POLICY ISSUE
INFORMATION

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FOR: The Commissioners

FROM: William D. Travers
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SUBJECT: STATUS REPORT: RISK METRICS AND CRITERIA FOR PRESSURIZED THERMAL SHOCK

PURPOSE:

To provide information on the status of the staff's work to identify risk metrics and associated criteria that can be used in reevaluating the technical basis of the pressurized thermal shock rule.

BACKGROUND:

In 1986, the U.S. Nuclear Regulatory Commission (NRC) established the PTS Rule in response to an issue concerning the integrity of embrittled reactor pressure vessels (RPVs) in pressurized water reactors (PWRs). The NRC staff is now reevaluating the technical basis of this rule in light of the results of subsequent extensive research on key technical issues underlying the rule. Analyses performed as part of this research suggest that the agency may be able to reduce unnecessary conservatism in the rule, while still maintaining safety.

The staff's approach for reevaluating the screening criteria that 10 CFR 50.61 prescribes for RPV material characteristics is described in SECY-00-0140, "Reevaluation of the Pressurized Thermal Shock Rule (10 CFR 50.61) Screening Criterion," dated June 23, 2000, and subsequent periodic status reports identified as SECY-01-0045 and SECY-01-0185, dated March 16, 2001 and October 5, 2001. This paper is the third report of the staff's progress in reevaluating the rule's technical basis. In SECY-01-0185, the staff committed to provide an evaluation of options for potential changes to the rule. This paper discusses options for risk metrics and possible quantitative values now being considered by the staff. The staff plans to identify and evaluate actual rule options as part of the rulemaking process, in the event that rulemaking is initiated, following the completion of the reevaluation effort.

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The current PTS rule establishes a series of steps that PWR licensees must perform. The initial step involves a deterministic evaluation of the RPV's RT_{PTS}[1] for welds and plate materials. If the computed RT_{PTS} values exceed the screening criteria established in 10 CFR 50.61, licensees are directed to accomplish reasonably practicable neutron flux reduction to avoid exceeding the screening criteria during the RPV's licensed life. Plants for which the computed RT_{PTS} values, even with neutron flux reduction, will still exceed the screening criteria are required, at least three years before exceeding the criteria, to submit a plant-specific safety analysis demonstrating that the risk associated with PTS events is acceptably low. NRC Regulatory Guide (RG) 1.154, "Format and Content of Plant-Specific Pressurized Thermal Shock Safety Analysis Reports for Pressurized Water Reactors," dated January 1987, describes one acceptable method for performing such safety analyses.

Preliminary results from the staff's reevaluation, that is considering improved knowledge regarding the response of RPVs to PTS challenges and the likelihood of such challenges, indicate that there may be more safety margin built into the current PTS rule than is needed and, therefore, there may be a sufficient technical basis for relaxing the rule. A risk-informed rulemaking process to revise the rule would address risk, defense-in-depth, and safety margin considerations and the associated uncertainties to establish revised criteria for managing RPV embrittlement during the RPV's licensed life. To support the development of a risk-informed rule, risk metrics and criteria need to be defined.

Figure 1 illustrates a conceptual example of a possible use of risk metrics and criteria. This figure features a set of curves illustrating uncertainties in the relationship between the risk metric specified in RG 1.154 (i.e., the PTS-induced RPV through-wall crack frequency, or TWCF) and RT_{PTS}. The spread between the 95^{th} and 5^{th} percentile curves reflects epistemic uncertainties reflecting our current state of knowledge regarding the value of TWCF for a given value of RT_{PTS}. These epistemic uncertainties can be reduced with the development of additional information.

