Containment Performance

MODULE 5:

- Failure Modes and Criteria -

Outline of Discussion

- Roles of containment structural analysis in Level 2 PSA
- Failure Modes & Mechanisms
  - Methods for determining Failure Criteria
- Research on containment aging

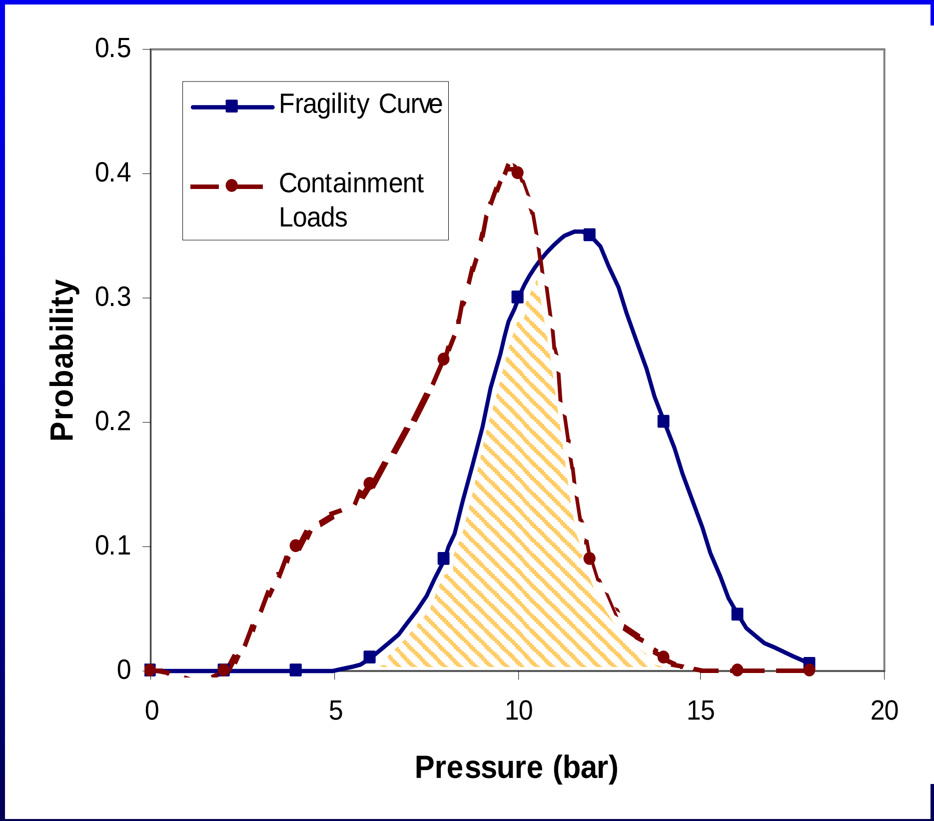
Containment Structural Analysis and Level 2 PSA

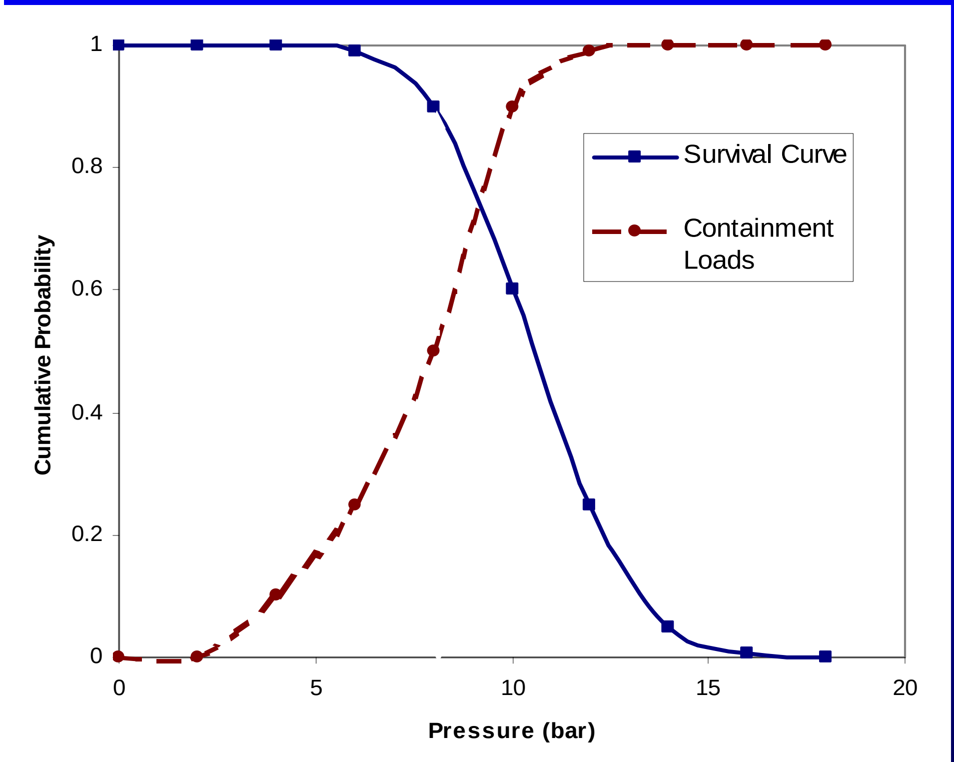
- **Objectives**
  - **Identify plant-specific failure mechanisms**
  - **Generate** realistic **values for failure criteria, associated failure locations and leak areas**
- **Product (result)**
  - **Conditional probability of failure (fragility curve)**

