NRC Staff Work on PTS Acceptance Criterion

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Presentation at Public Meeting
November 14, 2000

Recent Staff Work on PTS Screening Criterion

Summary of SECY-00-0140, June 2000

- Purposes:
  - Summarize staff work to revisit PTS rule
  - Describe staff's intended approach to reassess screening criterion
- Content:
  - Background information on PTS rule
  - Elements of current staff program
  - Recent risk-informed regulation guidance and framework
  - Issues

Recent Staff Work on PTS Screening Criterion

Summary of SECY-00-0140 (cont.)

- Background information on PTS rule
  - Accidents and events considered
  - Analysis requirements and acceptance criteria
  - Improvements in analysis methods and data
- Elements of current staff program
  - Identify initiating events
  - Perform thermal hydraulics
  - Perform probabilistic fracture mechanics
  - Assess probabilistic aspects of screening criterion
  - Calculate through-wall crack frequency
  - Reevaluate PTS screening criterion
  - Propose technical basis for rule revision

Recent Staff Work on PTS Screening Criterion

Summary of SECY-00-0140 (cont.)

- Recent risk-informed regulation guidance and framework
  - Regulatory Analysis Guidelines
  - Safety Goal and PRA Policy Statements
  - Regulatory Guide 1.174
- Issues:
  - Consideration of large early release frequency
  - Test of risk-informed regulation framework

LERF Scoping Study

- Objectives
  - To better determine the scope and nature of the containment performance issues and offsite consequences associated with a PTS-related vessel failure, and
  - the feasibility of addressing these issues as part of the PTS effort

LERF Scoping Study (cont.)

- Activities
  - Identification of phenomenological issues and potential sources of information (ongoing)
  - Study effects of 2-phase blowdown on structures (nearing completion)
  - Evaluate feasibility of addressing LERF using current technology and data

LERF Scoping Study (cont.)

- Potential outcomes
  - LERF analysis is not feasible => the PTS acceptance criteria developed need to address post core-damage issues through other means (e.g., through analyses of defense-in-depth)
  - LERF analysis is feasible => PTS-induced LERF estimates need to be developed for the study plants and appropriate acceptance criteria need to be developed

Activities and Preliminary Schedule

- Scoping study - containment performance issues and LERF analysis feasibility
- Alternative acceptance criteria
  - Formulation of alternatives
  - Application of SECY-00-198 framework
  - Public workshop
- Commission paper on PTS status (3/01)

Formulation of Alternatives

Questions being considered

- What is the appropriate form of the PTS screening criterion?
- What risk metrics should be used in determining the PTS screening criterion? (Should we be using TWCF? CDF? LERF?)
- What are the screening criteria for the selected risk metrics?
- What is the appropriate value for the PTS screening criterion to provide reasonable assurance that, in a screening process, the established risk criteria are met?
- If a plant doesn't pass screening, should a different set of risk criteria be used to determine acceptability?

PTS-Induced LERF Analysis

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November 2000

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Introduction

- PTS presents complex accident progression possibilities
- Most current severe accident analysis not applicable
- PTS-induced LERF estimates feasible through novel analyses

Objectives

- **For the task:**

  Develop approach for estimating PTS-induced LERF

- **For this presentation:**

  Describe developed approach assuming TWC initiation

Outline

- Present top level events
- Describe important aspects of top level events
- Discuss possible approach for quantification
- Summarize

Top Level Events

- RV break induced CD
- RV break size
- SI
- Recirculation core cooling
- Core water level
- Core debris retained in RV
- RV cavity dry
- Containment penetrations intact
- Containment isolation
- Short term containment pressure suppression
- Long term containment pressure suppression
- H_2 detonation containment failure
- Steam explosion containment failure
- Core/concrete containment failure

RV Break Induced CD

- Captures potential for early CD as a direct result of forces associated with RV failure
- Consists of simple split for 'CD' or 'no CD'
- Quantify through structural evaluation of
  - core barrel integrity
  - integrity of lower core support structures
  - integrity of fuel rods

SI

- *Consists of simple split for 'success' or 'failure' - although RCS pressurization not required for success*
- *Primarily requires RWST inventory, operable pumps, and appropriate valve alignment*
- *Quantify using standard PRA procedures and reliability analyses*

Recirculation Core Cooling

- Consists of simple split for 'success' or 'failure' - although RCS pressurization not required for success
- Primarily requires containment sump inventory, operable pumps, and appropriate valve alignment
- Quantify using standard PRA procedures and reliability analyses

Potential issue: loss of containment sump inventory by boiling and venting through CF

Core Water Level

- Core water levels determined by location of breaks if injection exceeds decay heat boil-off
- Split into those stabilizing in
  - Upper core (without CD)
  - Middle core (CD to be determined)
  - Lower core (CD assured)
- Quantify based on
  - Break location
  - TH analysis

