Background

- Security assessments of reactor events indicated that radiological releases for scenarios representative of "typical and important severe accident scenarios" are delayed and smaller than that assumed in past safety/consequence studies (1982 Siting Study)

- Offsite health consequences predicted for security assessments were substantially smaller than 1982 Siting Study values
  - Earlier studies were believed to be excessively conservative in their assumptions and treatment

- Used our most advanced, integrated, realistic modeling
  - Plant response using MELCOR code
    - Phenomenological modeling based on extensive severe accident research
  - Offsite consequences predicted using MACCS code

R/15

Background

- Staff developed plan for State-of-the-Art Reactor Consequence Analyses, SECY-05-0233
  - Plan addressed all operating reactors using radiological source terms for 8 reactor/containment designs
    - Focus on the more likely, risk important scenarios. Realistic, best estimate analysis of accident progression, radiological source terms and offsite consequences
    - Include all plant improvements/updates (e.g., EOPs, SAMGs, 10CFR50.44hh)
    - More detailed site-specific, realistic EP (evacuation)
    - Alternate treatments of low dose effects (LNT and dose threshold models)
    - Study of additional mitigation measures

Background

- Project anticipated and identified need for uncertainty analysis – separate but closely related study
- Project was coordinated among relevant NRC offices, technical team composed of NRC (RES, NSIR, NRR, NRO) and Sandia National Lab staff
- Senior management guidance through Steering Committee for policy related issues, risk communication
- Early public notice with feedback, RIC mtgs
- ACRS review
- Independent peer review

Background

<u>Early feedback and reviews</u>

- Commission
  - Focus on 2 pilot plants, effective risk communication, current mitigation capabilities including security related enhancements

- ACRS
  - Concern over frequency truncation and adequacy of scenarios selected versus traditional PRA approach
    - Full scope PRA
  - Seismic initiators and EP treatment
  - Inclusion of non-LNT health effects modeling
  - Extremely large seismic events (SBO+LOCA + Containment failure)
- Other
  - Risk metric vs consequences

SOARCA Objective

- To develop a body of knowledge on the realistic outcomes of severe reactor accidents
  - Incorporate plant improvements not reflected in earlier assessments (hardware, procedures, security related enhancements, emergency planning)
  - Incorporate state-of-the-art modeling
  - Evaluate the benefits of recent improvements (10 CFR50.54hh)
  - Enable the NRC to communicate severe accident aspects of nuclear safety to diverse stakeholders
  - Update the quantification of offsite consequences found in earlier publications such as NUREG/CR-2239 (1982 Siting Study)

Approach

- Perform plant specific pilot study for Peach Bottom and Surry
  - Realistic (best estimate) assessment of important severe accident scenarios (CDF ≥ 10^{-6})
  - Criteria modified to include bypass sequences with lower frequency (CDF ≥ 10^{-7})
  - Risk metric for consequences
  - Peer Review
- Elements of technical study
  - Sequence selection
  - Mitigation measures
  - Accident progression and source term
  - Offsite consequences
- Risk Communication activities

Approach

- Study has adopted new approaches in many areas
  - Focus on "important" scenarios (CDF≥10^{-6}, 10^{-7} for bypass)
  - Realistic assessments and detailed analyses versus simplified and conservative treatments used in past PRA
  - Integrated, self-consistent analyses
  - Incorporated recent phenomenological research
    - IRSN, PSI, NUPEC
  - Treatment of seismic impacts on EP
  - Range of health effects modeling (non-LNT latent cancer modeling)
  - Considered accident duration of 48 hours

ACRS Issues: Screening Criteria

- Letter dated February 25, 2008
- Concern over use of screening criteria
  - A priori CDF screening criteria can overlook many risk significant scenarios
  - Number of sequences and their aggregate contribution can increase at lower frequency
  - Does not provide a fully integrated evaluation of (total) risk
  - Level 3 PRAs should be performed
- In theory, concerns are reasonable, in practice, of lesser concern
  - Known designs with previous and current PRA
  - Potential vulnerabilities have long been identified – **what is needed is better, more rigorous, and scrutable quantification of accident progression, radiological source term, and offsite consequences**
  - SOARCA analyzes significant risk contributors (by comparison to NUREG-1150), not intended to capture total risk – not demonstrably true for existing PRA (e.g., security)

ACRS Issues: Screening Criteria

- ACRS comment on screening criteria does not reflect current imbalance between characterization of lower frequency internal events scenarios versus external events – what is a 10^{-8} (or lower) external event?
- SOARCA has indicated need for better external events PRA, especially seismic PRA
  - Dual unit SPAR models
  - Soil liquefaction
  - Mechanistic fragility modeling
- Internal event LOCA scenarios were comfortably below the screening criteria
- Station blackout is a bounding surrogate for many transients
  - SOARCA added short term SBO to Peach Bottom analysis in response to ACRS concern (included originally for Surry)

ACRS Issues: Seismic Events

- ACRS commented that scenarios did not include a very large earthquake (>1.0 g) resulting in SBO + LOCA + Containment failure
  - Deferred to future evaluation – many technical issues requiring research
  - Requires assessment of non-nuclear risk

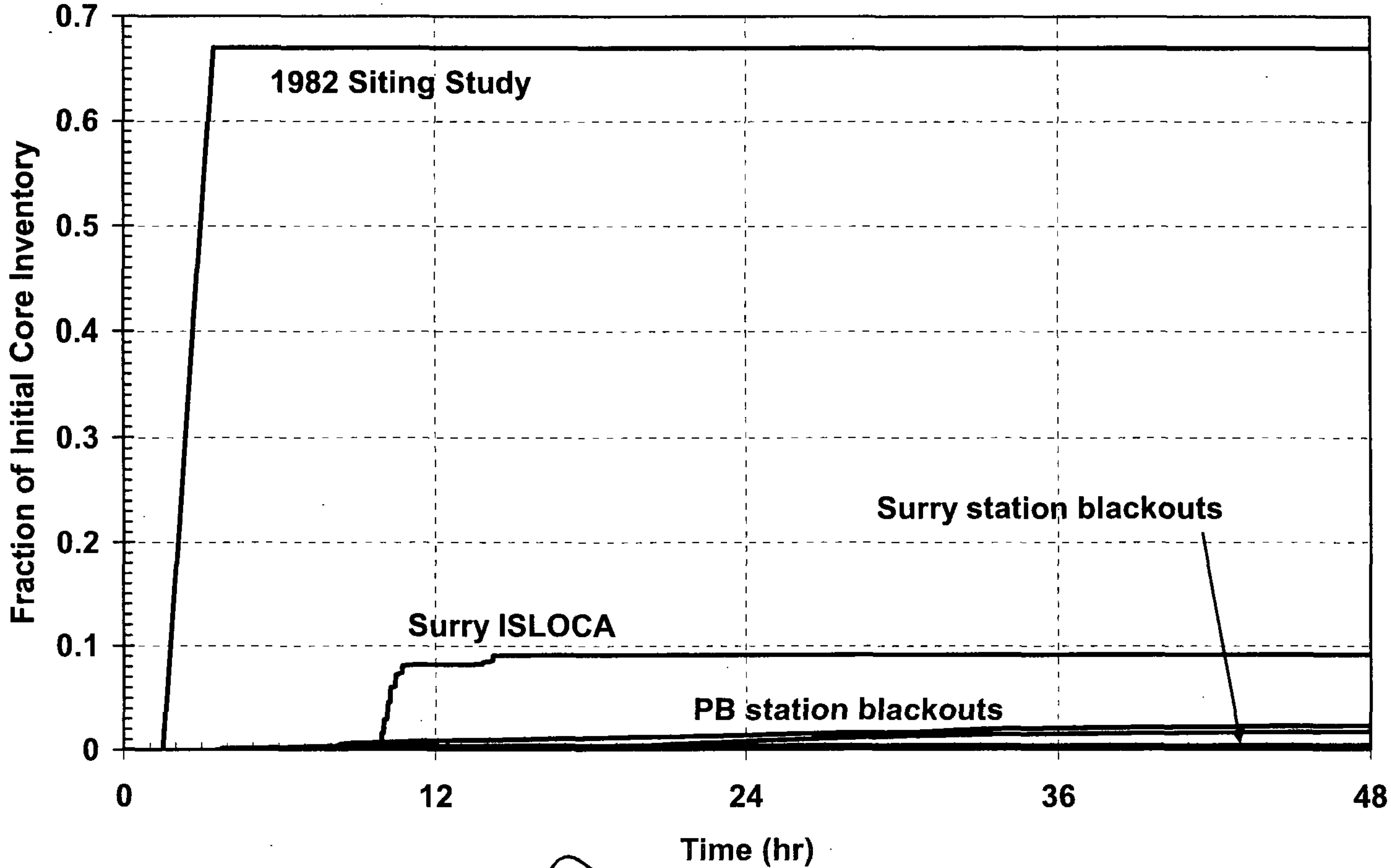
- ACRS concern that seismic events considered in SOARCA need to be addressed more comprehensively with consideration of impact on mitigation and EP
  - SOARCA project agrees – consistent, technically sound examination demands consideration of various seismic impacts
  - Mitigation measures assessment has factored in seismic impacts
  - EP modeling did not originally consider seismic impacts which may hinder EP implementation/execution
  - EP modeling has been extended based on assessment of seismic impact on EP infrastructure (communications, road network, etc)

Mitigation Measures

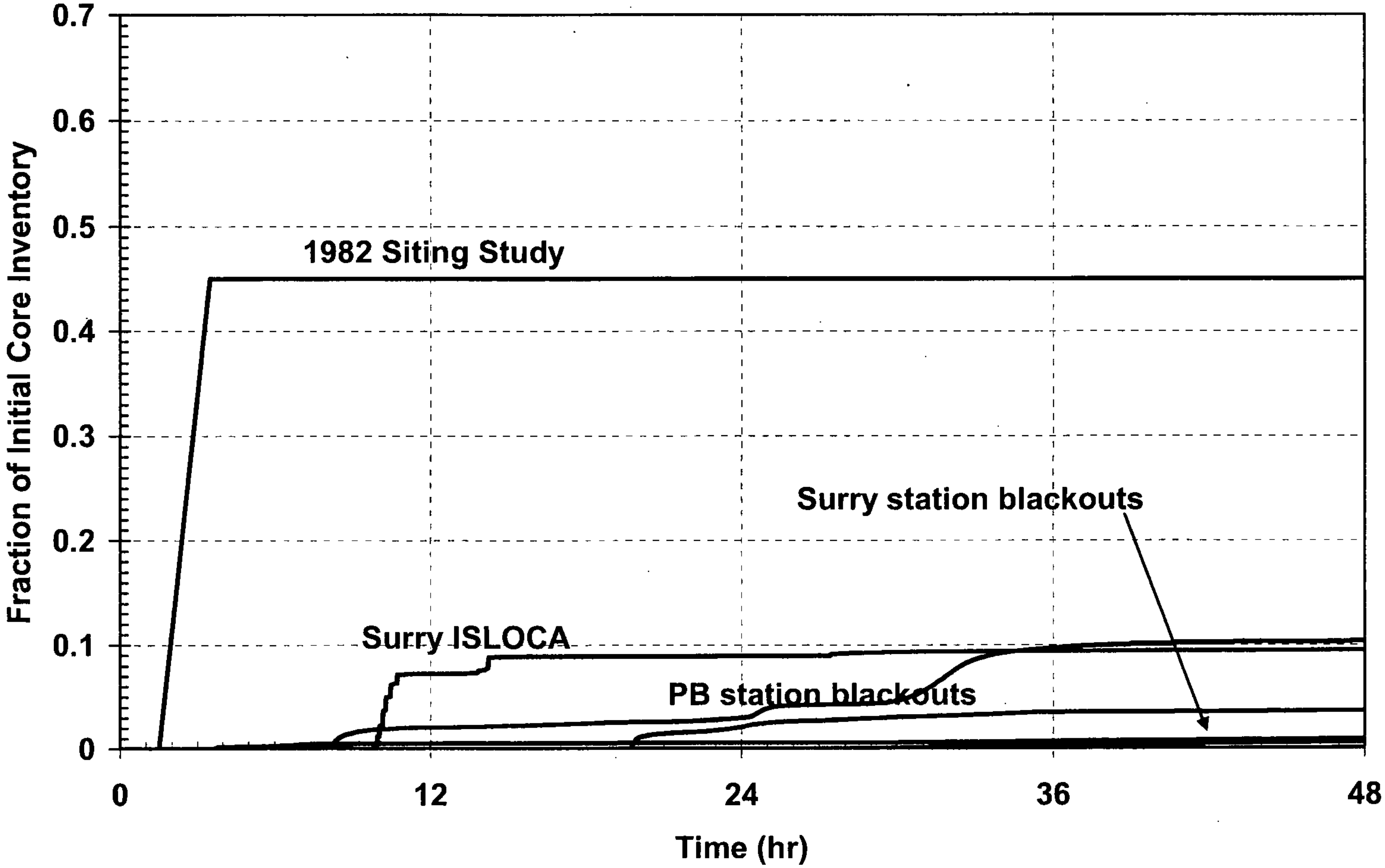
- For each sequence, staff performed table-top exercise with plant operators to elicit how plant staff would respond
  - Timeline of operator actions
  - Includes all mitigation measures
    - Emergency Operating Procedures
    - Severe Accident Management Guidelines
    - Post-9/11 enhancements
    - Technical Support Center

- Implementation of mitigation measures will either avert core damage or delay or reduce the radiation release. Implementation of mitigation measures was judged to be likely based on the table top exercises.

Cesium Release for Unmitigated Sensitivity Cases



Iodine Release for Unmitigated Sensitivity Cases



Offsite Consequences
Peach Bottom – Unmitigated Cases

Scenario	CDF per R-Y	LNT – Conditional Individual LCF risk (0 -10 miles)	LNT – Individual LCF risk per R-Y* (0 -10 miles)
Long Term Station Blackout (LTSBO)	3×10^{-6}	2×10^{-4}	6×10^{-10}
Short Term Station Blackout (STSBO)	3×10^{-7}	2×10^{-4}	7×10^{-11}

*U.S. average individual risk of a cancer fatality: 2×10^{-3} / year

Offsite Consequences
Surry – Unmitigated Cases

Scenario	CDF per R-Y	LNT – Conditional Individual LCF risk (0 -10 miles)	LNT - Individual LCF risk per R-Y (0 -10 miles)*
LTSBO	2×10^{-5}	$5 \text{ X } 10^{-5}$	7×10^{-10}
STSBO	2×10^{-6}	9×10^{-5}	1×10^{-10}
STSBO / TISGTR	4×10^{-7}	3×10^{-4}	1×10^{-10}
ISLOCA	3×10^{-8}	$8 \text{ X} 10^{-4}$	2×10^{-11}

*U.S. average individual risk of a cancer fatality: 2×10^{-3} / year

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Offsite Consequences

- More detailed modeling of plume release and azimuthal sectors
- Scenario-specific Emergency Action Levels based on site procedures
- Detailed evacuation and relocation modeling
  - Reflect actual ETEs and road networks at Surry and Peach Bottom
  - Treatment of multiple population groups
- Site-specific population and weather data
- Updated non-site-specific and health effects parameters
- Range of truncation doses for latent cancer prediction
- Sensitivities
- More detailed analysis of results

SOARCA results challenge common perceptions of severe accidents

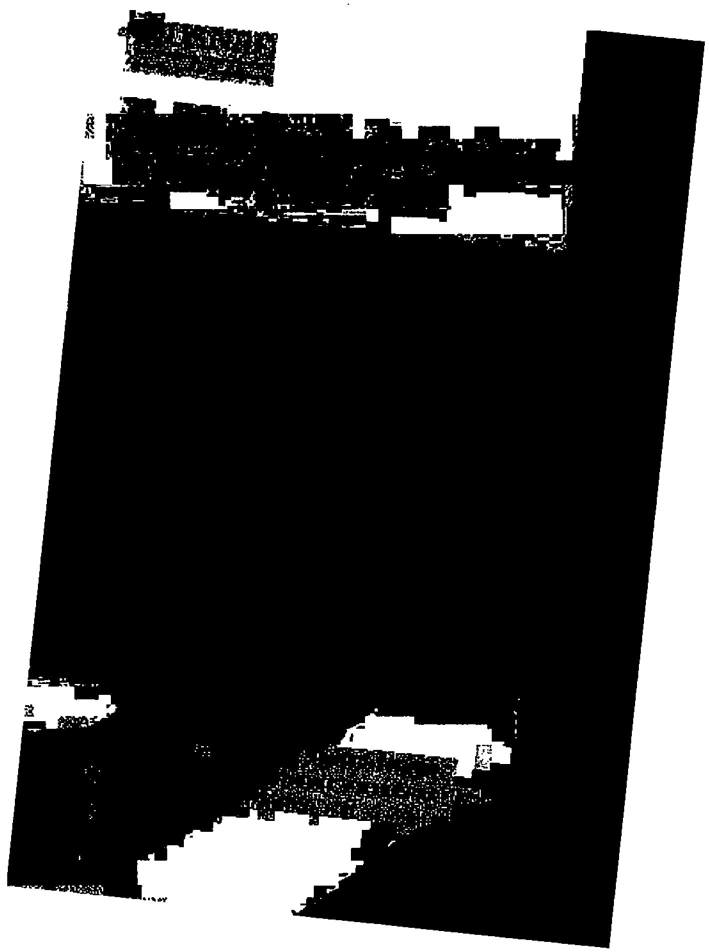
- Scenarios could reasonably be mitigated resulting in either averted core damage or delay or reduction of the radiation release.
  - PRA needs to address mitigation in a more realistic fashion (e.g., HRA)
  - New insights on level 1 CDF contributors (CRD, SGTR)
  - New insights on level 2/3 contributors (SBO-TISGTR, ISLOCA)
- For cases assumed to proceed unmitigated:
  - Accidents progress more slowly and result in smaller and more delayed radiological releases than previously assumed/predicted
  - Individual early fatality risk is essentially zero; no LERF contributors

