Treatment of MSIV Leakage in BWR Dose Analysis

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Overview

- **Up Front – summarize briefly the central issue and the proposed methodology for analyzing MSIV leakage**
- **Questions so far**
- **MELCOR code overview**
- **MELCOR applied to MSIV analysis**
  - **Vessel head source versus drywell source**
  - **Effect of reflooding vessel**
  - **Attenuation in steam lines and condenser**

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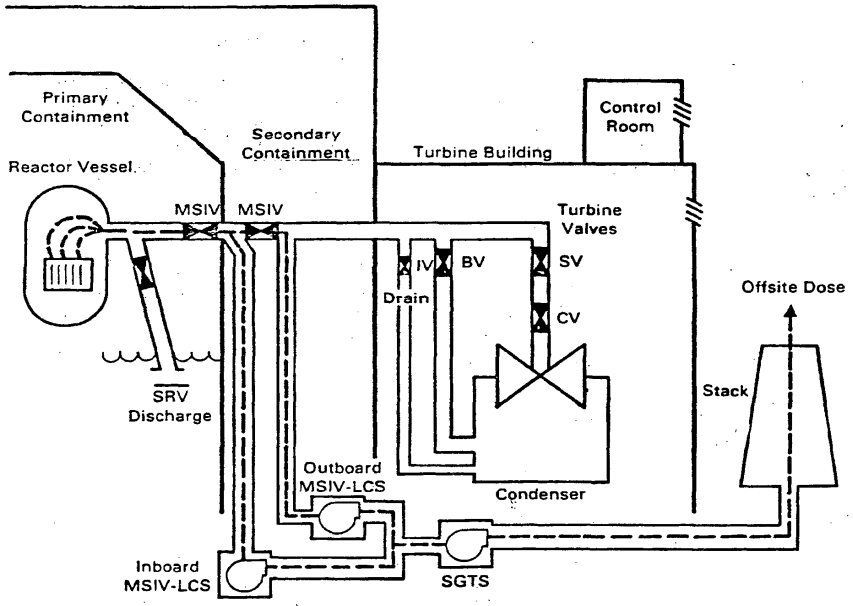
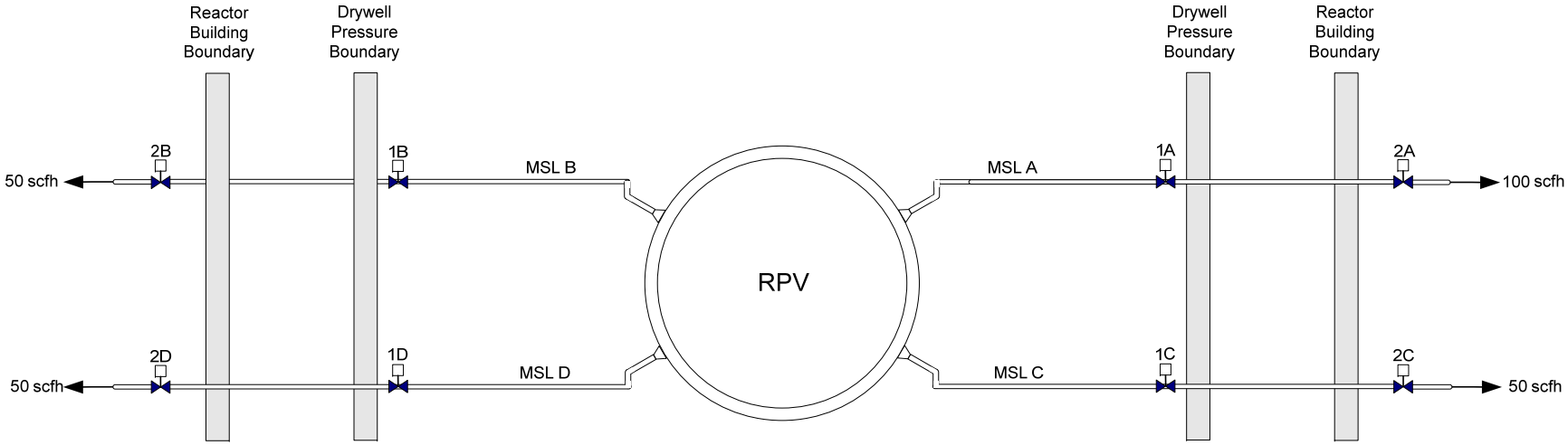
History

- **Regulatory Guide 1.183**
  - **Details use of NUREG-1465 Alternative Source Term in evaluating containment performance**
  - **MSIV leakage may be assessed using containment airborne fission product concentrations as a surrogate for the MSIV leakage environment**
    - **NUREG-1465 is a containment source term**
- **Problem is, the containment is not the source volume for the MSIV leakage**
  - **Staff recognition of issue dates to NUREG-1169**



MAIN Steam Lines



- **Inboard/outboard valves**
- **Tech spec leak based on standard test**
  - **Pressurize between valve and bleed down**
- **Characterize valve performance**
  - **SCFH @ test pressure**
  - **Implies a leak area**
  - **Necessary to scale standard leak to accident conditions**

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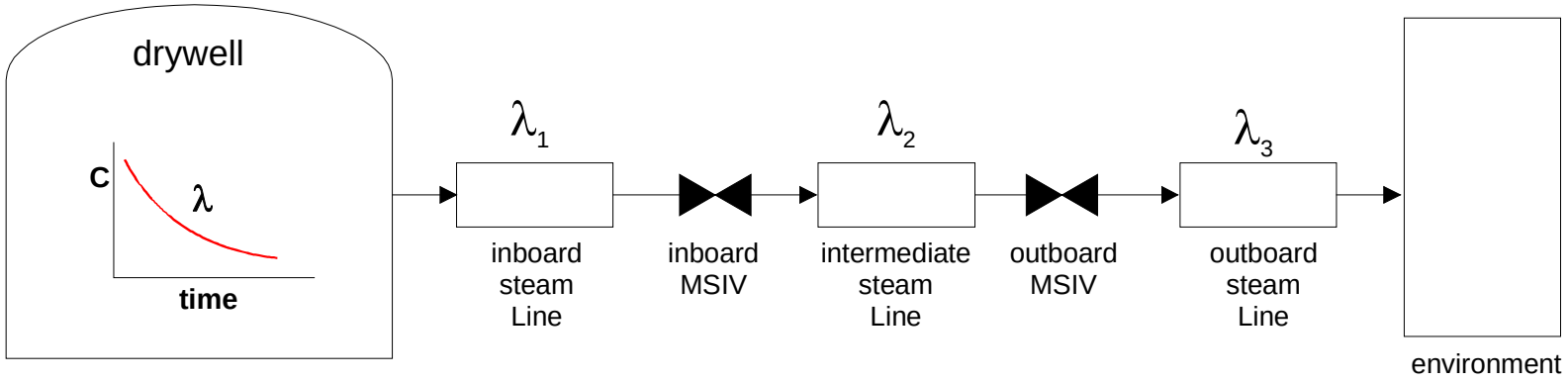
Current RG Method



- **Source - Drywell airborne from NUREG-1465**
- **Lambdas derived using AEB 98-03**
- **Flow rates - ideal gas law**

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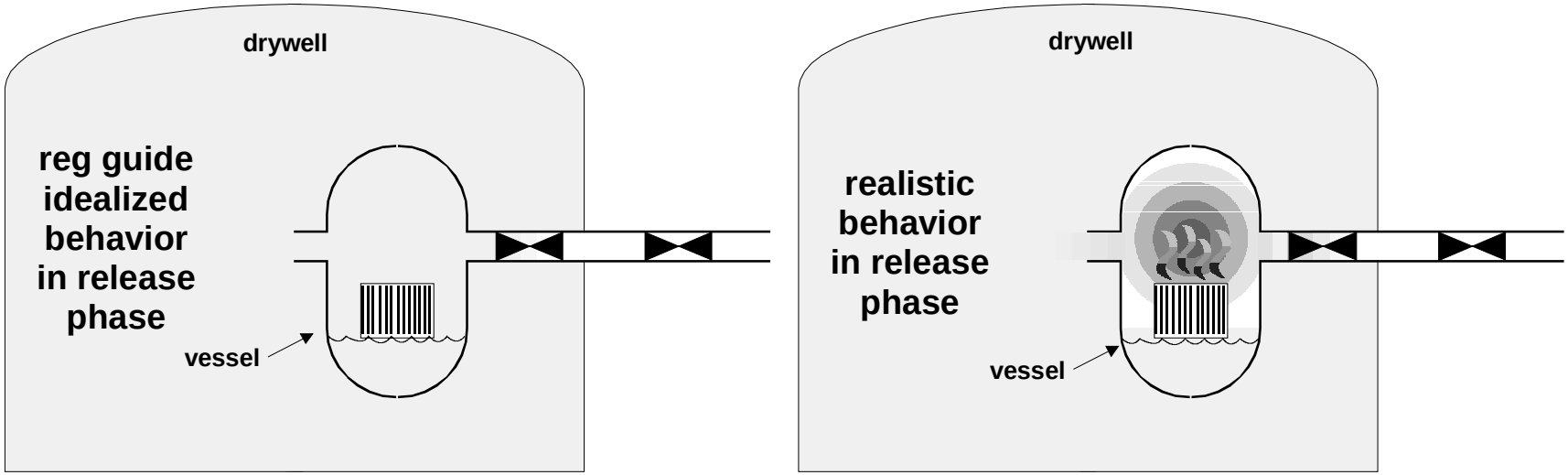
Reg Guide View Not Consistent with DBA Scenario