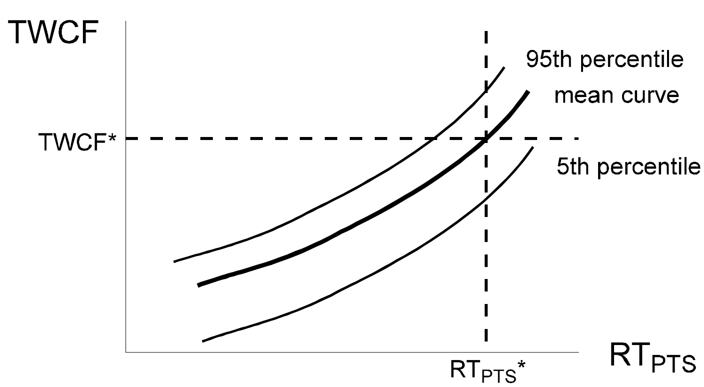

Figure 1. Conceptual Use of Risk Acceptance Criterion in Deriving RPV Embrittlement Criteria

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RT_{PTS} is a measure of the material ductile-to-brittle transition temperature at the end of the RPV's licensed life. On the basis of analyses summarized in SECY-82-465, "Pressurized Thermal Shock," dated November 23, 1982, RT_{PTS} has been used as an indicator of the ability of the RPV to withstand a PTS event.

The mean curve is calculated based on the epistemic uncertainties in TWCF. In the conceptual example shown in Figure 1, the intersection of the mean curve with a specified acceptance criterion for TWCF, shown as TWCF*, defines a possible limiting value for RT_{PTS}. As discussed later, defense-in-depth and safety margins considerations may provide stronger constraints in the definition of this limiting value.

The remainder of this paper addresses options for risk metrics and associated acceptance criteria being considered by the staff.

DISCUSSION

The discussion below describes the current PTS risk metric and criteria, current guidance on risk-informed regulation and the implications for PTS, options for PTS risk acceptance guidelines that are under consideration, and the next steps in the reevaluation relevant to the risk metric and acceptance criteria options.

Current PTS Risk Metric and Criteria

Two key parts of the PTS safety analysis approach described in RG 1.154 are estimation of TWCF and comparison of the estimated TWCF with an "acceptable" value of 5×10^{-6} per reactor year. Neither RG 1.154 nor Enclosure A to SECY-82-465 provides a detailed discussion regarding this specific value, although the Enclosure A does argue that an even higher TWCF value (i.e., 1×10^{-5} per reactor year) is consistent with the then-proposed Safety Goal Policy guidelines on "core melt frequency" and the desire that the core melt frequency ascribable to "one sequence" (such as PTS) should be a small fraction of the overall core melt frequency. Based on the assessed likelihood of potential PTS challenges, the predicted thermal-hydraulic response of the plant, and the predicted behavior of the RPV, the RT_{PTS} screening criteria recommended by the staff in 1982 and subsequently incorporated in 10 CFR 50.61 were determined to be consistent with a TWCF of around 5×10^{-6} per reactor year.

Enclosure A to SECY-82-465 also discusses the potential margin between a PTS-induced RPV failure and a large release of radioactive material to the environment. In particular, it identifies a number of factors that might reduce the likelihood that a large release will result from a PTS-induced RPV failure. However, it does not quantify the conditional probability of core melt, given a PTS-induced RPV failure, or the conditional probability of a large release, given a PTS-induced core melt. Thus, the enclosure does not define a quantitative relationship between the TWCF criterion and the quantitative health objectives provided in the Safety Goal Policy Statement.

Current Guidance on Risk-Informed Regulation and Implications for PTS

The NRC has established a considerable amount of guidance on the use of risk information in regulation since it issued SECY-82-465 in 1982 and published the original PTS Rule in 10 CFR 50.61 in 1986. Key documents include the final Safety Goal Policy Statement, which defined qualitative and quantitative goals for the acceptable risk of nuclear power plant operations; a June 1990 Staff Requirements Memorandum (SRM), which established a subsidiary CDF goal of 1×10^{-4} per reactor year; and RG 1.174 (and the associated revision to Standard Review Plan Chapter 19), which described a risk-informed approach for using PRA in decisions on plant-specific changes to the licensing basis.