SOARCA results challenge common perceptions of severe accidents

- Individual latent cancer fatality risk within the EPZ is very low
  - Thousands of times lower than the NRC safety goal and millions of times lower than other cancer risks (assuming LNT)
  - Generally dominated by long-term exposure to small annual doses (return criteria and LNT)
  - Non-LNT models predict risk is even lower (factor of 3 – 100)
- Bypass events do not pose higher risk
- Explicit consideration of seismic impacts on EP had no significant impact on predicted risk
- Dominance of external events suggests need for PRA focus and seismic research

Risk Communication

- Information brochure
- Risk communication principles
- Communication Plan and Information Booklet developed by communications specialists in OPA, EDO, RES (with technical content expert input from all offices)
- Tested with Region IV staff
- Additional tools
  - Website
  - Press releases/briefing
  - Public meetings



Peer Review

- Assess SOARCA approach, methods, results, and conclusions to ensure study is best estimate and technically sound
- Independent reviews – not intended to constitute a consensus among reviewers
- Broad array of content experts, series of meetings, draft documents
- Major areas of uncertainty raised by peer review have been addressed by sensitivity studies and/or text
  - Severe accident modeling
  - EP
  - Health effects due to low doses
- Integrated uncertainty analysis

SOARCA
Scenario Selection

Marty Stutzke, RES/DRA

ACRS Subcommittee Meeting

June 21, 2010

Outline

- General considerations
- Scenario selection
  - Approach
  - Results
  - Scenarios not in scope
- Peer review comments
- Conclusions

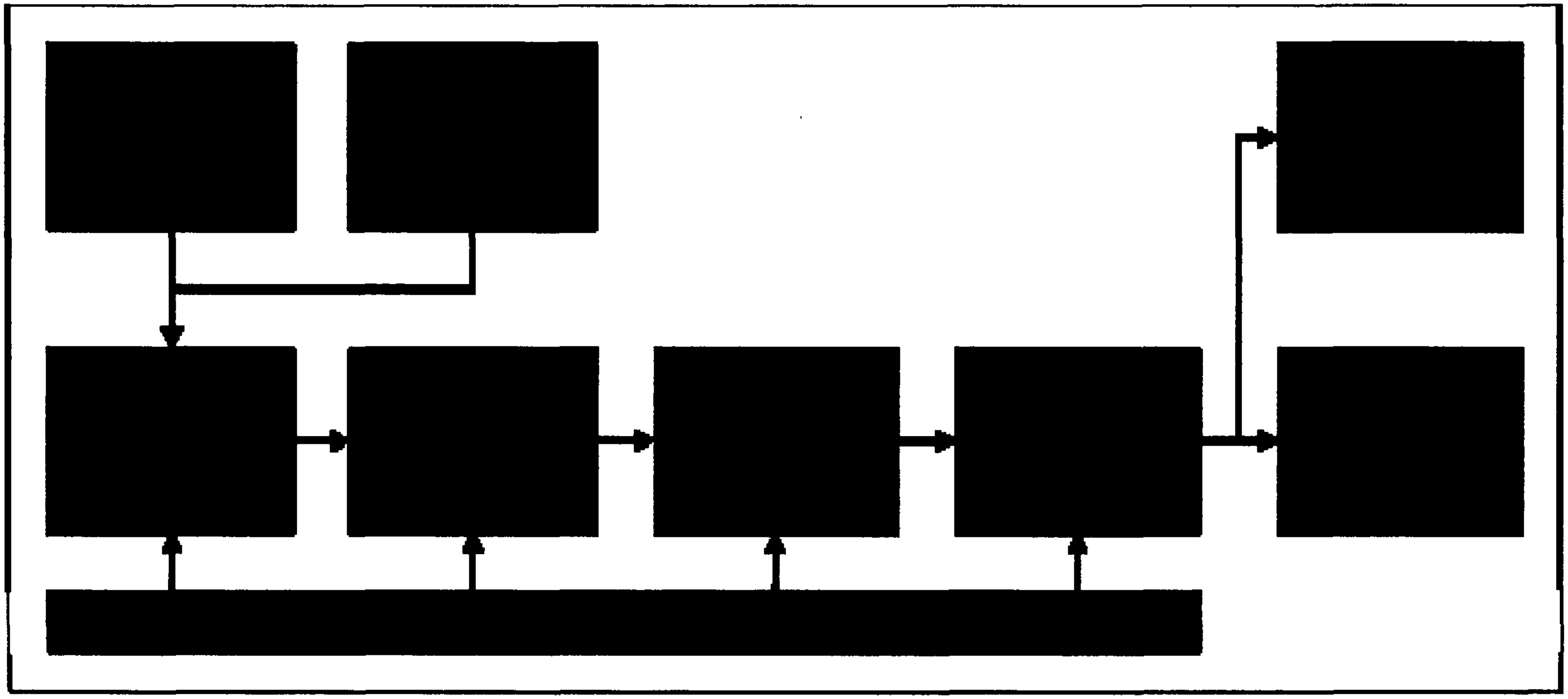
General Considerations

- The overall objective of SOARCA is to develop a body of knowledge regarding the realistic outcomes of severe reactor accidents:
  - SOARCA is a consequence analysis, and does not purport to be a Level 3 PRA.
  - Focus on a set of important accident sequences considering both likelihood and potential consequences.

- Scenario selection based on core-damage frequency (CDF) obtained from Level 1 PRA results:
  - SPAR models, licensee PRAs, general studies (e.g., NUREG-1150).
  - Lack of detailed Level 2 PRA information.

- Approach to identifying SOARCA scenarios:
  - CDF > 10^{-6} per reactor year
  - CDF > 10^{-7} per reactor year for core-damage sequences that imply containment bypass.
  - Qualitative insights were also used to select scenarios; numerical guidelines not strictly applied.

SOARCA Accident Scenario Selection Process



Surry Scenarios

- Spontaneous Steam Generator Tube Rupture ($5x10^{-7}$/y)
  - Failure to isolate faulted SG, depressurize and cool down RCA, and refill RWST or cross-connect to other unit
- Interfacing Systems LOCA in the LPI System ($7x10^{-7}$/y)
  - Rupture of both LPI inboard isolation check values; failure to refill RWST or cross-connect to other unit
- Seismic Initiated Long Term Station Blackout ($1x10^{-5}$/y to $2x10^{-5}$/y)
  - Moderately large earthquake (0.3–0.5 pga) causes loss of offsite and onsite AC power; TDAFWP fails due to battery depletion
- Seismic Initiated Short Term Station Blackout ($1x10^{-6}$/y to $2x10^{-6}$/y)
  - Unmitigated: large earthquake (0.5–1.0 pga) causes loss of offsite and onsite AC power, loss of DC power (no instrumentation), and failure of ECST (supply to TDAFWP)

Peach Bottom Scenarios

- Seismic Initiated Long Term Station Blackout ($1x10^{-6}$/y to $5x10^{-6}$/y)
  - Moderately large earthquake (0.3–0.5 pga) causes failure of offsite AC power, failure of onsite emergency AC power and failure of the Conowingo Dam power line resulting in a non-recoverable SBO event. Loss of room cooling and/or battery depletion results in eventual failure of HPCI and RCIC, leading to core damage.

- Seismic Initiated Short Term Station Blackout ($1x10^{-7}$/y to $5x10^{-7}$/y)
  - Large earthquake (0.5–1.0 pga) causes failure of offsite AC power, failure of onsite emergency AC power and failure of the Conowingo Dam power line resulting in a non-recoverable SBO event. HPCI and RCIC failed due to loss of DC power.

- Loss of AC Bus E-12 ($5x10^{-7}$/y)
  - Originally screened in, but removed after reconciling the SPAR model with the licensee's PRA.
  - MELCOR calculation indicates that this scenario can be mitigated using CRDHS flow (not modeled in SPAR), that is, without crediting mitigative actions using equipment and procedures called for in10CFR50.54(hh).

Scenarios Not in Scope

- Multi-unit accidents
  - Referred to the Generic Issues Program (screening analysis pending)
- Shutdown and low-power accidents
  - SOARCA focuses on scenarios that, historically, have been of interest (e.g., full-power scenarios)
  - Lack of detailed SD&LP PRAs
- Extreme seismic events that lead to direct containment failure
  - Further research needed to better understand the impact of extreme seismic events on plant SSCs (including soil liquefaction), operator performance, evacuation, etc.
  - EPRI pilot seismic PRA for Surry, which that staff reviewed under the EPRI/NRC MOU, indicates SCDF = SLERF = 10^{-8} per reactor year for these types of sequences.
- Spent fuel pool accidents
  - NUREG-1738 (February 2001) indicates that spent fuel pool risk is small, but may have large consequences.
  - Subsequent NRC research indicates that spent fuel pool risk is smaller than previously estimated in NUREG-1738 due to physical safety improvements and improved modeling capabilities.
- Security events
  - Previous security assessments of reactor events provided some of the motivation for the SOARCA project.
  - Excluded from the scope of SOARCA by Commission direction

Peer Review Comments

- Four reviewers stated that the selected scenarios support the project's objectives (one reviewer did not agree and the other reviewers were silent on this topic).
- Informal review of available PRAs by one reviewer did not identify any missing scenarios other than the large seismic event (same conclusions reached during staff independent review).
- One reviewer stated that seismically induced soil liquefaction should be addressed.
- One reviewer stated that care must be taken in communicating SOARCA results in any context that include a discussion of risk to the public.
- Five reviewers appear to support the development of new Level 3 PRAs:
  - Demonstrate completeness (assess the impact of individually non-significant accident sequences)
  - More completely characterize the results and communicate risks
  - May be beneficial for confirmatory purposes

Conclusions

- The SOARCA scenario selection process used the best available PRA information.
- The SOARCA scenario selection process is adequate to meet the project's stated objectives.
- ACRS and peer review suggestions are being considered in the proposed site Level 3 PRA that the staff is planning in response to meeting SRM M100208 dated March 19, 2010.

SOARCA
Emergency Preparedness

Randy Sullivan, NSIR/DPR

ACRS Subcommittee Briefing

June 21, 2010

EP Seismic Study

- ACRS questioned adequacy of EP modeling for seismically initiated scenarios given the potential effect on emergency response
- Past risk studies have not generally considered this effect except in simplified sensitivity calculations - delay times and evacuation speed or timing
- Policy issues were also considered
- SOARCA Approach
  - Seismic assessment of infrastructure damage
    - Bridges, roads, power network (notification, traffic signals)
  - Reassessment of response
    - Route alerting versus sirens
    - New ETE based on damage to road network
    - New cohort model developed for MACCS2
  - Recalculation of offsite consequences
- Conclusion – No substantial effect on offsite health consequences

Seismic Assessment of Infrastructure Damage

- Evacuation routes can be compromised by multiple mechanisms:

  - primary structural failure of bridges, culverts and over-passes,

  - loss of strength of foundation or abutment materials that support the roadway or bridge.

- Screening-level assessment was performed using readily available information (U.S.G.S, State Geological Surveys, Soil Conservation Service) and judgment.

Seismic (EP) Study

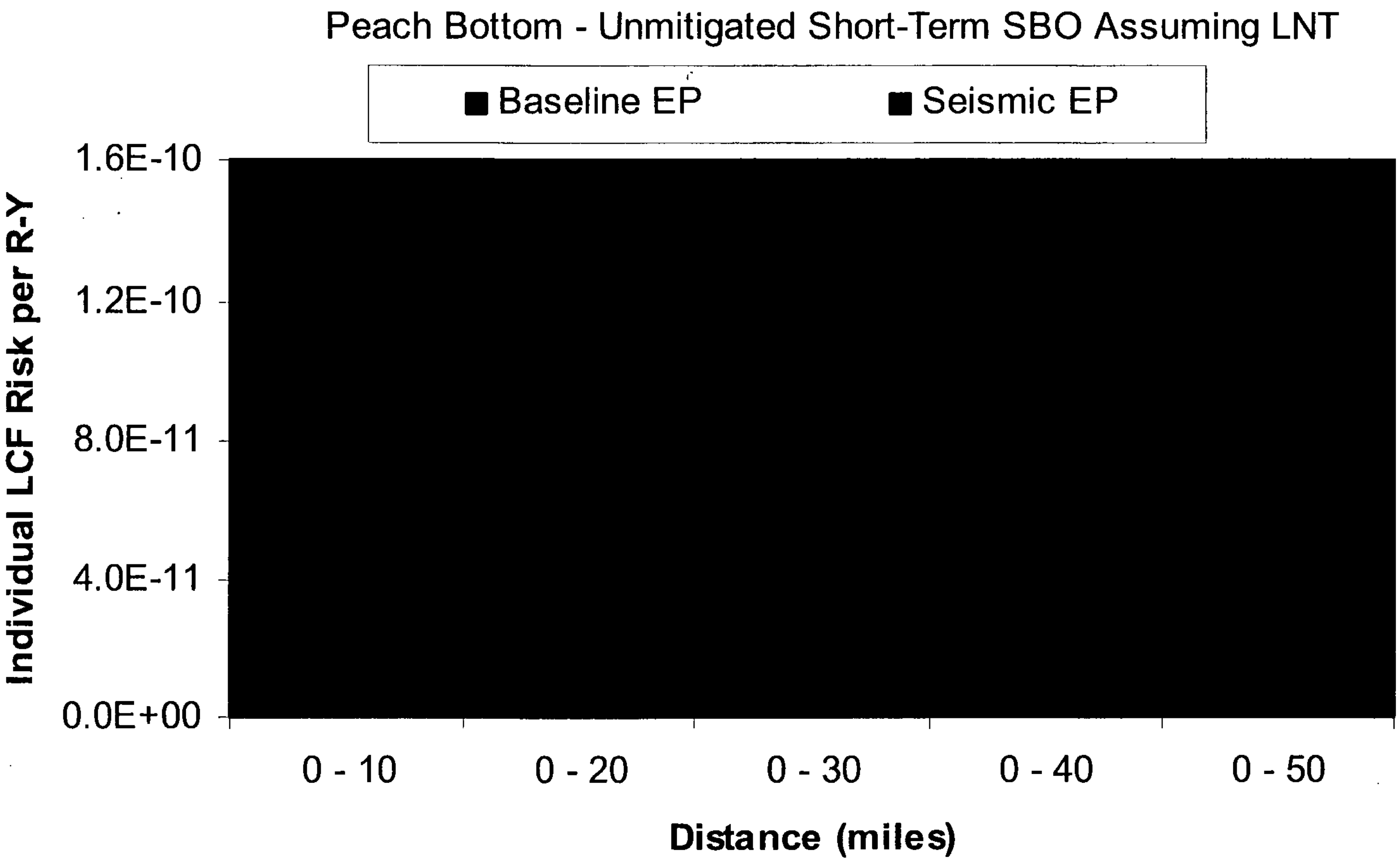
- Seismic effects are site specific
  - Peach Bottom
    - Sirens fail but alternative notification occurs
    - Larger shadow evacuation
    - Free span bridges fail – not key to evacuation,
    - Adequate road network remains and evacuation speeds are unchanged

Peach Bottom Seismic Analysis

- Effects of earthquake on infrastructure
- 12 bridges/roadways potentially affected
- Electrical system fails, no sirens sound
  - Public notification performed via Emergency Alert System, societal means and route alerting
  - Notification slower; people experienced earthquake and are more prepared to leave
- Power out, but few traffic signals in affected area
- Shadow evacuation increased to 30%
- Negligible effect on ETE

[redacted]

Seismic (EP) Study

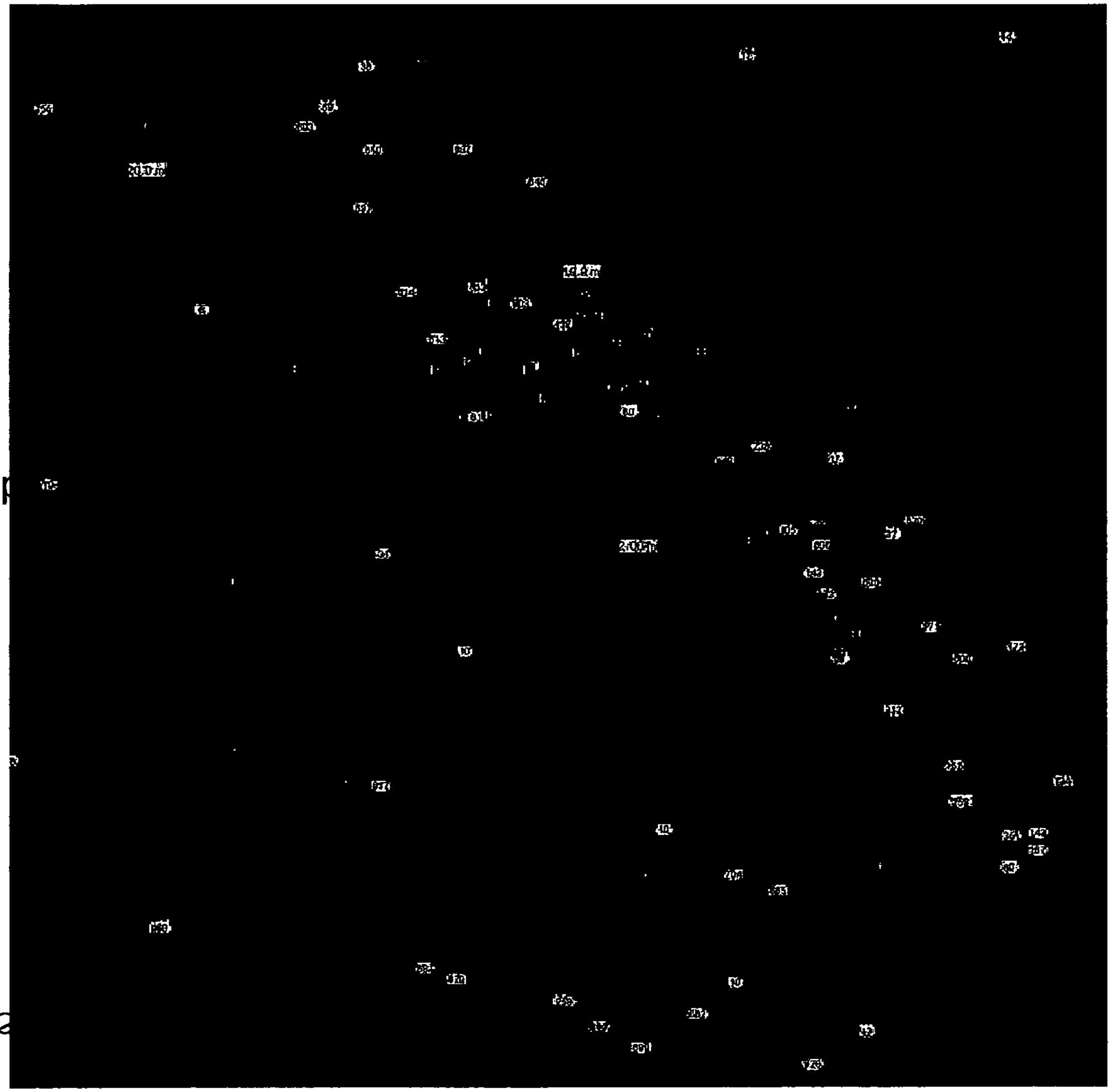


Seismic (EP) Study

- Surry
  - Sirens function (battery backup)
  - Public evacuation starts earlier
  - Larger shadow evacuation
  - Schools evacuation delayed
  - Bridge failures significantly retard evacuation
    - major effect on ETE
  - Smaller radiological release, LCF dominated by long term exposure

