TASK A-16

STEAM EFFECTS ON BWR CORE SPRAY DISTRIBUTION

Lead NRR Organization: Division of Operating Reactors

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Applicability: All GE BWRs

Projected Completion Date: December 31, 1979

1. Description of Problem

The core spray (CS) systems are one component of the Emergency Core Cooling System (ECCS) for all BWRs. CS systems have a nozzle or a set of nozzles arranged to distribute water over the top of the core following a postulated loss-of-coolant accident (LOCA). Each fuel bundle must receive a specified minimum amount of coolant (i.e., flow) from the CS system to provide the post-LOCA spray cooling assumed in the LOCA analyses.

During tests conducted in Europe (the results of which were later confirmed by tests conducted by the General Electric Company), it was discovered that the presence of steam and/or increased pressure in and above the upper core region could adversely affect the distribution of flow from certain types of core spray nozzles.

Prior to this discovery, GE had conducted full scale spray distribution tests in air at atmospheric pressure for all BWR/2 and later designs to ensure that the necessary minimum coolant flow would be provided to each fuel bund'e. Those tests were performed in a full scale test facility which used the actual core spray nozzle geometry (spacing, type, arrangement, and alignment) spraying water over a mockup of the top of the reactor core. Core spray flow into each mockup "fuel bundle" was collected and measured.

Prior to the European tests in steam and at higher pressure, such tests in air were accepted as an adequate demonstration that sufficient flow would be delivered to each fuel assembly to provide adequate cooling. However, the new test data in a steam environment and at various pressures raised questions regarding the safety margin previously thought to exist in the spray flow to individual fuel assemblies.

The new data in steam and at increased pressures were from a single nozzle spraying vertically downward. Depending upon the type of nozzle tested, various significant effects on spray distribution were noted. These included partial or complete collapse of the spray cone and/or a shift in the average direction of flow (i.e., in the spray axis). These effects were more severe for nozzles which produce small, high velocity droplets and/or a hollow cone spray pattern such as the "VNC" nozzle discussed in Section 3. Some BWRs do not utilize such nozzles, but others have a combination of such nozzles and larger droplets, lower velocity nozzles.

In contrast to the vertically oriented single nozzle tests, spray flow in most domestic BWR core spray systems comes from many nozzles spraying approximately horizontally over the core from a sparger (or spargers) surrounding the core. Therefore, with the exception of the Big Rock Point (BRP) reactor, where one of the two spray systems had a single nozzle directed vertically downward, the degree of applicability of the new data to domestic BWRs was not known.

Consequently, GE presented test results and calculations performed to justify acceptability of presently assumed core spray cooling credit during the interim period while the program outlined herein is being completed. As described in Section 3.0, the "interim" tests have received preliminary acceptance by the staff for that purpose.

However, areas of uncertainty exist regarding the test methodology and assumptions used in the "interim" tests, so that it is not presently possible to precisely determine how much of the margin previously thought to exist above minimum required spray flows actually would be present for each plant design and size. The "interim" tests were a "bounding" or "worst case" series of tests for a typical reactor size utilizing the type of nozzles whose spray patterns are believed to be most severely degraded by steam effects. Consequently, tests are needed which are more specifically applicable to each different plant design. Of more fundamental concern is validity of the basic assumption inherent in the "interim" tests, which is the separability of hydrodynamic phenomena (droplet-to-droplet interaction where spray patterns from two or more nozzles intersect) and thermal phenomena (steam condensation). This separability assumption is implicit in the "interim" results since only single nozzle tests have been performed in steam, and nozzle-nozzle interactions have been measured only in air (multi-nozzle tests in steam are not possible in present test facilities). Preliminary single nozzle test results in steam support the "separability" assumption by indicating that most steam condensation occurs in the first six inches of spray flow outside the nozzle. Individual nozzles on a BWR core spray sparger are sufficiently separated so that their spray patterns do not intersect within the first six inches outside the nozzle. Therefore, the hydrodynamic and thermal effects should occur in separate regions, thereby supporting the basic assumption made by the "interim" tests. Nevertheless, it remains for further testing, including multi-nozzle tests in steam, to provide final verification of this assumption and thereby rigorously demonstrate existence of the full spray flow margin indicated by the "interim" tests.

The program outlined in this Task Action Plan (TAP) is designed to provide results which can be justified as being applicable to each size and design BWR, including verification of the "separability" assumption.