RG 1.174 is aimed at voluntary changes to a plant's licensing basis. However, it provides a general template for improving consistency in regulatory decisions in areas in which the results of risk analyses are used to help justify regulatory action. The principles of integrated, risk-informed decisionmaking (involving consideration of risk information, defense-in-depth, safety margins, and uncertainties) discussed in that RG broadly apply to risk-informed regulatory activities. RG 1.174 provides risk-acceptance guidelines for changes in core damage frequency (CDF) and large early release frequency (LERF). These guidelines were developed to provide assurance that proposed increases in CDF and LERF are small and consistent with the intent of the Commission's Safety Goal Policy Statement. If the baseline risk can be shown to be acceptable (as indicated by a total mean CDF of less than 1×10^{-4} per reactor year and a total mean LERF less than 1×10^{-5} per reactor year), applications for plant changes leading to small increases in mean CDF (up to 1×10^{-5} per reactor year) and mean LERF (up to 1×10^{-6} per reactor year) will be considered for regulatory approval.

The staff's current activities on Option 3 for risk-informing 10 CFR Part 50, as described in SECY-00-0198, dated September 14, 2000, take advantage of the groundwork laid by RG 1.174. The Option 3 framework being developed employs the total mean CDF and mean LERF guidelines mentioned above (1×10^{-4} and 1×10^{-5} per reactor year, respectively). The framework also provides guidelines to limit the CDF and LERF associated with any single accident type from being a large fraction of the plant's total CDF and LERF.

As indicated earlier, the TWCF criterion of 5×10^{-6} per reactor year provided in RG 1.154 is aimed at ensuring that the risk associated with PTS is a small fraction of the risk level established by the Safety Goals and is consistent with the philosophy of distributing risk among accident types. However, the relationship between this criterion and the CDF and LERF guidelines established in RG 1.174 and those proposed in the draft Option 3 framework is not clear because there currently is an incomplete understanding regarding the progression of an accident following a postulated PTS-induced RPV failure.

A number of research efforts have addressed potential PTS-induced RPV failure modes and their effects on core cooling and containment integrity. In the late 1970s and 1980s, large-scale experiments on prototypic RPVs subjected to pressure and temperature transients characteristic of PTS loadings were conducted at the Oak Ridge National Laboratory (ORNL) as part of the NRC-sponsored Heavy Steel Section Technology (HSST) research program. These experiments demonstrated three potential outcomes of a PTS event (depending on the particulars of the transient, material embrittlement, etc.):

(1) No cracks initiate and the vessel remains intact.

(2) A crack initiates, propagates to some depth into the vessel wall, and stops. The vessel remains intact with little additional deformation.

(3) A crack initiates and propagates entirely through the vessel wall. In addition to large openings in the reactor vessel, this outcome involves significant additional deformation of the vessel.

In the context of RPVs, the third outcome presents a potentially significant challenge to core cooling and containment integrity. A number of factors influence the progression of the accident and whether a large early release follows the vessel failure. A representative list of post-RPV failure issues to be addressed in an accident progression analysis include:

- Reactor vessel break-induced core damage
- Reactor vessel break size
- Operation of emergency core cooling systems (injection mode)
- Operation of emergency core cooling systems (recirculation mode)
- Core water level
- Core debris retained in reactor vessel
- Containment penetrations intact
- Containment isolation
- Short-term containment pressure suppression
- Long-term containment pressure suppression
- Hydrogen detonation containment failure
- Steam explosion containment failure
- Core/concrete containment failure

These factors have not yet been studied in detail. Consequently, the margins between TWCF and PTS-induced CDF, and between PTS-induced CDF and PTS-induced LERF, remain uncertain.

Identification of Risk Acceptance Criterion Options

The staff is considering two sets of options for PTS risk acceptance guidelines. The first set of options concerns the metric to be used. The second concerns possible quantitative acceptance limits for that metric.

Regarding the risk metric, the staff is currently focusing on the PTS-induced RPV failure frequency (RVFF). The use of the RVFF metric recognizes the potentially risk significant consequences of a catastrophic RPV failure, but does not require a quantitative assessment of the margins between RPV failure, core damage, and large early release. Note that the potential changes to 10 CFR 50.61 currently envisioned by the staff involve revised screening limits for RPV embrittlement. The potential changes may affect RVFF but are not likely to affect the conditional probability of core damage (given a PTS-induced RPV failure) or the conditional probability of large release (given a PTS-induced core damage event). Thus, they will likely have little effect on the level of defense-in-depth against PTS challenges already provided by the current rule.

