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Overview of Degraded Containment Research at Sandia National Laboratories

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Sandia is a multiprogram laboratory operated by Sandia Corporation, a Lockheed Martin Company, for the United States Department of Energy under contract DE-AC04-94AL85000.

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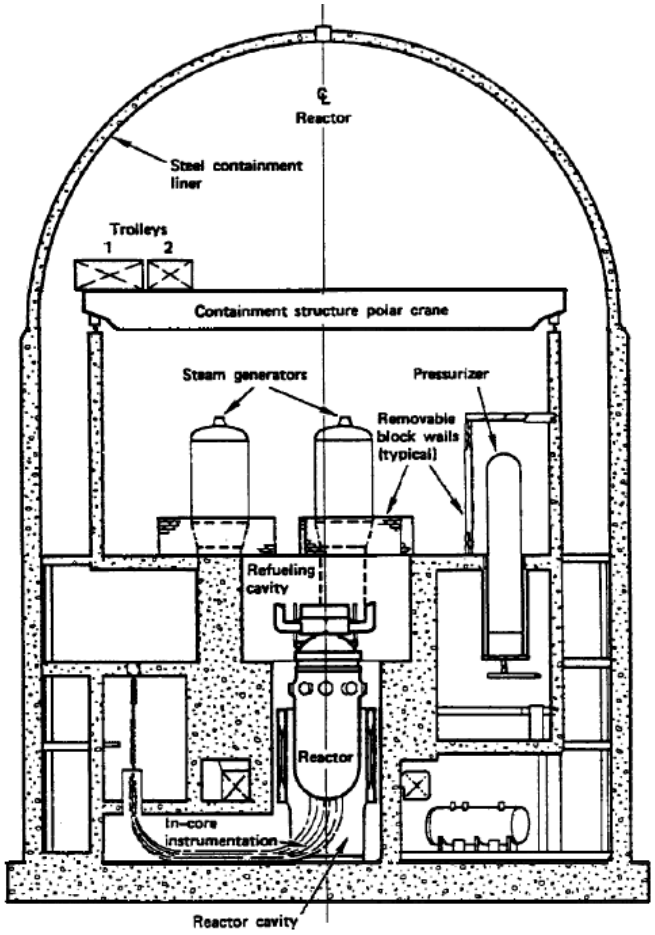
Degradation Containment Research Motivation

- The primary purposes of the containment system are:
  - to contain any radioactive material that may be released from the primary system in case of an accident.
  - to protect the nuclear system from weather and other external threats such as missiles produced by earthquakes, tornadoes, wind, etc.
  - to act as a supporting structure for operational equipment such as cranes.
- Designed to withstand high pressures (10-60 psig) and temperatures (>300 F)



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Degraded Containment Research Background

- Containment degradation has been discovered at a significant number of NPPs
- Degradation includes: liner corrosion, liner buckling exposed rebar, concrete voids, degraded liner coatings, loss of prestressing, etc.
- During a hypothetical severe accident, degradation of the containment could reduce the pressure capacity leading to an earlier leak or rupture of the containment
- Research on degraded containments can help demonstrate the potential effects of degradation on performance and can be used in consequence and risk assessments.
- The research can also be used to support regulatory action for the existing fleet of NPP's as well as future plants
  - Maintenance/Inspection/License Extension

Degraded Containment Research at Sandia

- Sandia has work with the US NRC in studying containment integrity and containment degradation research since the 1980s
- Integrity Experiments (scaled steel and concrete containments)
- Degradation Experiments
  - Bellows
  - Corrosion Coupons
- Computational Degradation Research
  - Degraded Containment Capacity
  - Risk-Informed Degraded Containment Assessment
  - Degradation Effects on Consequences
- Liner Corrosion Causes
  - Expert Panel Workshop on Outer Diameter Corrosion
- Ongoing Research