- **Reg guide assumes uniform f.p. in drywell – *NUREG-1465 is a containment source***
  - ***Valve leak source assumed to be drywell***
- **MELCOR shows vessel concentrations exceed drywell concentrations**
  - **Core and vessel ongoing source of f.p. to containment and steam lines**

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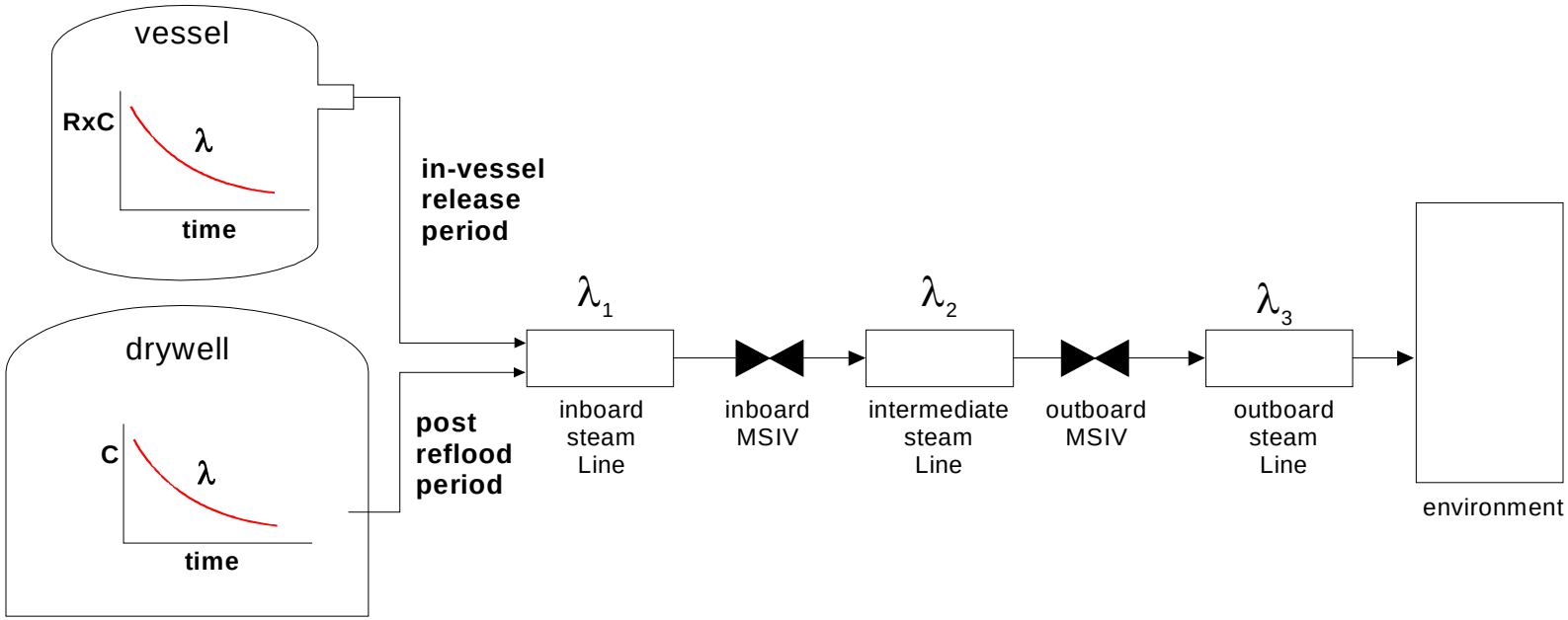
DG-1199 Model Source



- **Recognize vessel as MSIV leakage source prior to reflood**
- **Modify NUREG-1465 containment source to reflect vessel concentrations during first hour**
- **After 1 hour – assume drywell is MSIV leakage source (*like before*)**

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DG-1199 Model Lambdas

- Lambdas calculated by MELCOR
- Integrated phenomenology (ie. Thermal hydraulics, aerosol physics) provides a best estimate of removal in steamline
- Same method as used to model settling and sprays in containment
- Use of “filter efficiencies” are not technically correct
  - Fails to capture time dependencies of filling the volumes

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DG-1199 Model Flowrates

- **Flow equations proposed match the flow calculated by MELCOR and are more realistic**
- **Based on (mostly) critical flow through a nozzle**
- **Originally documented in Air Cleaning Conference Paper**
- **Standard engineering approach**

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DG-1199
Flowrates in Steamline

$$w = A \cdot \sqrt{2 P_{up} \rho_{up} \cdot \left(\frac{k}{k+1} \right) \cdot \left[\left(\frac{P_{dn}}{P_{up}} \right)^{\frac{2}{k}} - \left(\frac{P_{dn}}{P_{up}} \right)^{\left(\frac{k+1}{k} \right)} \right]} \qquad P_{cr} = P_{up} \cdot \left(\frac{2}{k+1} \right)^{\frac{k}{k-1}}$$

- **Flow equations proposed match the flow calculated by MELCOR and are more realistic**
- **Based on nozzle flow**
- **When sonic (most of the time), downstream pressure replaced with critical pressure**
- **Test conditions determine leakage area "A"**
- **Accident conditions determine actual flows**
- **In accident conditions, volume flow after second MSIV increases significantly owing to expansion**
- **Flow in condenser reduces due to cooling**

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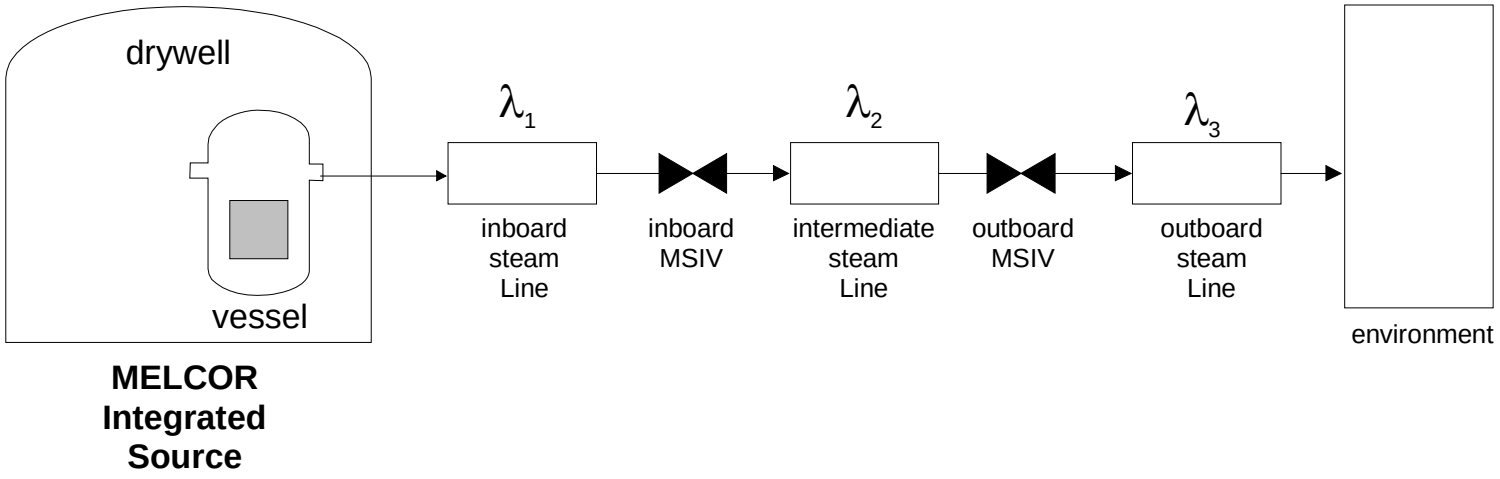
MELCOR Source to RADTRAD



- **Source implemented in *.RTF file**
- **Lambdas and flow rates are directly input into RADTRAD GUI**

