UNITED STATES
NUCLEAR REGULATORY COMMISSION
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SAFETY EVALUATION BY THE OFFICE OF NUCLEAR REACTOR REGULATION

SUPPORTING A LIMITED ECCS EXEMPTION FOR THE 1978 OPERATING CYCLE

CONSUMERS POWER COMPANY

BIG ROCK POINT PLANT

DOCKET NO. 50-155

1.0 INTRODUCTION

In the Commission Memorandum and Order dated May 26, 1976, (Reference 1), Consumers Power Company was granted an exemption for Big Rock Point (BRP) until the refueling outage scheduled for spring, 1977, from the single failure criterion in 10 CFR 50.46 and Appendix K as applied to a loss of coolant accident followed by a failure in the ring spray system. CPCo was also granted a lifetime exemption from the same single failure criterion as applied to a LOCA caused by a break in either core spray system.

As a condition of the Order, the Commission required CPCo to provide test data showing that the existing nozzle spray system provides adequate spray distribution during expected LOCA conditions or to modify the system to provide the required spray flow. This action was to be complete prior to the Cycle 15 startup.

An inherent assumption in granting both exemptions was the adequate performance of the ring spray system. The staff has recently received information regarding the steam effects on core spray distribution, (references 2 and 3), which has necessitated a re-evaluation of the BRP ring spray distribution.

Therefore, the performance adequacy of both BRP core spray systems was to be fully evaluated prior to the Cycle 15 startup. The staff's review of each system is discussed below.

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2.0 EVALUATION

2.1 Nozzle Core Spray System

CPCo conducted a test program to measure the spray distribution from the nozzle spray system (NSS) in a steam environment. The tests used a full-scale mock-up of the significant portions of the BRP reactor vessel and fuel assemblies and measured the spray flow to a representative 22 of the 84 bundles at the expected LOCA usage conditions. The tests showed that the existing single nozzle did not provide adequate spray distribution; therefore, a new-multiple nozzle was designed and constructed. After the new design was tested and an acceptable spray distribution measured, the new nozzle was removed from the test vessel and installed at BRP. CPCo submitted a report describing the test program methods, assumptions and results to the staff on August 9, 1977, "Big Rock Point Core Spray Test Report, Single Nozzle Test and Development Program," reference 2.

The two major aspects of the staff review of the NSS performance are: (1) the ECCS flow rate to the nozzle and (2) the acceptance criteria for bundle spray flow. Each aspect is discussed below.

2.1.1 Minimum Nozzle Flow

Before beginning the nozzle test program, CPCo estimated a minimum flow to the nozzle due to the most limiting ECCS pump and single failure combination. CPCo predicted the minimum nozzle flow to be 296 gpm. The new multiple nozzle was constructed and tested assuming this minimum flow. When acceptable bundle flows were achieved the multiple nozzle des gn was finalized. A hydraulic analysis was then conducted (by MPR, August, 1977, reference 4), to confirm the estimated minimum nozzle flowrate. The analysis determined the nozzle flow during bottom break and ring spray line break LOCA's while considering the most limiting single failure.

For the bottom break LOCA, the analysis showed a particular ECCS pump and valve failure combination that resulted in a nozzle flowrate less than 296 gpm. The problem occurs with both ECCS pumps running, a vessel pressure of 75 psig and an inadvertent opening of the backup containment spray system (CSS) valve. Although the present BRP technical specifications require both the primary and backup CSS to be operable, calculations submitted to the staff concerning the reactor depressurization system (RDS) performance in a LOCA (Special Report #21, May 15, 1975, reference 5) show that the CSS is not necessary to prevent exceeding containment design pressure. (In fact, the plant operating procedures allow manual bypass of the primary CSS valve if the operator decides that ECCS water should not be diverted from the core.) CPCo has proposed opening the power supply breaker to the backup CSS valve, thereby eliminating inadvertent valve opening. If necessary, power could be reinstated and the valve opened from inside the control room. Since the containment spray system is not predicted to be necessary during a LOCA, the primary CSS is always available without degrading the NSS performance, and the backup CSS can be rapidly made operable if needed, the staff concludes that power should be removed from the backup CSS valve. The Technical Specifications have been modified to require power removal from this valve. With this change the staff concludes that the nozzle spray system receives sufficient ECCS flow (e.g., $\geq$ 296 gpm) during bottom break LOCA's.