Surry Seismic Analysis

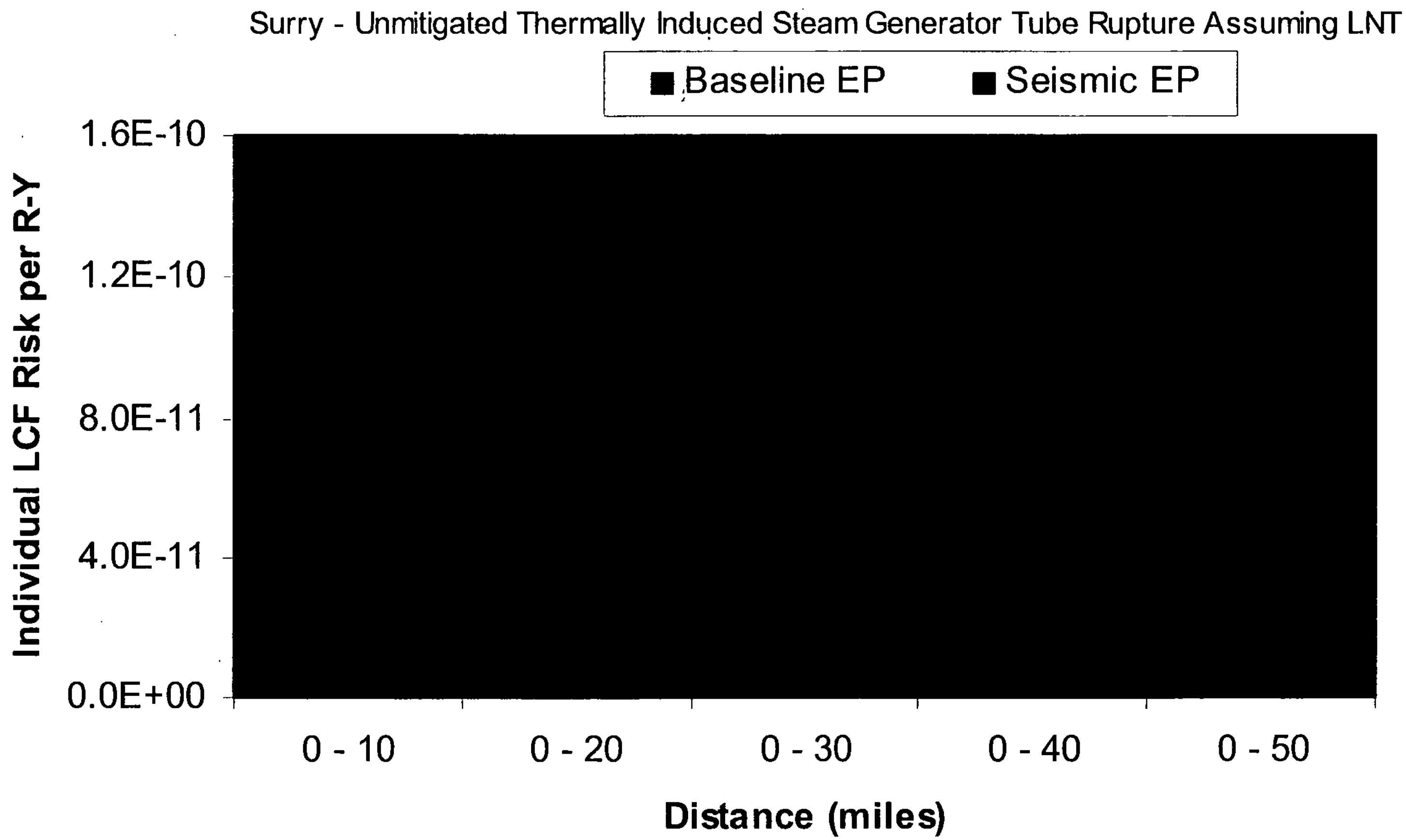
- 40 bridges/roadways potentially affected
- Interstate 64 fails within the EPZ
- Assume electrical system fails sirens have battery backup
- Public is prepared to leave
- Traffic signals default to 4-way sto
- Shadow evacuation increased to 30%
- Considerable effect north of the James River – 18 hour ETE
- Negligible effect on the rural area south of James River



Typical Bridge Affected by Seismic Event

- Significant bridges assumed to fail, with large effect on ETE
- Overpass and underpass become unusable in many locations
- Use of secondary routes to points outside of affected area – delays travel

Seismic (EP) Study



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Summary

- This evolutionary analysis presents the most detailed modeling of emergency response performed by NRC
- Integration of EP improves realism by modeling established and tested response programs
- EP modeling is set up in WinMACCS and then the source term applied to develop consequence estimates
- A screening-level identification of transportation routes that could be compromised by a significant seismic event was performed
- At these sites, seismic effect on consequences are minimal

SOARCA
Mitigating Measures

Robert Prato, NRO/DCIP
ACRS Subcommittee Meeting
June 21, 2010

Mitigating Measures: Peach Bottom

- Site visit on June 10, 2010
  - Performed table-top exercises for STSBO
    - Scenario added due to ACRS concern regarding lower frequency scenario potentially having higher risk
  - Viewed newly purchased B.5.b equipment
  - Performed plant walk-down from storage locations to connection points in reactor building
    - 165'-level – RPV level instrumentation
    - 135'-level – alternative SRV control, RCIC discharge valve
    - 91'6"-level – RCIC system (RCIC black start/black run)
  - Walked-down procedure for RCIC black-start/run to better understand implementation

Mitigating Measures: Peach Bottom

- Mitigative Measures
  - Equipment
  - Resources
  - Implementation

Mitigating Measures: Peach Bottom

– Equipment

- Portable power supplies
- Portable controls and AC/DC rectifier for opening SRVs
- Portable diesel driven pump
- RCIC black start/black run

Mitigating Measures: Peach Bottom

- Portable power supplies
  - Two hand-held gas powered generators
  - 24 hours of fuel
  - Access and procedures
- Portable diesel driven pump
  - 30 feet of intake hose
  - Discharge hose
  - 24 hours fuel
  - 180 psi discharge pressure when drafting from river
- RCIC Black Start/Black Run
  - Proceduralized
  - Manual operation of turbine each refuel cycle

Mitigating Measures: Peach Bottom

- Resources
  - Minimum required staffing
    - 4 equipment operators per unit
    - 2 I&C techs on shift
    - 1 HP tech
    - Security assistance
  - Staging
    - Equipment
    - Tools/Fuel
  - Access
  - Make-up sources
  - Communication

Mitigating Measures: Peach Bottom

Implementation

- STSBO - Large Earthquake, 0.5 – 1.0 pga; loss of all AC and DC power
  - Unmitigated Scenario, Variation 1
    - RCIC black-start fails
  - Unmitigated Scenario, Variation 2
    - RCIC black-start successful, eventually fails due to steam line flooding
  - Mitigated Scenario

Mitigating Measures: Peach Bottom

- STSBO - Time Line, Unmitigated Case 1
  - Event Initiation/Plant Response
    - AC and DC power fails
    - Reactor trips
    - Reactor and containment isolate.
    - RCIC black-start fails
  - Core damage at ~ 1 hour

Mitigating Measures: Peach Bottom

- STSBO - Time Line, Unmitigated Case 2
  - Event Initiation/Plant Response
    - Loss of AC and DC power
    - Reactor trips
    - Reactor and containment isolate

Mitigating Measures: Peach Bottom

- STSBO - Time Line, Unmitigated Case 2
  - T ~ 1 hr
    - RCIC black-start succeeds
  - T ~ 2 hrs, 45 min
    - Loss of RCIC due to steam flooding
  - T ~ 6 hrs
    - Core damage

Mitigating Measures: Peach Bottom

- STSBO - Time Line, Mitigated Event
  - T ~ 1 hr
    - RCIC black-start succeeds
    - Portable DC power supply-connected to SRV and RPV level
  - T ~ 1 hr
    - EOF manned

Mitigating Measures: Peach Bottom

- STSBO - Time Line, Mitigated Event
  - T ~ 1.25 hrs
    - EOF operational - recommend the following:
      - Portable power supplies-SRVs and RPV level indication
      - Portable diesel driven pump-RCS, hotwell, and CST make-up
      - Portable air supply-manual operation containment vent valves
      - Use off-site pumper truck as portable pump

Mitigating Measures: Peach Bottom

- STSBO - Time Line, Mitigated Event
  - T ~ 1.5 hrs
    - Operators assess and prioritize EOF recommendations
  - T ~ 2 hrs
    - Technical Support Center (TSC) manned

Mitigating Measures: Peach Bottom

- STSBO - Time Line, Mitigated Event
  - T ~ 2.25 hrs
    - TSC operational
  - T ~ 3.5 hrs
    - Portable air supply connected to containment vent valves
  - T < 10 hrs
    - Portable diesel-driven pump available

Mitigating Measures: Surry

– Equipment

- Portable power supply
- 2 Portable diesel-driven high-pressure pumps
- 1 portable diesel-driven low-pressure pump
- TDAFW black start/black run

Mitigating Measures: Surry

Implementation

- STSBO - Large Earthquake, 0.5 – 1.0 pga; loss of all AC and DC power; ECST – limiting scenario in terms of timing and equipment available
  - Unmitigated Case
  - Unmitigated Case, Variation 1
    - Same as unmitigated case above
    - Includes thermally induced S/G tube rupture (0.46 in^2) which has insignificant effect on thermal hydraulics and accident progression
  - Mitigated Scenario

Mitigating Measures: Surry

- STSBO - Time Line, Unmitigated Case
  - Event Initiation/Plant Response
    - LOOP, SBO, loss of DC power
    - Reactor shuts down, RCS and containment isolate
    - TDAFW pump fails due to loss of the ECST
    - Late RCP seal failures may occur
    - Loss of ECCS and containment cooling systems
    - Recovery of offsite and onsite power not expected during the mission time

Mitigating Measures: Surry

- STSBO - Time Line, Unmitigated Case
  - T ~ 30 min
    - Operations completes initial assessment and initiates the following action:
      - Attempt manual start of the EDG and SBO diesel generator
      - RCS pressure being maintained by code safety valves
      - PORVs not available due to loss of instrument and backup air
      - Use portable power supply to restore key instrumentation (RCS level, RCS pressure, SG level)
      - Manual start of EDGs and SBO diesel generator failed
      - EOF manned, primary function is to review initiating event, plant status, and operator actions and to provide guidance on alternative mitigation measures.

Mitigating Measures: Surry

- STSBO - Time Line, Unmitigated Case
  - T ~ 1.5 hrs
    - Offsite EOF recommends the following actions:
      - Maintain portable power supply for instrumentation
      - Connect the portable, high-pressure, diesel-driven (Kerr) pump for RCS makeup
      - Use portable bottles for manual operation of SG PORVs, as needed
      - Connect the portable, diesel-driven (Godwin) pump for containment spray or containment flooding
  - T ~ 1.75 hrs
    - Operations assesses offsite EOF recommendations, prioritizes recommendations based on plant conditions and begins implementation

Mitigating Measures: Surry

- STSBO - Time Line, Unmitigated Case
  - T ~ 2 hrs
    - TSC is manned and operational, reviewing initiating event, plant status, and operator action to provide guidance on alternate mitigation measures
  - T ~ 3 hrs
    - Core damage begins
  - T ~ 3.75 hrs
    - RCS hot leg fails, RCS depressurized
    - Mitigating measures focus on containment cooling and flooding

Mitigating Measures: Surry

- STSBO - Time Line, Mitigated Event
  - Event Initiation/Plant Response
    - LOOP, SBO, loss of DC power
    - Reactor shuts down, RCS and containment isolate
    - TDAFW pump fails due to loss of the ECST
    - Late RCP seal failures may occur
    - Loss of ECCS and containment cooling systems
    - Recovery of offsite and onsite power not expected during the mission time

Mitigating Measures: Surry

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Mitigating Measures: Surry

- STSBO - Time Line, Mitigated Event
  - T ~ 2 hrs
    - TSC is manned and operational, reviewing initiating event, plant status, and operator action to provide guidance on alternate mitigation measures
  - T ~ 3 hrs
    - Onsite EOF is operational
  - T ~ 3.75 hrs
    - Portable power supply continues supplying instrumentation
    - Portable air to be connected to S/G PORVs to depressurize RCS
    - Portable diesel-driven pumps being connected based on plant needs

Mitigating Measures: Surry

- STSBO - Time Line, Mitigated Event
  - T ~ 6.5 hrs
    - Depressurize RCS using portable air bottles. Accumulators will provide RCS make-up
  - T > 6.5 hrs
    - Unable to connect portable injection systems
    - No other mitigation attempts are successful
  - T ~ 8 hrs
    - Connect portable, diesel-driven pump (Godwin) to containment spray system to mitigate a release and delay containment failure

SOARCA
Accident Progression and Source Term

Jason Schaperow, RES/DSA
ACRS Subcommittee Meeting
June 21, 2010

SOARCA Approach

- Perform MELCOR calculations including mitigation measures according to the time lines from the table-top exercises
  - Confirm timing and capacity of measures is sufficient to either prevent core damage, delay release, or reduce release
- Perform MELCOR calculations assuming no credit for actions critical to prevent core damage
  - Assess benefits of mitigation measures (risk averted)
  - Provide basis for comparison to past analyses of unmitigated severe accident scenarios

Peach Bottom Accident Scenarios

- External events (CDF)
  - Long-term SBO – $3x10^{-6}$/yr
  - Short-term SBO – $3x10^{-7}$/yr
- Internal events (CDF)
  - Loss of vital AC bus E12 – < $1x10^{-6}$/yr *- no unmitigated sensitivity case*
    - MELCOR demonstrated core damage averted by RCIC injection (until battery exhaustion) and CRD – B.5.b measures not needed

Surry Accident Scenarios

- External events (CDF)
  - Long-term SBO – $2x10^{-5}$/yr
  - Short-term SBO – $2x10^{-6}$/yr
    - Short-term SBO with thermally induced SGTR – $4x10^{-7}$/yr
- Internal events (CDF)
  - ISLOCA – $3x10^{-8}$/yr [SPAR], $7x10^{-7}$/yr [licensee]
  - Spontaneous SGTR – $5x10^{-7}$/yr - *no unmitigated sensitivity case*
    - MELCOR demonstrated core damage was delayed for 2 days due to the long time until RWST exhausts (11 hours) and ECST exhausts (33 hours) – B.5.b measures not needed

Accident progression timing for unmitigated sensitivity cases – Peach Bottom

Scenario	CDF* (per year)	Time to start of core damage (hours)	Time to lower head failure (hours)	Time to start of release (hours)	Cs release through 48 hours (fraction)
Long-term SBO	$3x10^{-6}$	10	20	20	0.017
Short-term SBO with RCIC B/S at 10 min	$3x10^{-7}$	5	13	13	0.021
Short-term SBO	$3x10^{-7}$	1	8	8	0.023

*An unmitigated case CDF assumes probability of B.5.b mitigation is zero

Accident progression timing for unmitigated sensitivity cases - Surry

Scenario	CDF* (per year)	Time to start of core damage (hours)	Time to lower head failure (hours)	Time to start of release (hours)	Cs release through 48 hours (fraction)
Long-term SBO	2×10^{-5}	16	21	45	<0.001
Short-term SBO	2×10^{-6}	3	7	25	0.001
Thermally induced SGTR (CTFP=0.25)	4×10^{-7}	3	7.5	3.5	0.004
Interfacing systems LOCA	3×10^{-8}	9	15	10	0.092