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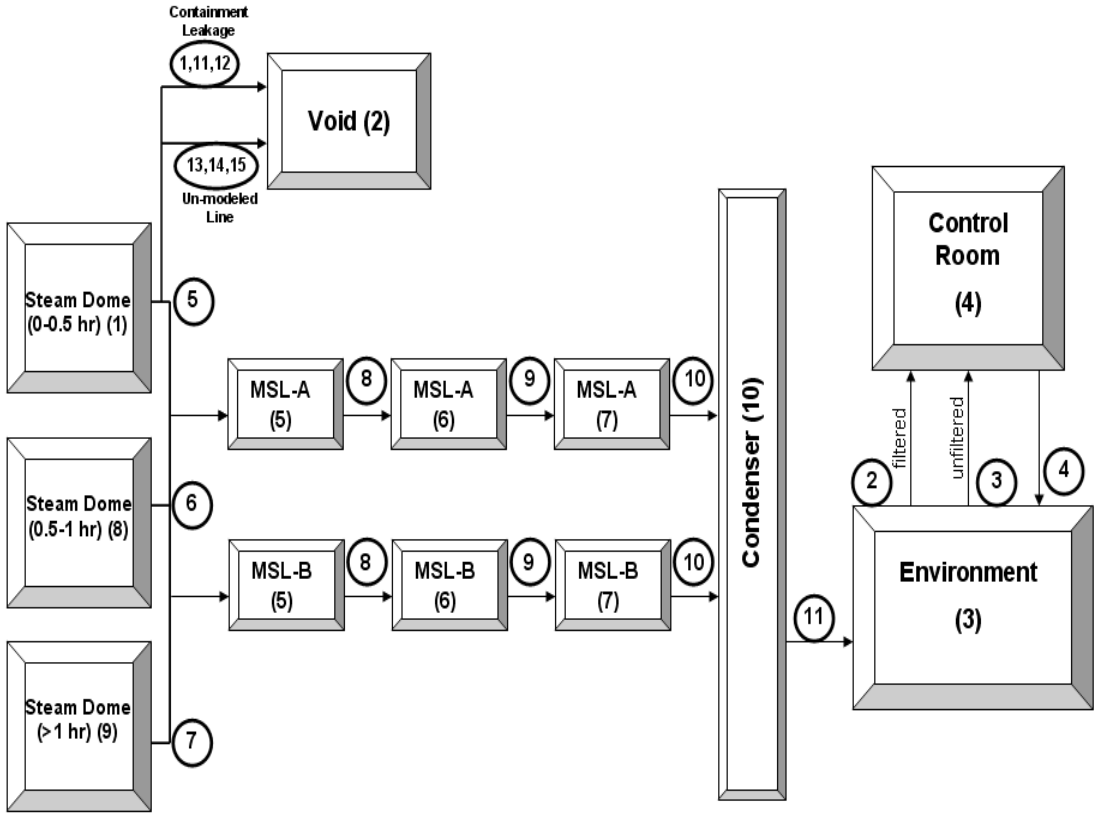
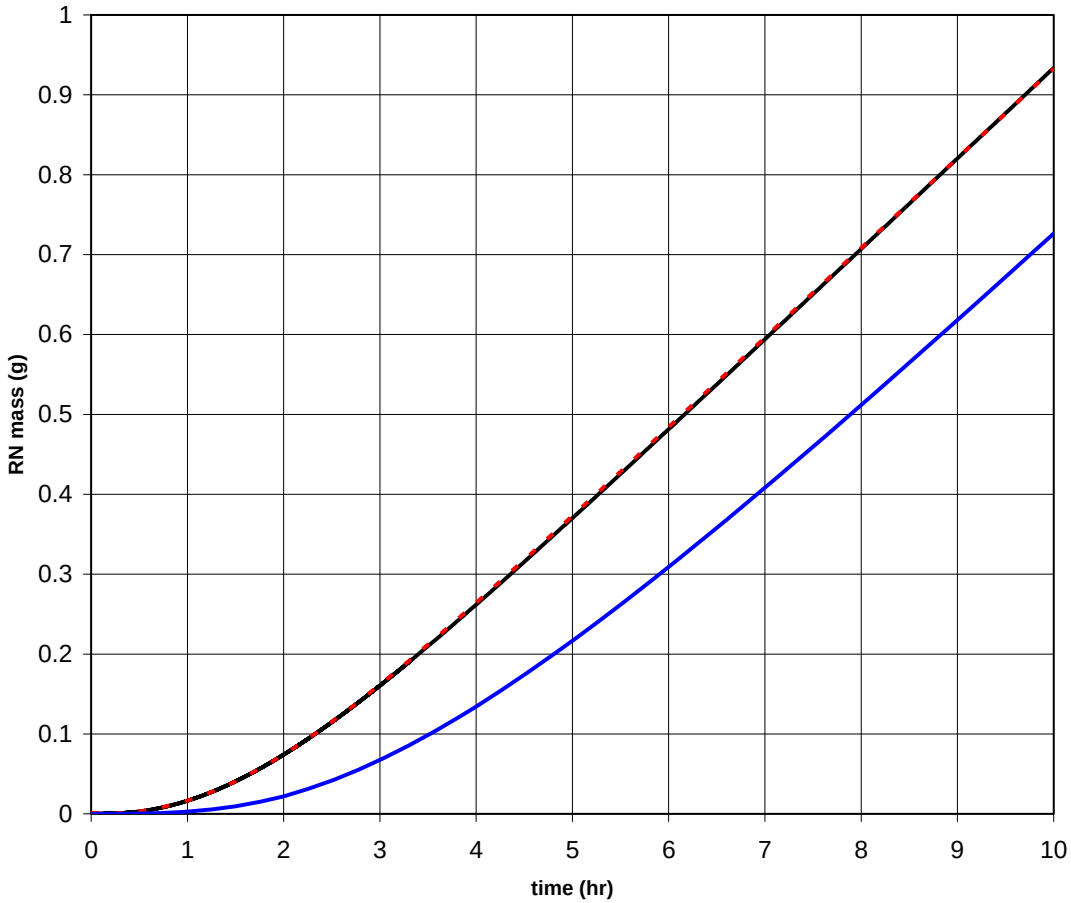
DG-1199 Model



Lambdas vs. Filter Efficiencies



Use of filter efficiency captures
Correct rate of attenuation
But does not recognize the storage of material in the volume

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Questions so Far ?

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Details on Work Done

- **Overview of MELCOR Code**
- **Realistic unrecovered DBA analysis of source from core/vessel to MSIV's**

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What has Been Done

- Perform MELCOR analyses of DBA sequences
  - MSLB and RLB
  - With and without Drywell sprays
  - Couple releases to RADTRAD
- Perform uncertainty analyses on main steam line deposition behavior (determining lambdas)
  - Aerosol physics
  - Leak area
  - Piping length
- Explore potential modifications to Regulatory Guide
  - Correct for drywell versus steam dome source term
- Clarify other Regulatory Guidance issues

