SAFETY EVALUATION REPORT ON TAP GENERIC ISSUE A-16 STEAM EFFECTS ON BWR CORE SPRAY DISTRIBUTION

1.0 Introduction

The core spray (CS) systems in all BWRs are designed to provide water to cool the reactor core in the event of a loss of coolant accident (LOCA). The function of the CS system is to distribute core spray water across the top of the core such that the minimum spray flow provided to each fuel bundle will achieve the core spray heat transfer coefficient assumed in the General Electric (GE) Emergency Core Cooling System (ECCS) Evaluation model.

Prior to 1974, GE demonstrated the adequacy of BWR CS Systems by showing that the minimum required bundle flow is available. The supporting test data were taken from full-scale mock-ups of the BWR/2 through BWR/5 core spray sparger assemblies in air at atmospheric pressure. In 1974, tests conducted in Europe (the results of which were confirmed in tests conducted by GE) indicated that the presence of steam and/or increased pressure in and above the core region could adversely affect the spray water distribution from certain types of core spray nozzles. To assess these effects, GE developed a core spray methodology that measures the effects of steam, and factors the effects into the core spray sparger design. The Task Action Plan (TAP)-A-16, sponsored by NRC, EPRI, and GE, was established to demonstrate the adequacy of this methodology by conducting full scale 30-degree sector steam tests (Ref. 1). Presently, all of the core spray tests under TAP-A-16 have been completed. The results of 30-degree sector steam tests for a simulated BWR/6 are documented in Reference 2, and the staff evaluation report is included in Reference 3. The results of a similar core spray test for a BWR/4 core are documented in Reference 9 and the staff evaluation of the safety implications on core spray distribution of these test data in conjunction with evaluation of similar foreign test data is included in References 4 and 5. This report summarizes the TAP-A-16 tests and staff evaluation results.

2.0 Evaluation Model

Section I.D.6 of Appendix K to 10CFR50 indicates that during spray cooling following the blowdown period in a LOCA, convective heat transfer for BWR fuel rods must be calculated using coefficients based on appropriate experimental data. A spray cooling heat transfer coefficient of 1.5 Btu/hr-ft^2-°F, the minimum value specified in Section I.D.6 of Appendix K for the spray cooling heat transfer coefficient, is employed in the GE ECCS Evaluation Model. GE has confirmed by tests that if the fuel bundle flow is approximately one gallon per minute, a convective heat transfer coefficient of 1.5 Btu/hr-ft^2-°F will be achieved (References 4, 5, 6, and 7). Additional tests performed by GE (Ref. 8) indicate that even if no core spray cooling water exists, a heat transfer coefficient greater than 1.5 Btu/hr/ft^2-°F will be achieved by steam cooling only.

3.0 Evaluation of Core Spray Cooling Effectiveness for BWR/6 Reactors

Under the TAP-A-16 program, a 30-degree sector steam test was designed with a test configuration representative of a reference BWR/6 with a 218-inch diameter core. Prototypical hardware was used, and the upper plenum of the test apparatus was a full scale mock-up of a 30-degree sector of the reference upper plenum with accurate simulation of its geometry. The results of these tests (Ref. 2) confirmed the capability of the GE methodology to predict spray distribution performance in steam of a multiple nozzle core spray system similar to that of the BWR/6 design. The staff concluded in the evaluation report (Ref. 3) that the pre-test predictions compare reasonably well with the test results. The staff also found that the data taken from the 30 degree sector steam test facility for a simulated BWR/6 core indicates a core spray distribution which results in a minimum bundle flow of larger than one gallon per minute, which justifies the core spray cooling convective heat transfer coefficient of 1.5 Btu/hr-ft^2-°F used in the GE ECCS Evaluation Model. Later test data obtained from the GE Two Loop Test Apparatus (TLTA) using 8x8 fuel bundles (Ref. 8) indicate that steam cooling alone with no core spray water flow results in a significantly greater convective heat transfer coefficient than 1.5 Btu/hr-ft^2-°F. Therefore, the staff has concluded that core spray distribution is not a safety concern for a BWR/6.

4.0 Evaluation of Core Spray Cooling Effectiveness for BWR/4 and BWR/5 Reactors

The 218 inch diameter BWR/6 30 degree sector steam test facility was used to perform a similar test on a simulated BWR/4 core spray system. The test results (Ref. 9) confirmed GE's capability to predict spray distribution performance in steam using the GE core spray methodology for a BWR/4 core. The data (Ref. 9) also showed that the minimum bundle flow is greater than one gallon per minute (gpm), which justifies the assumption of the core spray cooling heat transfer coefficient of 1.5 Btu/hr-ft^2 -°F used in the GE ECCS model.

