UNITED STATES
NUCLEAR REGULATORY COMMISSION
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MEMORANDUM FOR: Thomas E. Murley, Director
Office of Nuclear Reactor Regulation

FROM: Eric S. Beckjord, Director
Office of Nuclear Regulatory Research

SUBJECT: RESEARCH INFORMATION LETTER NO. 166, "EMERGENCY CORE COOLANT BYPASS IN A PWR"

This Research Information Letter transmits the results of emergency core coolant (ECC) bypass tests conducted under the 2D/3D International Loss-of-Coolant Accident (LOCA) Research Program. A series of ECC bypass tests were conducted in the full-scale, separate effect test facility called the Upper Plenum Test Facility (UPTF) and in the 1/21 volume-scale, integrated test facility called the Cylindrical Core Test Facility (CCTF). These tests have been analyzed by MPR Associates, Inc., and reported in the attached report, entitled, "Summary of Results from the UPTF Downcomer Separate Effects Tests, Comparison to Previous Scaled Tests, and Application to U.S. Pressurized Water Reactors" (Attachment 1). Data from these tests were used to assess the TRAC-PF1/MOD1 and MOD2 computer codes, and the results have been documented in the attached report, entitled, "Posttest Analysis of the Upper Plenum Test Facility Downcomer Separate Effects Tests with TRAC-PF1/MOD2" (Attachment 2).

The UPTF is a full-scale model of a four-loop 1300 MWe pressurized water reactor (PWR) with simulated core, steam generators and pumps. The CCTF is a 1/21-scale model of a four-loop 1100 MWe PWR with a full-height pressure vessel, steam generators, and simulated pumps. Both facilities are designed to simulate the end of blowdown, refill, and reflood phases of a large break LOCA.

1. Regulatory Issue

When ECC is injected into the cold-legs in response to a LOCA, a significant portion of this ECC may bypass the core by flowing around the downcomer to the break. This bypass is expected to occur until the vessel is depressurized to the containment pressure. If this refilling process starts late in the LOCA transient and takes a long time to complete, the core can be reheated significantly after the blowdown cooling ends and before the liquid fills the lower plenum and starts reflooding the core.

This ECC bypass concern has been studied extensively in small-scale test facilities. However, the extension of the small-scale test results to a full-scale reactor involved a significant uncertainty. Because of this uncertainty and because of its importance, NRR requested that the ECC bypass concern be resolved as part of the 2D/3D Program (Attachment 3). NRR also emphasized that RES should verify thermal-hydraulic codes with respect to ECC bypass and other thermal-hydraulic issues (Attachment 4). Therefore, the objectives of this study were to determine the following:

A. At what time and/or pressure does the ECC start penetrating into the lower plenum, and to what extent does ECC bypass the core in the refill period in a full-scale test facility, and

B. How reliably can the TRAC-PF1/MOD1 and MOD2 codes predict the extent of the ECC bypass.

2. <u>Conclusion</u>

A series of experiments in the UPTF showed that the ECC started penetrating into the lower plenum well before the blowdown ended. Under simulated PWR conditions, the ECC started penetrating rapidly at a rate equivalent to about 90% of the injection rate starting at 8 to 11 bar, while the blowdown was still taking place, and refilled the lower plenum in about 16 seconds, or about 5 seconds after the blowdown ended. This refilling rate included liquid accumulation due to condensation of steam which was estimated to be about 80% efficient. The favorable delivery rate of ECC is achieved by the two-dimensional behavior of the downcomer; most of the ECC injected into the two cold-legs farthest away from the broken loop entered the lower plenum, while most of the ECC injected near the broken loop bypassed the core. TRAC-PF1/MOD2 calculations simulated these phenomena.

The above behavior is much different from the smaller scale CCTF results which showed no discernable differences between loops and no initiation of refilling process until the vessel pressure was completely depressurized. However, the 1/50-scale LOFT test results tended to support the UPTF test results.