*An unmitigated case CDF assumes probability of B.5.b mitigation is zero

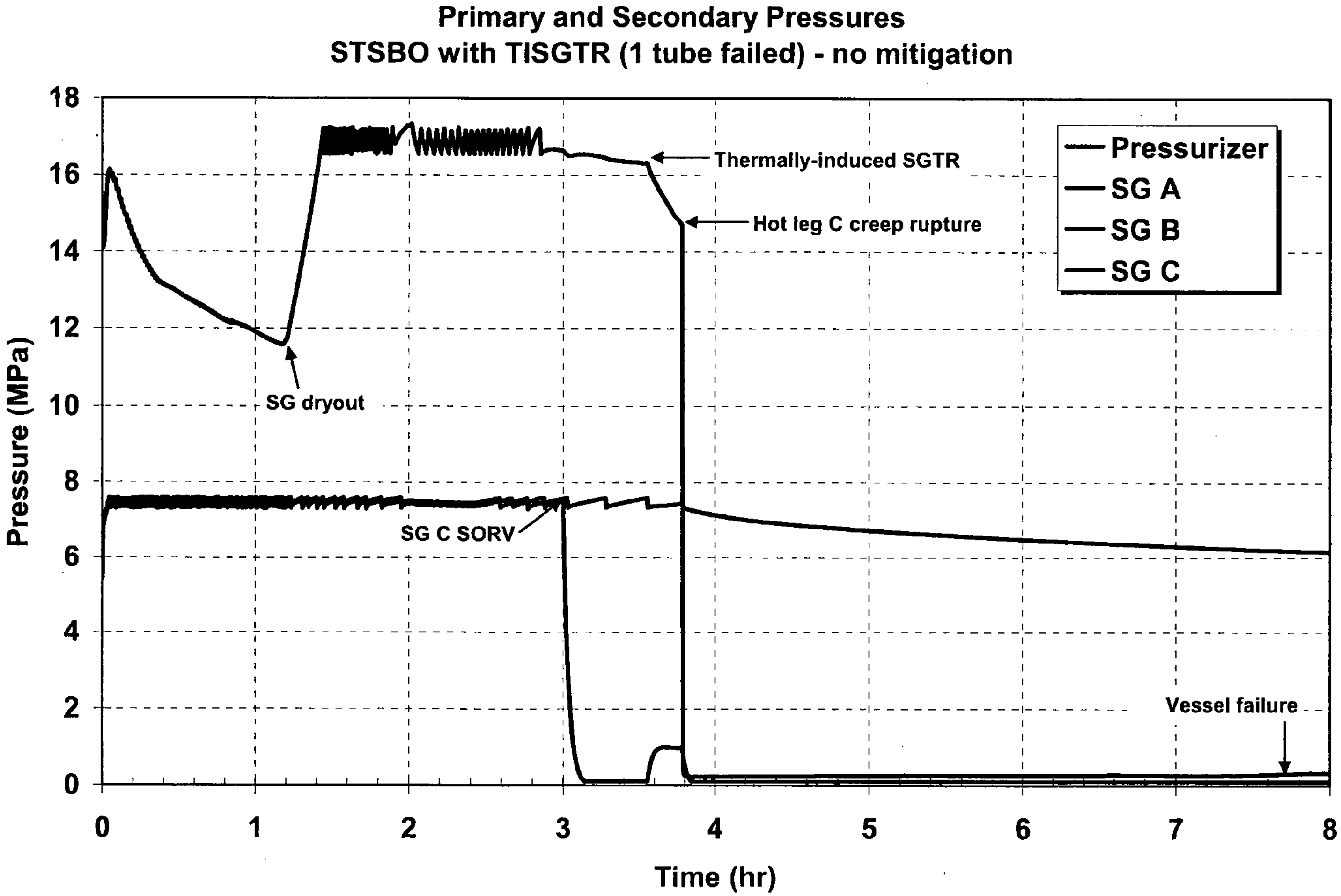
Recent Analysis

- Analysis since 2007 ACRS meeting on SOARCA
  - Accident progression and source term
    - Surry STSBO with thermally induced SGTR
    - Surry ISLOCA
    - Peach Bottom STSBO

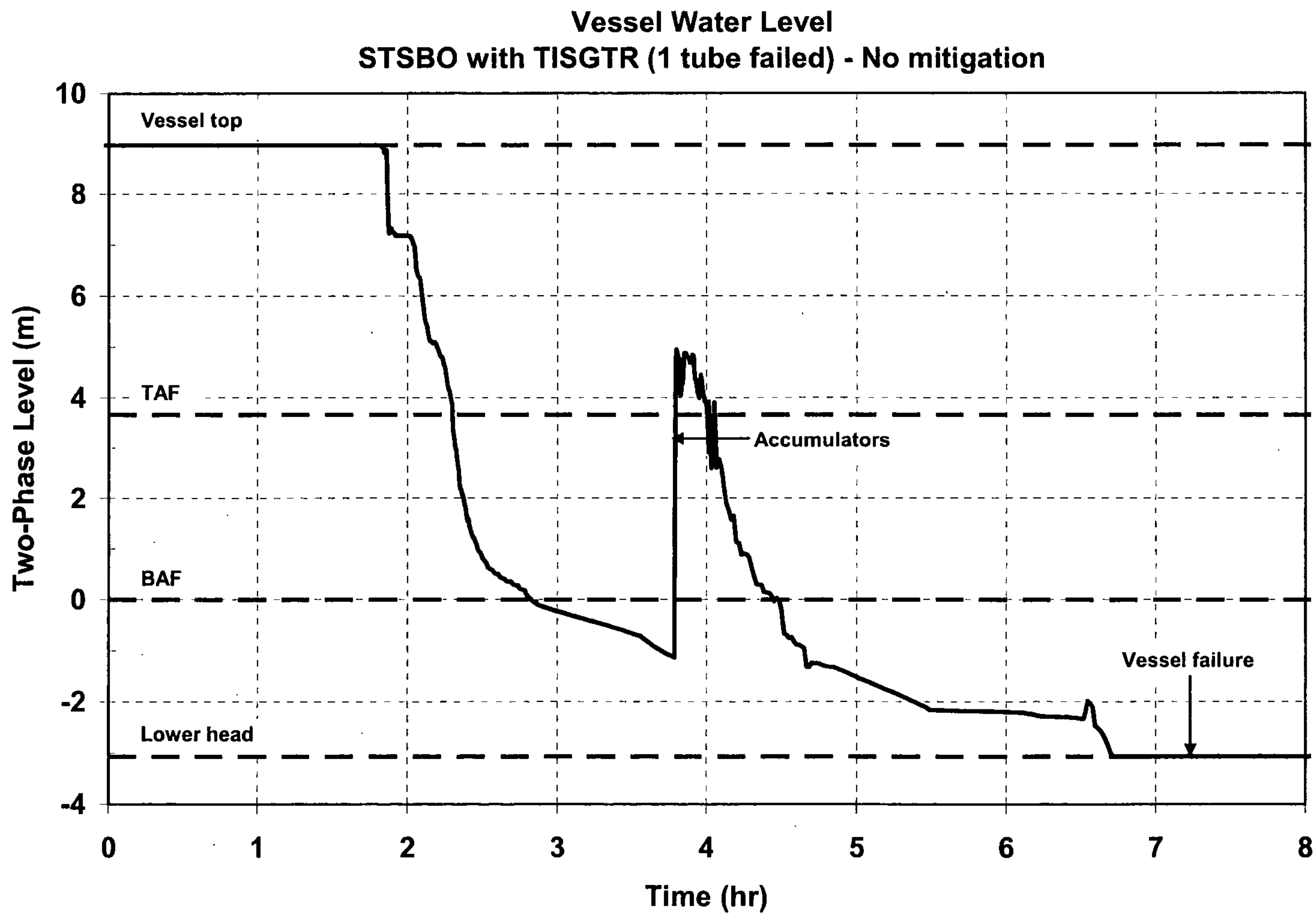
Surry Thermally Induced SGTR

- SOARCA analyses built upon body of T/H (natural circulation) and severe accident analysis done to address this generic issue
  - Westinghouse 1/7th scale experiments
  - CFD (FLUENT)
  - SCDAP/RELAP5
  - VICTORIA
  - ARTIST experiments
- MELCOR SOARCA analyses first revealed that regardless of whether SG tube fails first (due to flaws), the potential for early hot leg failure is very high
  - Confirmation (again) of the value of integrated, consistent analysis

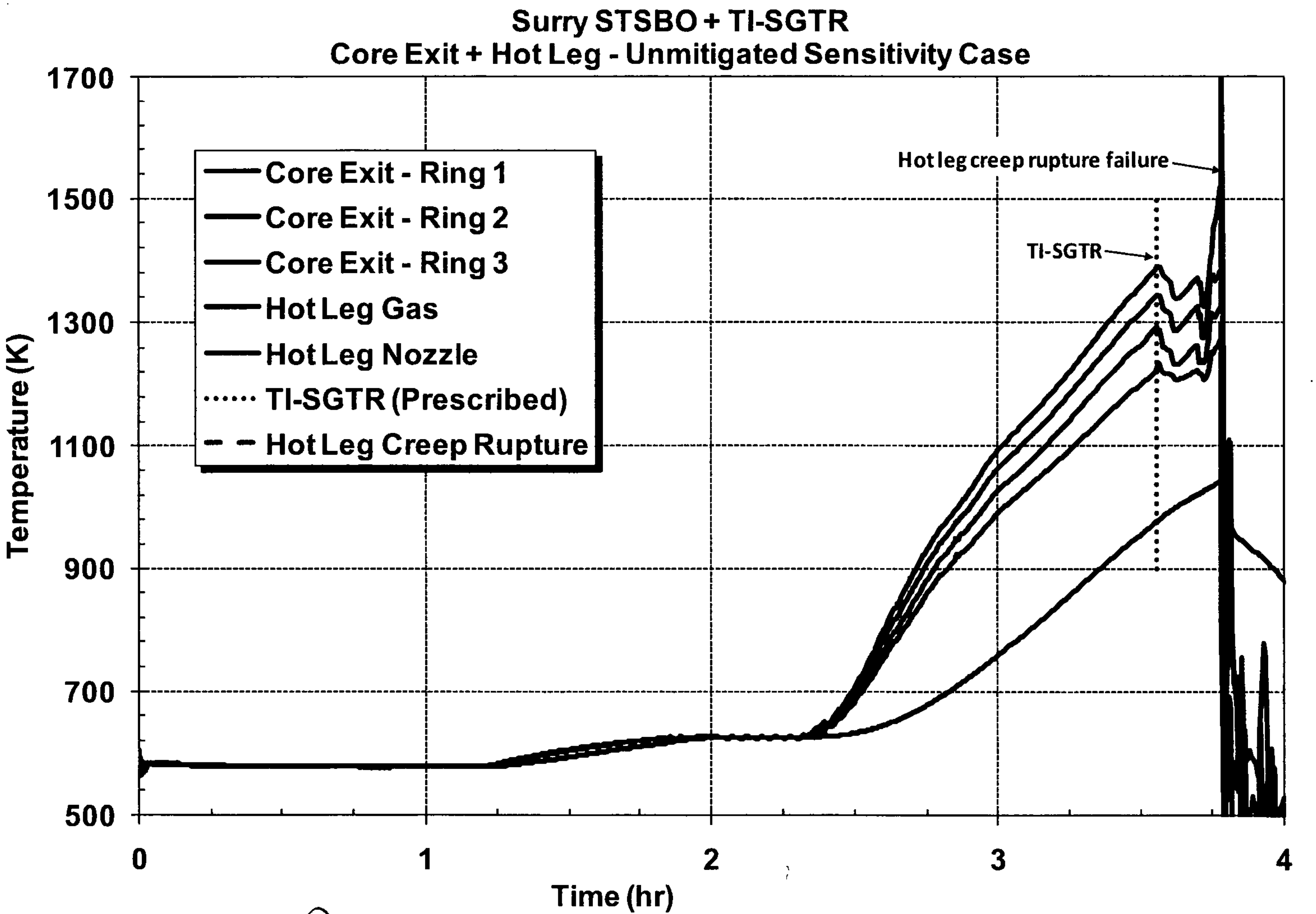
Surry Thermally Induced SGTR – Unmitigated Sensitivity Case



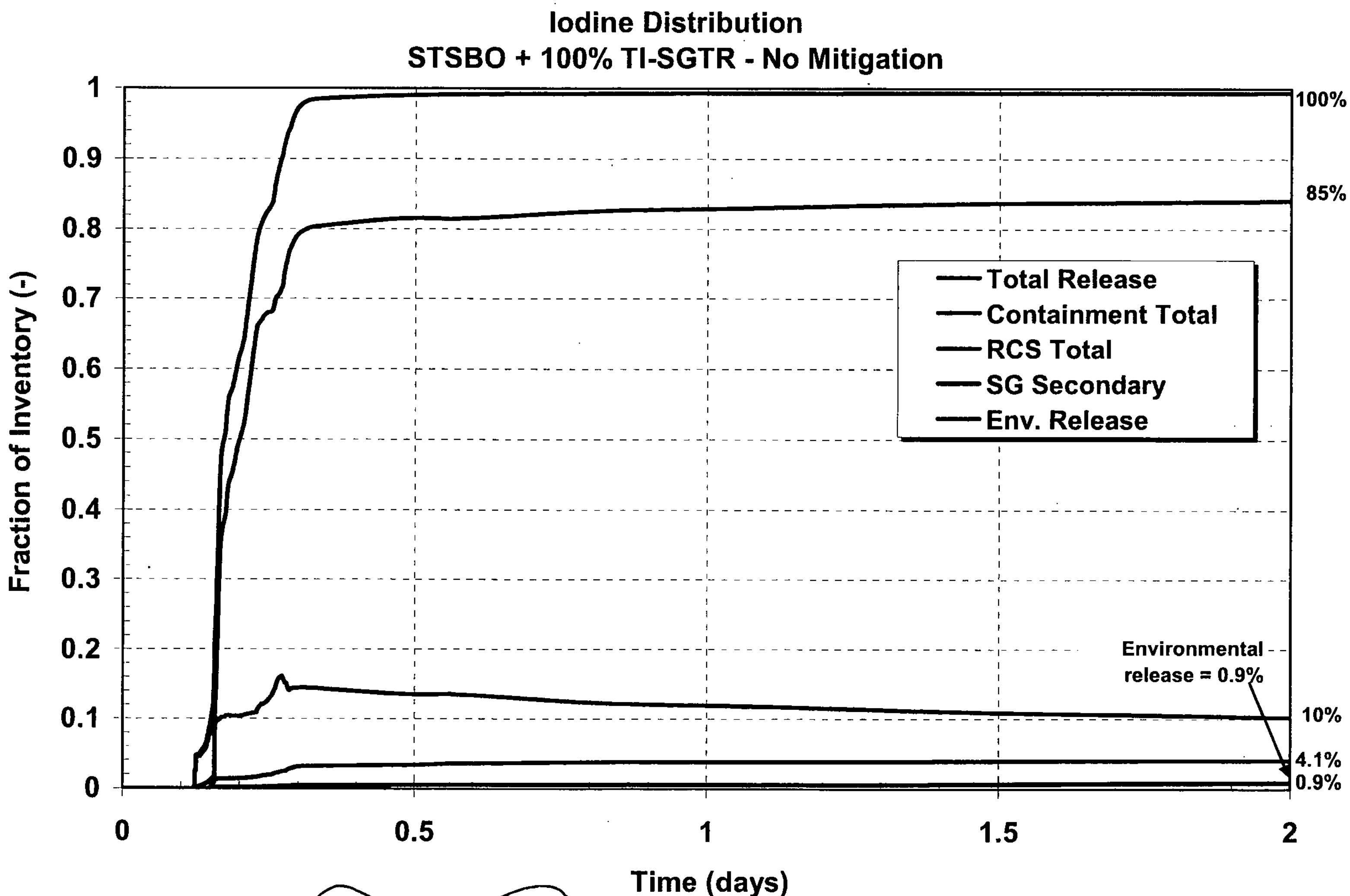
Surry Thermally Induced SGTR – Unmitigated Sensitivity Case



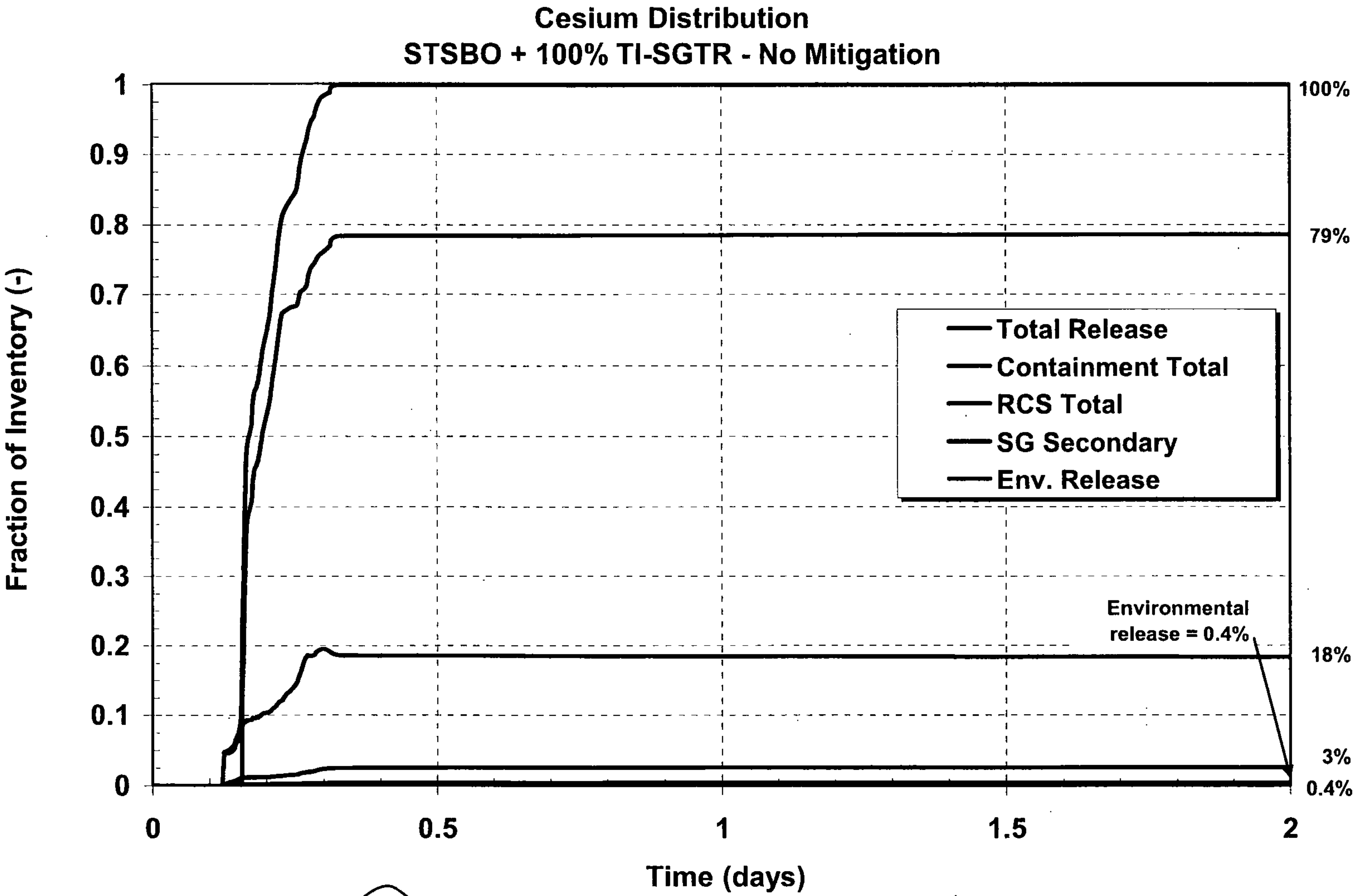
Surry Thermally Induced SGTR – Unmitigated Sensitivity Case