Design versus Failure Pressure

- **Design criteria:**
  - Internal loads generated by conservative analysis of design-basis events
  - Incorporate factor-of-safety in structural design to account for construction flaws, etc.
- **True failure criteria:**
  - Actual failure pressures often exceeds design pressure by factors of 2-5.
  - Failure analysis for Level 2 PSA requires consideration of a wider range of containment loads (e.g., higher temperature)

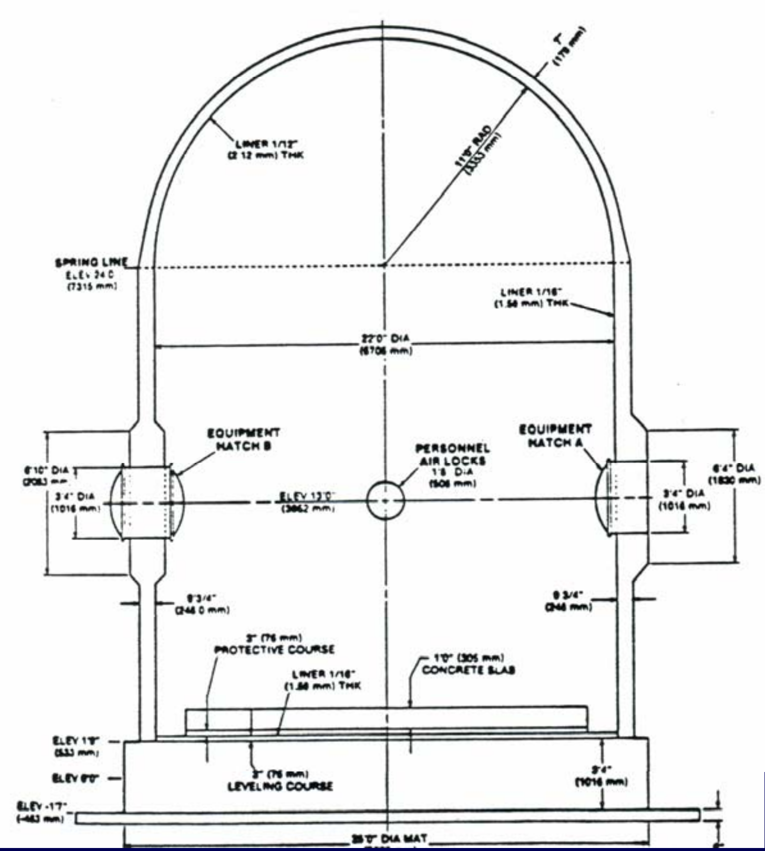
Use of Fragility Curve in Level 2 PSA





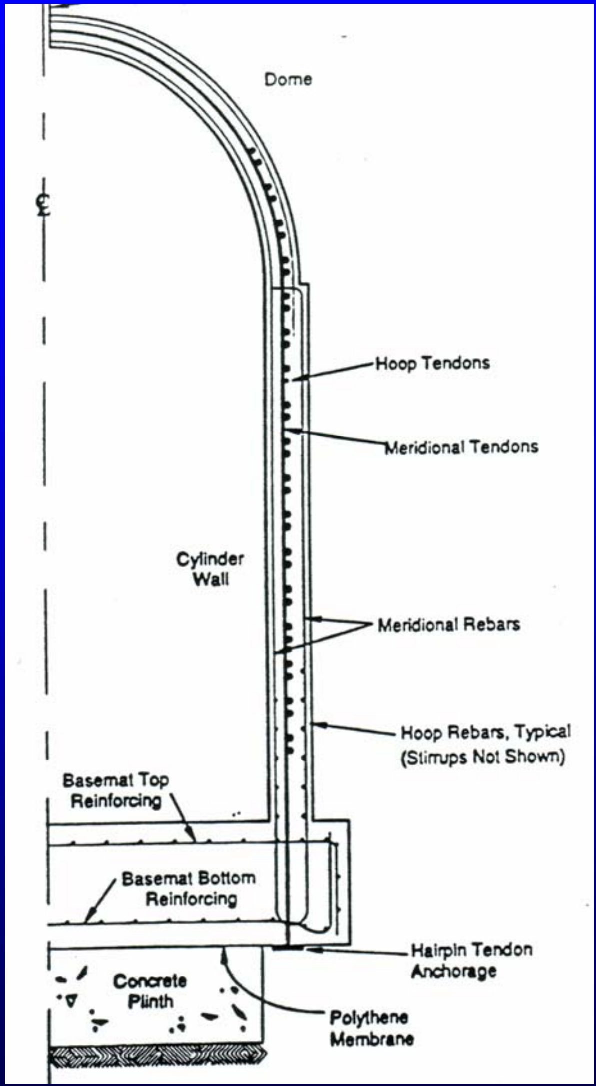
Data Required to Perform Realistic Failure Analysis

- Geometric data
  - General configuration
  - Details of structural discontinuities
  - Penetration details