In 1981, a test of core spray distribution in steam conducted in a foreign country raised concern that the central fuel bundles of a BWR/5 core may receive low spray water flow. Since the BWR/4 and BWR/5 spray nozzle designs are similar, the foreign test data also caused concern about BWR/4 core spray distribution adequacy. The NRC staff notified Licensing Boards (Ref. 4) of this concern and further pursued the matter to obtain more detailed information about the foreign tests via the international information exchange program.

In 1982, the staff received and reviewed the foreign test report. The tests were conducted in a 60 degree sector steam test facility for a simulated BWR/5. The results indicate that the flow of water to the fuel bundles decreases as the distance from the center of the core decreases and results in a minimum flow of about 1.5 gpm at a radius of approximately five inches from the center of the core. The available data do not provide information showing the core spray flow rate to the central fuel bundles. The minimum bundle flow obtained from the available data is greater than the bundle flow of one gpm required to justify the heat transfer coefficient of 1.5 Btu/hr-ft^2 -°F for core spray cooling employed in the GE ECCS Evaluation Model. However, because of concern about the spray distribution to central bundles, the staff required GE to analyze the limiting LOCA for BWR/4 and BWR/5 cores to evaluate the effect of no core spray cooling on the peak cladding temperature.

During the BWR core spray injection, spray injected in the upper plenum will either be distributed to the core or bypass the core and drain to the lower plenum region, which results in a rapid bottom reflood rate. Presently, credit is not taken for this rapid bottom reflood effect in the GE ECCS Evaluation Model. Any liquid accumulated at the top of the tie plate before exceeding the counter-current flow limit is assumed to be discharged from the system and does not contribute to the reflood. Tests for the 30 degree sector steam evaluation of ECCS mixing phenomena performed in the GE Lynn facility in 1981 (Ref. 10) show that spray flow injected into the upper plenum drains to peripheral bundles and increases the bottom reflood rate. In response to the staff request, GE presented analytical results based on a model which assumes that the core spray coolant drains through the peripheral channels to the lower plenum, thus increasing the reflood rate as observed in the Lynn tests. The calculated peak cladding temperature using this model based on experimental data, but with no credit taken for the spray cooling effect (i.e., the heat transfer coefficient for spray cooling is assumed to be zero), did not exceed the 10 CFR 50.46 temperature limit of 2200°F. Therefore, in the safety evaluation report (Ref. 5), the staff concludes that the core spray distribution does not pose a safety concern for BWR/4 and BWR/5 cores.

5.0 Evaluation of Core Spray Cooling Effectiveness for BWR/3 Reactors

Because of the concern about core spray distribution as a result of the foreign test data, the staff reevaluated BWR/3 core spray systems with respect to applicability of available test results. Although the BWR/3 core spray nozzle design is similar to that of the BWR/4 and BWR/5 reactors, the arrangement of the nozzles for spray distribution differs.

In order to evaluate the concern about spray distribution in BWR/3 reactors, the staff requested GE to perform a sensitivity study for a limiting BWR/3 case using their model with credit taken for fast bottom reflood but no credit taken for core spray cooling as discussed for the BWR/4 and BWR/5 reactor types (Section 4.0).

The staff has reviewed the results of these analyses (Ref. 11) and concludes the following:

(1) GE has demonstrated that for the limiting case of different sizes of BWR/3s with core spray assumed flowing down peripheral channels to increase the reflood rate as observed in the Lynn test, the calculated peak cladding temperature (PCT) does not exceed the 10 CFR 50.46 limit of 2200°F with no credit taken for the core spray cooling effect. (see results in Attachment 1).

(2) GE indicates that the use of their improved loss-of-coolant accident Evaluation Model (SAFER/GESTR) currently under review by the staff, would be expected to lower the calculated PCT's further.

We, therefore, conclude that the core spray distribution adequacy is not a safety concern for all BWR/3s.

6.0 Review Status of Core Spray Systems for Non-Jet Pump Type Reactors (BWR/1 and BWR/2)

BWR/1 and BWR/2 are the non-jet pump type reactors. Big Rock Point is the only domestic operating BWR/1. The staff has previously reviewed the design of the core spray system for Big Rock Point and concluded that the core spray system is acceptable (Ref. 12).