2. Plan for Problem Resolution

The earlier TAP (Revision 0) included plans to obtain interim justification of credit presently assumed for core spray cooling effectiveness. As indicated in Sections 1 and 3 of this TAP (Revision 1), that interim justification has now been obtained and has received preliminary acceptance by the staff. This has been done without extensive utilization of the Big Rock Point (BRP) test facility as discussed in the TAP (Revision 0).

This change was made for the following reasons:

1) Preliminary evidence was provided as discussed in Section 1 that the "separability" assumption (hydrodynamic and thermal effects) is correct. This allowed somewhat more credit to be taken for the "interim" test results discussed in Section 3 which rely heavily on that assumption of separability.

2) Plant specific results were provided showing that considerable margin is present between the spray flow believed to exist (without consideration of steam effects) and the flow required to justify the cooling credit currently assumed. That is, considerable reduction in spray flow could be tolerated before cooling effectiveness could be degraded to levels below those assumed in the present analyses.

3) The geometry and size of the BRP facility is considerably different from modern BWR designs, so that test results obtained in that facility would be of questionable applicability to modern BWRs.

This Revision 1 of the TAP reflects the present near completion of the "interim" phase which was described in Revision 0. Therefore, Revision 1 describes plans for the "final" phase.

The series of tests and calculations described below will be performed in the first part of the "final" phase for each size BWR/6 plant (218, 238, and 251 inch inside diameter). When sufficient test results become available to establish confidence in ability to predict similarities and differences between spray flow patterns with different nozzle designs and different size plants, a decision will be reached regarding the extent of the testing program that will be required for older plants (the remainder of the "final" phase). It is expected that each BWR-owning utility will follow progress of the BWR/6 core spray distribution testing program so that he can meaningfully participate in making that decision.

For each size BWR/6, the following program is planned:

1) Single nozzle, full scale tests will be performed in steam for each spray nozzle type. The Horizontal Spray Facility (HSF) will be used for these tests, allowing the single nozzle to spray over a full scale representation of the reactor upper plenum region that would be covered by a single nozzle. The near-horizontal spray trajectory present in the reactor will be duplicated in this test facility (unlike the vertical spray flow used in the European tests which was not representative of modern BWRs).

2) Data from the HSF will be used for three purposes: (a) a "simulator" nozzle will be developed which will simulate, in air, the spray pattern produced by the actual nozzle in the HSF in steam; (b) the data will be used to calibrate a single nozzle calculational model which can extend the HSF data base, and (c) the data will be used directly as input to a multiple-nozzle model.

3) Multiple nozzle full scale tests will be conducted in air to determine nozzle-to-nozzle interaction effects on overall spray distribution patterns. These tests will be conducted using the "simulator" nozzles developed as described in 2)-(a) above. The data obtained will be used with the single nozzle model described in 2)-(b) above so that the model will predict spray distributions from multiple nozzles in steam.

4) A Full-Reactor representation of core spray distribution in steam will then be obtained by utilizing the multi-nozzle model described in 3) above in conjunction with a full scale, 360° spray test conducted in air using the "simulator" nozzles previously described.

This process will be confirmed by a representative 218" BWR/6 multi-nozzle steam test. This test will be conducted at the new facility in Lynn, Massachusetts to confirm the assumption (inherent in the above described procedure and in the "interim" tests described in Section 3) that hydrodynamic and thermal effects are separable. The Lynn facility is a full scale mockup of a 30° sector of a BWR/6 upper plenum, complete with that 30° sectors' core spray spargers and actual, unmodified nozzles. Hence, nozzle-to-nozzle interactions can be determined using actual, unmodified nozzles in a full scale, steam environment.

The important improvements between the above described "final" tests and the less extensive "interim" tests described in Section 3 below are:

1) the "final" tests will be plant size and design specific, with 360° full scale, in-air tests for the particular plant size and with all nozzle types used on the particular plant design represented by nozzles which have been modified to simulate steam effects (the "interim" tests were for only one plant size, and only the nozzle type most affected by steam was modified to simulate steam effects);

2) the "final" tests will utilize a much more extensive data base to determine nozzle-to-nozzle interactions, and will make extensive use of analytical capability to compliment the experimental work, both in design of the experiments and in interpretation of the results (whereas the "interim" tests were largely an experimental approach to obtaining a worst case degradation in spray distribution due to steam effects); and

3) the "final" tests will include multi-nozzle full scale 30° sector tests in steam to verify the assumption that hydrodynamic and thermal effects are separable (that assumption is inherent in both the "interim" and the "final" tests, but the interim tests did not utilize full scale, multi-nozzle, in-steam tests for verification).