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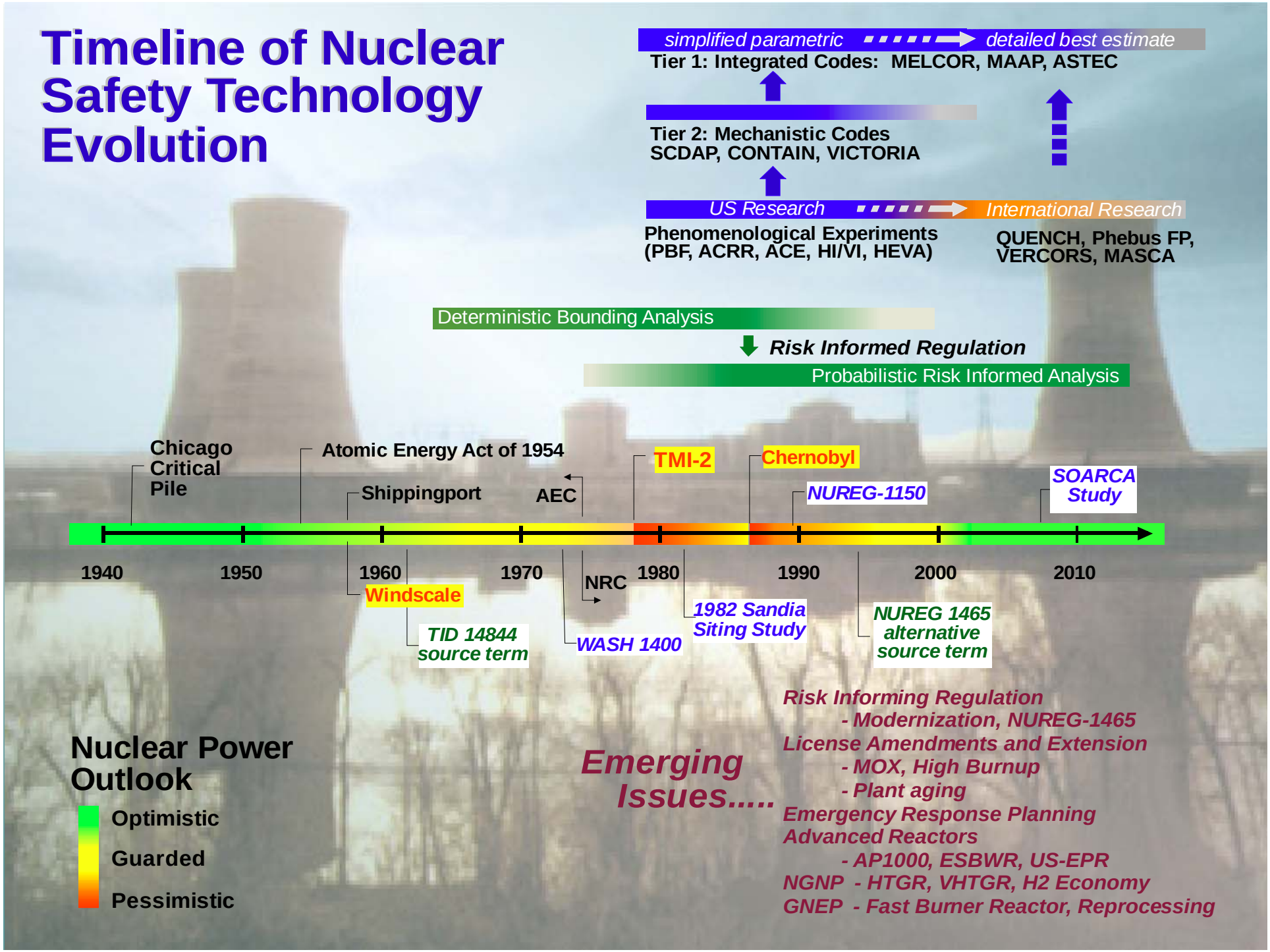
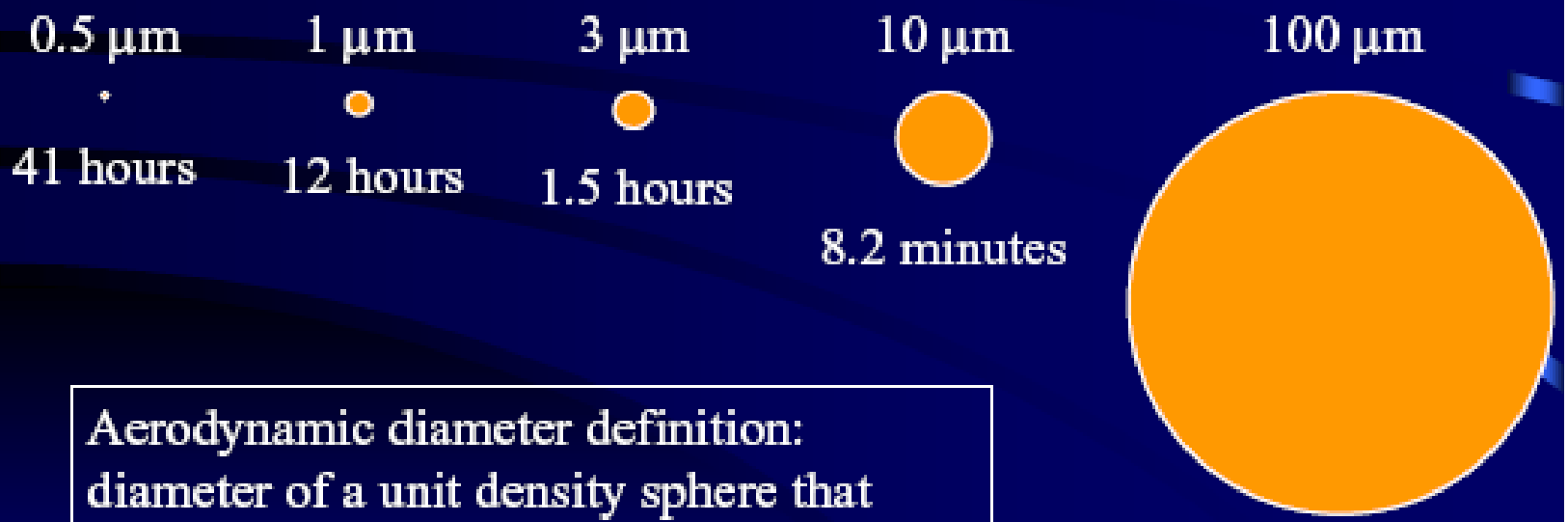
Timeline of Nuclear Safety Technology Evolution



Particle Settling in Still Air

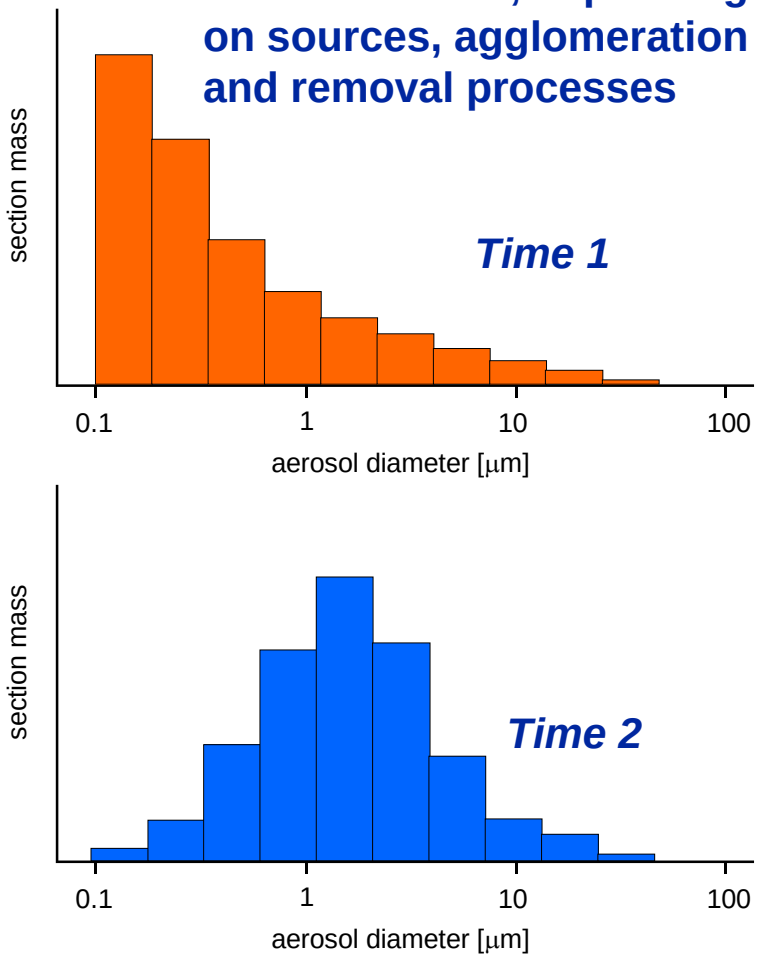
Time to settle 5 feet by unit density spheres



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

Aerosols: MAEROS

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



- MAEROS sectional model of Gelbard
  - 10 sections [.1 - 50 μm]
  - Condensed FP vapor sourced into smallest section
- 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 revolatilizes when reheated

Validation Experiments

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

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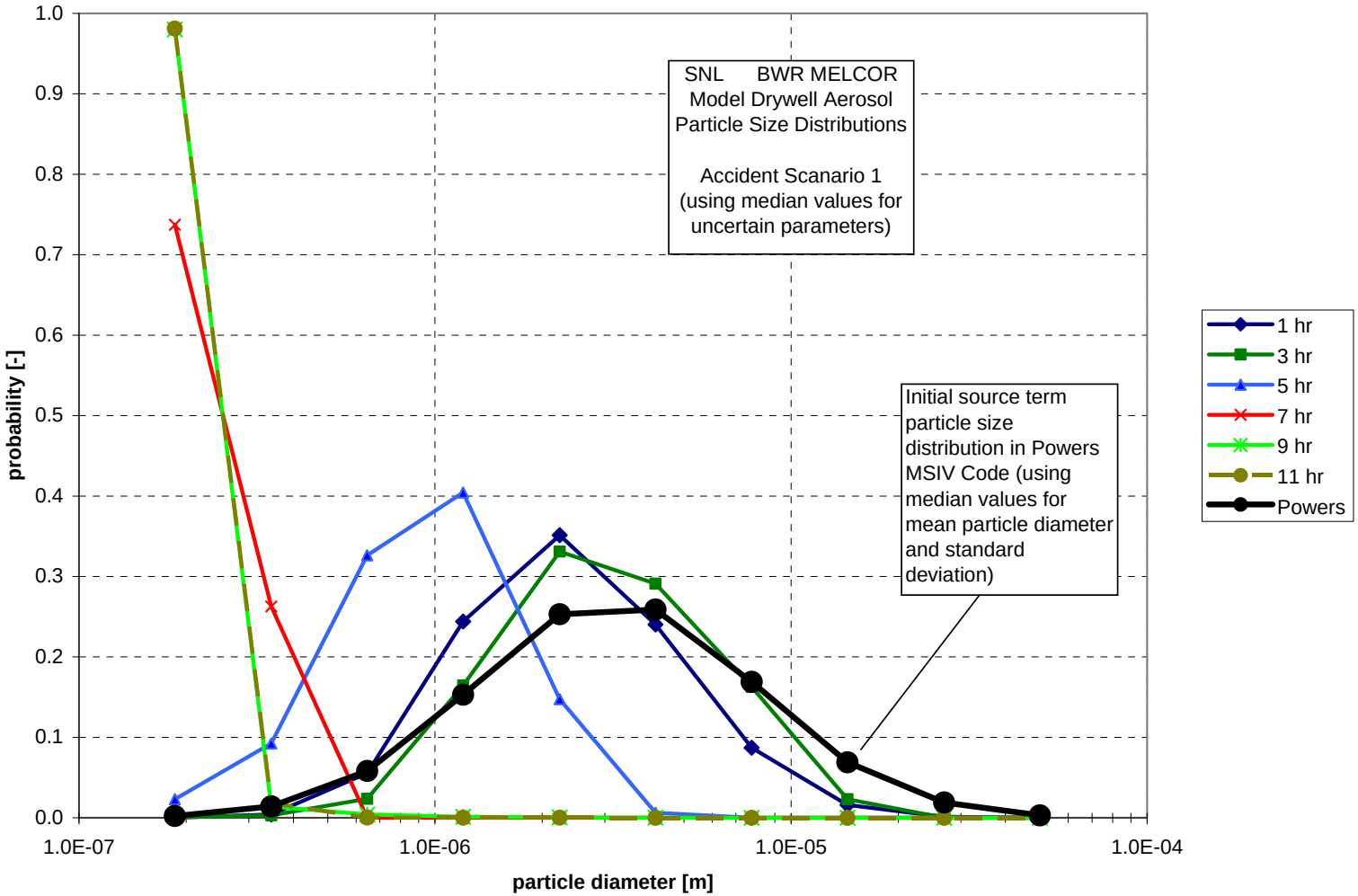
Aerosol Size vs. Time