  - Weld locations



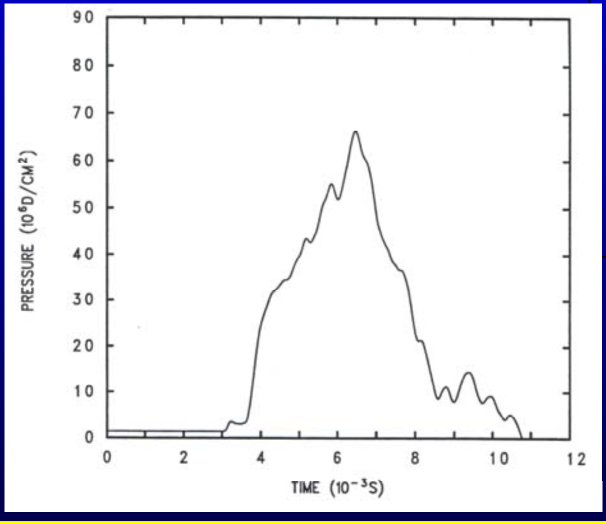
Data Requirements (2)

- Construction materials
  - Rebar, stiffeners, aggregate for concrete
  - Steel type(s) and tension
  - Results of component testing (if any)
  - Seal design/composition



Data requirements (3)

- **Definition of loads**
  - **Pressure & temperature history (quasi-static load)**



  – Impulse (dynamic load)

Typical Failure Modes

- Isolation failure or bypass
- Over-pressure (global)
  - Variable temperature histories
  - Hydrogen burn vs sustained heating
- Creep (axial growth)
- Corium-concrete interaction
  - Concrete erosion and penetration
  - Direct contact between debris and steel boundary

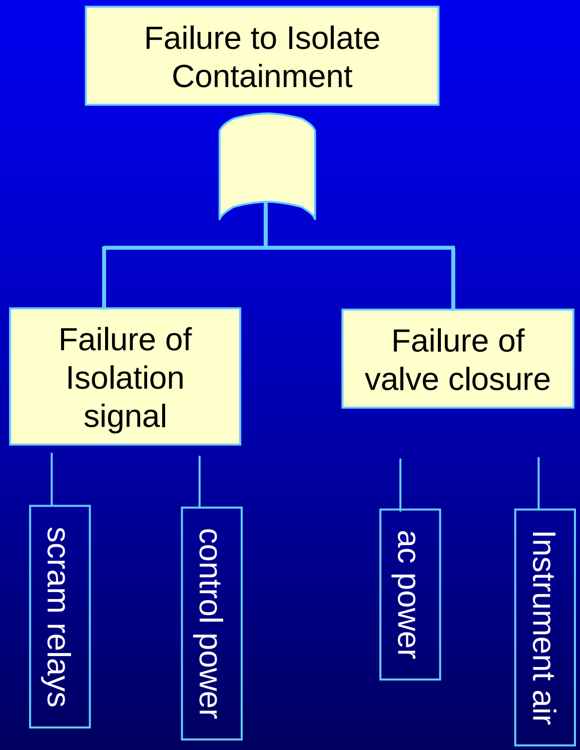
more →

Failure Modes (2)

