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INDIAN POINT 3 - ECCS REVIEW

Attached for inclusion in your report to the ACRS are the conclusions of our review of the ECCS and LOCA analysis for the Indian Point 3 reactor.

/S/

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INDIAN POINT # 3

EMERGENCY CORE COOLING SYSTEM (ECCS)

1. ECCS Functional Requirements

We require an ECCS to provide the following functions: (a) limit the peak clad temperature to well below the clad melting temperature, (b) limit the fuel clad-water reaction to less than one percent of the total clad mass, (c) terminate the temperature transient before the core geometry necessary for core cooling is lost and before the clad is so embrittled as to fail upon quenching, and (d) reduce the core temperature and remove core heat until the core will remain covered without recirculation and replenishment of coolant. The ECCS should be designed to provide this protection for all sizes and locations of pipe breaks up to and including the instantaneous double-ended rupture of the largest reactor coolant pipe.

2. ECCS Design

2.1 General

The ECCS for this plant more closely resembles that of Indian Point #2 than that of Diablo Canyon and Zion. The differences in hardware do not result in differences in performance as discussed below. This ECCS consists of (a) one high pressure coolant injection and recirculation subsystem (HPS), (b) one low pressure coolant injection and recirculation subsystem (RHRS), (c) one low pressure coolant recirculation subsystem (LPS) located entirely within containment and (d) on accumulator subsystem.

The three pumps in the HPS are normally aligned to a common suction header which is fed by the refueling water storage tank. In addition, the suction of all high head pumps can be remotely realigned to the discharge of the low head subsystems. The three high head pumps discharge to a header which feeds an injection line to the hot legs of reactor coolant loops 1 and 3 and an injection line to the cold legs of reactor coolant loops 2 and 4. Two high head pumps have sufficient capacity to accommodate spillage from one of these four injection lines.

The two RHRS pumps take suction from the refueling water storage tank for short-term coolant injection and from the containment sump for long-term coolant recirculation. These pumps discharge through a common line to the two residual heat exchangers and then to the primary system by four cold leg injection lines. Each of the two heat exchangers is capable of transfering the decay heat to the component cooling system within about 4 days following a LOCA.

The LPS contains two low head recirculation pumps which are located within containment. They take suction from a recirculation sump and discharge to either of the two residual heat exchangers. One of four low pressure pumps (two each in the RHRS and the LPS) is capable of supplying the required post-accident recirculation flow to the core. The four accumulators discharge through the low pressure, cold leg injection lines, and the accumulators are sized on the basis that one of the four spills through a break.

2.2 Failure Mode Analysis

We require an ECCS to have sufficient component redundancy to ensure that the failure of a single active component cannot prevent coolant injection. We have done a failure mode analysis of the proposed ECCS and have concluded that it is designed to provide coolant injection at both high and low vessel pressure even if a single active component fails to operate. The accumulator subsystem is the only subsystem which can reflood the core in time to adequately limit clad temperature, oxidation, and deformation for breaks larger than about 6 inches in diameter. This single subsystem is acceptable for coolant makeup because (a) it stores the energy required for operation, (b) it requires no external controls or signals for operation, and (c) it has sufficient capacity to accommodate anticipated spillage and core flow bypass. In evaluating the coolant injection capability of the ECCS, we have not postulated the failure of check valves to operate because (a) all such valves can be inspected during plant shutdown, (b) the check valves nearest the accumulators can be tested with the reactor at operating pressure, (c) check valves require no external control or power and are therefore inherently reliable, and (d) check valve redundancy could reduce overall reliability by unnecessarily complicating the piping configuration of the system. Testing procedures and frequency should be considered at the operating license review so that appropriate technical specifications can be developed to assure the operation of these check valves.

We require an ECCS to include at least two completely independent subsystems for coolant recirculation to ensure that the failure of a single component, active or passive, cannot prevent long term core cooling. Our failure mode analysis has shown that the two completely independent flow paths from the containment sumps, through the ECCS, to the core, provide the capability for long-term core cooling by recirculation of coolant to the top or to the bottom of the core even if a single component, active or passive, fails to operate.