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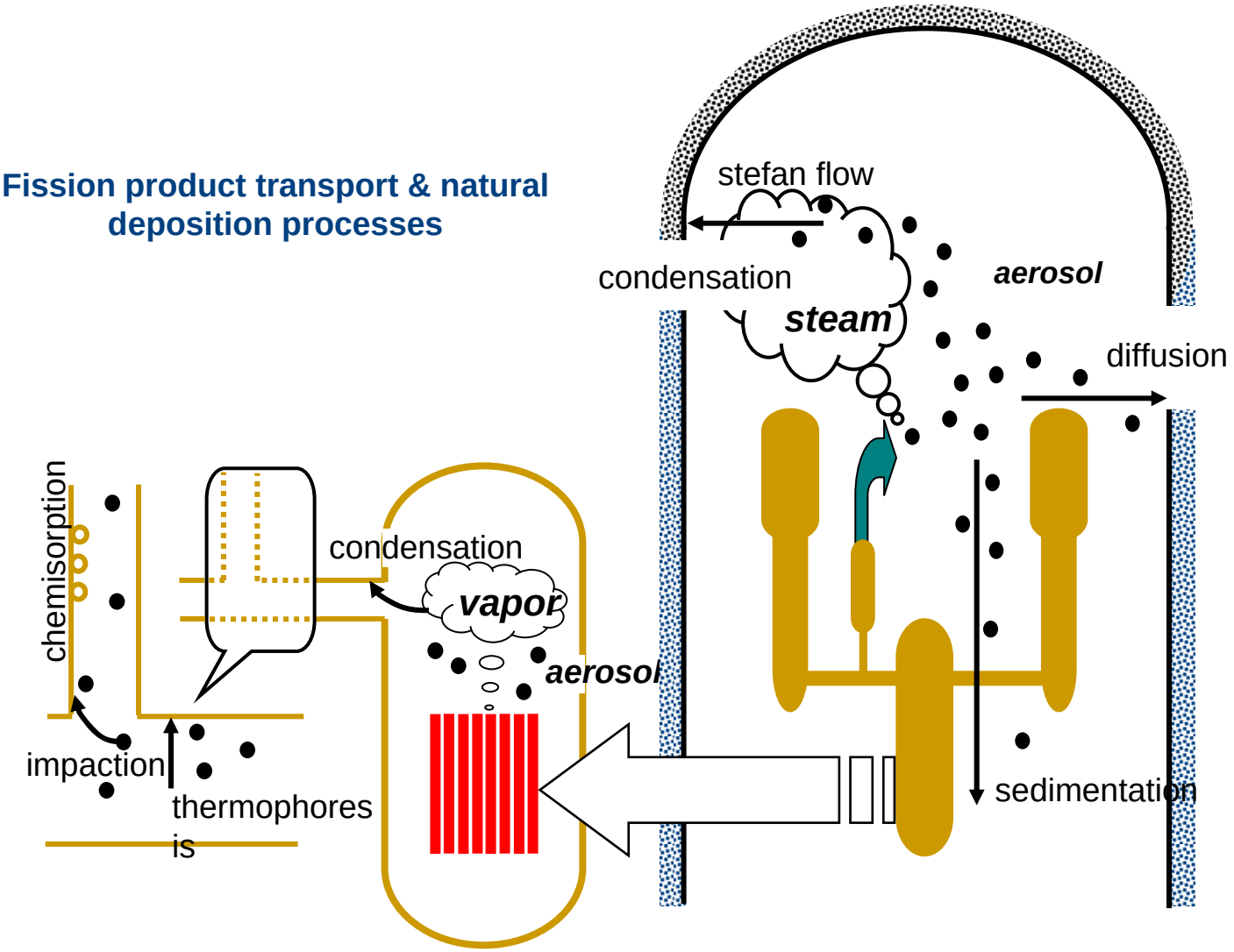
RadioNuclide Overview

Fission product transport & natural deposition processes



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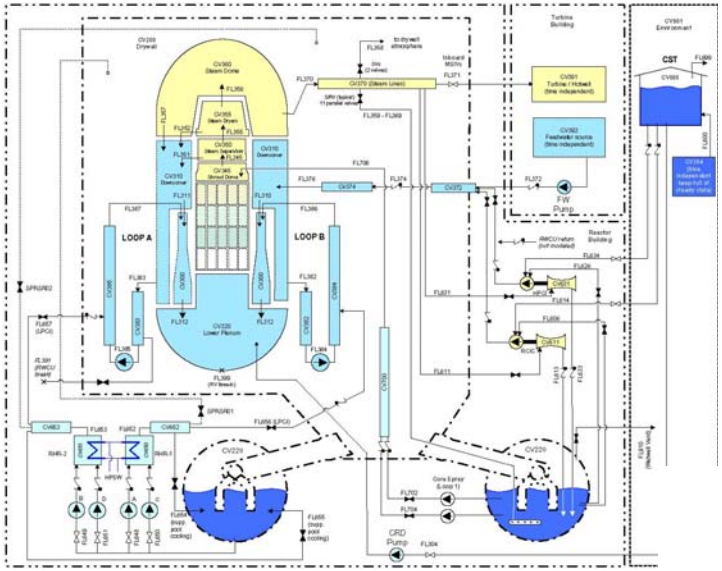
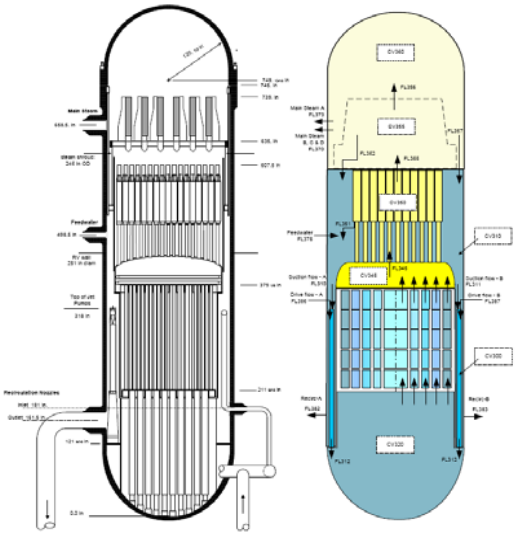
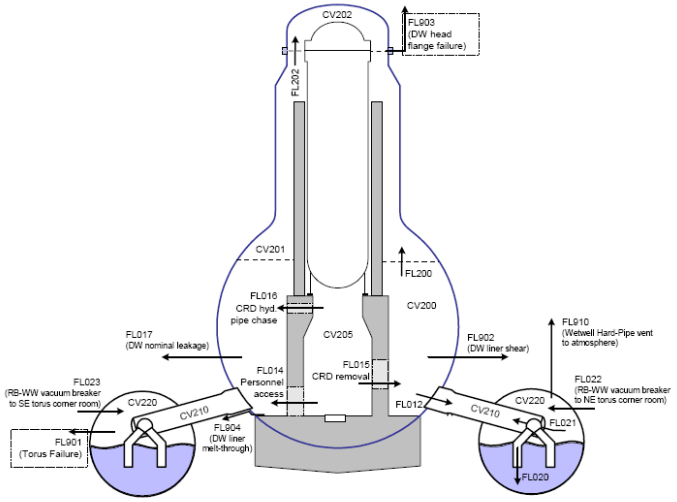
MELCOR Analysis of Full Plant DBA







- **Mark-I and III**
- **MSLB and RLB**
- **With and without drywell sprays**
- **Assess drywell airborne versus steam dome**

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Issues

- **Source – Steam dome vs. Drywell**
- **Pathway**
- **Removal in Steamline**
- **Flow in Steamline**
- **Lambdas vs. filter efficiency**
- **Other - Sprays**

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Source Term
Steam Dome vs. Drywell

- MSLs are connected to the reactor vessel.
- NUREG – 1465
- Provides Magnitude, Mix, Speciation for Containment Source Term
- Does not provide aerosol size distribution for Source Term
- Does not provide source term for reactor vessel
- Regulatory Guide 1.183
- Assumes the source for MSIV leakage is the drywell activity (NUREG-1465) up to two hours
- At two hours reactor assumed to be re-flooded and 1465 homogenized over DW & WW free space
- MELCOR analyses show that during the first two hours of the SL break in containment and RLB that the concentrations in the steam dome are much greater than in the DW.