- Blowdown reaction forces
  - Thrust loads and pipe movement at penetrations
- Local heating of pressure boundary penetrations or seals
- Localized dynamic loads
  - H_2 detonation or steam explosion

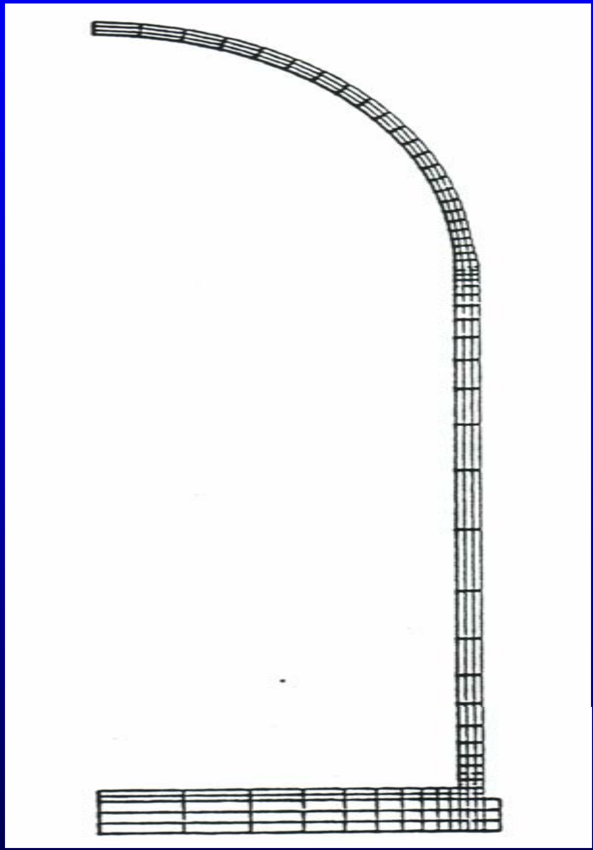
Isolation Failure

- **Fault analysis of isolation signal(s), control system, and reliability of valve closure**
  - **Integrated with Level 1 PSA to properly capture support system dependencies**



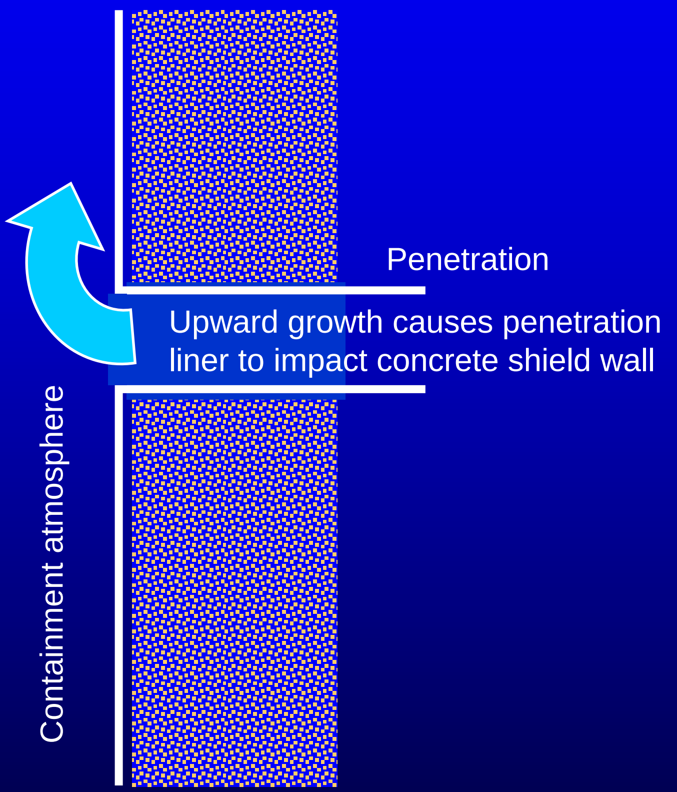
Over-pressure Failure

- Non-linear finite-element analysis of structural response to internal loads is generally considered the most defensible approach
  - ABAQUS, ADINA, CASTEM, NEPTUNE, NFAP, PAFEC and TEMP-STRESS
- Simpler approaches (e.g., scaling analysis) have been developed and shown to be adequate for certain applications (e.g., seismic margins)
  - [Ref: Nucl. Eng. Design, 79(1)]