Surry Thermally Induced SGTR – Unmitigated Sensitivity Case



Surry Thermally Induced SGTR – Unmitigated Sensitivity Case



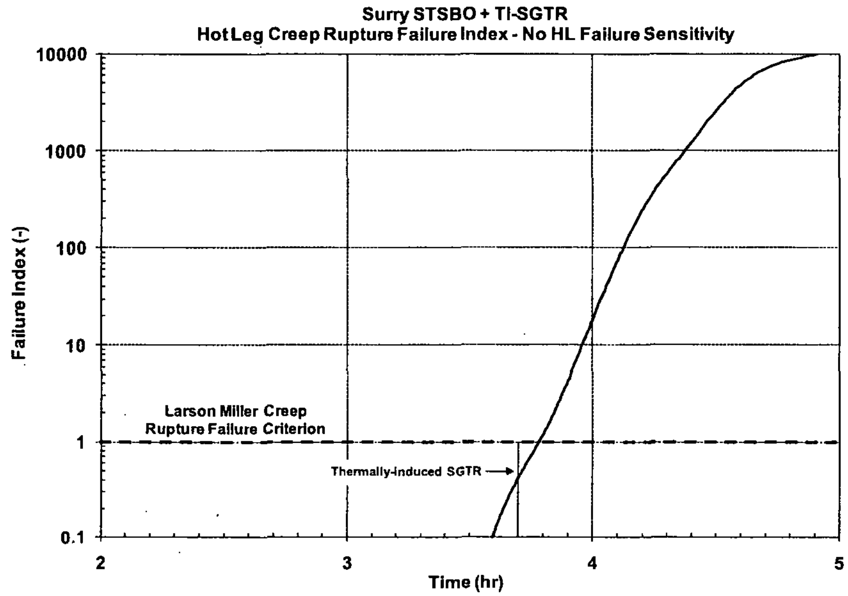
Surry Thermally Induced SGTR – Peer Review

- Peer review focused on uncertainties, not so much on challenging best-estimate
  - Creep damage index, margins
  - Gaseous iodine

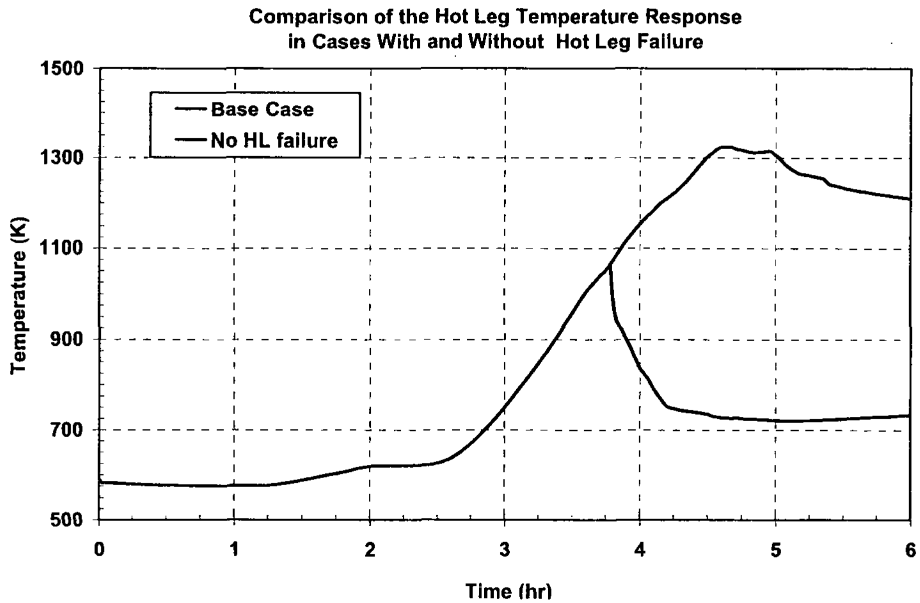
Uncertainties in RCS Failures Counterpart SCDAP/RELAP5 Analyses

- SCDAP/RELAP5 analyses performed using latest FLUENT modeling and modeling for hottest tube, NTR (normalized temperature ratio) = 0.5
- 2 cases modeled a single DE tube rupture
  - Tube rupture predicted for tube with assumed stress multiplier of 2.0 on the hottest tube (occurs at 03:46)
    - Hot leg failed 1.2 min later
  - Tube rupture predicted for tube with assumed stress multiplier of 3.0 on the hottest tube (occurs at 03:39)
    - Hot leg failed 8.8 min later
- Additional extreme case modeled as multiple tube rupture (with stress multiplier of 2.0)
    - Hot leg failed 1.3 min later
- Counterpart SR5 hottest tube calculations confirm hot leg fails shortly after tube rupture for assumed seriously flawed tube (just above the tube sheet)
  - MELCOR prediction is slightly conservative

Unmit. STSBO w/TI-STGR – T/H Response



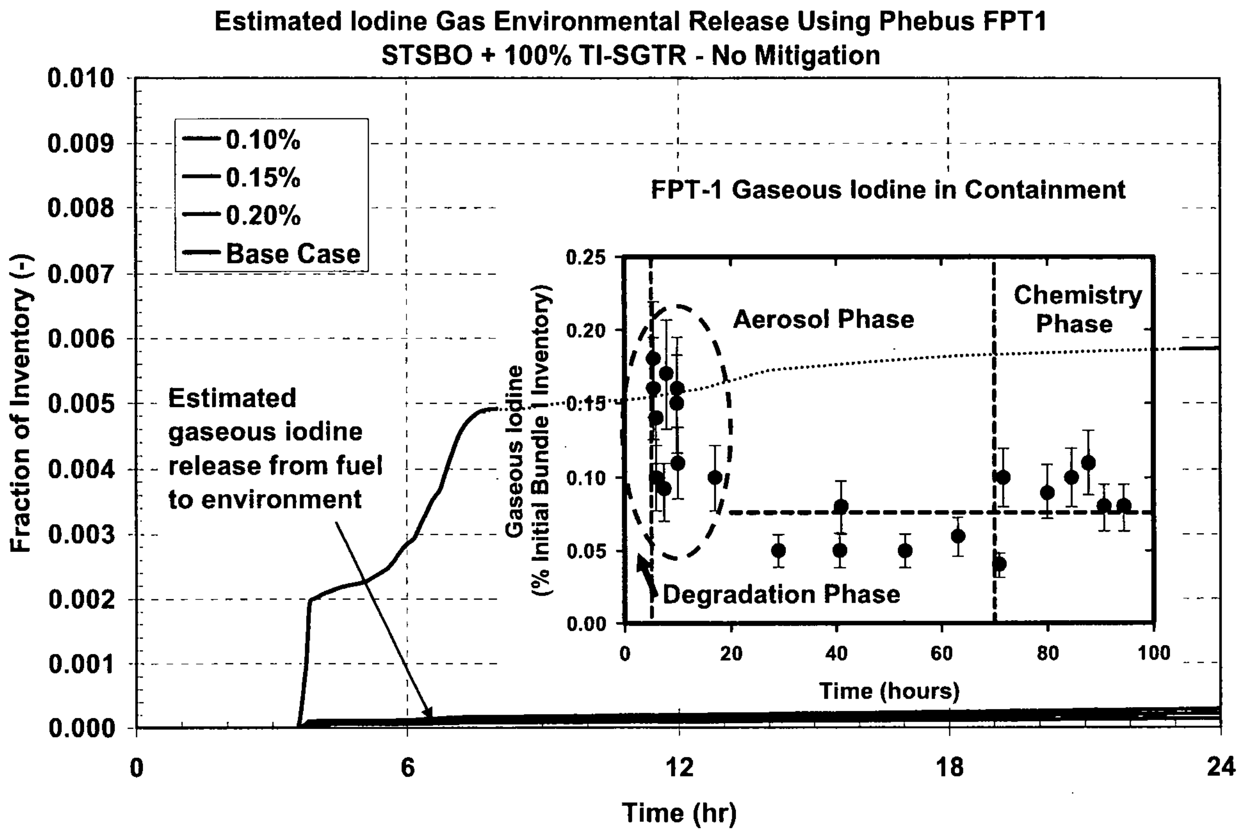
- Hot leg nozzle continues to heat following SG tube failure
  - ~250 K hotter than base case



- No hot leg nozzle failure considered incredible
  - Larson Miller index 4-orders of magnitude above failure criterion
  - High sensitivity to thermal stress at >1000 K

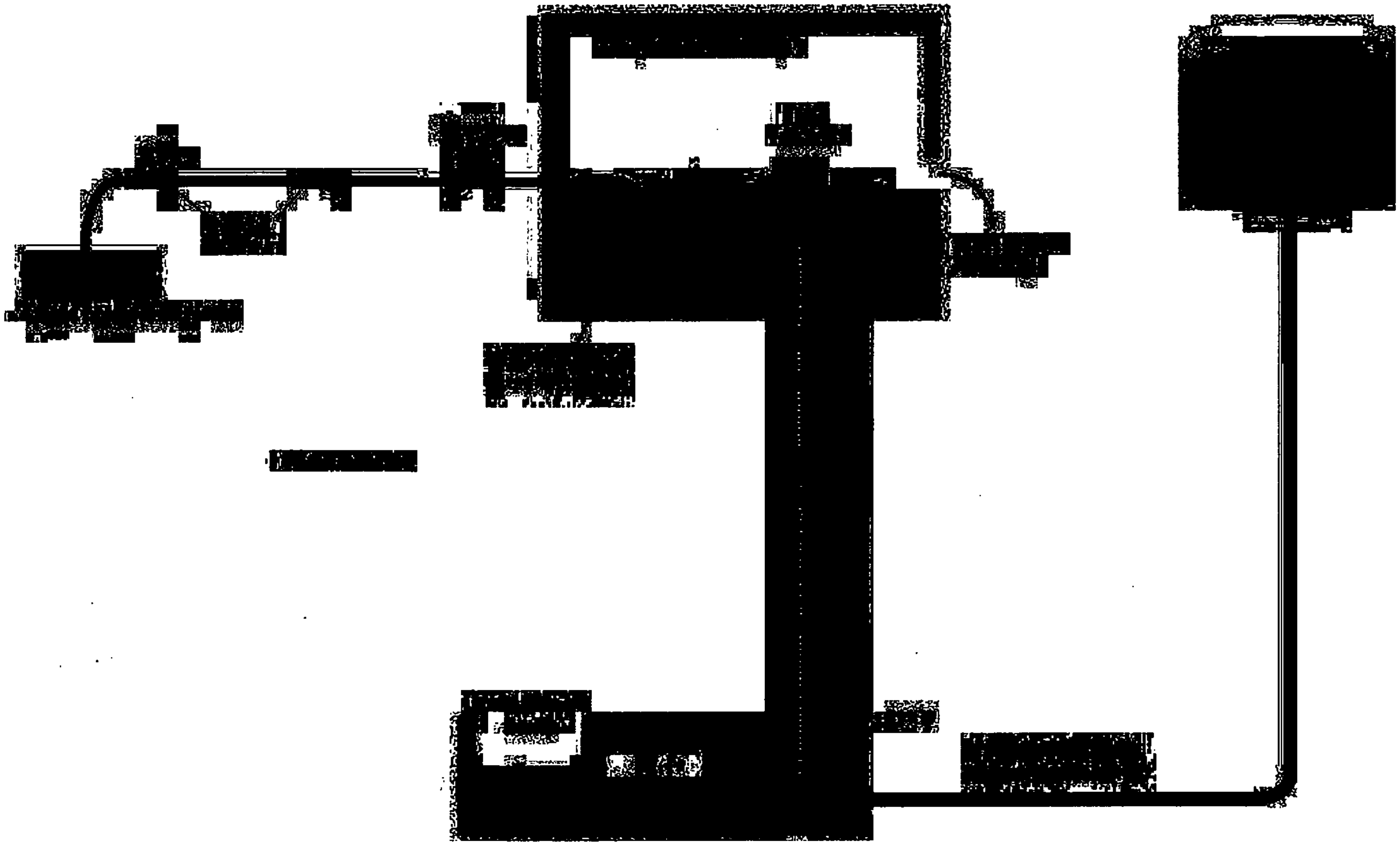
Uncertainties in Iodine Chemical/physical Behavior

- Used Phebus FPT1 data to estimate additional STSBO w/TI-SGTR source term
- Phebus FPT1 containment data shows early ~0.08 – 0.18% release of gaseous iodine
- Gaseous iodine would pass through TI-SGTR to environment with little retention
- Not significant relative to iodine aerosol release