The hydraulic analysis for the ring spray line break LOCA showed that with the most limiting single failure the nozzle flowrate was in excess of 296 gpm.* Therefore, the staff concludes that the nozzle spray system receives sufficient ECCS flow during the ring spray line break LOCA.

2.1.2 Minimum Assembly Spray Flow

CPCo assumed satisfactory performance of the new nozzle design if test data showed that each assembly received at least 1.0 gpm of spray flow at reactor vessel pressures and nozzle flowrates predicted in the ECCS analysis. The staff requested the licensee to provide a detailed justification of the 1.0 gpm acceptance criteria.

CPCo and the NRC staff examined numerous reports concerning the Full Length Emergency Cooling Heat Transfer (FLECHT) experiments and the minimum spray flows conservatively predicted to be present in other BWR's of various designs and the corresponding spray cooling coefficient assumed for those reactors. It was noted that a certain "vaporization" or "evaporation" flow could be defined for each fuel assembly such that vaporization of that amount of water would remove the total amount of power being produced in the bundle. The bundle power is a function

*The ring spray line break ECCS analysis takes credit for nozzle spray cooling at a vessel pressure of about 75 psig, but the hydraulic analysis demonstrates sufficient nozzle flowrate (>296 gpm) with a vessel pressure of 38 psig. The conflicting vessel pressure assumption was explained by the licensee by referencing a revised blowdown analysis (submitted to the staff on March 26, 1976, reference 6) and fuel heatup sensitivity studies (submitted as Attachment 3 to the CPCo submittal dated February 27, 1976, reference 7). These calculations showed that if credit for nozzle spray cooling were delayed until the vessel pressure had been reduced to 38 psig, the PCT would be about 1700°F which is well below the Appendix K limit.

2.2 Ring Core Spray System

The ring core spray system is redundant to the nozzle spray system. Its performance is required to satisfy the single failure criterion of 10 CFR §50.46, Appendix K, Paragraph I.D.1 for postulated failures in the NSS concurrent with all LOCA's except a postulated break in the NSS. For postulated breaks in spray systems, the Commission has previously evaluated the likelihood and consequences of breaks in either spray system with concurrent failures in the other (i.e., intact) spray system and granted a lifetime exemption based partly on the expected performance of the reactor feedwater system. However, at that time the spray distribution in a steam environment was only thought to adversely affect the single nozzle spray system. As discussed earlier, the staff requested CPCo to reevaluate this aspect of BRP ring spray system performance.

The licensee had no data that defined the ring sparger spray distribution in either an air or steam environment, so investigating the ring spray system adequacy would have to be based on conservative estimates. The staff suggested the licensee first estimate the spray distribution in air by the use of a geometric/trigonometric approach. The projected cone angle from each individual nozzle on the ring would be superimposed on a core map. From that projection, an estimated bundle spray flow in air could be calculated. To account for steam environment effects, the bundle spray flow would be conservatively reduced. The resulting estimated flow could then be compared to the "vaporization" flow, described in section 2.1.2 herein. The ratio of estimated flow to vaporization flow for each bundle would then be used to evaluate the ring spray system performance.

The licensee utilized the staff's suggested approach described above, and the results indicated questionable ring spray distribution in an air environment. Although CPCo does not believe the staff's suggested approach accurately predicts the ring spray distribution, no test or design information or substitute approach was available to confirm the system adequacy. To allow sufficient time to conduct a test program to investigate this question, CPCo requested a one-cycle exemption from the single failure criterion of 10 CFR 50.46 as applied to a LOCA followed by a concurrent single failure of the redundant NSS. The exemption and supporting calculations were presented to the staff in the licensee's September 15, 1977 submittal (reference 10).

CPCo performed two sets of calculations in support of the exemption: (1) the probability (which they call "risk") of all LOCA's plus single failure combinations which would result in total core cooling being provided by the ring spray system and (2) for top break LOCA's, the ability of the feedwater system to reflood the vessel and maintain cladding temperatures within 10 CFR 50 Appendix K limits. The staff's evaluation of the licensee's calculations is discussed below.