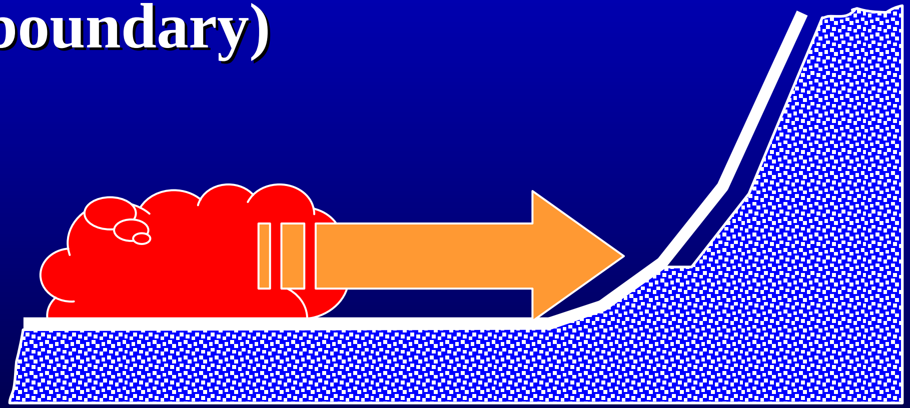
Creep

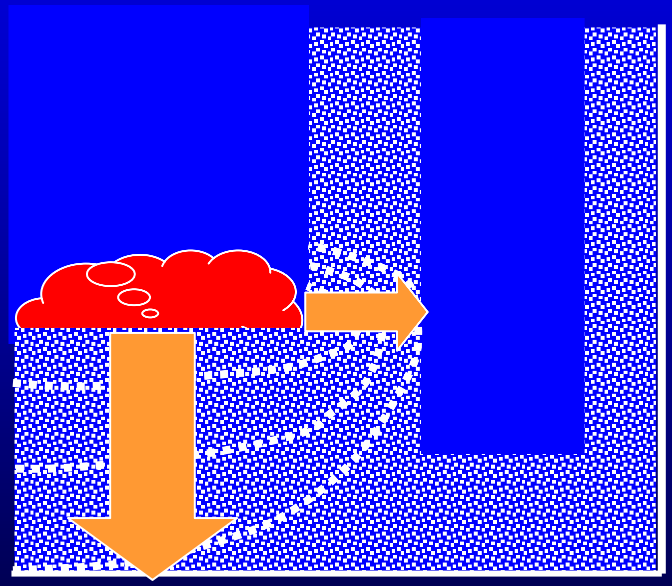
- Typically only a concern for containment designs with constrained steel shells or liners
  - Free-standing steel shell with penetration constraints
  - Accident scenarios with elevated temperatures for <u>long</u> periods of time