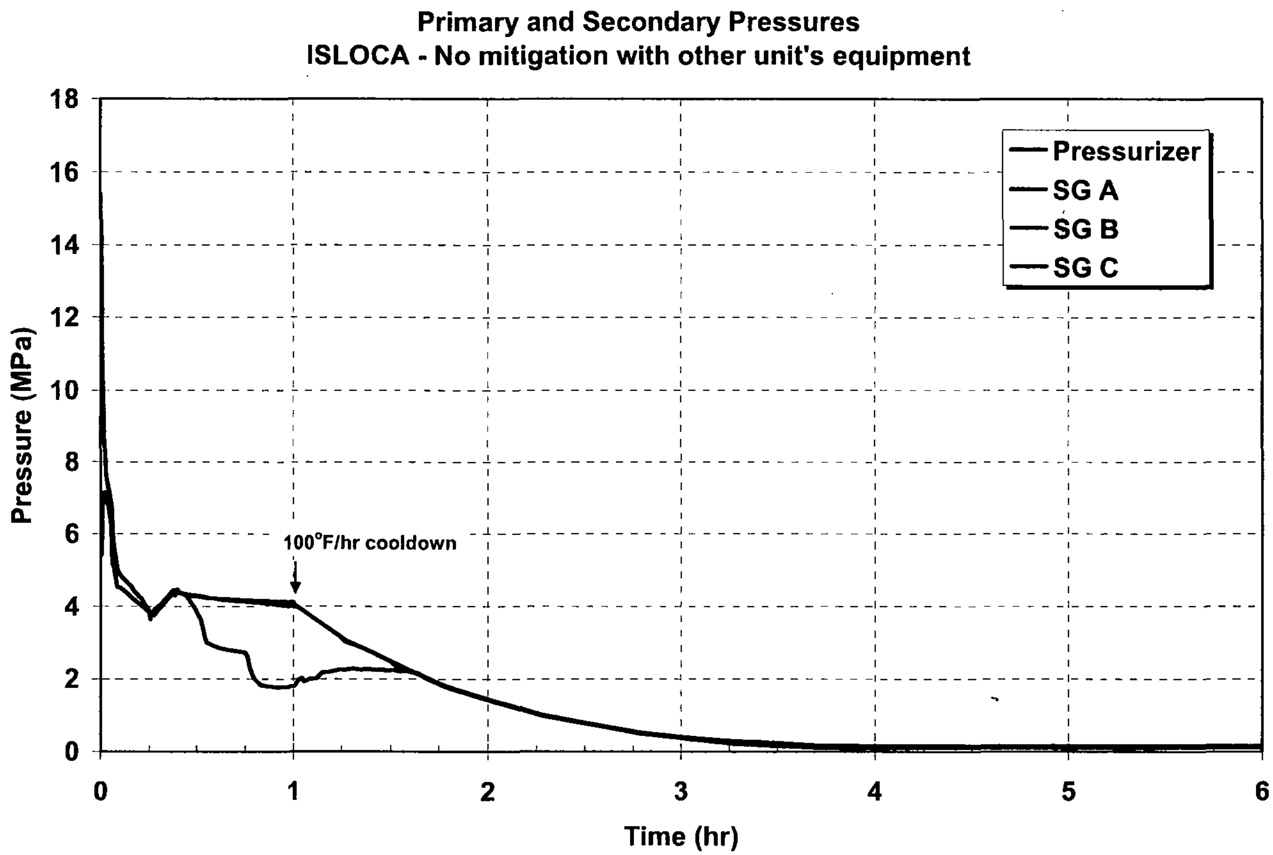


Surry ISLOCA

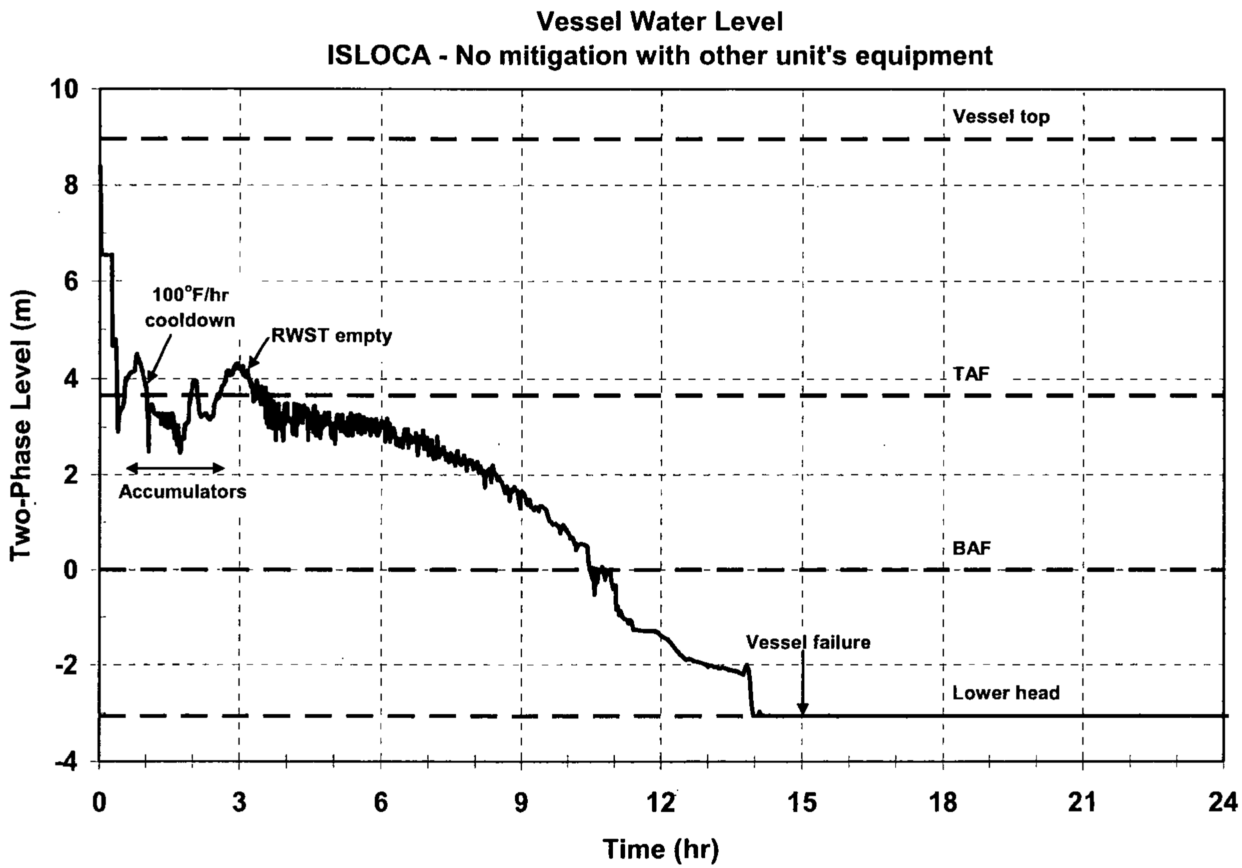
- Initial condition
  - Common mode failure of both inboard check valve disks results in overpressurization of LHSI piping in the Safeguards Bldg



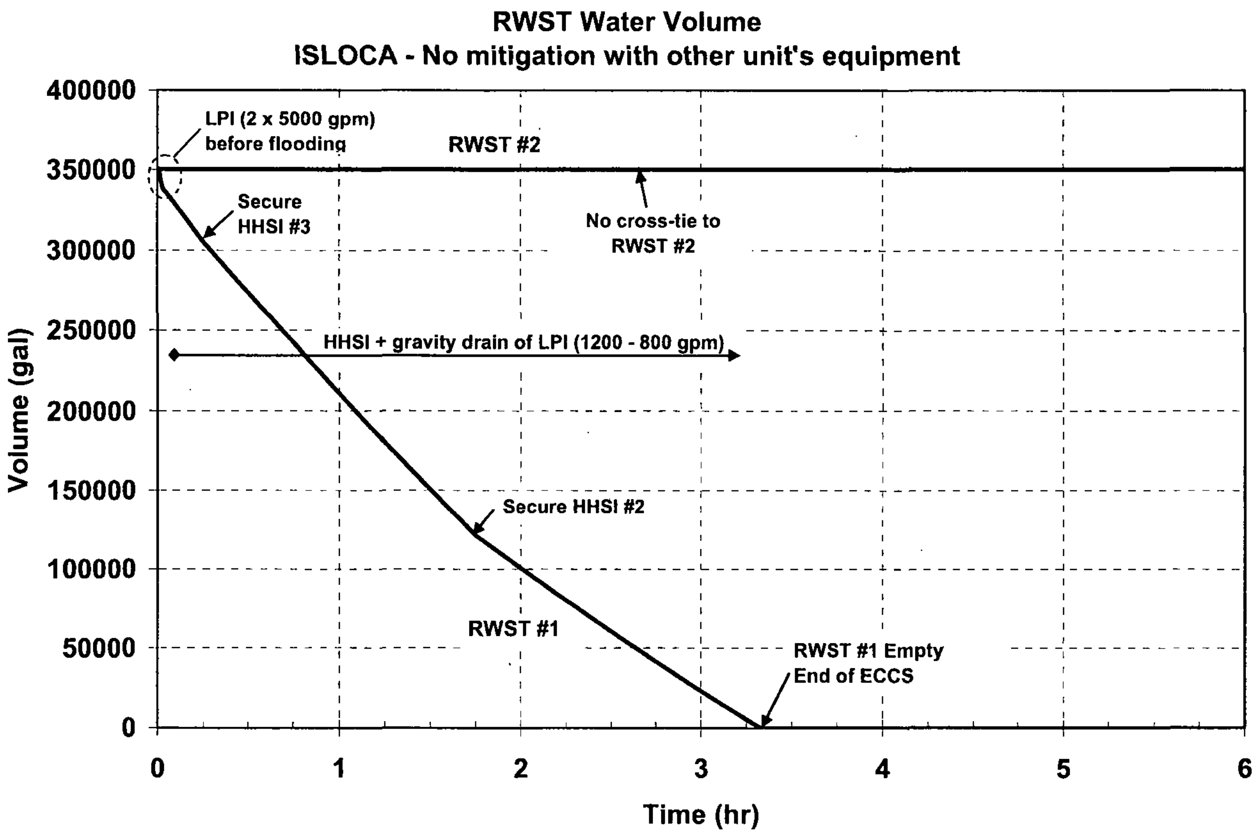
Surry ISLOCA – Unmitigated Sensitivity Case



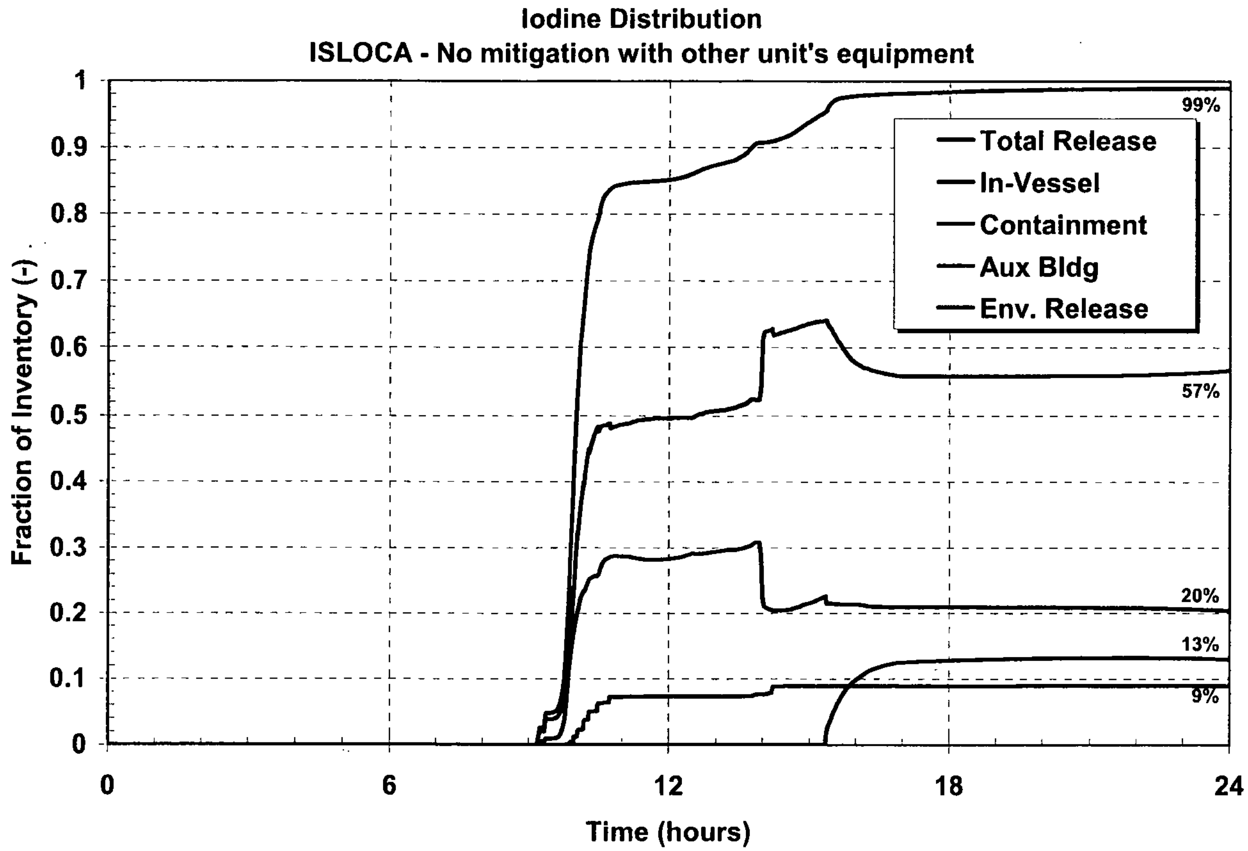
Surry ISLOCA – Unmitigated Sensitivity Case



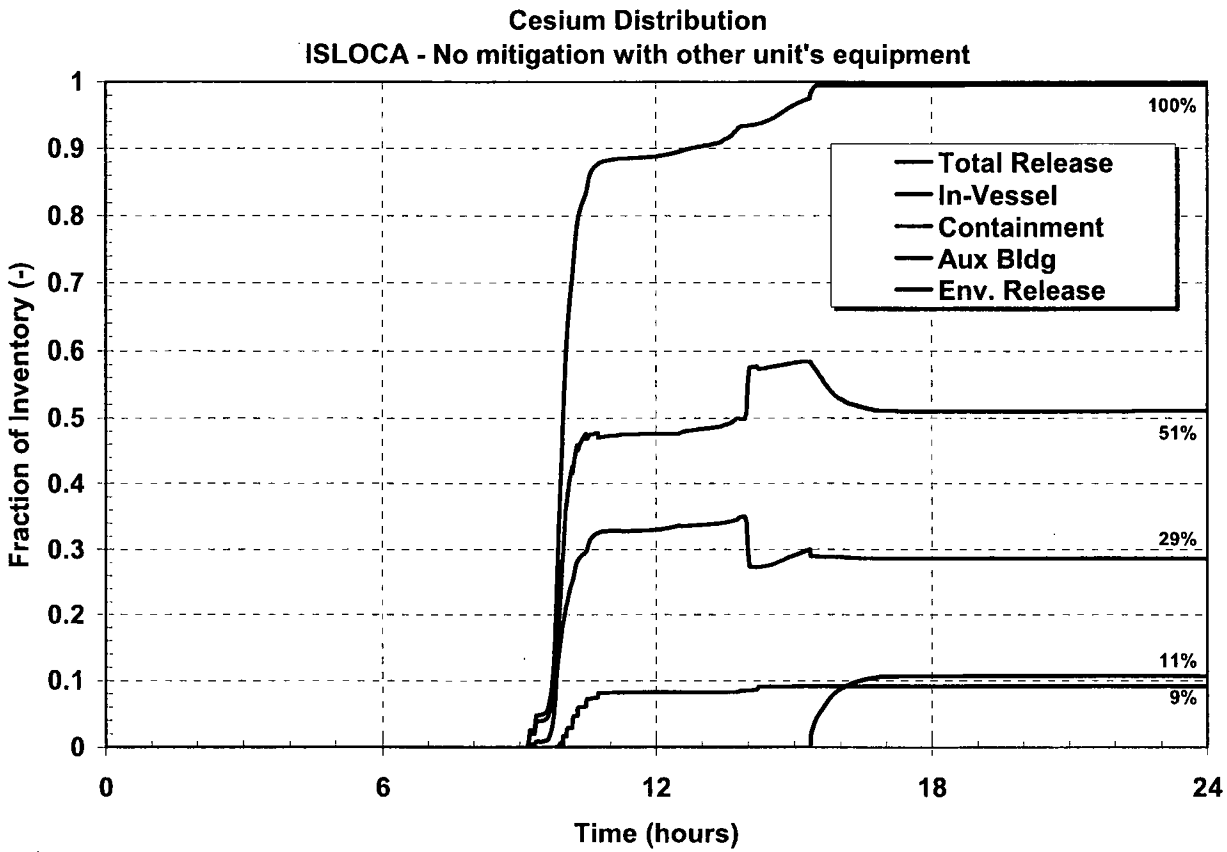
Surry ISLOCA – Unmitigated Sensitivity Case



Surry ISLOCA – Unmitigated Sensitivity Case



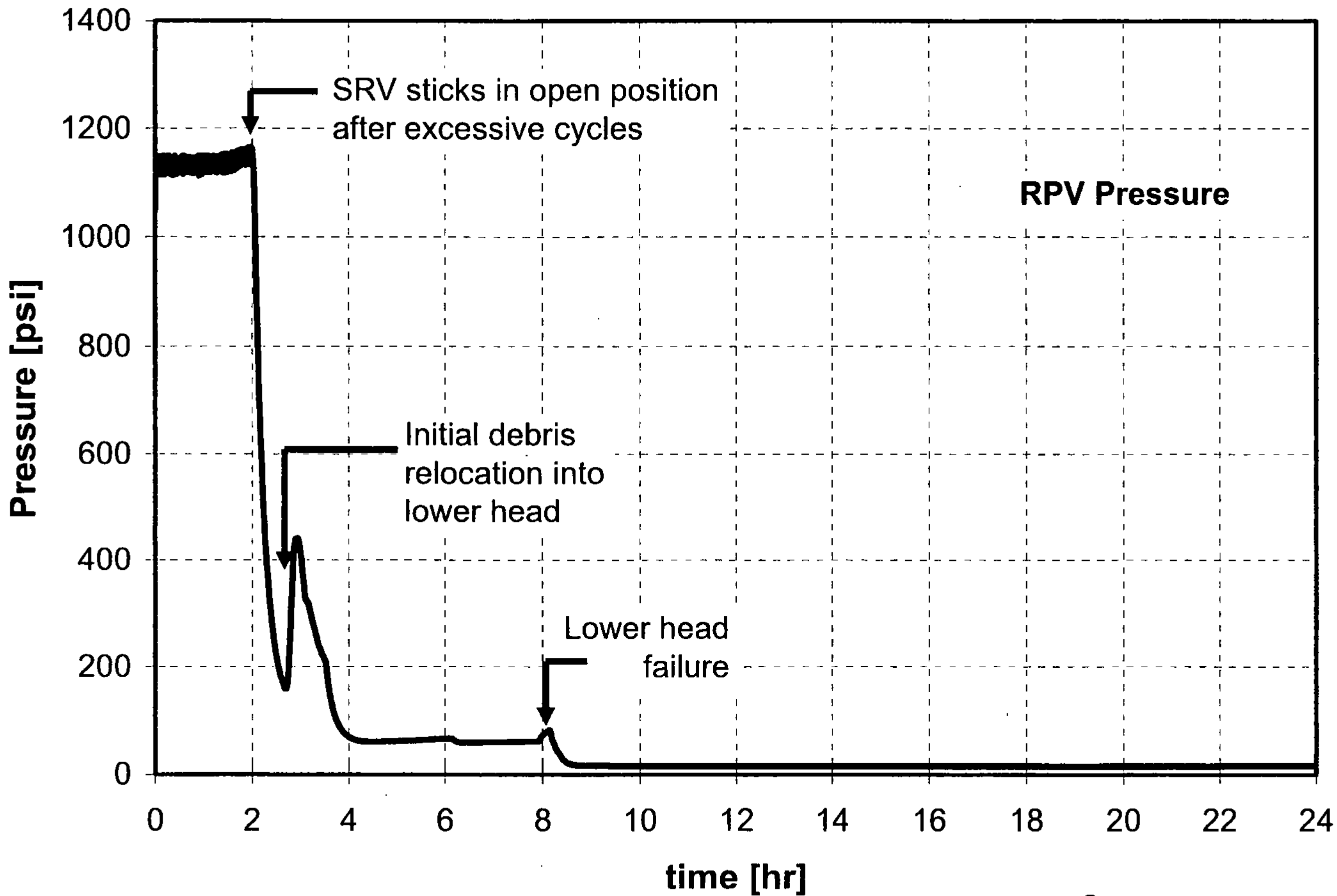
Surry ISLOCA – Unmitigated Sensitivity Case