The staff's decision regarding the requested one-cycle exemption is not based only on the probability assessments or the feedwater system performance appraisal. Rather, these calculations have been used along with an evaluation of other ECCS considerations to reach its decision. The other ECCS considerations are also discussed below.

2.2.1 Feedwater System Reflood

Since the ring sparger's performance adequacy cannot be substantiated for this cycle, the licensee must rely on the reactor feedwater system for core cooling during the LOCA caused by a break in the redundant NSS line. The ability of the feedwater system to keep cladding temperatures within Appendix K limits had not been previously confirmed for the redundant NSS break.

Appendix A of CPCo's letter to the staff dated March 26, 1976, reference 6, presented a blowdown analysis for the NSS line break LOCA. The analysis predicted the minimum reactor water level would be one foot above the bottom of the core, thus the fuel is never completely uncovered. Normally, core cooling is accomplished by both spray systems (two are required to satisfy the single failure criteria). Because of the uncertainty in the ring spray distribution, consideration was given to the performance of the feedwater system, even though it is not a principal safety system. Taking credit for a feedwater flowrate of 1600 gpm at ten minutes after the LOCA, CPCo analyzed the fuel heatup before reflood was complete and determined the PCT to be well below 2200°F.

The attachment to CPCo's letter to the staff dated October 12, 1977, reference 11, discusses the performance aspects of the feedwater system so that reflood can be started at ten minutes. Water makeup to the hotwell normally comes from the condensate storage tank via two paths: the makeup line or the fill line. Both lines have automatic control valves that sense the hotwell level and open to keep level within a of the fission product decay heat generation rate at the time of rated spray when the ECCS analysis takes credit for spray cooling. Therefore, the "vaporization" flow depends on the time of rated spray.*

It was further noted from the FLECHT tests and from conditions present in other BWR designs that if the minimum spray flow available to each bundle is at least 30% above the "vaporization" flow for that bundle, the convective spray cooling heat transfer coefficients in the ECCS-LOCA calculations are conservatively justified.

The licensee submitted their calculations to the staff in a letter dated September 19, 1977 (reference 8), which determined the highest bundle peaking factor at any time in Cycle 15 for each bundle location. The calculations also assumed the American Nuclear Society decay heat fraction for infinite irradiation at the earliest time at which rated spray flow was assumed to occur in the ECCS analysis (e.g., 20.4 seconds for the DBA). These two factors gave the highest power of each bundle at the time of rated spray. The "vaporization" flow was determined using this bundle power and the vessel pressure at the time of rated spray.

The actual flow delivered to each bundle was determined from the full scale tests using the minimum predicted nozzle flow of 296 gpm at 75 psig vessel pressure or higher flows at lower vessel pressure consistent with the pump lead flow performance. Using the bottom plus top steam entry condition flow data, which the staff believes to conservatively bound the worst LOCA condition,** the ratio of actual flow to vaporization flow for each bundle was calculated. Both the licensee's and the staff's calculations show that the ratio is above 1.30 for every bundle. Therefore, the staff concludes that each bundle will receive adequate flow from the NSS.

*The "vaporization" flow will also depend on the vessel conditions at the time of rated spray since the heat of vaporization, h_{fg}, and the specific volume, v_f, depend on the system pressure.

**The licensee discussed the relation of various steam entry conditions used in the nozzle testing program to actual LOCA conditions in their October 5, 1977 submittal, reference 9.

predetermined control band. The combined makeup and fill valve flowrates under a gravity flow situation was determined and used to calculate the hotwell refill rate.*

For the most limiting initial conditions, CPCo calculated that the hotwell will have sufficient inventory for condensate pump restart at about five minutes after the LOCA, and enough inventory for core reflood ten minutes after the LOCA.**

The plant procedures would require the operator to restart the feed system once hotwell level has been restored and to initiate reactor reflood at about ten minutes after the LOCA, or when hotwell inventory is adequate. Operator action soon after a LOCA is normally not desireable; however, the procedure is routine for BRP startups, the instruments and controls are familiar to the operators, and there is adequate margin in the calculation so that slight delays in reflood would not lead to an unacceptable PCT. Additionally, the operators will be informed and trained to restart the feedwater system to assure adequate reflood capability following a LOCA. The staff considers the required operation of the feed system soon after a LOCA acceptable for the next operating cycle.