Corium-concrete Interaction

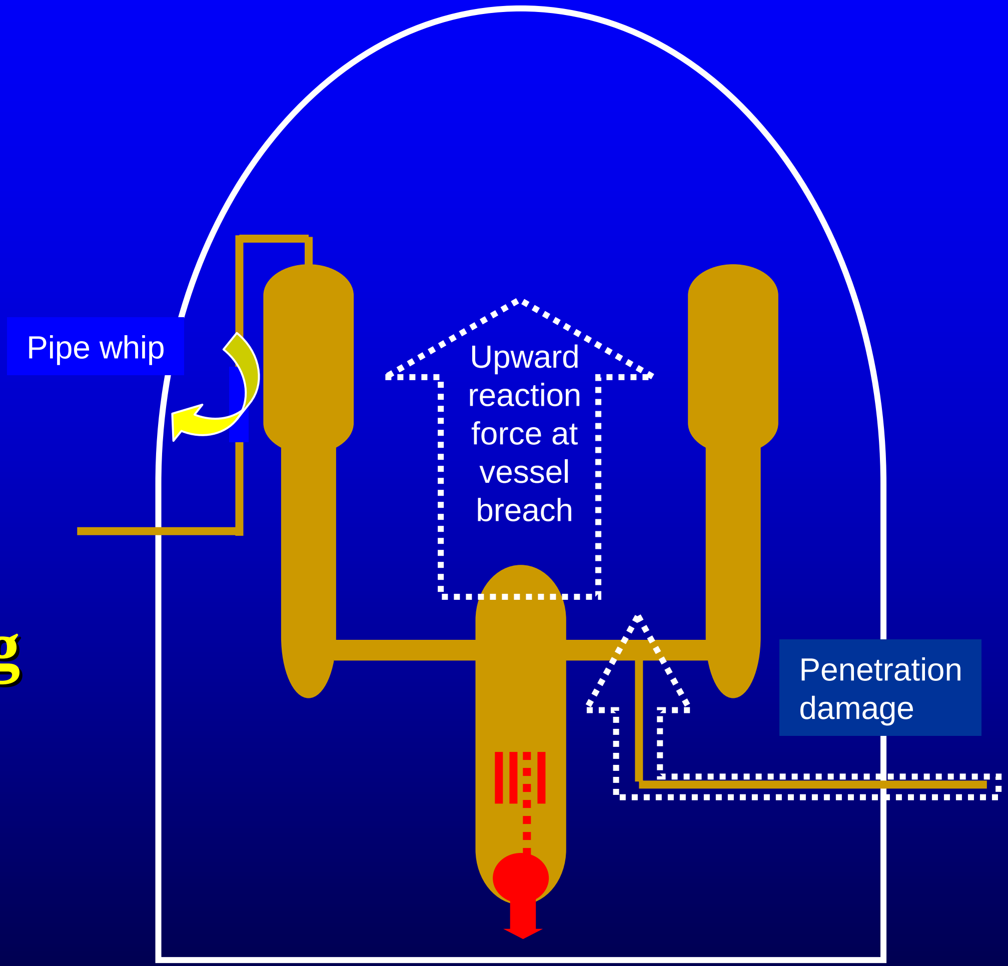
- **Aggressive ablation of concrete basemat can lead to penetration**
  - **Usually subterranean**
- **Debris spreading on containment floor may lead to direct contact with steel liner (true pressure boundary)**





Blowdown Reaction Forces

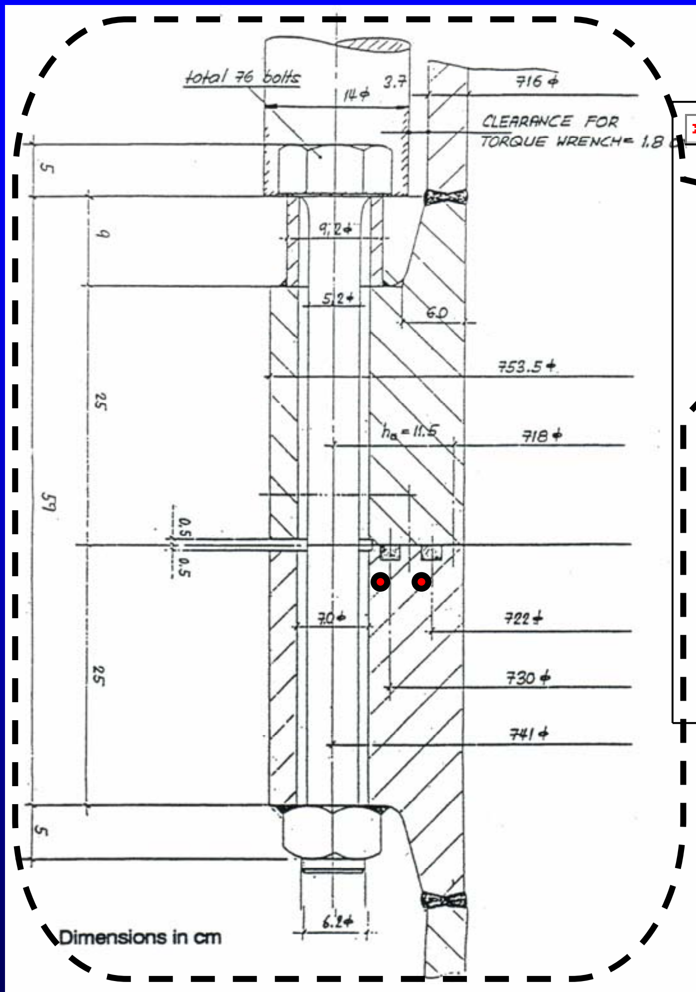
- Reaction forces to failure of reactor coolant system pressure (at high pressure)
  - Reactor vessel failure
  - Pipe breaks (initiating event or induced failure)