2.3 Injection Points

For cold leg breaks in a PWR there is a possibility that some "steam binding" may occur. Steam binding is attributed to a steam pressure buildup above the core due to the pressure drop for steam flowing from the core through the primary loop to the cold leg break. As the pressure increases due to steam generation and subsequent liquid entrainment in the rising steam, the downcomer level of emergency coolant rises faster than the coolant level in the core. For the Westinghouse vessel and loop configuration, a sufficient head of water can be developed in the downcomer to drive the steam generated in the core through the loop and out the cold leg break, thus allowing the water level to rise above the core. However, if a steam generator were to fail during the blowdown from a cold leg break, secondary steam could increase the steam binding. Scoping calculations done by us indicate that some 14 steam generator tube ruptures could increase the steam binding to the point of preventing the coolant level from rising above the core midplane. If the minimum high head injection above the core is assumed to be converted to steam in the upper plenum, the number of steam generator tube failures which could be accommodated is increased by about one tube. The capability to accommodate up to 15 tube failures provides reasonable assurance that the ECCS cannot be defeated by the unlikely event of secondary energy addition.

The ECCS design makes it possible to establish a recirculation flow path through the core for either hot or cold leg breaks. Thus, boiling in the core can be terminated in about 4 days when the recirculating coolant has been sufficiently subcooled by the containment heat removal systems. The nonboiling mode of long term core cooling should reduce the rate of hydrogen production by radiolysis in the core.

2.4 Component Maintenance

Redundancy of the low head pumps is sufficient to allow maintenance of one LPS pump during normal reactor operation without requiring plant shutdown. That is, only one of the four low head pumps is required to operate during recirculation, and with one LPS pump out for maintenance the ECCS will still meet our single active failure requirement . For the high and low head coolant injection pumps, an appropriate technical specification can be developed at the operating license review to allow isolation of one HPS pump or one RHRS pump for repair without requiring shutdown of the reactor, provided that (1) the remaining pumps are tested and/or run continuously without blocking the injection path to the reactor, (2) a suitable limit is placed on the time for successful repair of the isolated pumps, and (3) an emergency diesel is run continuously during this time period to increase the overall reliability of the system.

The performance capability of the accumulator subsystem was analyzed by the applicant assuming one accumulator spills through the break and either two or three accumulators deliver coolant to the vessel. For the case of two accumulators delivering, the peak clad temperature is predicted to be about 2600 F, which is too high for us to accept at this time. For the case of three accumulators delivering, the peak clad temperature is predicted to be 2225 F which we find more acceptable. Based on these numbers and in light of the current state of technology, we conclude that the technical specifications should require plant shut-down if one accumulator is inoperable or if one accumulator is isolated for repair.

2.5 Isolation Capability

All but one of the ECCS lines which penetrate containment are equipped with remote operating valves inside and outside containment which can be used to isolate an ECC subsystem. The exception is the sump suction line in the RHR subsystem. This line is equipped with an exterior (to containment) isolation valve and a concentric guard pipe which extends from the sump out to a leak-tight chamber which encloses the isolation valve.

It is planned to use the LPS for long term core cooling. This subsystem circulates coolant from the sump, through the residual heat exchangers, and back to the reactor without leaving the containment. In the event that recirculation at high pressure is required, the RHRS and the HPS will be used and the coolant will leave containment. Leakage from these subsystems has been calculated to be acceptably low and periodic testing throughout plant life should assure that it will remain low. Gross leakage or failure during recirculation could be detected by the available flow instrumentation. The operator could then isolate the operating chain of equipment and start a second chain.

2.6 Power

In accordance with our requirement, all of the ECC subsystems can accomplish their functions when operating on emergency (on-site) power. Three diesel generators provide the emergency power. If one of the three diesels fails to start a minimum of two low head and two high head pumps would be available for operation. The diesel loads and the ECCS starting sequence are arranged so that the ECCS will be pumping at minimum acceptable capacity, assuming no further component failures following the diesel failure, within about 30 seconds following a LOCA.