Oyster Creek and Nine Mile Point-1 are the only domestic operating BWR/2 type reactors. The design of these core spray systems to achieve the core spray cooling effectiveness is currently under review by ORAB of Division of Licensing, which will publish a separate safety evaluation report for each plant.

7.0 Safety Evaluation Summary

Based on the review discussed above, the staff concludes that the core spray distribution is not a safety concern for BWR/1, BWR/3, BWR/4, BWR/5 and BWR/6 reactors and that TAP-A-16 concerns are resolved based on the following:

1. All of the tests under TAP-A-16 have been completed.

2. All of the core spray sector steam tests conducted in the U. S. and abroad indicated that the minimum spray bundle flow is greater than 1 gpm, which test data have demonstrated is sufficient flow to justify the assumption of the spray cooling heat transfer coefficient of 1.5 Btu/hr-ft ^{2}-°F which is used in the GE ECCS Evaluation Model.

3. New analyses performed by GE have shown that for limiting BWR/3, BWR/4 and BWR/5 cases with core spray assumed to drain through peripheral channels to increase the reflood rate as observed in the Lynn tests, the calculated peak clad temperature did not exceed the 10 CFR 50.46 limit of 2200°F with no credit taken for the spray cooling effect.

4. Recent test data (Ref. 8) show that even without any of the core spray water flowing through 8x8 fuel bundles, steam cooling alone would result in a significantly greater convective heat transfer coefficient than the 1.5 Btu/hr-ft ^{2}-°F assumed in the GE ECCS Evaluation Model.

The designs of core spray systems for Oyster Creek and Nine Mile Point-1 are under review by the NRC staff and a separate evaluation report of the review results will be prepared.

Reference

1. NUREG-0371, Approved Category A Task Action plan, November 1977.

2. NEDO-24712, Core Spray Design Methodology Confirmation Test, August 1979.

3. Letter from R. Tedesco (NRC) to G. Sherwood (GE), Acceptance for Referencing Topical Report NEDO-24712 - Core Spray Design Methodology Confirmation Tests, January 30, 1981.

4. BN-81-49, Board Notification - Japanese Spray Distribution Tests on a Simulated BWR/5 Configuration, December 11, 1981.

5. NUREG-0420, Safety Evaluation Report for the Shoreham Plant, Supplement 2, February 1982.

6. Letter from O. Parr (NRC) • G. Sherwood (GE), Review of General Electric Topical Report NEDO-20566 Amendment 3, "General Electric Company Analytical Model for Loss-of-Coolant Analysis in Accordance with 10 CFR 50 Appendix K - Effect of Steam Environment on BWR Core Spray Distribution", June 13, 1978.

7. APED · 5529, Core Spray and Core Flooding Heat Transfer Effectiveness in a Full- le Boiling Water Reactor Bundle, June 1968.

8. NUREG-2229 (Volume 1), BWR Large Break Simulation Tests - BWR Blowdown/ Emergency Core Cooling Program, April 1982.

9. NUREG/CR - 1707, BWR Refill/Reflood Program Task 4.2 - Core Spray Distribution Final Report, March 1981.

10. NUREG/CR - 2786, BWR Refill/Reflood Program Task 4.4 - CCFL/Refill System Effect Tests (30° Sector Steam Evaluation of ECCS mixing factor phenomena)- to be published.

11. Letter from H. Pfefferlen (GE) to C. Berlinger (NRC), Effect of Fast Reflood on Peak Clad Temperature (PCT) for BWR/3's.

12. Letter to D. Bixel (CPCo) from D. Ziemann (NRC), dated April 10, 1979.

ATTACHMENT 1

BWR/3 - EFFECT OF FAST REFLOOD

Plant(inches Size in diameter)	Critical Break Size	Single Failure	Appendix K PCT °F	Fast Reflood w/o CSHT* PCT** °F
205	40% DBA*** Suction	LPCI**** Injection Valve	2200	1896
224 (Slow Flooder)	100% DBA Suction	LPCI Injection Valve	2200	1748
224 (Fast Flooder)	100% DBA Suction	LPCI Injection Valve	2114	1937

* CSHT: Core Spray Cooling Heat Transfer

** PCT: Peak Cladding Temperature

*** DBA: Design Basis Accident

**** LPCI: Low Pressure Core Injection