United States Nuclear Regulatory Commission

POLICY ISSUE
(information)

November 17, 1983 SECY-83-472

For: The Commissioners

From: William J. Dircks
Executive Director for Operations

Subject: EMERGENCY CORE COOLING SYSTEM ANALYSIS METHODS

Purpose: To inform the Commission of revised analysis methods the staff proposes to find acceptable for conformance to Appendix K to 10CFR50.

Background: ECCS research conducted over the past 10 years has shed considerable light on the safety margin provided by Appendix K. Results from major RES-sponsored experimental programs such as LOFT, Semiscale and TLTA (Two-Loop Test Apparatus) have provided an abundance of data to verify the advanced, realistic, ECCS analysis computer codes which have been developed.

Specifically, LOFT tests L2-2 and L2-3 have been used to demonstrate the ability of advanced computer codes such as RELAP5 and TRAC-PD1 to predict the realistic behavior of a large cold leg break loss of coolant accident in a PWR. Similarly, eight Two-Loop-Test-Apparatus (TLTA) tests simulating both 7x7 and 8x8 fuel assembly designs in BWR/4 and BWR/6's have been used to demonstrate the ability of both TRAC-BD1 (BWR version) and GE's SAFER code to predict the realistic behavior of large break LOCA's in BWRs.

The Office of Nuclear Regulatory Research is currently preparing a proposed revision to the Appendix K rule. This proposed revision will account for new information, and will propose changes to certain ECCS model features presently required by Appendix K. However, this rule

CONTACT: B. W. Sheron, RSB/DSI/NRR
X27460

revision process is potentially lengthy, and, if a hearing is required, it could take well over a year to implement. Until this rule revision is implemented, the staff proposes to accept, at the licensees' or applicants' option, revised analysis methods for demonstrating conformance to Appendix K to 10CFR50 for large break LOCAs.

Discussion: 10CFR50.46 specifies the acceptance criteria for Emergency Core Cooling System (ECCS) performance. Included is the requirement that analysis models used to calculate the thermal-hydraulic performance of the ECCS conform to the requirements specified in Appendix K to 10CFR50. Appendix K to 10CFR50 includes such requirements as the use of the 1971 proposed ANS Standard on decay heat increased by twenty percent, use of the Moody break flow model, and the assumption of the worst single active failure. In addition, Appendix K identifies other analysis models and correlations, primarily for the large break LOCA, which while not required, are stated as acceptable for use. These required and acceptable features of evaluation models have been used to provide a substantial level of conservatism in large break LOCA ECCS performance analyses.

There are two other sources of conservatism in ECCS analyses. One source is imposed by the NRC staff and results from the NRC staff review of ECCS evaluation models. In many instances, specific models and correlations used in evaluation models (but not specified in Appendix K) may have large uncertainties. To account for these uncertainties, the staff required that the models and correlations conservatively bound the phenomena or the experimental data. A second source of conservatism is imposed by the industry and is derived from the industry's approach to analysis. Many models, correlations, and initial conditions used in ECCS evaluation models were conservatively specified by the industry during their development. In many instances, the industry chose to conservatively model certain phenomena rather than spend the engineering and financial resources to develop and justify a more realistic but less conservative model.

The combined effect of conservatisms in ECCS performance analyses has resulted in calculated large break LOCA peak fuel cladding temperatures (PCTs) approaching (usually within 100°F to 200°F) the 10CFR50.46 cladding temperature limit of 2200°F. Originally, this limit restricted the operation of only a few plants. However, in more recent years, more and more plants are operationally restricted by the 10CFR50.46 PCT limit combined with the Appendix K requirements. One reason is