2.7 Component Sharing

The RHRS pumps, heat exchangers, and injection lines are shared with the shutdown cooling system. When the reactor is at power the ECCS function of these components is ensured by two closed isolation valves between the shutdown cooling system and the RHRS.

3. Performance

3.1 Analytical Methods

The applicant has established that the proposed ECCS meets our functional requirements by presenting performance analyses based on computer codes developed by Westinghouse. These codes are: FLASH-R which is used to calculate rate of coolant blowdown through a break, rate of coolant influx from the ECCS, core and loop pressure drop and flow, energy influx from the core, and energy efflux via the steam generators; CHIC-KIN which is the reactor kinetics code used to calculate the fuel energy input to the coolant during blowdown and to calculate the void shutdown for large breaks; LOCTA-R2 which is used to calculate the transient temperatures of the fuel pellet and cladding and to calculate the extent of clad-water reaction; and SLAP which is used for small break blowdown calculations.

In using these codes to determine the performance capability of the ECCS, the applicant has made conservative assumptions with regard to the more significant parameters, as follows: break opening time (all breaks assumed to occur instantaneously), reactor coolant pumps trip (loss of AC power coincident with shutdown), reactor shutdown (minimum void formation model for the void shutdown calculation), blowdown heat transfer (no credit taken for transition boiling and DNB assumed at 0.5 sec for all breaks), vessel water level (no credit taken for boiling froth height), accumulator spillage (one of four assumed to spill for all cold leg breaks), high head subsystem spillage (one of four injection lines assumed to spill through the break), and core heat transfer during reflooding (uniform coefficient of 25 Btu/hr-ft^2-°F).

Based on our present understanding of the blowdown and core heatup phenomena, we conclude that the codes have been used conservatively to predict the course of the loss-of-coolant accidents. However, we cannot conclude that the models employed in these codes completely simulate the complicated blowdown heat transfer process or account for all of the blowdown mechanisms that might occur. AEC safety research programs in the areas of blowdown heat transfer and emergency core cooling (e.g., LOFT semiscale and FLECHT) should, in the next several years, provide adequate confirmation of the conservatism in the Westinghouse blowdown and core heatup models. The data from these programs should be available at the time of the Indian Point 3 application for an operating license.

3.2 Results for Large Breaks

The applicant presented the results of blowdown and core heatup analyses for the double-ended, 6 ft^2, 3 ft^2, and 0.5 ft^2, breaks in the cold leg and in the hot leg of one of the reactor coolant loops. The cold leg breaks result in higher peak clad temperatures than hot leg breaks of corresponding size because of core flow reversals during blowdown, steam binding above the core during accumulator injection, and spillage of one accumulator; all of these effects were considered in the applicant's analyses. The performance of the minimum ECCS (i.e., 3 or 4 accumulators for a cold leg break or 4 of 4 for a hot leg break, 1 of 2 high head injection pumps, 1 of 2 low head injection pumps, and emergency power) is summarized by the following table.

Break Size, ft^2	Maximum Clad Temperature, °F	Total Percent Rod Perforations	Total Percent Clad-Water Reaction
D.E. cold leg	2225	90	negligible
6.0 cold leg	1990	85	negligible
3.0 cold leg	1700	77	0
0.5 cold leg	2020	89	negligible
D.E. hot leg	2110	--	negligible
6.0 hot leg	1840	--	negligible
3.0 hot leg	1510	--	0
0.5 hot leg	1350	--	0

The peak clad temperatures conservatively calculated for these breaks are well below the Zircaloy melting temperature. The peak temperatures for some breaks are above the Zircaloy-water reaction threshold (1800°F), but they are generally below the accelerated reaction temperature range (>2200°F). The total clad-water reaction calculated for each of the breaks is much less than 1 percent of the total fuel clad mass. Furthermore, the clad temperature calculations reported by the applicant show that the clad hot spot is above 1800°F for only about 50 seconds and that only about 2.0 percent of the total clad volume exceeds a temperature of 1800°F for the double-ended cold leg break. This is reasonable assurance that the clad will not be severely embrittled by oxidation and thus that the clad heat transfer geometry will not be significantly altered by thermal shock upon quenching. We base this conclusion on the data thus far released by ANL which indicate that longer periods at higher temperatures are required to cause Zircaloy clad embrittlement by oxidation.