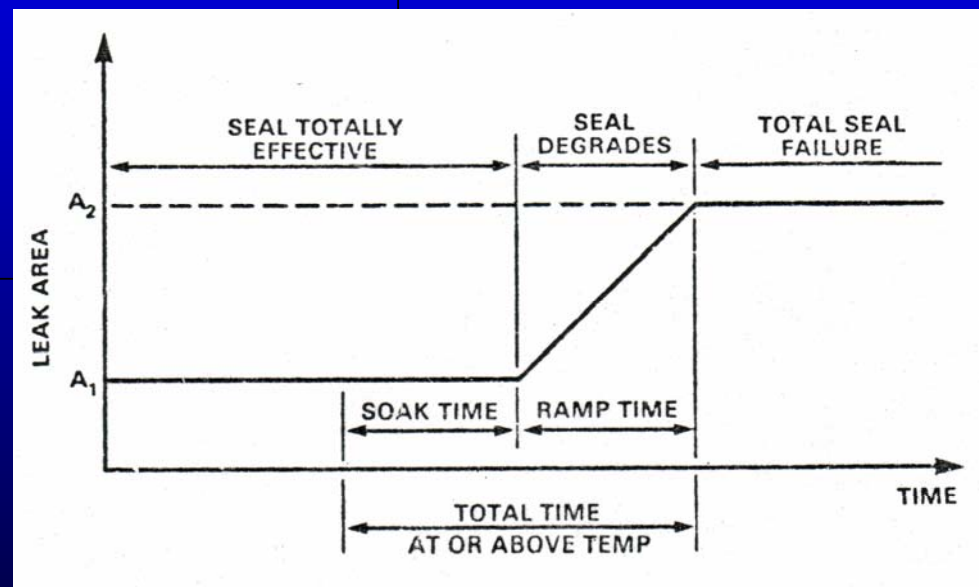


Heating of Pressure Boundary Seals or Penetrations

- Coupled heat transfer and structural response analysis at pressure boundary seals and penetrations
  - Must know local geometry and gasket material properties
  - Failure properties tested extensively for typical seal geometries and materials

Example: BWR Drywell Head Seal





Dynamic Loads

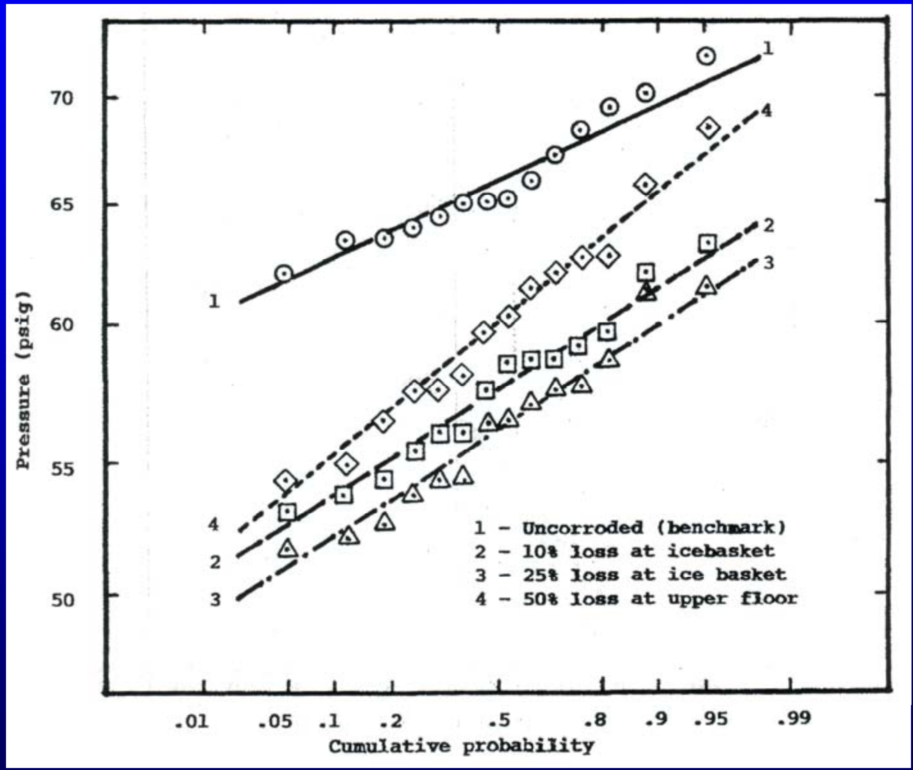
- Impulse loading typically only a concern for:
  - Ex-vessel steam explosions (submerged structure)
  - Hydrogen detonations
- Requires realistic fluid-structure interaction model

