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MEMORANDUM FOR: A. Thadani, Task Manager, TAP A-9 (ATWS)

FROM: Ralph O. Meyer, Leader, Reactor Fuels Section, Core Performance Branch, DSS

SUBJECT: REACTOR FUELS RESPONSE TO GE POSITION ON ATWS-INDUCED PCI FAILURE

Background

Appendix 7.5, "Relationship Between PCI and Boiling Transition," of the May 1979 General Electric report, "Assessment of BWR Mitigation of ATWS," contains GE's response to our ATWS requirement for consideration of PCI-induced fuel damage (presented in Section VIII, pp. 36-38 of Enclosure 1 of Dr. Mattson's February 15, 1979 letter to vendors). As part of our early verification approach, we had indicated that the number of rods predicted to be in boiling transition during an ATWS should be used as an estimate of the total number of fuel rod failures for radiological dose considerations. In our judgement, the number of rods in boiling transition would encompass the number that might actually fail as a result of both MCPR and PCI combined (because not all of the rods in boiling transition are sure to fail). We believed that the application of a boiling-transition criterion for PCI-induced failures was made necessary for BWR ATWS safety analyses because we lack accepted analytical methods for PCI analysis (although we are making progress in developing an empirical PCI model).

In Appendix 7.5 of the May submittal, GE contended that the analyzed BWR ATWS events would not result in a significant number of PCI failures. The crux of GE's argument was that fuel failures due to PCI are likely to occur after a rapid power increase (such as would occur during a BWR main steamline isolation valve closure) only if the fuel remains at the higher power for a relatively long period of time (many minutes to many hours). However, MSIV closure and the other defined ATWS events are of short duration (3 to 5 seconds at the overpower conditions), and, thus, do not meet the hold-time condition that GE views as a requisite for PCI-induced fuel rod failure.

Response

GE's belief in a hold-time requirement for PCI failures appears to be predicated on the assumption that all PCI phenomena involve environmental effects such as stress corrosion cracking and liquid metal embrittlement. This implies that PCI failure is stress-dependent and that it will occur only when the local cladding stress reaches a value

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sufficient to nucleate and propagate a crack through the embrittled cladding; a hold time (i.e., time at which the cladding is under stress and subject to fission product stress corrosion) is required for crack nucleation and propagation. However, based on the following considerations, we believe that the stress dependency, hold-time PCI failure theory lacks conclusive support:

1. Analytical and statistical analyses of five substantial and independent PCI fuel failure data sets indicate that cladding strain not stess is the pertinent parameter for PCI failure. These data and analyses were discussed with GE and some other industry representatives in Portland, Oregon on May 31, 1979, and will be further presented in a forthcoming report (Ref. 1).

2. Out-of-reactor tests, such as split ring tests or internal pressurization tests, do produce stress-corrosion cracking failures, but the conditions imposed during those tests do not exist in fuel rods in-reactor. We currently believe that under increasing-power conditions in the core, differential thermal expansion between the fuel pellet and the cladding provides the driving force for PCI. This differential expansion does indeed produce a stress in the cladding, but it also produces a displacement, i.e., a strain. We believe, based on the above-cited analyses, that the experimental data indicate that PCI fuel failure (whether dominated by thermo-mechanical interaction, thermo-chemical interaction, or both) is strongly dependent on the degree of strain, strain-rate, and/or strain-energy-absorption to failure (SEAF). A strain/strain-rate/strain-energy-absorption PCI mechanism allows a "time-to-failure" concept but does not require the concept of a "hold time" as a necessary precursor to PCI failure.

3. There are observed times-to-failure which are substantially shorter than the 18-minute "dwell time" reported for the Pickering 8-bundle shift data. In fact, the 18-minute dwell or hold time is a unique characteristic of the CANDU 8-bundle shift on-line refueling manauver. It is not known whether the PCI failures observed as a result of the on-line refueling maneuver occurred during the 1½ minutes required to move a CANDU fuel assembly from its prior-to-peak-power position or at some other time during the 18-minute period during which the fuel resided at the peak power position within the pressure tube fuel channel. References 2 to 10 (below) contain descriptions of PCI failures that were observed to occur at substantially less than the 18-minute CANDU experience that was cited by GE in support of its position.

4. Time-to-fail observations are generally made and reported on the presumption that there is a tell-tale fission product release immediately upon failure of the cladding. Few of the reported time-to-fail PCI data sets are corrected for any delay between fission product release and downstream detection. There are instances where PCI failures have been detected in post-irradiation examination (PIE), but without any tell-tale fission product release in the reactor core or in subsequent discharge basin tests for failure. On the whole, the time-to-fail data must be considered to possess an uncertainty of unknown magnitude.

PCI fuel failure probability estimates have been made (Ref. 11) for a BWR MSIV closure ATWS by a staff consultant at Battelle Pacific Northwest Laboratories using the PCI failure model called PROFIT (Ref. 1). The PCI failure probabilities ranged from 0 to 50%, depending primarily upon the assumed rod power and burnup. The PROFIT-calculated PCI failure values are reasonably consistent with the 10 to 17% boiling transition values calculated by GE for the MSIV closure ATWS. Thus, we feel justified in continuing to recommend that the number of rods in boiling transition be used as a current best-estimate of the total rod failures for BWR ATWS dose calculations.

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