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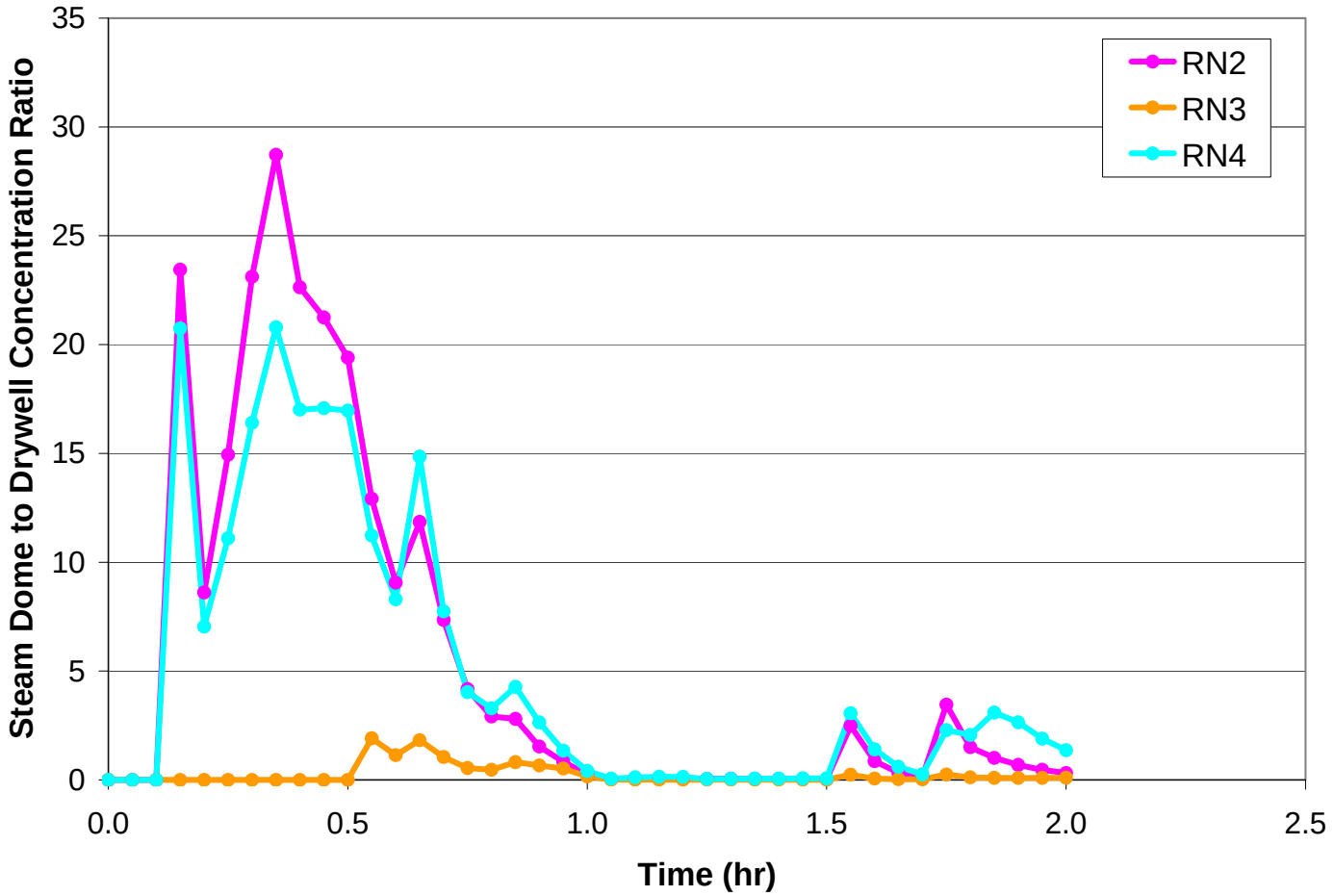
Source Term
Steam Dome to Drywell Concentration MELCOR, Mark I



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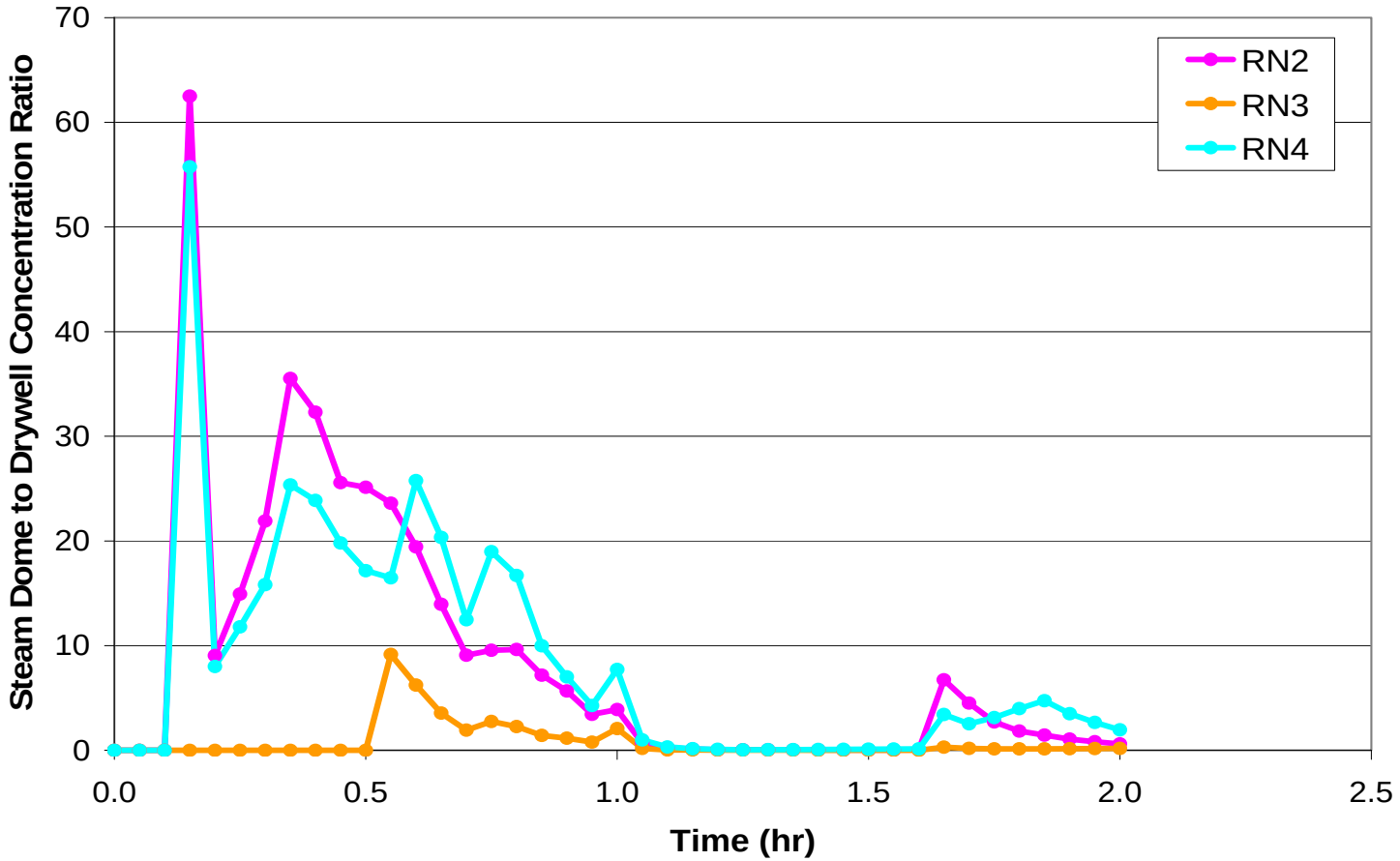
Source Term
Steam Dome to Drywell Concentration
MELCOR, Mark III