While not normally a safety related system, given its important ECCS function for the next operating cycle, the feedwater system was reviewed to improve its reliability. The staff and licensee noted that several components in the feedwater system, if failed, would disable the system's ability to provide adequate core reflood. Accordingly, the staff has added Technical Specification

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*The contents of the hotwell at the time of the LOCA are conservatively assumed lost out the break. The condensate pumps trip on low hotwell level then the feedwater pumps trip on low suction pressure. Once the pumps trip, refilling of the hotwell is accomplished by flow through the makeup and fill valves from the condensate storage tank.

**The most limiting initial condition for the hotwell is a high level since this delays condensate pump trip (on low hotwell level). The condensate pumps are removing hotwell water at about 2200 gpm, so that the sooner these pumps trip the sooner the makeup flow can begin to increase the hotwell level.

The licensee has calculated that about 1815 gallons are needed to completely cover the core, thus about 6.7 minutes of hotwell makeup are required.

limiting conditions for operation and surveillance requirements to better ensure feedwater system operability in the event of a NSS line break LOCA. These components are the condensate pumps, the hotwell fill valve* and the condensate storage tank.

Based on the fuel heatup calculations, the reflood calculations and the added Technical Specifications regarding the feedwater system, the staff concludes that the feedwater system provides adequate reflood in a nozzle spray line break LOCA.

2.2.2 Probability Assessment

CPCo evaluated all combinations of break location and component failure which would result in the reliance on the ring spray system alone for core cooling. Two LOCA scenarios of importance were identified: (1) unrefloodable LOCA's (caused by bottom breaks), coupled with a failure of the redundant NSS, and (2) the refloodable LOCA (caused by a break in the redundant NSS line), coupled with a failure of the feedwater system.

The probability of each LOCA scenario was calculated by CPCo and reported to the staff in the September 15 submittal, reference 10. The staff noted that CPCo had omitted the effects of operator error,** the component unavailability due to testing and/or maintenance, and the possible common mode failures. These facets were addressed

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*The makeup valve is a solenoid operated butterfly valve and the fill valve is an air operated (solenoid actuated pilot) gate valve. The makeup valve line provides little flow under a gravity drain situation because a section of this line is only slightly below the CST water level. The fill valve alone, however, provides the majority of the gravity flow to the hotwell since the entire line is much lower than the CST water level. If the solenoid, the level switch or the air supply should fail the fill valve is inoperative and cannot be manually opened.

**The operator errors the staff identified that were omitted by the licensee are (1) the erroneous isolation of the redundant NSS during a bottom break LOCA, (2) the improper restarting of the feedwater and condensate pumps or systems, (3) the failing to initiate hotwell makeup from either the firemain (ECCS) or the condensate storage tank, and (4) the improper manual control of an inoperative feed control valve or its bypass.

The most significant of these errors is considered by the staff to be the first since it totally disables the only proven core cooling system for this break location. This error appears to have a relatively high probability since the operator has a complicated procedure to perform within a fairly short time after the LOCA. The procedure isolates the broken core spray line by comparison of ECCS flows through each spray line.

by CPCo in their October 12, 1977 submittal (reference 11). The revised probability calculations took these factors into account, and slightly different scenario probabilities resulted.

The staff did not agree with the licensee's calculations so we conducted an independent study. The staff's calculations showed the inadvertent NSS isolation potentiality to be a major contributor to the overall failure probability. Therefore, the staff and licensee discussed possible techniques to improve the operator reliability, or to remove the required isolation procedure.

As a result of these discussions and a detailed review of the original bases for the requirement,* the staff and licensee agreed that the NSS isolation procedure is no longer required and should be deleted.