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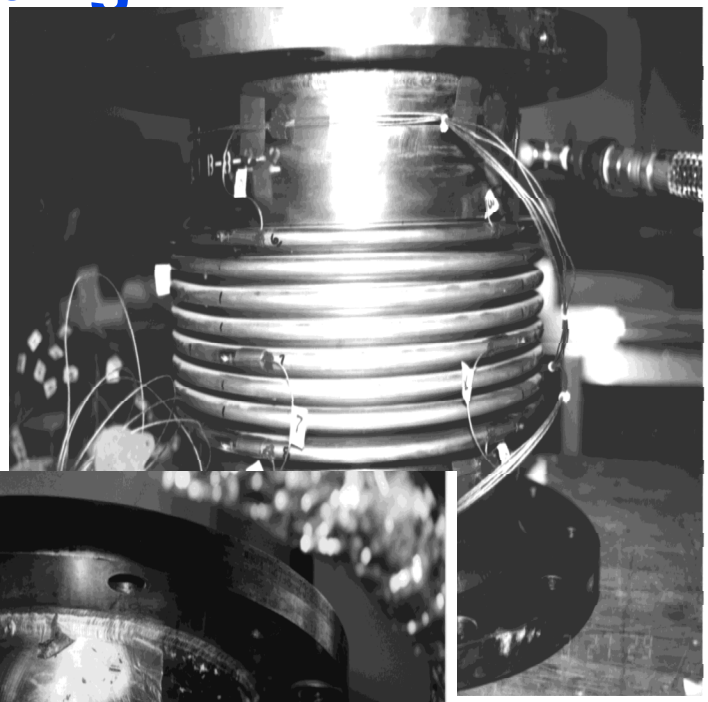
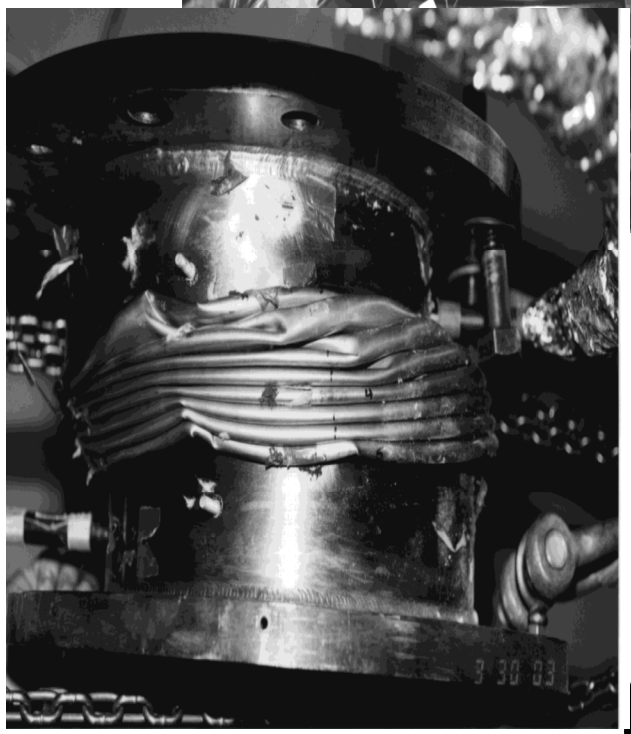
Degraded Containment Research
Bellows Testing

- Bellows are used to…
- Experimental study examined the performance of bellows under hypothetical severe accident conditions
- Tests examined variations to internal pressure, temperature, axial deformation, lateral deformation, and corrosion
- The presence of corrosion showed a significant affect on the performance of the bellows





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Degraded Containment Research
Corroded Steel Coupon Tests