During review of the BWR/6 testing program, a decision will be reached regarding the extent of testing required for other BWR reactor designs (i.e., BWR/1 through BWR/5 plants).

Following review of the test program results for all BWRs, it is anticipated that a Safety Evaluation will be published in the form of a NUREG report on this generic issue The NUREG report can then be referenced as covering this generic item in future Safety Evaluation Reports (SERs) on NEDO-20566 including "Amendment 3" and in future SERs on the GE-ECCS "Appendix K" Evaluation Model. The NUREG report will state the NRR conclusions regarding acceptability of the analytical and experimental techniques used to determine the safety margin present in core spray distributions for all operating BWR plants and all BWR plants under construction or being planned.

3. <u>Basis for Continued Operation and Licensing Pending Completion of Task</u>

The potential safety concern addressed by this Task Action Plan (TAP) is applicable to all General Electric Company Boiling Water Reactors (GE-BWRs). As discussed in Section 1, if the reactor is to strictly conform to the post-loss-of-coolant accident (LOCA) requirements established by 10 CFR 50.46 to ensure the health and safety of the public, the Core Spray (CS) systems must supply a specified minimum amount of coolant to each fuel bundle (i.e., the spray flow assumed in the LOCA analyses must actually be supplied in the post-LOCA steam environment).

For BWRs currently operating, the staff has received and is reviewing a topical report describing a series of tests that were conducted by GE

1742 293

to quantify the degradation of core spray distribution due to steam effects (Amendment 3 to NEDO-20566). That report describes a series of single nozzle tests in steam using different types of nozzles, typical of those used in BWR/2 through BWR/5 plants. These tests quantified the amount of single nozzle cone collapse and spray axis shift due to the steam environment that would be expected in the upper plenum of a BWR following a LOCA. A particular nozzle (designated the "VNC" nozzle) that was designed to produce a hollow cone spray pattern was found to be most adversely affected by the presence of steam. These effects on the "VNC" nozzle were then simulated in a full scale testing (air only) facility. That is, each "VNC" nozzle in the air testing facility was modified so that it would reproduce, in air, the spray pattern that the single nozzle steam tests showed would be produced by an identical "VNC" nozzle in a steam environment. Full scale air tests, with the "VNC" nozzles so modified, were then performed for a typical BWR/4 or BWR/5 plant (core spray spargers are identical for plants of the same size with these two designs). Results of those tests indicate that, even allowing a considerable margin to cover uncertainties in the test methodology and assumptions, minimum spray flow to any channel following a LOCA will not be less than half of that previously determined by tests and calculations which did not include steam effects. Since core spray distributions for other plants (with nozzles that are less severely affected by steam) should be less severely degraded, this factor of two is believed to be a bounding or maximum degradation factor for all plants.

Therefore, if spray flow distributions previously determined without consideration of steam effects demonstrate considerably more than a factor of two above the minimum spray flow necessary to provide the cooling assumed in LOCA analyses, then the air tests described above are evidence that adequate spray flow exists even with conservative consideration of steam effects. Results have been provided to the NRC staff for each size and type of BWR/2 through BWR/5 plant indicating that, for the worst size and location break with the worst attendant single failure, considerably more than the above indicated factor of two exists. A contributing factor to the existence of this margin is that the limiting break with the worst single failure leaves two core spray systems available (plus one or more flooding systems in certain plants). Flow typical of the minimum flow to any group of fuel bundles from only one-spray-system-operation was present in tests previously run to measure spray heat transfer coefficients (Full Length Emergency Core Heat Transfer tests).

Although not specifically included in the tests described above, the same type of "flow margin" information has been provided on an individual plant-by-plant basis for each currently operating BWR/1 plant, with similar acceptable margins indicated in all cases.

Furthermore, in the unlikely event that the confirmatory tests outlined by this Task do not support the margins presently believed to exist, two relatively simple alternatives exist for operating plants:

1) LOCA re-analyses could be performed, using lower spray cooling coefficients for which an adequate spray flow margin can be demonstrated. This could result in operating restrictions on some plants. Such future LOCA re-analyses might be allowed to take credit for other compensating effects pending confirmatory experimental results, such as less severe reflooding delays due to counter-current-flow limiting effects.

2) It is anticipated that relatively simple modifications could be developed as a result of this Task which would produce a better spray distribution in the post-LOCA steam environment. Such modifications would probably involve re-aiming presently installed nozzles, replacing some or all of the presently installed nozzles with one of the currently available nozzle designs which have been shown to be more effective in the post-LOCA steam environment, or replacing presently installed nozzles with an improved nozzle design which may be developed, if necessary, during conduct of this TAP. Such modifications would be feasible for operating plants to accomplish.