The ECC penetration data from the UPTF showed much higher delivery rates of ECC than the correlation recommended in RIL 128 which was based on previous small scale test results. For instance, under the countercurrent flow limit (CCFL) conditions used in UPTF Test 6, none of the ECC would have been predicted to be delivered to the UPTF Vessel lower plenum if the Creare 1/5 scale K^* correlation were applicable, and only about 10% of the observed UPTF rate would have been delivered if the Creare 1/5 scale J^* correlation were applicable.

The UPTF and CCTF data also show that the liquid level in the downcomer is somewhat lower than the bottom of the cold leg during most of the reflood period because of entrainment of liquid by steam entering the downcomer from the intact loops, then going out the break. For a typical PWR condition, the liquid level in the downcomer during most of the reflood period is analytically estimated to be about 0.7m below the bottom of the cold legs. This reduction in liquid level corresponds to 20% of downcomer height measured from the bottom of the core to the bottom of the cold legs. This reduction is estimated to cause a peak clad temperature increase of about 13^{o} C.

The TRAC-PF1/MOD1 code predicted much more bypass of ECC than the UPTF data. For instance, the UPTF Test 6 Run 133, a countercurrent flow test, showed that 47% of total ECC injected was delivered to the lower plenum whereas TRAC-PF1/MOD1 predicted only 24% delivery. In comparison, the improved modeling in TRAC-PF1/MOD2 predicted about 47% delivery. Overall, TRAC-PF1/MOD2 predicted the UPTF countercurrent flow and lower plenum refilling data within an acceptable error band of 20%.

3. <u>Regulatory Implications</u>

The ECC bypass tests conducted in the UPTF confirmed that the required feature for ECCS analyses models in 10 CFR 50 Appendix K contained large conservatisms in the treatment of ECC bypass. The Appendix K model requires that all ECC injected during the bypass period be subtracted from the liquid inventory in the test vessel, whereas the data showed that about 90% of ECC injected during the later part of the bypass period would be delivered to the lower plenum. These ECC bypass test data further support the technical basis of a revised ECCS rule which was promulgated in October 1988. Since the ECCS rule was already revised to reflect these and other LOCA test data, no additional regulatory action is needed.

4. <u>Restriction on Application</u>

The ECC bypass tests conducted in the UPTF closely simulate a PWR condition. However, there are certain discrepancies such as a difference in vessel wall heat content and the ECC injection rate. The heat release from a PWR downcomer wall is estimated to be about 3 to 5 times that of the UPTF downcomer wall. Therefore, during the initial injection period a slightly greater bypass may occur in a PWR than in the UPTF. However, the ECC injection rate (500 kg/s) used in the UPTF is considerably less than the 700 kg/s used for a Westinghouse plant or the 970 kg/s used for a Combustion Engineering plant. Therefore, the PWR injection rate would result in a higher delivery rate of ECC to the vessel, tending to counterbalance the slightly greater bypass mentioned previously. Through use of the code, these minor discrepancies can be properly accounted for. Consequently, there is no serious limitation on the application of the ECC bypass data.

5. Unresolved Questions

There is no unresolved question concerning the ECC bypass issue. The successful TRAC-PF1/MOD2 analysis of UPTF data, coupled with previously scaled test data, and the TRAC analysis of full-scale PWR behavior have shown that our understanding of the ECC bypass issue is sufficient.

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Attachments:
1. "Summary of Results from the UPTF Downcomer Separate Effects Tests, Comparison to Previous Scaled Tests, and Application to U.S. Pressurized Water Reactors," MPR-1163, June 1990.
2. "Posttest Analysis of the Upper Plenum Test Facility Downcomer Separate Effects Tests With TRAC-PF1/MOD2," D.A. Siebe and H.J. Stumpf, Los Alamos National Laboratory, June 1990.
3. Memorandum from H. Denton to S. Levine on NRR Position to LOCA/ECCS Research Commission Paper, July 25, 1978.
4. Memorandum from H. Denton to R. Minogue, NRR Thermal-Hydraulic Research Needs, September 12, 1984.