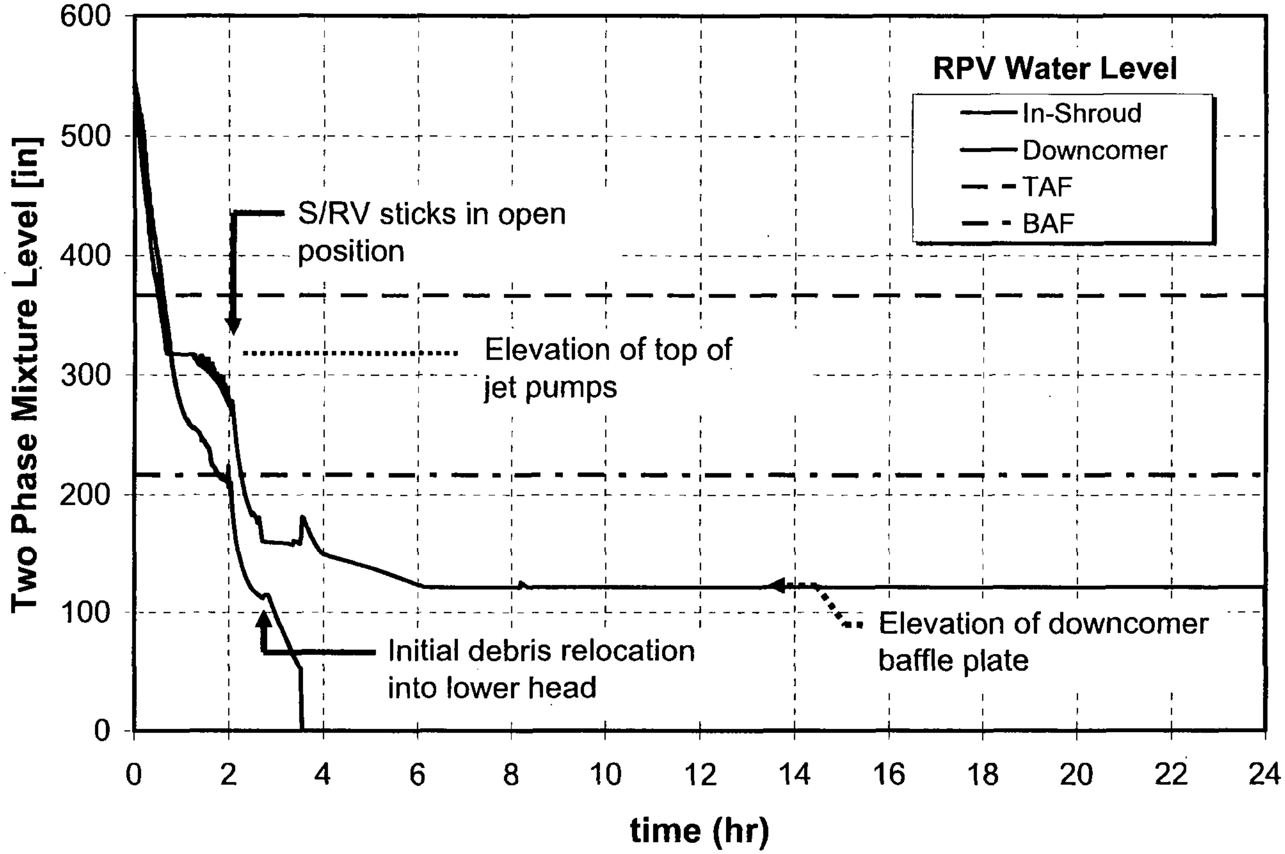
Peach Bottom STSBO

- Scenario added to address ACRS comments regarding completeness
- CDF is $3x10^{-7}$/yr (assumes likelihood of B.5.b mitigation is 0)
- Two cases analyzed
  - No RCIC black-start
  - RCIC black-start and no level indication, resulting in vessel overfill and RCIC termination due to water in RCIC turbine

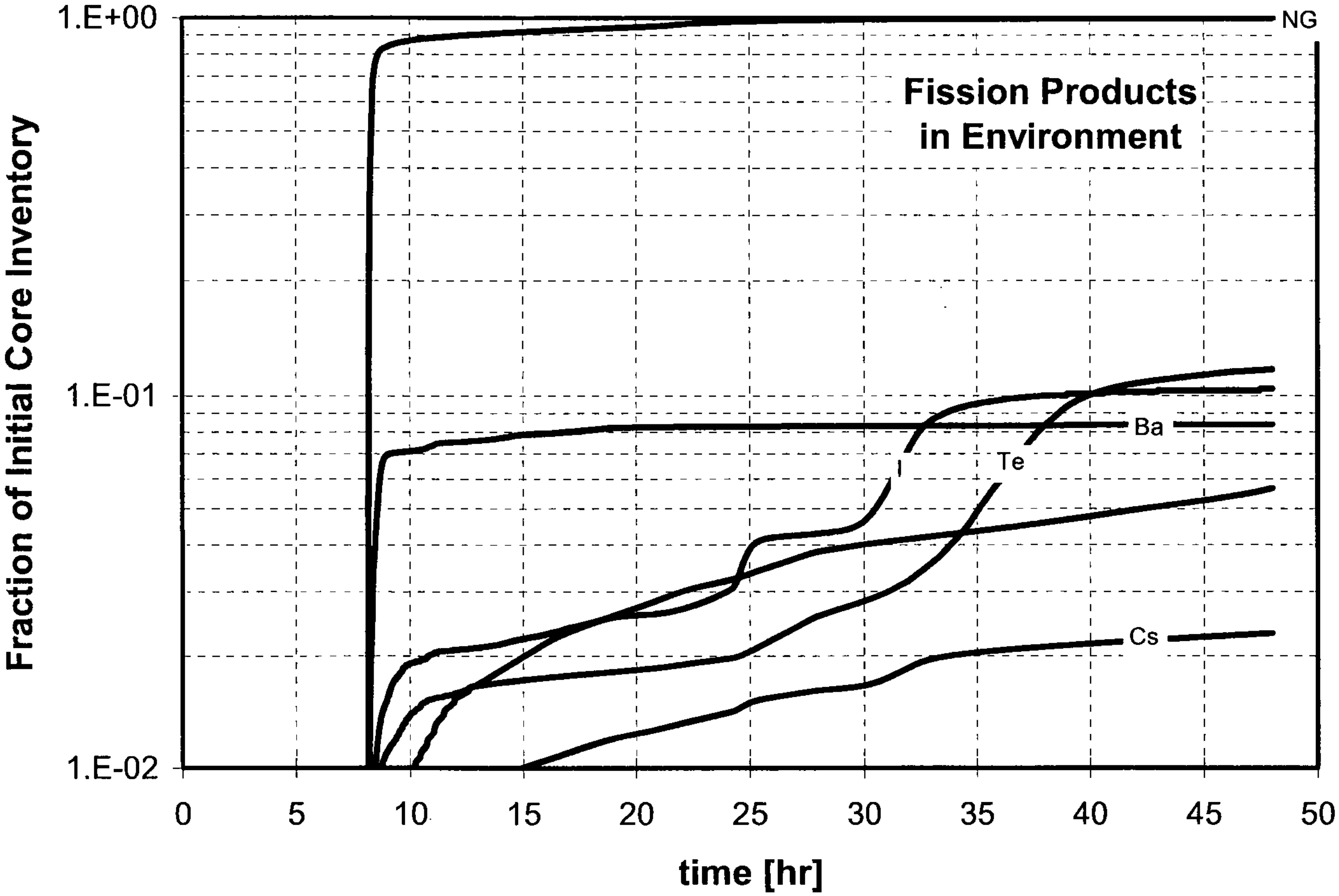
Peach Bottom STSBO – No RCIC Black-start



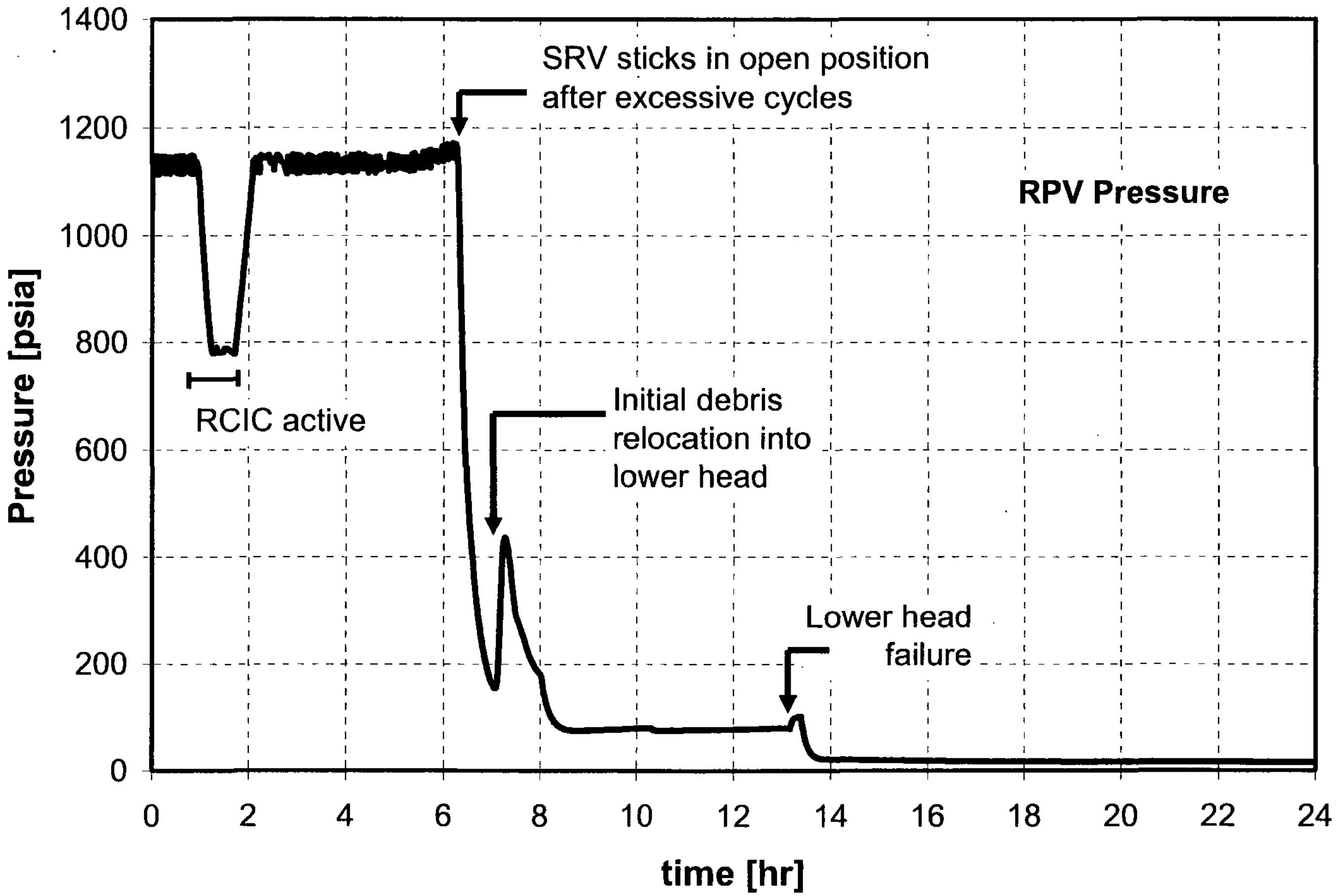
Peach Bottom STSBO – No RCIC Black-start



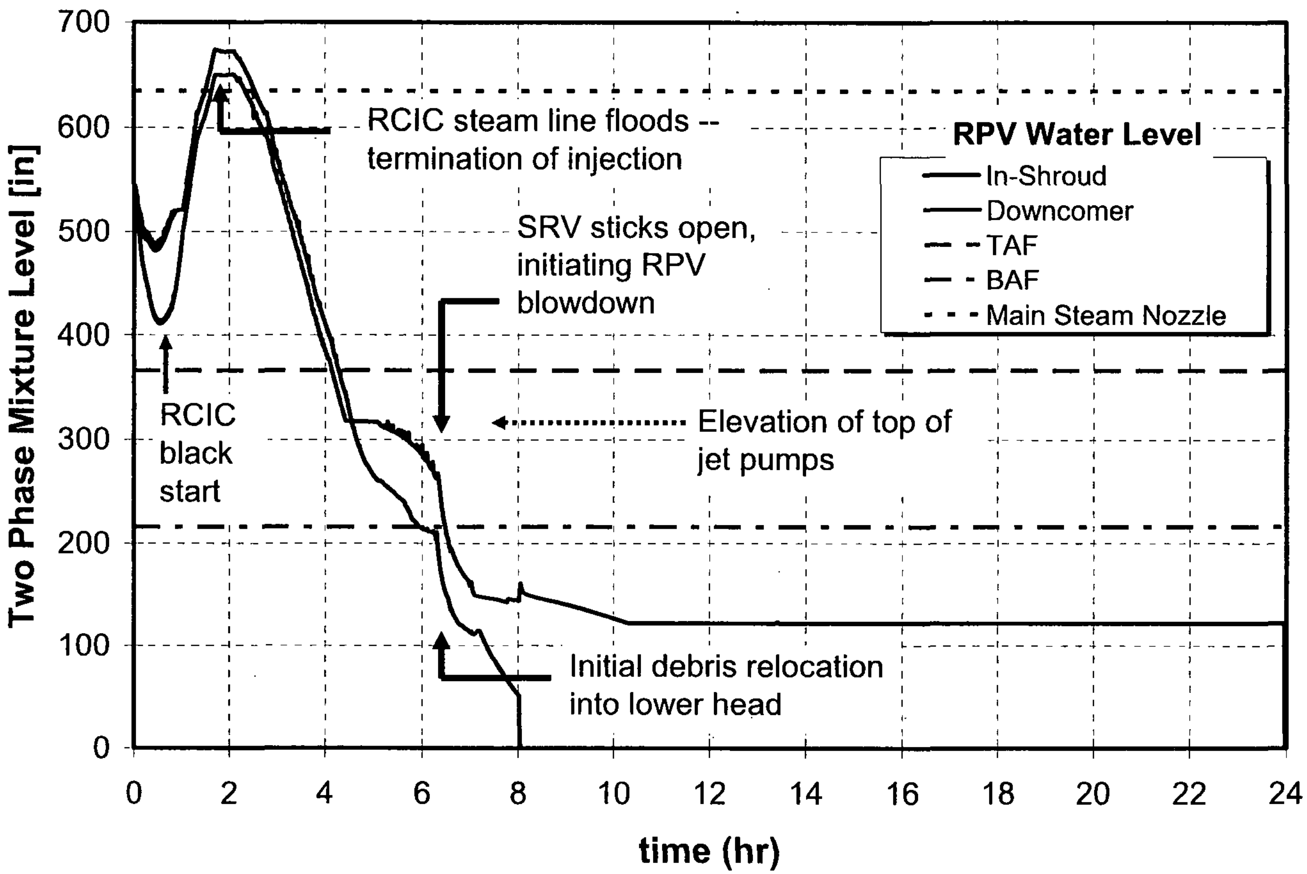
Peach Bottom STSBO – No RCIC Black-start



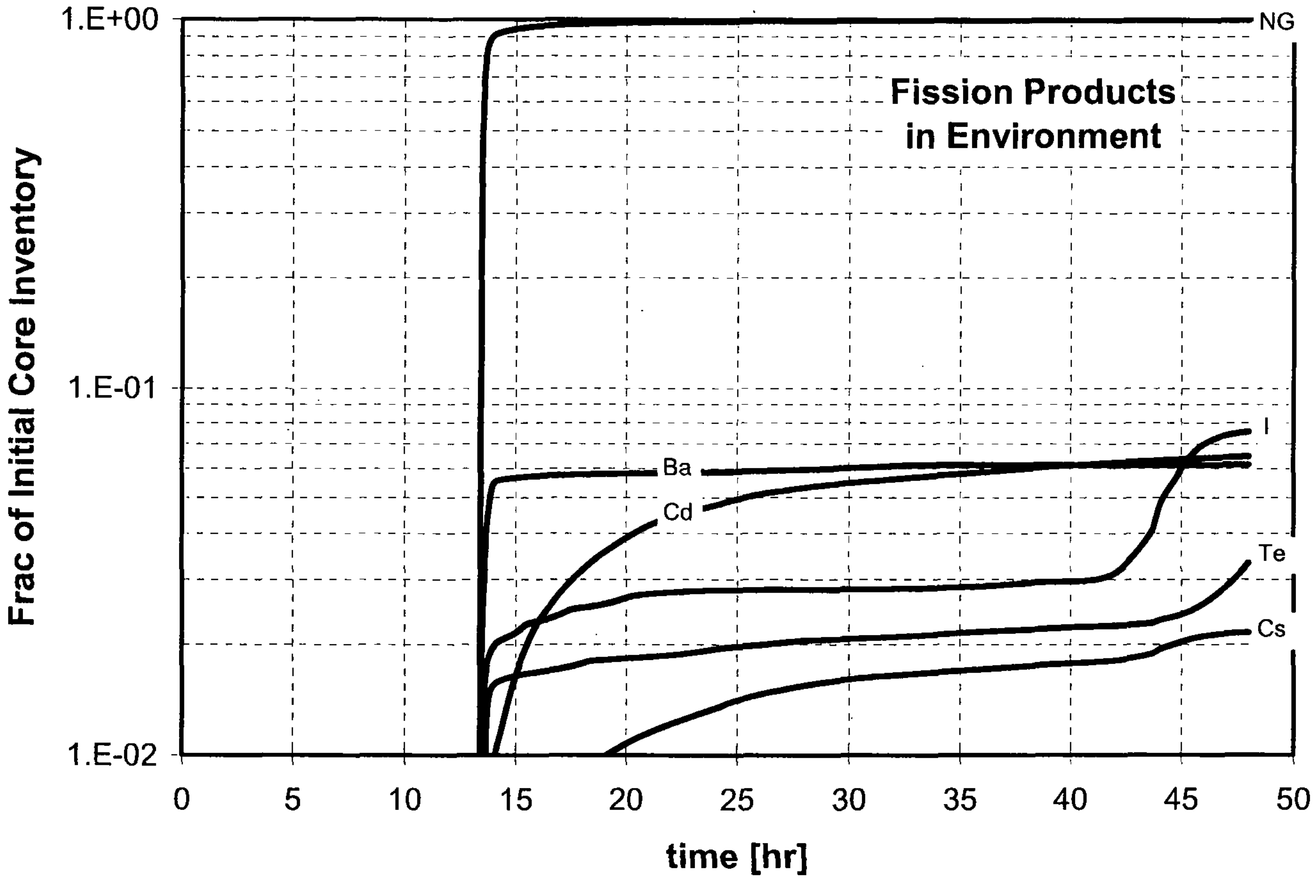
Peach Bottom STSBO – RCIC Black-start and Overfill



