathway
- Available dynamic analyses for SSCs in alternate pathway
- Documented walkdowns of pathway SSCs by licensee staff
- Site-specific seismic risk using lower bound median fragility parameters
- Adequate flexibility at major branch connections (e.g., equalizing header and turbine bypass)
- Option of performing fragility analysis for SSCs in pathway

Looking Forward

- Consider feedback from stakeholders
- Continue development of updated draft RG 1.183 Rev. 1
- Planning for an ACRS meeting in October 2021
- Draft RG 1.183 Rev. 1 issued for public comment (4th Quarter CY 2021)
- Hold additional public meeting as necessary prior to the end of public comment period
- Staff review and disposition of public comments
- Update draft RG 1.183 Rev. 1 as necessary
- ACRS and OGC review of final draft (1st Quarter CY 2022)
- Issuance of RG 1.183 Rev. 1 (2nd Quarter CY 2022)

Feedback/Discussion

Questions/Comments?

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