that proposed fuel operating limits optimized for maximum burnup and fuel management considerations (also low neutron leakage) result in higher calculated PCTs. Another reason is that more and more plants are plugging steam generator (SG) tubes, and this increases the calculated PCT. In addition, correction of earlier coding errors has sometimes resulted in higher calculated PCTs. The cumulative conservatisms from the various sources previously mentioned have caused calculated large break LOCA PCTs to be close to the 2200°F limit of 10CFR50.46. Subsequent changes to ECCS models to account for new information such as SG tube plugging can result in the calculated PCTs exceeding the 2200°F limit. In order to justify continued operation of their plant in such situations, licensees have expended considerable engineering resources proposing and making modifications to their analysis models to offset the PCT increases and bring the calculated PCTs back below the 2200°F limit. This in turn consumes considerable staff resources during the review and approval process to assure compliance with the regulations. For the most part, these efforts have resulted in a negligible impact on actual plant safety, since the outcome of such exercises has usually not involved any significant change in operational flexibility or any operational limit.

Recent analyses indicate that the most probable PCT that would be experienced during the limiting large LOCA* would be 1000°F to 1200°F for both BWRs and PWRs. These results have been obtained from advanced computer codes (TRAC and RELAP5), developed independently at two separate national laboratories. Industry calculations with realistic LOCA computer codes reach the same conclusion; namely that there is approximately a 1000°F to 1200°F margin between the PCT expected during the limiting large break LOCA and the 10CFR50.46 limit of 2200°F. These analytical estimates are now well verified for both classes of reactors by the LOFT and TLTA experiments.

*The limiting large LOCA is defined by the combination of break size, location and worst single failure which results in the highest calculated PCT. For some plants the limiting break size may be less than the area of a full double ended break of the largest pipe in the reactor coolant system. However, even for discharge coefficients as small as 0.4, the resultant equivalent break area for a PWR cold leg break or BWR recirculation line break falls well within the range of those sizes considered in WASH-1400 to be large breaks.

Based on the above, the staff has concluded the following:

1. The safety margin in peak cladding temperature provided by current evaluation models to assure compliance with 10CFR50.46 limits is approximately 1000°F to 1200°F for the large break LOCA.
2. This margin is more than adequate to assure successful ECCS performance in the event of a LOCA.
3. This margin can be reduced without adverse effect on plant safety.
4. Acceptable reduction in this margin may be warranted to avoid unnecessary restrictions in operation as a result of excessive conservatism imposed in ECCS evaluations.

Proposed Approach: The staff has established an approach that would permit a reduced margin in large break LOCA* ECCS analyses without changing the required features of Appendix K. Such reduced margin can come from careful consideration of alternatives for treating the acceptable (but not required) features of Appendix K, the conservatisms that have been imposed as a result of NRC reviews, and the conservatisms that were otherwise contained in industry analyses.

In the proposed method, the licensee or licensees** would employ "best estimate" models to calculate the PCT, both at the realistic, or most probable (50 percent probability) level and at the more conservative 95 percent probability level.*** When calculating the PCT at the 95 percent probability level, other uncertainties, such as the precision with which the code can calculate actual behavior, input or plant parameter uncertainties (such as power level, initial temperatures and pressures) and nuclear parameters not otherwise considered would be accounted for.

Acceptable methodologies for calculating the 95

*This approach is currently only proposed for the large break LOCA analysis. Many of the features in Appendix K do not apply to Small breaks and the acceptability of this approach for small break LOCAs has not been thoroughly examined at this time.

**This approach could be used on a generic basis by groups of owners, such that many similar plants could utilize a single evaluation.

***Appendix A to this paper provides a discussion of the basis for selecting the 95% probability. We interpret the 95 percent probability level of the peak cladding temperature to mean that in 95 out of 100 LOCAs of a particular size, the peak cladding temperature would be below this value.