Peach Bottom STSBO – RCIC Black-start and Overfill



Peach Bottom STSBO – RCIC Black-start and Overfill



SOARCA
Off-Site Consequences

Jocelyn Mitchell, RES/DSA
ACRS Subcommittee Meeting
June 21, 2010

Outline

- MELMACCS
- MACCS2 Inputs and Modeling
- Results
- Conclusions

MELMACCS

- Source term
  - Transfers source term from MELCOR to MACCS2
  - Includes: timing, height, heat, radionuclide inventory (9 chemical bins), aerosol size (10 aerosol bins)
  - 1-hour plume segments
- Dry deposition velocity
  - Input wind speed, choice of percentile, surface roughness
  - Equation and parameters from US/CEC study
  - Bin aerosol sizes correspond to MELCOR

MACCS2 Inputs and Modeling

- Non-site-specific data from US/CEC Study
  - Only "measurable" parameters
  - Teams of experts from US and Europe
  - More than 100 questions based on PIRT-like process
    - Significant or moderate influence on results
  - Used 50th percentile in SOARCA
- Meteorological data from sites
  - Surry 2004, Peach Bottom 2005
- Population data from SECPOP

MACCS2 Inputs and Modeling (continued)

- Atmospheric Dispersion and Transport Modeling
  - Compass directions: 64 vs 16
  - Morning and afternoon mixing heights
  - Briggs plume rise model, better NIST comparison
  - Long range plume spreading, distance model
  - Non-uniform weather bin sampling
    - About 1,000 samples for SOARCA

MACCS2 Inputs and Modeling (continued)

- Early Phase
  - Relocation parameters
    - 5 rem/wk hot spot and 1 rem/wk normal
      - EPA guidelines for considering emergency action
    - Timing based on estimated availability of personnel after evacuation complete
  - Dose conversion factors from FGR-13
    - “Residual” cancer “tissue” from pancreas
  - LCF Risk Factors from BEIR V
    - Values for tissues from Eckerman
    - BEF=20 (for high LET)
      - except breast=10, bone marrow=1

MACCS2 Inputs and Modeling (continued)

- Early Phase (continued)
  - Shielding from NUREG-1150, regional specific
    - Normal: 81% inside, 19% outside
  - KI ingestion
    - 50% take, non-optimal time

MACCS2 Inputs and Modeling (continued)

- Late Phase
  - Habitability criterion
    - PB uses PA-specific 500 mrem/yr
    - Surry uses implementation of EPA 4 rem/5 yr
    - "Voluntary," but costly
    - DHS suggesting 19 criteria optimization
  - No food/water pathway
    - Uncontaminated food available from outside
  - Economic parameters from NUREG-1150
    - Inflation adjusted
    - Costs not reported, but economic model affects doses

MACCS2 Inputs and Modeling (continued)

- Dose-Response Modeling for LCF
  - No unanimity on dose-response at low doses (<10 rem)
    - Opinion ranges from supralinear to hormesis
  - SOARCA History
    - Last ACRS meeting SOARCA was to use HPS position (5 rem/yr, 10 rem lifetime)
    - SECY-08-0029 changed to individual risk of LCF for LNT and threshold of 10 mrem for 0-10, 0-50, 0-100 miles from site
      - Now only report 0-10 and 0-50 miles from site
    - Almost no difference in LCF 0-50 miles for LNT and 10 mrem
    - Add 2 more thresholds
      - 620 mrem/yr U.S. average dose (including medical)
      - HPS position
  - SOARCA now has a range of dose-response models
    - LNT; 10mrem/yr; 620mrem/yr; 5 rem/yr or10 rem lifetime

MACCS2 Inputs and Modeling (continued)

- Dose-Response Modeling for LCF (continued)
  - DDREF
    - =2 (except for breast =1)
    - Late Phase applies to all doses
    - For early phase, apply if whole body dose <20 rem
- Threshold applied as truncation of LNT model

Results – Early Fatality Risks

- Both mitigated and unmitigated cases of the scenarios examined predict that essentially no early fatalities will occur
  - The average individual early fatality risk is essentially zero for the only case, Surry Unmitigated ISLOCA, that predicts early fatalities

Surry Results – LCF Risks (Assuming LNT Dose-Response Model)

Scenario	Core damage frequency* (per reactor-year)	Average Latent Cancer Fatality Risk for an Individual Located Within 10 miles				
		With Deployed Mitigation		Without Deployed Mitigation		Percent Risk Reduction from Deployed Mitigation
		Conditional risk (per event)	Scenario risk (per reactor-year)	Conditional risk (per event)	Scenario risk (per reactor-year)	
Long-term SBO	$2x10^{-5}$	No core damage		$5x10^{-5}$	$7x10^{-10}$	100%
Short-term SBO	$2x10^{-6}$	No containment failure		$9x10^{-5}$	$1x10^{-10}$	100%
Thermally induced-SGTR**	$4x10^{-7}$	$2.8x10^{-4}$	$1x10^{-10}$	$3.2x10^{-4}$	$1x10^{-10}$	13%
Spontaneous STGR	$5x10^{-7}$	No core damage		Core damage prevented		100%
Interfacing systems LOCA	$3x10^{-8}$	No core damage		$8x10^{-4}$	$2x10^{-11}$	100%

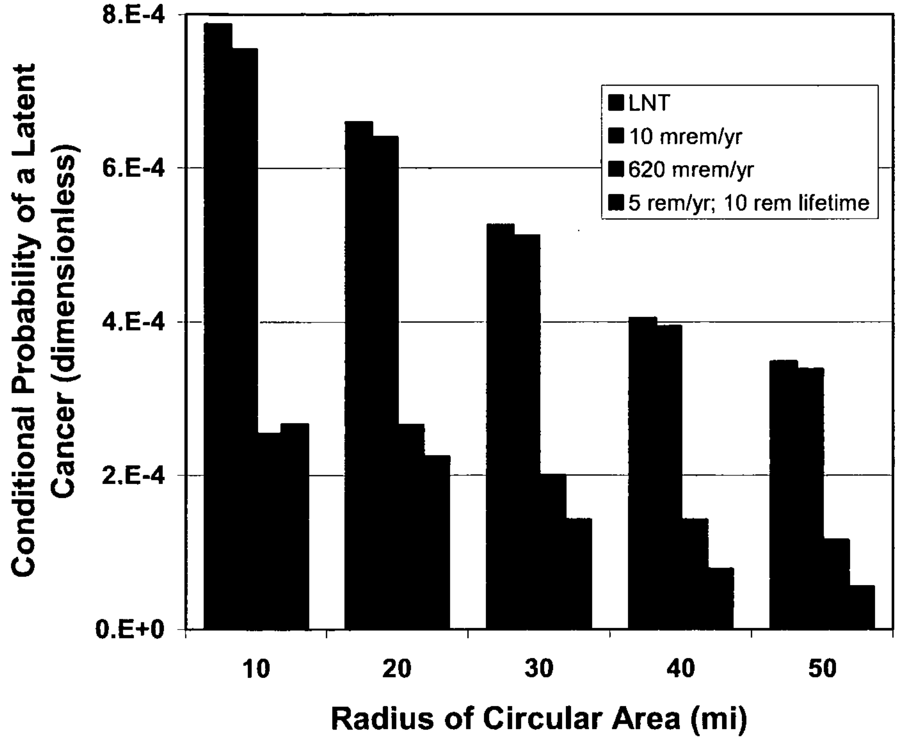
*As determined by NRC's SPAR model (i.e., before consideration of mitigation measures).
**Scenario is a subset of SBO. It is analyzed for the short-term case because it is more challenging to consequence

Peach Bottom Results – LCF Risks (Assuming LNT Dose-Response Model)

Scenario	Core damage frequency* (per reactor-year)	Average Latent Cancer Fatality Risk for an Individual Located Within 10 miles				
		With Deployed Mitigation		Without Deployed Mitigation		Percent Risk Reduction from Deployed Mitigation
		Conditional risk (per event)	Scenario risk (per reactor-year)	Conditional risk (per event)	Scenario risk (per reactor-year)	
Long-term SBO	$3x10^{-6}$	No core damage		$2x10^{-4}$	$6x10^{-10}$	100%
Short-term SBO	$3x10^{-7}$	Delayed Release		$2.3x10^{-4}$	$7.0x10^{-11}$	
Short-term SBO with RCIC blackstart**				$2.2x10^{-4}$	$6.7x10^{-11}$	

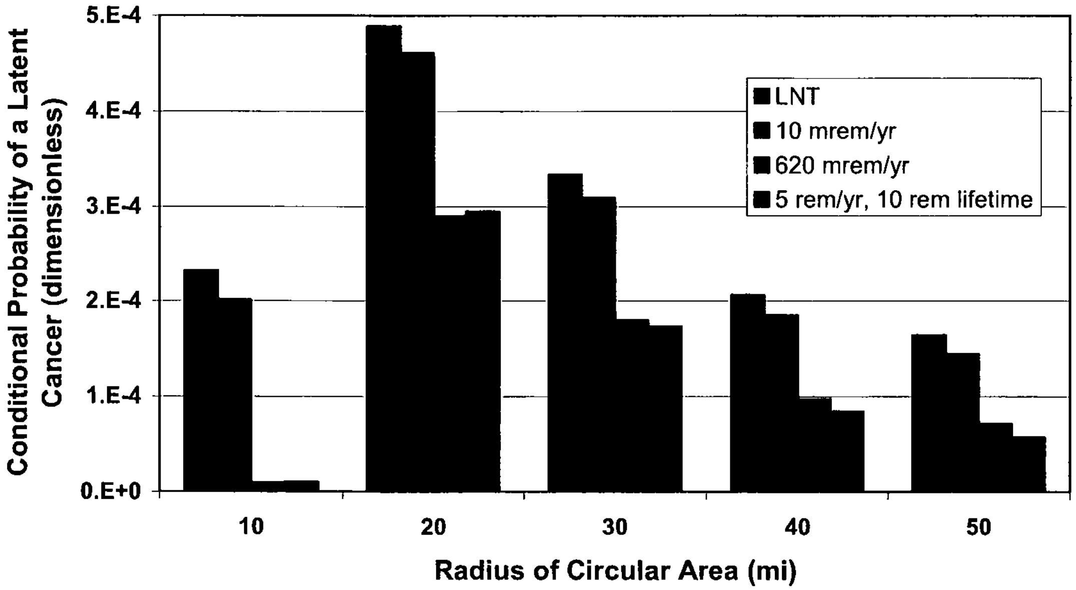
*As determined by NRC's SPAR model (i.e., before consideration of mitigation measures).
**STSBO with RCIC blackstart but RCIC fails later due to steam flooding.

Results – Select Comparison of Dose Response Models



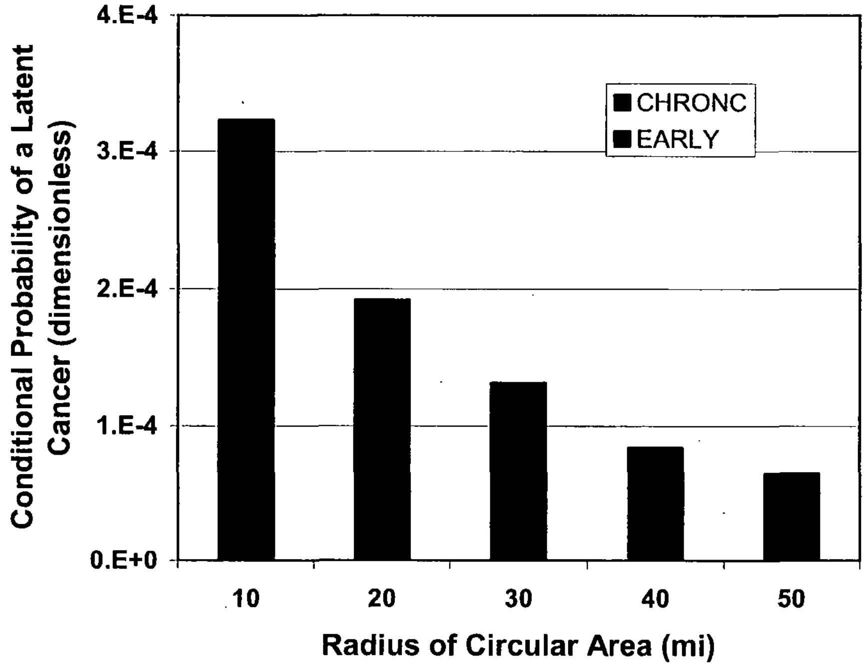
- Conditional, mean, latent cancer fatality probabilities from the Surry unmitigated ISLOCA sequence for residents within a circular area of specified radius from the plant. The plot shows four values of dose truncation level.

Results – Select Comparison of Dose Response Models (continued)



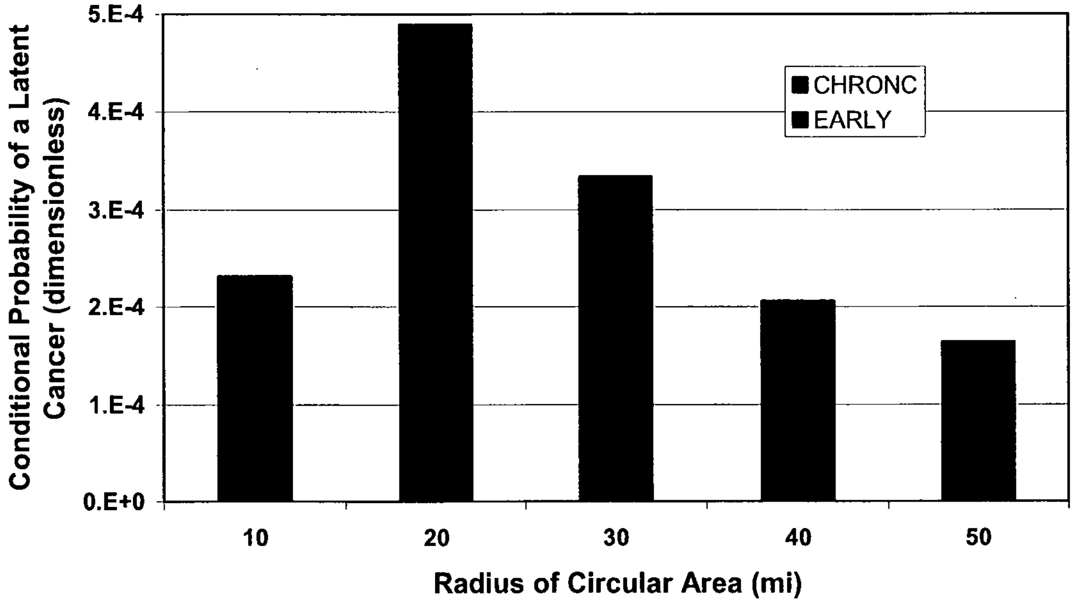
- Conditional, i.e., assuming accident occurs, mean, latent cancer fatality probabilities from the Peach Bottom unmitigated STSBO sequence for residents within a circular area of specified radius from the plant. The plot shows four choices of dose-truncation level.

Results – Select Comparison of Emergency vs. Long-Term Phase



- Conditional, mean, LNT, latent cancer fatality probabilities from the Surry unmitigated STSBO with TISGTR sequence for residents within a circular area of specified radius from the plant. The plot shows the probabilities from the emergency phase (EARLY), long-term phase (CHRONC), and the two phases combined.

Results – Select Comparison of Emergency vs. Long-Term Phase (cont)



- Conditional, i.e., assuming accident occurs, mean, LNT, latent cancer fatality probabilities from the Peach Bottom unmitigated STSBO sequence for residents within a circular area of specified radius from the plant. The plot shows the probabilities from the emergency phase (EARLY), long-term phase (CHRONC), and the two phases combined.

Conclusions for the Analyzed Scenarios

- The results of this project indicate that reactor safety has improved over the years as a result of efforts by industry to improve plant design and operation and by NRC to develop improved regulations to enhance safety.
- If mitigation actions are successful, they will significantly reduce core damage frequency.
- Our analyses indicate that potential radiation releases would occur several hours later than earlier thought, and they would be substantially smaller.
- Essentially no early fatalities will occur. Our best estimate of early fatalities from severe accidents at nuclear power plants would be far fewer than previously calculated.

Conclusions for the Analyzed Scenarios (continued)

- The SOARCA individual latent cancer risk values for the selected scenarios in total are significantly smaller than the NRC-established safety goal.
  - Using a dose response model which truncates annual doses below normal background levels (including medical) results in a further reduction to the latent cancer risk, (by a factor of 100 for smaller releases and a factor of 3 for larger releases).
  - Latent cancer fatality predictions are generally dominated by long term exposure in conjunction with return criteria for calculations using the LNT assumption.
  - Bypass events do not pose higher latent cancer fatality risk, higher conditional risk is offset by lower frequency.

Backup Slides

LCF Comparison to SSS

- Comparisons to any previous study not clean
  - New metric being reported
  - Important input values not fully described in the older documentation
  - Non-linear, importance dependent on all other input
- Comparisons assume LNT and SST1
- Dose-response important, next subject

Changes Raising LCF vs SSS

- Risk factors from BEIR V factor of 2.5
- Dry deposition velocity factor of 2
- Population 30%
- Inventory 15%
- Evacuation 3%
- Groundshine shielding could be up or down, SSS documentation not clear
  - +/- 20-30%

Changes Lowering LCF vs SSS

- Habitability criterion ~80%
- Compass directions 10%
- Relocation 7%
- No food/water pathway 5%
- KI 2%

Closing Remarks

- Feedback from the Meeting
- SOARCA Next Steps
  - Incorporate Comments: ACRS, Peer Review, Fact Checks by Plants, NRC
  - Publish Information Brochure
  - Release for Public Review and Comment
  - Hold Public Meetings
- ACRS Full Committee Meeting in October
  - Present Results and Recommendation
  - Expect ACRS letter
- Final “draft” NUREG with Recommendation to Commission in October