In view of the spray flow margin presently believed to exist for operating plants, and in view of the alternatives available in the unlikely event that the confirmatory tests outlined by this Task do not confirm the margins presently believed to exist, we conclude that continued operation of licensed GE-BWRs, during the interim period pending final resolution of this Task, does not present undue risk to the health and safety of the public.

For BWRs currently under review for an Operating License (OL), all of the above statements, alternatives and conclusions are equally applicable. In addition, depending upon the particular schedule involved for a given plant, this Task may have proceeded further toward completion. In that event, alternative 2) immediately above will be more viable because results of further tests will be available for consideration in determining desirable design changes, and those design changes could be incorporated more readily into a (non-radioactive) core that has not been operated at power. In view of the margin in spray flow presently believed to exist for plants applying for an OL (as previously described) and in view of the alternatives available in the unlikely event that the confirmatory tests outlined by this Task do not confirm the margins presently believed to exist, the staff has concluded that, pending completion of this TAP, Operating Licenses can be granted with reasonable assurance that operation will not present undue risk to the health and safety of the public.

For BWRs currently applying for a Construction Permit, again all of the above statements, alternatives and conclusions are equally applicable. In addition, the timing involved virtually ensures that this Task will be completed before construction is completed. Since necessary modifications, if any, to the plant design as a result of this Task can be accomplished while the plant is being constructed, the staff has concluded that, pending completion of this TAP, Construction Permits can be granted with reasonable assurance that (1) there will be a satisfactory resolution of this concern prior to operation, and (2) operation will not present undue risk to the health and safety of the public.

4. NRR Technical Organizations Involved

A. Reactor Safety Branch, Division of Operating Reactors

RSB/DOR has overall lead responsibility for the conduct of this generic review. RSB/DOR will be primarily concerned with effects on operating reactors, but will review all material generically relative to plants in all stages of licensing in cooperation with the other two branches involved. This Branch will have primary responsibility for the decision to be made regarding additional testing required for operating plants, once initial test results for the BWR/6 become available. This Branch will also participate in review of the BWR/6 test results, with primary emphasis on implications of those tests for operating reactors.

Manpower Estimates: 0.33 man-year FY 1977; 0.33 man-year FY 1978; 0.33 man-year FY 1979; 0.16 man-year FY 1980.

B. Reactor Systems Branch, Division of Systems Safety

RSB/DSS will be primarily concerned with effects on reactors not yet licensed for operation, but will review all material in cooperation with the other two branches involved. This Branch will have primary responsibility for the decision to be made regarding additional testing required for new (non-operating) plants, once initial test results for the BWR/6 become available. This Branch will participate in review of the BWR/6 test results, with primary emphasis on implications of those tests for the BWR/6 and other non-operating designs.

Manpower Estimates: 0.16 man-year FY 1977; 0.16 man-year FY 1978; 0.33 man-year FY 1979; 0.16 man-year FY 1980.

C. Analysis Branch, Division of Systems Safety

AB/DSS will evaluate and compare test results to analytical results to determine the adequacy of current analytical techniques, and will

1742 296

review any proposed changes in analytical techniques as a result of the tests reviewed. This Branch will review the BWR/6 test results in cooperation with the other two branches with primary emphasis on implications of those tests for analytical techniques. Principle review subjects will include, but not necessarily be limited to, analysis techniques used to predict spray vaporization, counter-current-flooding phenomena (i.e., liquid-vapor interaction), droplet entrainment, channel and fuel quenching, parallel channel effects, and modeling of any new phenomena discovered in future tests.

Manpower Estimates: 0.16 man-year FY 1977; 0.33 man-year FY 1978; 0.33 man-year FY 1979; 0.16 man-year FY 1980.

5. Technical Assistance Requirements

None is presently anticipated.

6. Interactions with Outside Organizations

A. General Electric Company (GE)

Requests for additional information resulting from NRC staff review of all generic testing and analytical methods development, including such initial work for the BWR/6 design, will be addressed to GE. All communications regarding additional tests that would be generic to all BWRs or to a large group of BWRs will be jointly addressed to GE and to the licensees and applicants involved, so that procedures for conducting such tests could be jointly discussed by all parties involved.

