

NRC Staff Work on PTS Acceptance Criterion

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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

D. Knudson

November 2000

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Idaho National Engineering & Environmental Laboratory



Introduction

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

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Objectives

- ***For the task:***

Develop approach for estimating PTS-induced LERF

- ***For this presentation:***

Describe developed approach assuming TWC initiation

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Outline

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

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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**
- **H₂ detonation containment failure**
- **Steam explosion containment failure**
- **Core/concrete containment failure**

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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***

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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**

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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

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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*

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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***

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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***

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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**

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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***



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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**

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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**

LINEEL

H₂ 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***

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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/FCL analysis***

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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***

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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**

LINEEL

**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

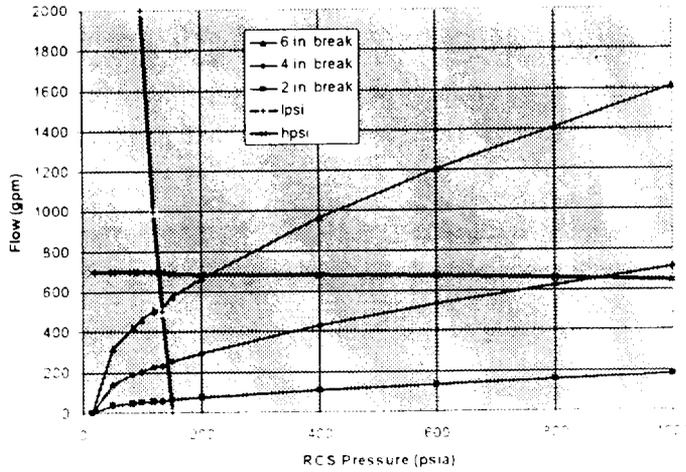
PTS Definition for LERF - Additional Considerations

- **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 Injection 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 not 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 from 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 uncover 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