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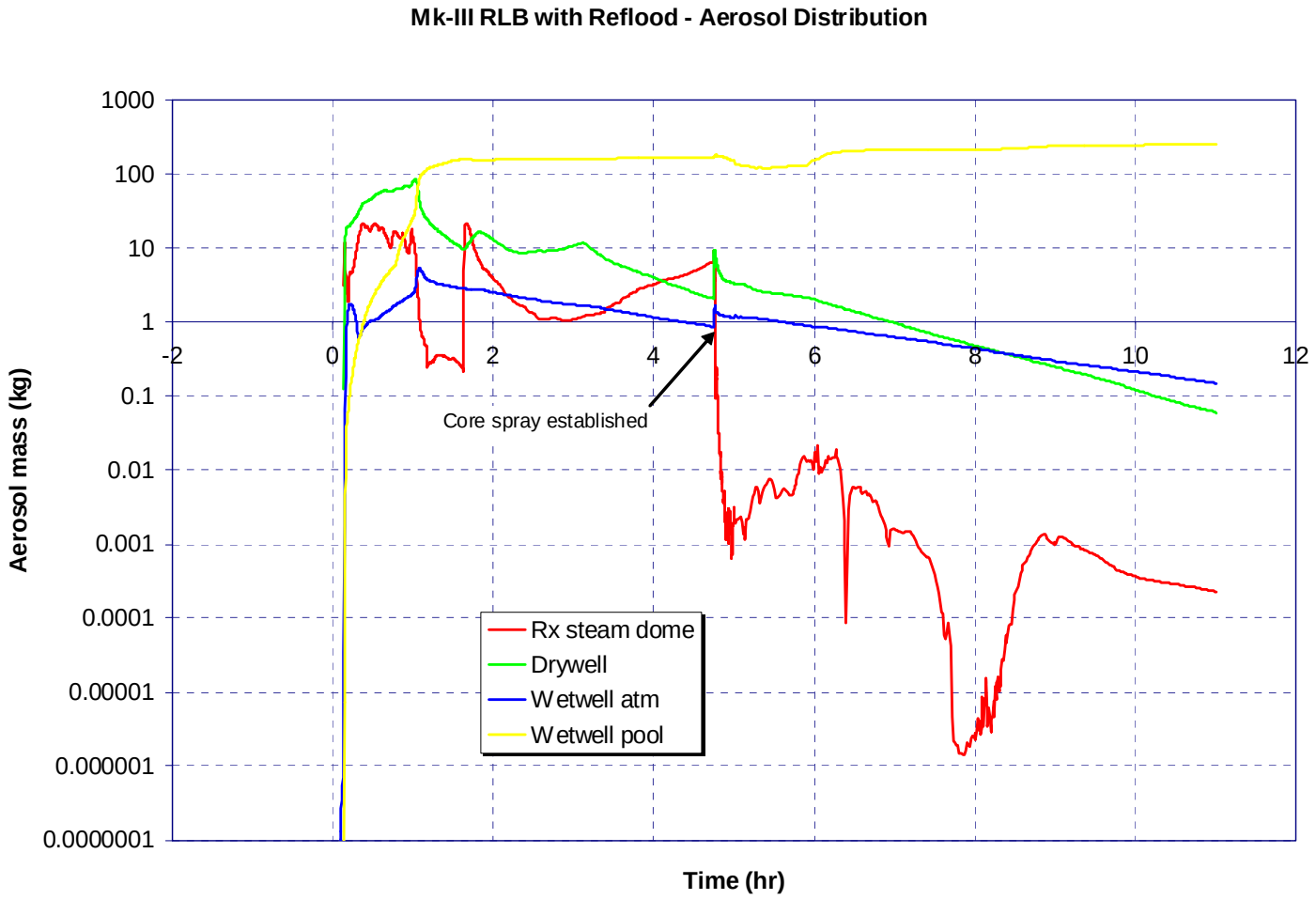
Source Term after after Reflood



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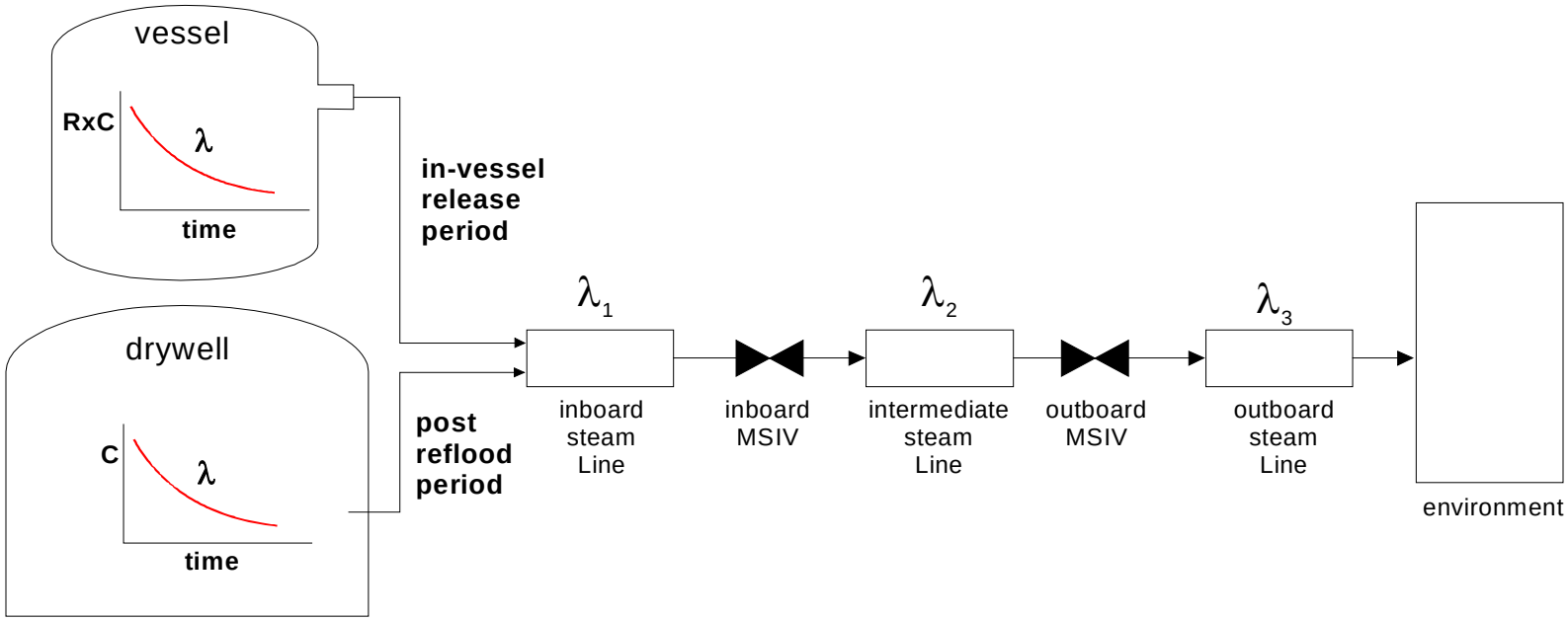
DG-1199 Model Source



- **Recognize vessel as MSIV leakage source prior to reflood**
- **Modify NUREG-1465 containment source to reflect vessel concentrations during first hour (*to keep it simple*)**
- **After 1 hour – assume drywell is MSIV leakage source (*like before*)**
- **Containment spray does not reduce vessel concentration but can reduce driving pressure**

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Removal/Attenuation in Steamline

- **Credited Mechanisms for SSE qualified piping and condenser**
- **Gravitational Settling**
- **Holdup**
- **Elemental I_2 Plateout**

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Gravitational Settling

- **Removal coefficient (or lambda value) dependent on settling velocity.**
- **Settling velocity depends on shape, diameter, density and shape factor of aerosol and viscosity of fluid.**

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Uncertainty Study on MSL Deposition

- **RADTRAD often requires “lambda” values to assess attenuation of source term**
- **MELCOR uncertainty analysis of MSL piping was done to bound aerosol removal coefficients used on RADTRAD**
- **MELCOR estimates instantaneous lambda from known deposition rate and airborne concentrations** $\dot{m}_{dep} = \lambda m$
- **Uncertainties considered aerosol physics, valve leak area and piping length variations**