B. BWR Licensees

In certain cases, requests for information regarding design of certain plant specific or unique spray systems will be addressed to the licensee. For example, design or droplet size distribution data for a certain nozzle or spray system used on a specific plant would be addressed to the individual licensees. This would be most likely the case for older, unique plants such as BWR/1s. Also, all communications regarding additional testing will be jointly addressed to GE and to the plants involved.

7. Assistance Requirements from Other NRC Offices

There is a proposal currently before the RES committee for NRC participation in a joint GE-EPRI-NRC funding of the Lynn, Massachusetts facility (the multi-nozzle, full scale 30° sector, steam test facility).

It is the current understanding that testing will be conducted at Lynn sufficient to complete this TAP even without RES participation. However, the RES funds requested would be used to provide more extensive instrumentation and testing, and would result in a more thorough understanding of the basic phenomena. It would therefore be in the best interest of this Task if the requested funds are approved.

8. Schedule for Problem Resolution

The major milestones for the Steam Effects on BWR Core Spray Distribution task are as follows:

A. Submittal by GE of "Amendment 3" to NEDO-20566 - May 1977 (Complete).

B. Transmit to GE results of preliminary review of "Amendment 3", including the staff position that an "Air Mockup of Steam Environment" test should be conducted as soon as possible to predict the Consumer's Power Corp. full scale ring spray tests (to be run in the steam test facility for Big Rock Point) - 07/22/77. (Complete)

C. Review of "Amendment 3" by the three specified NRR branches and submittal of requests for additional information to the Task Manager for transmittal to GE and/or licensees - 08/15/77. (Complete)

D. Response received from GE and/or licensees to additional information requests - 11/01/77. (Complete)

E. Meeting with GE to discuss and reach agreement on test program to be pursued beyond the nearly completed "interim" program - 01/19/78. (Complete)

F. Letter received from GE documenting spray flow margins believed to exist for all BWR/2 through BWR/5 plants, without consideration of steam effects. This information, plus material presented at the item (E) meeting above and information contained in the item (A) report, complete the documentation required for the "interim" period for this TAP, i.e., GE has provided justification for continued credit for currently assumed spray cooling until completion of this TAP - 03/01/78. (Complete)

G. Completion of SER on GE ECCS-LOCA model, including final conclusion regarding interim justification of continued core spray cooling credit while this Task is being completed - 04/17/78.

H. Informal report from GE or meeting with GE to present progress report. At this date, the single-nozzle-in-steam-tests in the Horizontal Flow Facility (HSF) and the first full scale 360° tests in air (for the 218" BWR/6) will each be slightly more than half completed. (June 20, 1978).

I. Informal report from GE or meeting with GE to present progress report. At this date, the HSF tests will be completed, and the 218" BWR/6 full scale 360° (and smaller sector, probably 30°) tests will be complete. (October 27, 1978)

J. Meeting with GE, licensees, and applicants to discuss progress and reach a decision regarding extent of testing to be required for other BWR designs. At this date, all full scale 360° air tests for the 238" BWR/6 will be in complete, full scale 360° air tests fo the 251" BWR/6 will be in progress (the last scheduled air tests), and confirmatory testing using multiple nozzles in steam (at Lynn, Massachusetts) will have been underway for about 2 months. (February 13, 1979)

K. Issuance of letters to licensees and applicants stating testing requirements for final justification of core spray distributions (and resulting spray cooling credit) for all BWR/1 through BWR/6 plants. (March 12, 1979)

L. Submittal of final report from GE regarding BWR/6 testing (including all air tests and all confirmatory multi-nozzle in steam tests). (August 13, 1979).

M. Submittal of reports, from all licensees and applicants, containing their plant-specific results as required by NRC letter (See K above). (November 12, 1979)

N. Review of all information complete - SER (NUREG report) issued - 12/31/79.

O. Requests issued for modifications to plant hardware and/or Technical Specifications (if necessary as a result of conclusions in the SER) - 12/31/79

8. Potential Problems

The above schedule assumes that since any additional testing and analysis will be conducted to answer questions regarding margins of safety, safe plant operation and orderly licensing procedures can continue while the program is completed. It is conceivable that questions regarding the safety of continued plant operation might arise during this review that indicate an urgent need for further test results. Such is not anticipated at this time but could result, for example, if the test program shows that hydrodynamic and thermal phenomena are not separable, as was assumed by both the "interim" and the "final" tests described in this TAP. If such concerns regarding safety of continued plant operation are found, it might become necessary to grant exemption to certain of the requirements of 10 CFR 50.46 if plant operation is to continue while the Plan is completed.