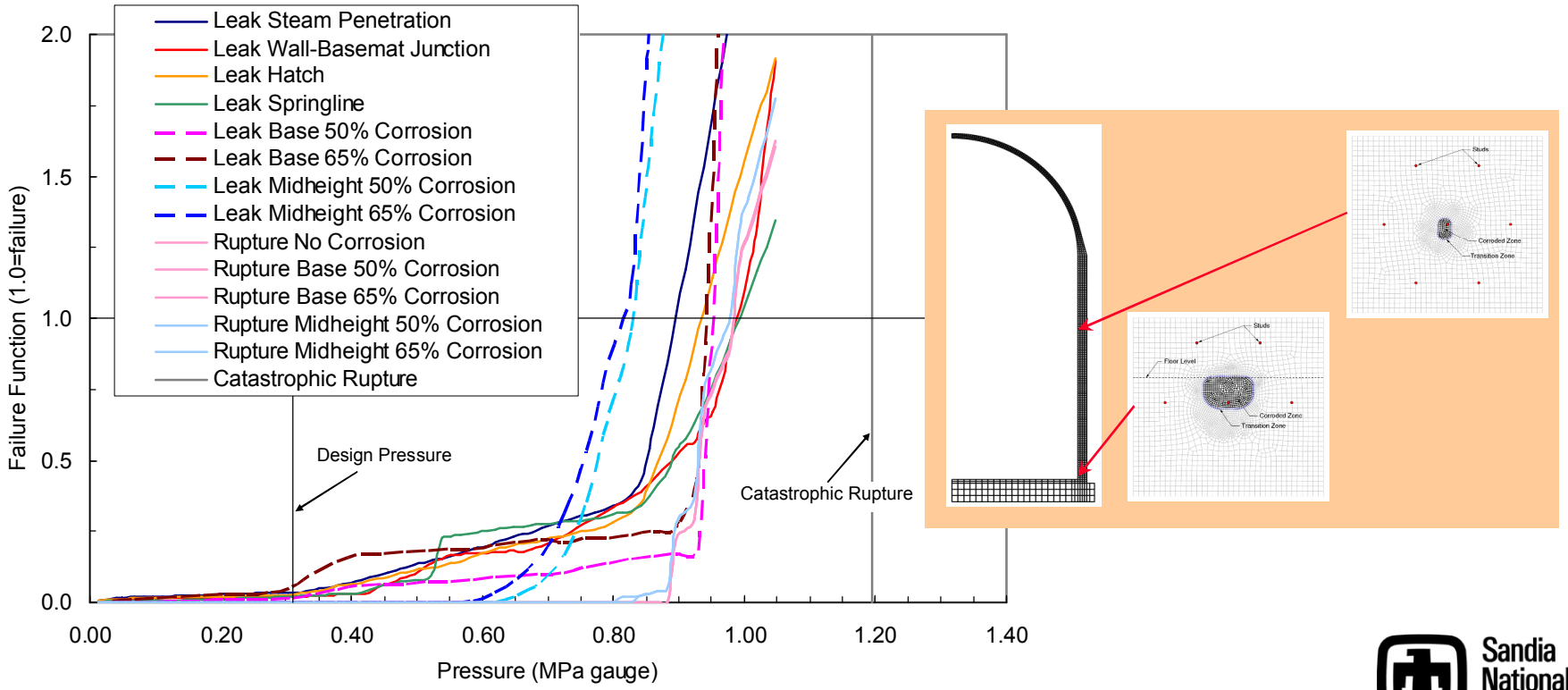
- Under NUREG/CR-6706 by Cherry and Smith a series of uniform corrosion and pitted corrosion coupon tests were conducted
- Goal was to determine the reduction in the strain to failure for use in computation models
- Due to the stress concentrations created by the corroded/pitted surfaces, the strain to failure reduced noticeably (approximately one half)

Degraded Containment Capacity

- Also under NUREG/CR-6706, Cherry and Smith performed computational analyses of 4 typical containments under original and hypothetical degraded conditions.
  - PWR Ice Condenser (Free standing steel shell)
  - BWR Mark I (Steel shell drywell and wetwell)
  - PWR Reinforced Concrete with Steel Liner
  - PWR Prestressed Concrete with Steel Liner
- Liner/shell corrosion were the primary cases examined
- Analyses showed that decreases in the leak pressure when corrosion was placed in regions of high strain
- Additional work under SAND2001-1762, Smith further explored degradation the Prestressed Concrete containment vessel
  - Showed that the hoop tendon degradation was most likely to cause decreases in the leak pressure

Risk Informed

- **NUREG/CR-6920 by Spencer et al., the examined the same 4 typical containments as in the previous study to develop a methodology to couple integrity analyses with probabilistic risk analyses**
- **Used strain based failure criterion with and without various cases of hypothetical degradation (typically liner/shell corrosion).**