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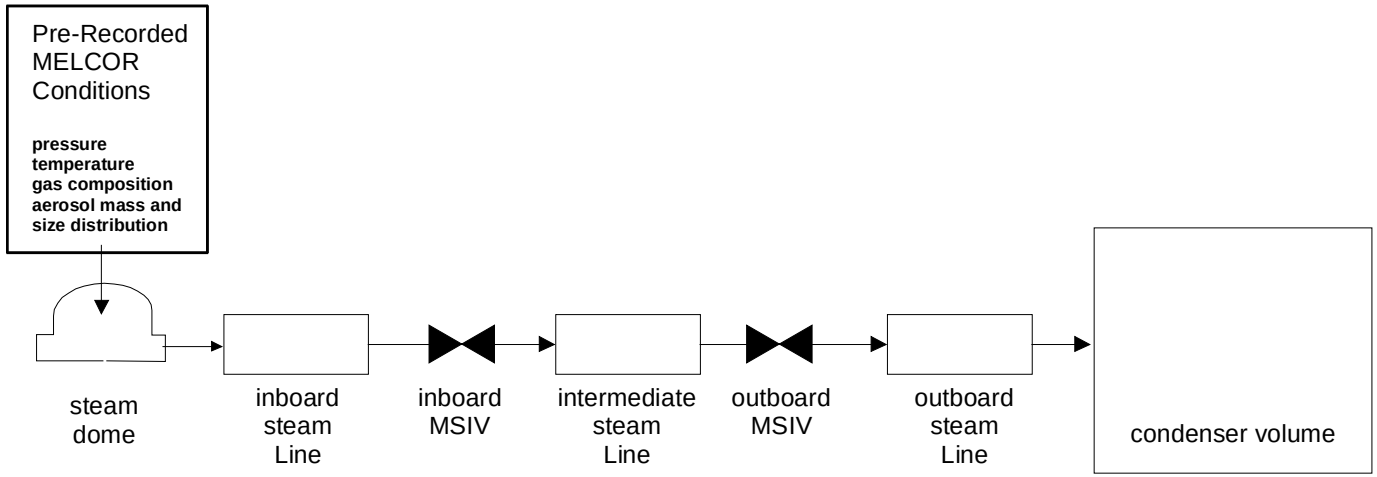
MELCOR Main Steam Line Deposition Analyses



- **Reduced nodalization**
- **Boundary conditions from RLB analysis**
- **Monte Carlo sampling used to derive distributions**
- **Removal coefficients determined for each piping section**
- **Inboard line experienced revaporization**

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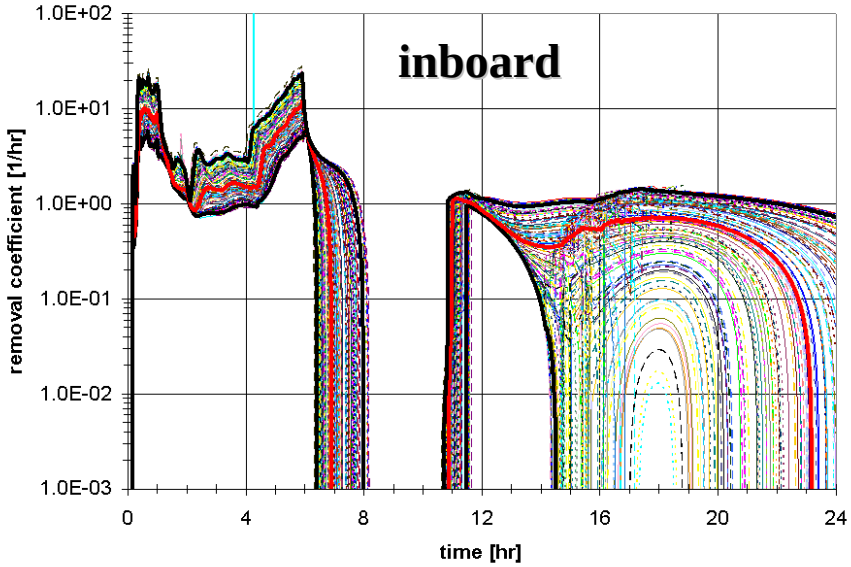
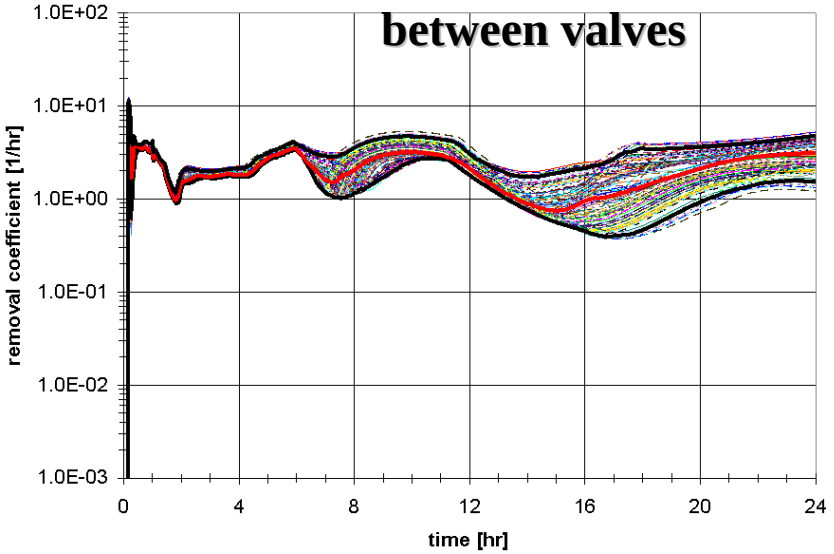
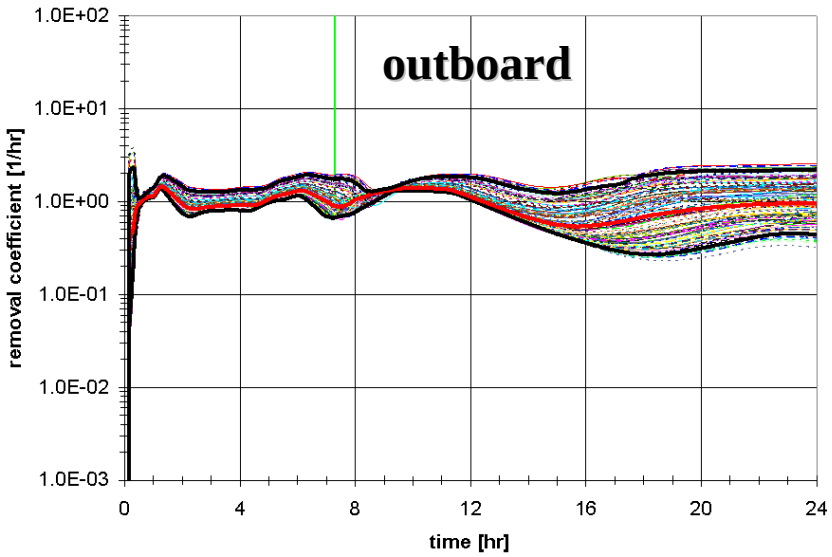
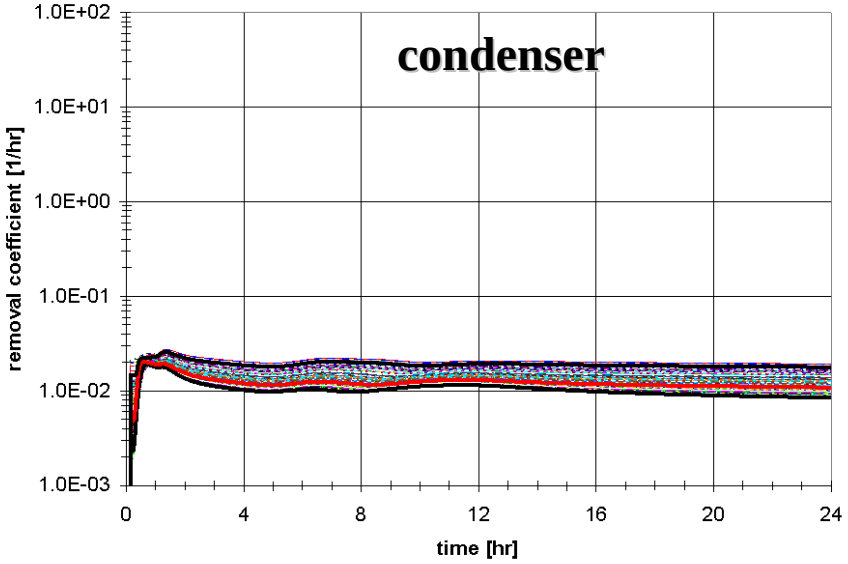
Example Results from Deposition Analysis
Aerosol Deposition Physics Uncertainty









MSL and Condenser Removal Coefficients (50th Percentile)

MSL section	0 - 2 (hr)	2 - 12 (hr)	12+ (hr)
in-board	0*	0*	0*
between MSIVs	3.1	2.4	2.0
out-board	1.4	1.2	1.0
condenser	0.021	0.018	0.015

note. removal coefficients are given in 1/hr

* Not credited because of Re-evolution, thermal bi-directional Flow, turbulence, containment boundary

- **Circulation and mixing in inboard piping one reason for disallowing deposition credit**
  - **Size distribution effect is important**
- **Lambdas decrease as remaining aerosol becomes smaller**
- **Condenser lambdas strongly affected (reduced) by geometry**
  - **Significant deposition results from long residence time**

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END

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