Core Debris Retained In RV

- Addresses potential for late CF
- Consists of simple split for retention success or failure
- In-vessel retention depends on heat transfer
- Currently subject of international research
- Quantify through literature review

RV Cavity Dry

- Affects potentials for steam explosions and core/concrete interactions
- Consists of simple wet or dry split
- Primarily depends on break impact on cavity draining
- Quantify possibilities through
  - Assignment of equal probabilities
  - Expert elicitation

Containment Penetrations Intact

- Presents potential for containment penetration failures as direct result of PTS-induced motion of RCS
- Consists of simple 'intact' or 'not intact' split
- ECCS lines and feed/steam lines potentially vulnerable
- Quantify through dynamic load analysis of piping

Containment Isolation

- Primarily requires appropriate valve alignment
- Presents release potential without direct CF
- Consists of simple split for 'success' or 'failure'
- Quantify using standard PRA procedures and reliability analyses

Short Term Containment Pressure Suppression

- Addresses potential for early CF
- Consists of simple split for 'success' or 'failure'
- Primarily relies on containment sprays (dry containment designs) and presence of ice (ice condenser designs)
- Quantify using standard PRA procedures and reliability analyses

Long Term Containment Pressure Suppression

- *Addresses potential for late CF*
- *Consists of simple split for 'success' or 'failure'*
- *Primarily relies on fans and containment sprays (dry containment designs) and fans, containment sprays, and ice availability (ice condenser designs)*
- *Quantify using standard PRA procedures and reliability analyses*

H_2 Detonation Containment Failure

- Presents CF potential if CD (oxidation) occurs and igniters fail
- Consists of simple 'CF' or 'no CF' split
- Quantify using standard PRA procedures and reliability analyses

Steam Explosion Containment Failure

- *Presents CF potential if in-vessel retention fails and RV cavity is wet*
- *Consists of simple 'CF' or 'no CF' split*
- *Quantify through combined TH/FCI analysis*

Core/Concrete Containment Failure

- Presents CF potential if in-vessel retention fails and RV cavity is dry
- Consists of simple 'CF' or 'no CF' split
- Quantify through combined TH/CCI analysis

Summary

- PTS-induced LERF estimate feasible through quantification of 14 top level events
  - 6 events quantifiable using standard PRA methods
  - 2 events quantifiable based on research in progress (RV break size, Core debris retained in RV)
  - 5 events may require modest analytical efforts (RV break induced CD, Core water level, Containment penetrations intact, Steam explosion CF, Core/concrete CF)
  - 1 event lacks data and methodology (RV cavity dry)
- PTS-induced LERF estimate feasible without new experiments or code development

An Assessment of the Potential for Pressurized Thermal Shock Induced Reactor Vessel Failure to Result in a Large Early Fission Product Release

Presented at:

NRC Public Meeting

November 14, 2000

Presented by:

Bob Lutz

Westinghouse Electric Co. LLC

PTS / LERF Issue

- **Can a failure of the reactor pressure vessel due to pressurized thermal shock (PTS) lead to condition where there is a potential for a large early release (LERF) of fission products?**
  - Are there new considerations for core damage sequences with PTS failure of the reactor vessel?
  - Are core damage sequences with PTS reactor vessel failure similar to existing core damage sequences that have a high LERF contribution?

Approach

- **Develop a working definition for PTS and LERF**
  - Considers variations in use
- **Develop screening criteria to define a PTS - LERF issue**
  - Conditions that must occur for further consideration of sequences
- **Define PRA LERF contributors**
  - Sequences and phenomena, based on current PRA analyses
- **Identify PTS Impact on LERF contributors**
  - Qualitative assessment of impact on sequences and phenomena
- **Identify new LERF contributors**
  - Qualitative assessment of impact of new sequences / phenomena
- **Develop conclusions and recommendations**

PTS & LERF Working Definitions

- **PTS Vessel Failure**
  - Failure of the reactor vessel which results in core damage due to the inability to unsuccessfully maintain core cooling
    - For purposes of this assessment, a PTS vessel failure is of unspecified size and location
- **LERF**
  - A failure of the containment fission product boundary such that the timing and magnitude of fission product releases following core damage can result in acute offsite consequences.
    - This assessment is independent of the detailed LERF definition
      - Any failure of the containment fission product boundary that occurs prior to or shortly after core damage is considered a potential LERF condition

Screening PTS Definition for LERF

- **Pressurized Thermal Shock (PTS) is only a concern if it leads to a breach of the reactor vessel that results in core damage. Two conditions must be met:**
  - the failure location is such that the the core cannot be maintained in a water covered, cooled state
    - requires a failure location at or below the belt-line region of the reactor vessel
  - the failure size is large enough that the break flow exceeds the capacity of the ECC injection
    - requires a break size of greater than about a 4 inch equivalent diameter
- **The conclusions are not sensitive to these requirements**