The other operator errors are not as significant and do not contribute appreciably to the redundant NSS or feedwater system failure probabilities. However, in evaluating the potential operator errors in initiating hotwell makeup, the staff noted that opening the ECCS fire system to hotwell makeup line could result in a redundant NSS flow rate less than the minimum 296 gpm required. This flowpath was not evaluated in the hydraulic analysis so CPCo has deleted the procedure to initiate ECCS fire system to hotwell makeup. Instead, makeup to the hotwell would be allowed only from the condensate storage tank.

The staff's independent study was altered to reflect these changes in required operator action. The results indicate that the dominant failure mode in the redundant NSS is the failure of the in-series MOV's to open. The major failure mode in the feedwater system is either the failure of off-site power, a condensate pump or the hotwell fill valve. Thus, the staff has added Technical Specification limiting conditions of operation and surveillance requirements for these components (except off-site power which was already subject to the Technical Specifications).

*The ring spray system MOV's were located at a height such that within two hours after the worst LOCA, containment flooding would render them inoperable. Since long term cooling required isolation of the broken spray line, the operator had to evaluate the spray system flows and locate, then isolate the break. This had to be done before the RSS valves were flooded. However, the RSS valves have been raised and are no longer subject to flooding, so isolation for long term cooling can be done long after the LOCA where operator errors have less effect on ECCS performance.

Since the staff's and licensee's probability studies used different individual failure rates, the overall system failure probabilities differed. However, the overall results were not appreciably different and the staff concludes that the probability of a LOCA and failure combination resulting in the ring spray system alone having to provide core cooling is sufficiently low such that there is reasonable assurance that operation during the 1978 fuel cycle will not endanger life or property.

2.2.3 Additional ECCS Considerations

Several other factors have been considered by the staff in reaching its decision on the requested one-cycle exemption. These factors when combined give the staff an overall assessment of the BRP ECCS performance.

The staff and CPCo have assumed that the ring sparger's performance is totally inadequate. Such an assemption is very conservative. Although the geometric/trigometric approach used to estimate the spray distribution in air indicated questionable performance, neither the staff nor CPCo believes that the ring spray pattern provides no spray cooling. The effects of spray cone mixing, reflection off vessel internals and updraft have not been accounted for and can only be adequately determined by a rigorous test program (similar to the single nozzle test and development program just completed by BRP). The assumption of ring spray total inadequacy was necessary, but very conservative, since the staff did not have information available to judge its effectiveness.

CPCo's calculation of the fuel heatup before the completion of core reflood during the nozzle line break LOCA takes no credit for any spray cooling afforded by the ring sparger. Unlike the feedwater that refloods from the bottom, the ring sparger flow is from above the core and must afford some cooling as it travels down the assembly to the lower plenum. This extra cooling has not been considered by CPCo.

The water in the hotwell at the time of the LOCA has been conservatively assumed to be totally lost out the break. The blowdown analysis does not take credit for the pressure reduction or vessel inventory afforded by this flow, and the heatup analysis ignores this flow in lowering fuel temperatures.

The redundant NSS is a fully tested system that provides more than adequate flow to each fuel assembly in the anticipated LOCA steam environment. The calculations used to substantiate the system adequacy are quite conservative. Also, there is significant spray flow before the time that the ECCS model assumes spray cooling heat transfer.

The plant operating procedures require restart of the feed and condensate systems and initiation of reactor feedwater flow as soon as possible after the LOCA (see section 2.2.1). If a bottom break LOCA occurs, the feedwater will eventually be lost out the break, but some of the feedwater added to the steam drum may, depending on break location and size, flow down the steam riser or the reactor coolant recirculation lines and provide some core cooling. If the LOCA is caused by a break in the ring spray line, CPCo has shown that the redundant NSS alone provides adequate spray cooling; however, the procedures at BRP require the restart of the feed and condensate pumps and initiation of feed flow regardless of break locations. The extra coolant inventory provided by the feedwater is significant, yet has not been considered.

The ECCS reliability has been increased by the correction of several items discussed in the staff Safety Evaluation Report for Amendment No. 10 dated June 4, 1976, and in the Commission Order, dated May 26, 1976 (reference 1). The staff's evaluation of these items is discussed in the attached Safety Evaluation.

The emergency diesel generator and diesel driven fire pumps have been made more reliable by making improvements in their trip circuitry. Inadvertent diesel trips caused by erroneous signals have been virtually eliminated by the addition of coincident trip logic.