percent probability level would have to be formulated by the industry and approved by the staff. It would be expected that the industry would take into account systematic as well as random errors when establishing probability estimates. Once an acceptable methodology was established, the realistic PCT at the 95 percent probability level would be calculated. The licensee or licensees would then perform a conventional ECCS analysis, except they would be permitted to use their realistic model augmented only with the required features of Appendix K. This would constitute a new evaluation model which conforms to Appendix K. The PCT calculated using this model would then be compared to the realistic PCT at the 95 percent probability level. If the evaluation model PCT exceeded the PCT at the 95 percent probability level and remained below the 2200°F limit, we would find the evaluation model analysis acceptable. If the evaluation model PCT were calculated to be less than the realistic PCT 95 percent probability level, this would indicate that the overall evaluation model, including the required Appendix K conservative features, was not providing sufficient margin in excess of the estimated statistical uncertainty. Therefore, we would require additional margin be included in the evaluation model such that the calculated Appendix K temperature was in excess of the 95 percent probability level.*

The proposed approach would allow a reduction in the excess conservatism of ECCS analyses with the remaining conservatism being quantifiable at or above the 95 percent probability level of the realistic PCT. We conclude this level is sufficiently conservative based on:

- The now extensive experimental data base supporting the LOCA analysis methods
- The probability of a large break LOCA combined with the probability of a core melt resulting from a LOCA.**

This approach does not relax any regulations and, in fact, was always available to the staff since the model changes we propose to allow are not prohibited by Appendix K.

It also allows for productive use of research results and encourages design improvements.

---

* Appendix B to this paper describes an approach proposed by GE to assure that the Appendix K PCT is always in excess of the 95 percent probability.

** See Appendix A

<u>Expected Impact</u>

Present estimates of the difference between the 95 percent probability level PCT and the realistically calculated nominal PCT during a LOCA are on the order of 200°F to 400°F. Adding this uncertainty to a realistic PCT of approximately 1000°F to 1200°F would result in realistic predictions of PCTs at the 95 percent probability level of about 1200°F to 1600°F. We also anticipate that realistic analysis codes combined with the required Appendix K features would predict PCTs on the order of 1400°F to 1700°F using current linear heat generation rates.

This indicates that a maximum of 500°F to 800°F of margin would be available for the industry to use in the form of increased linear heat generation rates, optimized fuel utilization, etc.

Because this approach has not yet been implemented (nor do we intend to make it a requirement), we do not yet have a definite assessment of how the industry will ultimately use the additional margin being made available. However, we do not anticipate that the industry will treat Appendix K as a "speed limit" and use all of the available margin in the form of increased power levels or increased linear heat generation rates to move the calculated peak cladding temperature back up to the 2200°F limit. This conclusion is based on a number of reasons:

- A prime objective of the industry is to reduce the resources expended on ECCS model revisions to offset the penalizing effect of new information that occasionally arises. Licensees and vendors have told us that they will use the margin between their calculated PCT and the 2200°F limit to reduce these resource expenditures.
- One vendor, General Electric, has indicated it would use the margin primarily in obtaining extended fuel cycles, higher burnups, and in general, more efficient fuel management.
- For many plants, if not most, other current fuel performance limits (e.g., departure from nucleate boiling ratio) will restrict the degree to which this margin can be used.
- Although operating limits are expected to increase, overall plant power level increases are not likely to be proposed since most plants are limited in their power output by the installed turbine/generator capacity.
- <u>PWRs could use the margin to implement neutron flux reduction programs to minimize</u>

pressurized thermal shock potential while maintaining the same power levels.

The staff will closely monitor the implementation of this approach by the industry. We will keep the ACRS periodically advised of our experiences regarding implementation, and will report back to the Commission if necessary.

Implementation: The approach described in this paper is not a requirement. Present ECCS evaluation models that comply with Appendix K would still be acceptable for performing ECCS analyses to demonstrate compliance with 10CFR50.46 criteria. Use of this approach by the industry would be voluntary.

We have had discussions with the General Electric Company and we understand this approach would be beneficial to GE-designed reactors. GE indicated it would pursue this methodology with the staff. Westinghouse has also recently approached the staff to explore methods for obtaining relief from Appendix K restrictions. Therefore, we anticipate a positive industry response to this approach.

Concurrence: The ACRS has been briefed on this proposal and has voiced no objection. The Office of the Executive Legal Director has no legal objection to the use of this approach.