Two options being considered for defining RPV failure are as follows:

(1) RPV failure occurs when a PTS-induced crack penetrates the RPV wall (i.e., RVFF = TWCF).

(2) RPV failure occurs when a PTS event initiates a crack in the RPV wall (i.e., RVFF = Vessel Crack Initiation Frequency, or VCIF).

The first option uses the current definition of RPV failure. In addition to being a more direct measure of the likelihood of events with potentially significant public health consequences, it has the advantage of regulatory stability. The second definition reflects the position adopted by some non-U.S. regulatory bodies. As part of the reevaluation study, the staff will develop a recommended definition. The recommendation will reflect current uncertainties in the prediction of crack progression within the RPV wall and the current understanding of the characteristics of potentially risk-significant PTS scenarios.[2]

Regarding the possible quantitative acceptance limits for RVFF (denoted by RVFF*), the staff has identified the following three options:

(A) RVFF* = 5 x 10^{-6}/reactor year
(B) RVFF* = 1 x 10^{-5}/reactor year
(C) RVFF* = 1 x 10^{-6}/reactor year

Option A is suggested by the current value in RG 1.154. Option B is suggested by current guidelines on CDF provided by RG 1.174 and the Option 3 framework for risk-informing 10 CFR Part 50. Option C is suggested by current guidelines on LERF.

The staff's PTS reevaluation will yield a recommendation regarding the above risk metric and acceptance limit options. A key question in the development of the recommendation of acceptance limits is whether an RPV failure scenario is likely to directly cause core damage but not large early release, or if it is likely to cause large early release as well. This question was considered in the original development of 10 CFR 50.61. The staff is determining the feasibility of an effort to identify and assess, if available, any additional information on this issue developed since that time. Such an effort, if successful, would likely better characterize and perhaps even reduce current uncertainties in post-RPV failure accident progression, and thereby support the selection of an RVFF acceptance limit.

The need for an investigation of post-RPV failure accident progression also depends on the estimated value of RVFF. Preliminary results of the PTS reevaluation indicate that, given currently anticipated plant operational lifetimes, the mean RVFFs for U.S. plants could be very low (i.e., well below 1 x 10^{-6}/reactor year). This would imply that the PTS risk is very low, since the PTS-induced CDF is bounded by RVFF (i.e., $CDF_{PTS} \leq$ RVFF) and LERF is bounded by CDF (i.e., LERF $\leq$ CDF). Should the RVFFs be very low, there would likely be room to relax the current PTS screening criteria, despite the uncertainties in post-RPV failure accident progression. Furthermore, the estimated PTS risk may not be a limiting factor in establishing the revised criteria. Other engineering considerations, including the RPV toughness required for normal operational transients which is addressed by the requirements in Appendix G to 10 CFR Part 50, may be shown to be more limiting than PTS concerns. These considerations will be addressed in the staff's reevaluation recommendations regarding the revision of the PTS screening criteria.

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[2]The distinction between crack initiation and crack arrest can be significant for scenarios involving a delayed repressurization of the reactor coolant system.

Next Steps

The next steps in the reevaluation relevant to the risk metric and acceptance criteria options are as follows:

(1) Complete the plant-specific analyses of TWCF being performed as part of the reevaluation. Generalize the results of these analyses to address the broader population of plants that are potentially at risk as a result of PTS scenarios.

(2) Assess the need for and feasibility of performing a scoping study of post-RPV failure scenarios. Such a study, if performed, would collect and evaluate available information relevant to the assessment of the margins to core damage and large early release and would be completed in time to support the development of risk metric and acceptance criteria recommendations by the overall reevaluation study.

(3) Interact with international RPV-relevant research programs and collect information needed to support the reevaluation. Interact with the Committee on the Safety of Nuclear Installations (CSNI) on a PTS benchmark problem and incorporate relevant insights.

The staff anticipates completing its reevaluation and passing the results on to NRR for consideration in potential rulemaking in December 2002.

COORDINATION

The staff has interacted, and will continue to interact, with the Advisory Committee on Reactor Safeguards (ACRS) throughout its reevaluation of the PTS Rule. The staff’s approach to the identification of risk metrics and acceptance criteria options is currently scheduled for discussion with the ACRS in July 2002.

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