The ECCS instrumentation has been modified to allow complete on-line testability of the actuation sensors, (low water level and low primary pressure sensors). Also, Technical Specification changes have been proposed by CPCo and approved by the staff that require increased on-line ECCS testing.

CPCo has modified several ECCS annunciation and indication circuits to remove their susceptability to certain single failures. Since the operator must have these circuits to assess ECCS performance during the LOCA, the correction of the defects significantly improves the system reliability.

The position of the ring spray line isolation valves has been changed so that these components are no longer subject to flooding during a LOCA. As a result of this alteration, a relatively complicated procedure that had required operator action soon after a LOCA has been eliminated. Since the likelihood of operator error is high during a high stress condition and for an infrequent situation such as a LOCA, the deletion of core spray isolation requirements is an important addition to the reactor's safety.

The reliability of portions of the ECCS required for long term cooling has been improved by the addition of flexible hose that can bypass the underground portion of the fire system. Technical Specification surveillance requirements have been added to ensure the availability and operability of the hose.

Continued operation of the facility during this period will provide electric power for the surrounding community. The licensee has provided information demonstrating that continued operation results in savings of significant quantities of fuel oil that would otherwise be consumed.

3.0 CONCLUSIONS

The staff concludes that the redundant NSS provides sufficient ECCS cooling water flow with the most limiting single failure and produces an acceptable core spray distribution during expected LOCA conditions and this provides reasonable assurance that operation during the next refueling cycle will not endanger life or property. To ensure the adequate redundant NSS core spray performance, removal of power from the backup containment spray system valve has been required.

The staff concludes that granting the requested short-term exemption, to permit BRP to resume operation, subject to the conditions specified below, is warranted in view of the staff's assessment of the overall ECCS performance and reliability:

1. Prior to the BRP Cycle 16 startup, CPCo must provide an evaluation of the ring spray system demonstrating acceptable performance at the anticipated LOCA environments, or modify the ring spray system such that acceptable performance is achieved, and

2. If a new core spray sparger design is developed, the hydraulic characteristics of the ECCS must be evaluated to ensure adequate performance of both spray systems considering the most limiting single failure.

We have concluded, based on the considerations discussed above, that the exemption is authorized by law and will not endanger life or property or the common defense and security and is otherwise in the public interest.

Date: October 17, 1977

REFERENCES

1. Memorandum and Order, by the Commissioners, NRC In the Matter of CPCo, Big Rock Point, dated May 26, 1976.

2. Big Rock Point Core Spray Test Report, Single Nozzle Test and Development Program, NUS-3005, NUS Corporation, August 1977. (Included as attachment to the letter from W. S. Skibitsky, CPCo to Samuel J. Chilk, Secretary to the Commission, NRC, dated August 9, 1977).

3. Effects of Steam Environment on BWR Core Spray Distribution, Amendment #3 to NEDO-20566, April, 1977.

4. Hydraulic Evaluation of the Big Rock Point Plant Emergency Core Cooling System, MPR Associates, Inc., August, 1977.

5. Responses to Additional Information Requested verbally May 13, 1975 Regarding Big Rock Point Plant, Special Report No. 21, May 15, 1975.

6. Attachment 1 to the letter from Ralph B. Sewell, CPCo to Samual J. Chilk, Secretary to the Commission, NRC dated March 26, 1976 (subject: additional information on the BRP ECCS adequacy report).

7. Report on Evaluation of Adequacy of Emergency Core Cooling System, Consumers Power Company, February 27, 1976.

8. Letter from David A. Bixel, CPCo to Director of NRR, NRC, dated September 19, 1977 (subject: verification of nozzle spray flow rates).

9. Letter from David A. Bixel, CPCo to Director of NRR, NRC, dated October 5, 1977 (subject: comparison of top entry steam data with predicted LOCA blowdown phenomena).

10. Letter from David A Bixel, CPCo to Director of NRR, NRC, dated September 15, 1977 (subject: request for one-cycle exemption).

11. Letter from David A. Bixel, CPCo to Director of NRR, NRC, dated October 12, 1977 (subject: Addendum to exemption request).