PTS Definition for LERF - Additional Considerations

- **Failure location**
  - Failure locations above about the mid-plane of the core may not result in core damage due to continued cooling of the core
    - LERF requires core damage
  - Other failure locations in the belt-line region would likely result in core damage, but subsequent refreezing of core debris at elevations below break location
    - Some LERF contributors are not possible
  - Failure locations in the reactor vessel bottom head may result in some refreezing of core debris due to water flowing out the break
    - Not considered in this assessment
  - The reactor cavity is likely to be flooded due to the pathway for water to escape from the RCS

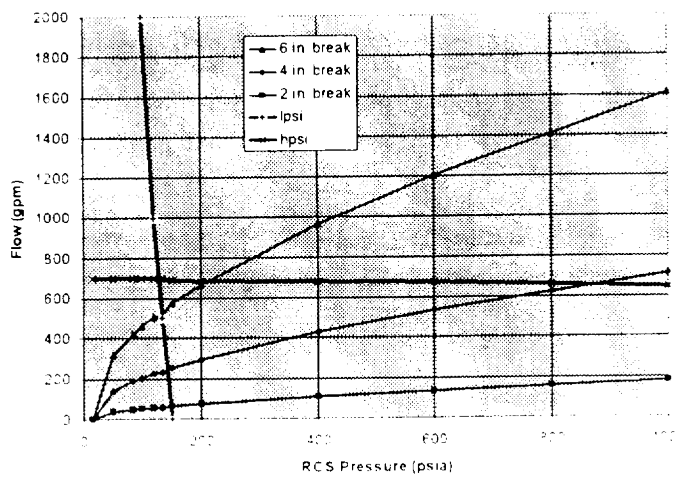
PTS Definition for LERF - Additional Considerations

- **Failure location (Continued)**
- **Conclusion:**
  - Not all PTS induced reactor vessel failures result in core damage
  - Location can negate the possibility of some LERF contributors (e.g., ex-vessel LERF contributors)
  - The break location is not important for the following assessment of LERF impacts

PTS Definition for LERF Additional Considerations

- **Failure Size**
  - Failure size in excess of 4 inch equiv. diameter is needed to exceed the capacity of one High Pressure Safety Injection (HPSI) pump
    - 4 inch break size is based on simplified break flow / pump flow comparison (Next Slide)
    - RCS pressure for this case is less than about 900 psia
    - Larger break size would be required with more ECC capacity (e.g. 2 trains) available
  - Other failure sizes were considered

PTS Break and Injeciton Flows



PTS Definition for LERF Additional Considerations

- **Failure Size**
  - For initial failure size of 4 inch equiv. Diameter
    - RCS pressure with break location covered is less than about 900 psia
    - When core damage occurs and core relocation takes place, the break location is likely to become uncovered
      - Uncovered 4 inch break results in RCS pressure less than 400 psia
    - Effective break area would be increased when pressurizer PORVs are opened in response to high core temperatures
    - RCS pressure at vessel melt-through would be less than 200 psi based on uncovered break and PORVs

PTS Definition for LERF Additional Considerations

- **Failure Size (continued)**
  - For breaks greater than about 6 inch equiv. diameter:
    - RCS pressure may be below the LPSI shutoff head;
    - LPSI flow could be effective in maintaining the core covered
    - RCS pressure would be less than 150 psig for these cases
  - For breaks less than 4 inch equiv. diameter:
    - HPSI flow could be effective in maintaining the core covered
  - For hinged vessel head failure, RCS is depressurized at core heatup
- **CONCLUSION:**
  - PTS induced core damage sequences would have a low RCS pressure at the time of core damage

Present PTS Considerations in PRA

- **PTS is not typically addressed in current PRA studies**
  - Vessel Rupture is considered as an Initiating Event for completeness
    - Vessel rupture is typically modeled to go straight to core damage
    - Vessel rupture typically is not a significant contributor to core damage
    - Vessel Rupture is typically binned with large LOCA in the Level 2 PRA
  - There are typically no links from small LOCA and Transient Initiating Events to a vessel vessel rupture based on:
    - EOPs and operator training provide high degree of confidence that PTS conditions will no occur
    - Probability of operator errors that can lead to PTS conditions is judged to be very small
- **Therefore it is difficult to quantify PTS contributions**

Sensitivity to PTS Precursor Conditions

- **PTS induced vessel failure is not limited to Level 1 PRA**
  - **Prior to Core Damage**
    - Accident recovery using EOPs leads to PTS conditions
    - Core geometry intact
  - **After Core Damage**
    - Accident Recovery using SAMG leads to PTS conditions
    - Core geometry may not be intact
  - **No significant differences in the subsequent accident progression**
    - Accident progression similar to large LOCA with failure of ECC injection
    - Case of PTS after Core damage may have more total in-vessel zirc-water hydrogen generation due to multiple heatup cycles