William J. Dircks
Executive Director for Operations

Enclosures:
1. Appendix A - Basis for 95 Percent Probability
2. Appendix B - Proposed GE Model

DISTRIBUTION:
Commissioners
OGC
OPE
ACRS
SECY

APPENDIX A
BASIS FOR 95 PERCENT PROBABILITY

The establishment of an acceptable probability level is a difficult task. Because it is statistically based, it is not considered a fixed, deterministic criterion, but ultimately involves quantifying an acceptable level of risk. The problem is initially simplified if, instead of establishing an acceptable level of risk, an acceptable probability of core melt is established. However, since there is no universally acceptable probability of core melt, a more reasonable approach is to select a probability level and from it infer that the probability of core melt is acceptably low. The probability level selected for use with this methodology was 95 percent, or 1.645 (one-side limit) times the standard deviation (1.645σ).

Ninety-five percent was selected for a number of reasons. Primary was its historical significance in regulatory matters involving thermal-hydraulic performance. Many parameters, most notably the departure from nucleate boiling ratio (DNBR) were proposed by the industry and accepted by NRC to be conservatively established at the 95 percent probability level. Secondary was the fact that in a similar approach previously presented by GE, the 95 percent probability level was proposed and defended.

With a probability of a large pipe rupture of approximately 10^{-4} per reactor year (as reported in WASH-1400), and assuming the acceptable probability of exceeding the 2200°F limit in 10CFR50.46 is a maximum of 0.05 (corresponding to the 95 percent probability level), the probability of large pipe rupture resulting in a PCT exceeding 2200°F would be

approximately $5x10^{-6}$*. It should also be noted that peak cladding temperature analyses are for the hot pins only, which comprise only a few percent of the total number of fuel pins. Therefore, even if the hot pins exceeded 2200°F and fragmented upon quenching, there is a good chance that the resulting damaged core would be coolable. In fact, the TMI-2 core, which apparently lost more than 35% of its fuel cladding integrity, remained coolable. If it is assumed that 1 out of 10 such damaged cores utlimately resulted in gross core melting, the overall probability of core melt would still be approximately $5x10^{-7}$.

This probability is well below many other significant contributors to core melt risk such as loss of all AC power or small break LOCAs with no high pressure injection available. It would not, therefore, represent a dominant contributor to risk.

---

*Note that most plants will have Appendix K PCTs below 2200°F, so the probability of exceeding 2200°F for most plants will actually be lower than $5x10^{-6}$.

APPENDIX B

PROPOSED GE MODEL

The model proposed by GE was designed to satisfy two basic requirements. These are:

1. Satisfy Appendix K Specifications for ECCS Evaluation Models
2. Show that the Appendix K licensing analysis results in PCTs that bound the 95 percent probability level of the realistic PCT.

To accomplish this, GE proposes to calculate the Appendix K PCT as follows:

$$(PCT)_{\text{Appendix K}} = (PCT)_{\text{Realistic}} + \text{ADDER}$$

$$(\text{ADDER})^2 = [(PCT)_{\substack{\text{Realistic Model + Appendix K}\\ \text{Specifications}}} - (PCT)_{\text{Realistic Model}}]^2 + \sum_i (\delta PCT_i)^2_{\text{plant variable uncertainties}}$$

$$\delta PCT_i = (PCT)_{\substack{\text{parameter i perturbed}\\ \text{from nominal}}} - (PCT)_{\text{nominal}}$$

As can be seen, if the plant variable uncertainties are set to zero, the Appendix K calculated PCT reduces to that calculated with the realistic model augmented with only the required features of Appendix K.

Therefore. the combination of terms in the ADDER equation should result in PCT that is in excess of a PCT calculated using a realistic model augmented with the required Appendix K features.

We believe the basic methodology presented by GE is acceptable and meets Appendix K. The plant variables selected, as well as their associated 95 percent probability level, have not yet been reviewed in detail.