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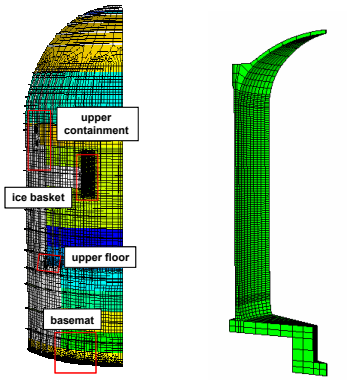
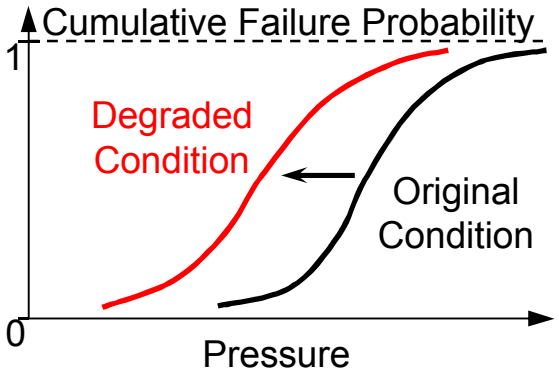
Risk Informed

- Developed fragility curves (probability of leak vs. pressure) for each containment with and without various cases of hypothetical degradation





- Computed changes in the Large Early Release Frequency (LERF) due to degradation using NUREG-1150 PRA models
- Attempted to assess changes in LERF using Regulatory Guide 1.174 to assess acceptability (Degradation treated as a change in a plant's licensing basis)
- Showed that local liner corrosion in concrete containments effects the probability of developing of a leak with little effect on the global rupture pressure.
- PRA analyses showed little increase, no increase, or even decreases in LERF due to local corrosion in many cases (early leaks increased the small early release frequency, SERF, due to binning definitions).
- Determined that LERF may not be the appropriate metric for assessing containment degradation.

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Consequence Analyses

- Under a recently completed study (NUREG to be published), structural analyses of a PWR plant with a reinforced concrete containment were coupled with a series of deterministic severe accident simulations
- These severe accident simulations were performed using MELCOR and MACCS.
- MELCOR code developed for the U.S NRC to evaluate source terms for hypothetical severe accidents at nuclear power plants based on specified initiating events (e.g., station blackout – loss of offsite power)
- MACCs code developed for the U.S NRC to evaluate offsite consequence of hypothetical severe accidents at nuclear power plants based on calculated or assumed fission product releases
- The structural analyses performed under the previous risk study were used to develop input for MELCOR for various hypothetical degradation cases.
- Long-Term Station Blackout (LTSBO) and Short-Term Station Blackout (STSBO) were both examined
- Goal was to assess changes/sensitivities in consequences due to degradation and not to compute absolute consequences for the given scenarios

Consequence Conclusions

- Small local degradation has the potential to cause earlier leaks and raise consequences.
- Typically, more corrosion area or deeper initial corrosion depth lead to higher consequences, but not always, as shown
  - Heavy corrosion can lead to larger crack areas at lower pressures which occur earlier in the accident – leading to increased consequence
  - However, in some cases, the earlier release of material partially depressurizes the containment prior to the accident generating the most consequence significant material. When the consequence significant material is then generated, the pressure is lower within the containment and the material is not pushed out to the environment as quickly.
- Containment degradation must be examined on a case-by-case basis and is dependent on the timing of the accident.

Liner Corrosion Workshop

- In September 2010, an expert panel workshop was conducted to examine observed cases of liner corrosion
- Panel members were gathered from national labs, academia, and industry
- Focused on outer-diameter initiated through-wall corrosion
- The panel members specifically discussed five areas:
  - Corrosion mechanisms of steel containment liners
  - Containment structure design, construction, and operation
  - Concrete aging and degradation
  - Concrete/steel NDE
  - Concrete repair and corrosion mitigation
- Summary report recently provided to the NRC

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Ongoing Research

- Continue to develop methods and explore metrics for examining containment degradation effects.
- Goal is to provide NRC with information to help assess the condition of containments when degradation is found.
- Areas that may be explored include through-wall liner holes, tendon degradation, and torus corrosion

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