Older Containments

- the effects of aging structures -

Steel Pressure Boundary Corrosion

- **Corrosion of steel liners has been reported in several reactor containments with loss of shell thickness as large as 50%.**
- **Locations vary**
- **Degradation has been observed in nearly all types of containment designs.**



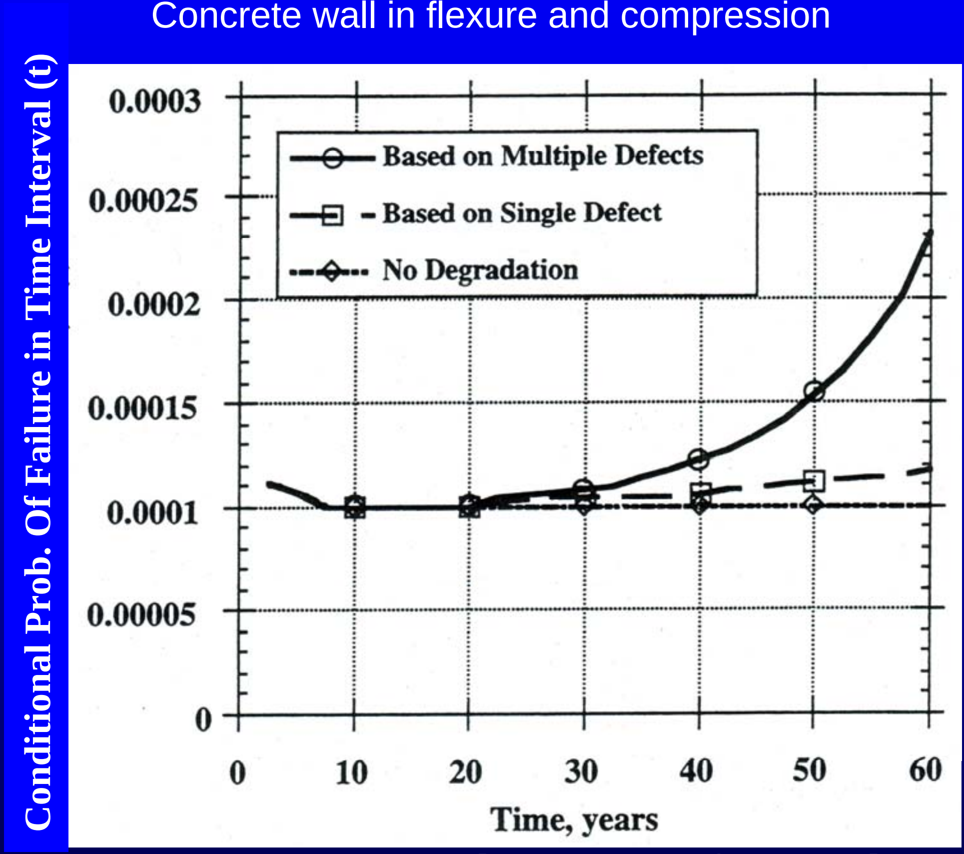
[Ref: NUREG/CR-6631]

Older Containments
- the effects of aging structures -

Concrete Structure Degradation

- Chemical attack due to sustained exposure to
  - Water in subterranean areas
  - Chemical/oil spills on floors or slabs
- Thermal cycling
- Fatigue/vibration
  - Liner anchors
  - Equipment supports

Concrete wall in flexure and compression



[Ref: NUREG/CR-6424]

Older Containments

- the effects of aging structures (2) -

Closure gaskets & penetration seals

- **Hardening of organic seal materials**
- **Degradation/cracking of organic and ceramic electrical penetration assemblies**
- **Intergranular stress corrosion of expansion bellows**

Leaks of this type have been detected during periodic containment leak rate testing. Reduced capacity at high-temperatures would be undetected.

Older Containments
- the effects of aging components -

Containment isolation (CI)

- **~80% of CI-component failures reported in NPRDS between 1988-1993 are aging related [Ref: NUREG/CR-6339]**
  - **Most were not safety-significant**
  - **Valves and valve-operator failures dominate**
  - **Combination of long-term environmental stresses and operation/testing stresses**
  - **Large fraction (~65%) of electric-power operator failures were detected during testing**
  - **Roughly half of pneumatic operator failures were detected during testing (others during routine maintenance)**

Closing Comments

- Evaluation of potential failure modes must be plant-specific.
- Rigorous engineering analysis needed to define realistic containment failure criteria
- Analysis should be based on an as-found condition assessment; not design conditions
  - Current assessment of structure conditions
  - Current data on isolation system performance