LERF Contributors

- **Typical PWR PRA provides the following LERF contributions**
  - Containment Bypass Events > 90%
  - Containment Isolation Failures < 5%
  - Early Containment Failures < 1% *

* except for ice condenser containments where station blackout hydrogen burns can result in a 1% to 15% contribution

Assessment of PTS Impact on LERF Contributors

- **Containment Bypass**
  - No impact on LERF for ISLOCA or SGTR core damage bypass accident sequences
    - Sequences already lead to LERF
    - RCS depressurization as a result of PTS vessel failure would reduce fission product releases for these sequences and may move them to non-LERF categories
  - If core damage frequency increases as a result of PTS vessel failure, LERF would increase accordingly
- **Containment Isolation Failure**
  - No impact on core damage bypass accident sequences with containment isolation failures
    - Sequences already lead to LERF
    - No additional isolation failure modes as a result of PTS

Assessment of PTS Impact on LERF Contributors

- **Early Containment Failure**
  - Induced SG Tube Ruptures - No impact from PTS
    - RCS would be at low pressure at the time of core damage which prevents induced SG tube ruptures
  - In-Vessel Steam Explosions - No impact
    - For failure locations in the RPV bottom head, there would be no water for steam explosions
    - For failure locations at higher elevations, the low RCS pressure would be conducive to steam explosions
      - Current expert opinion is that in-vessel steam explosions do not challenge containment integrity
  - Direct Containment Heating - No Impact
    - RCS would be at low pressure at the time of core damage which prevents induced SG tube ruptures

Assessment of PTS Impact on LERF Contributors

- **Early Containment Failure (continued)**
  - Direct Containment Heating - No Impact
    - RCS would be at low pressure at the time of reactor vessel melt-through which prevents direct containment heating
    - Current expert opinion is that DCH does not challenge containment integrity
  - Ex-Vessel Steam Explosions - No Impact
    - Reactor cavity flooding and low RCS pressure as a result of PTS at reactor vessel melt-through is conducive to ex-vessel steam explosions
    - There is no difference in consequences of ex-vessel steam explosions form that currently assessed in PRAs

Assessment of PTS Impact on LERF Contributors

- **Early Containment Failure (continued)**
  - Hydrogen Burns - No impact
    - For the case of PTS vessel failure during recovery (SAMG), additional hydrogen may be generated
      - The total hydrogen generation will be limited to the equivalent of 75% zirc-water reaction
      - Steam inventory will not be high during core heatup after PTS failure due break flow of water vs. steam boil-off core uncovery mode.
    - For large dry containments, the robust containment strength will not result in a new challenge
    - For ice condenser plants, the igniters will prevent hydrogen accumulation that could challenge containment integrity
      - The dominant cause of igniter unavailability is station blackout -- PTS vessel failure is not predicted due to the lack of ECC injection sources for this sequence.

Assessment of PTS Impact on LERF Contributors

- **Early Containment Failure (continued)**
  - Direct Contact - No impact
    - Not a contributor to LERF for PWRs
    - Low pressure vessel melt-through for postulated PTS induced core would reduce the potential for this failure mode.
- **CONCLUSION:**
  - Early containment failure is not a current contributor to LERF
  - No new early containment failure LERF contributors have been identified

Areas for Further Investigation

- **Impact of Vessel Movement at PTS Failure on Containment Penetrations**
  - The issue is discharge of water through a failure location on the side of the reactor vessel
    - Present PRA studies only consider reactor vessel bottom head failures
      - "Jet Thrust" from core debris is not sufficient to move the vessel
    - Review of DBA asymmetric loads assessments may provide additional information
- **Impact of PTS Failure on Cavity Walls and Containment Integrity**
  - The issue is discharge of water through a failure location on the side of the reactor vessel
    - Review of DBA asymmetric loads assessments may provide additional information

Areas for Further Investigation (continued)

- **Impact of PTS Failure on Missile Generation That Challenges Containment Integrity**
  - The issue is discharge of water through a failure location on either the side or the bottom of the reactor vessel
    - No possible projectiles of significant mass inside the biological shield or below the reactor vessel
    - Torturous path to containment pressure boundary

Conclusions

- **The impact of PTS induced reactor vessel failure on the frequency of large early fission product releases (LERF) is negligible**
  - Not all PTS failures will lead to core damage based on break size and location screening
  - The reactor coolant system will be at low pressures at the time of core heatup and vessel melt-through, based on the break size and location screening
  - Existing PRA Containment Bypass sequences that lead to LERF would be mitigated by PTS failures
  - No new LERF contributions due to PTS induced reactor vessel failure were identified.
    - Areas identified for further investigation are not expected to be significant