The Westinghouse calculation predicts large numbers (~90%) of clad perforations for some of the intermediate size breaks; e.g., the 0.5 ft^2 cold leg break. We believe that Westinghouse has made conservative assumptions with regard to blowdown heat transfer and water level for the intermediate size breaks and that the resulting temperatures are conservatively high. To demonstrate this the applicant has analyzed breaks of less than 0.5 ft^2 for the following two cases: (1) using their standard conservative assumption that DNB occurs at 0.5 seconds after all breaks, regardless of size, on all the rods in the core, and (2) using a three-dimensional thermal and hydraulic code (THINC) which calculates flow redistribution during blowdown and which predicts the time of DNB. The results of the second more realistic calculation show that the number of clad perforations decreases with break size to about 30 percent and 20 percent for the 0.5 ft^2 and the 0.3 ft^2 cold leg breaks, respectively.

We will continue to explore the degree of conservatism in such calculations and the affect of this conservatism on the number of rod perforations. Westinghouse is currently doing R&D work on rod perforations to improve their calculational model and to establish that the core heat transfer geometry is maintained after large numbers of perforations. We intend to continue our examination of this area in the review of subsequent reactors.

3.3 Results for Small Breaks

The applicant has also presented results of blowdown analyses for small breaks in the cold leg of a reactor coolant loop. In this analysis the flow out the break was defined by the Moody correlation for two phase critical discharge and the water levels are quiet levels: i.e., no credit is taken for the actual froth level that would occur due to void formation in the core. The following table summarizes the results of these analyses for the case of 1 of 2 high head pumps operating at 3/4 flow (1 of 4 injection legs assumed to spill).

Break Diameter, in	Minimum Water Level, ft From Top of Core
1 (0.005 ft^2)	Slight decrease in normal level
2 (0.022 ft^2)	Above core
3 (0.049 ft^2)	- 2.0
4 (0.087 ft^2)	- 5.0
6 (0.196 ft^2)	-10.0

As indicated by this table, the core hot spot, which is located at about the axial midplane of the core, is conservatively calculated to remain covered for break sizes up to 4 inches in diameter.

The applicant has also presented core heatup analyses for the 6-inch diameter break. This analysis was performed with the THINC code described above. The code predicts nucleate boiling in the core throughout the blowdown transient for the 6-inch break and the resulting peak clad temperature is about 725F.

The clad heatup process for a break of less than 4 inches in diameter, i.e., a break which does not uncover the core hot spot, is described as follows. The reactor will scram on low pressurizer level or pressure and the core heat will decrease to less than 4 percent of full power by the time the top of the core uncovers. Core coolant flow will decrease during the blowdown as the reactor coolant pumps coast down following the assumed loss of off-site power; natural circulation of coolant will follow pump coastdown. Boiling heat transfer will occur in the core throughout the blowdown because the heat flux is low (~20,000 Btu/hr-ft^2-F) at the time of minimum water level (~100 seconds) and DNB is not predicted to occur. Even if DNB were to occur, it is likely that the transient film boiling which should ensue will provide sufficient cooling to prevent clad burnout. It appears, therefore, that the ECCS should be able to prevent all clad damage for breaks of less than 4 inches in diameter.

For those breaks between 6 inches and 0.5 ft^2 (9.5 inches) the hot spot is uncovered for only a brief period and the clad temperature transients should be less severe than those calculated for the intermediate size breaks where the core uncovers more rapidly. The hot spot will be cooled by the two-phase mixture of coolant rising from the quiet water level as steam is formed by depressurization and boiloff. The accumulators will refill the vessel for these breaks and terminate the core temperature transient.

We have done calculations to verify that breaks with an equivalent diameter of less than 3/4 inch will cause loss of coolant at a rate which can be accommodated by the reactor charging pumps (no ECCS action required). These pumps will maintain an operational level of water in the pressurizer, permitting the operator to execute an orderly shutdown. Since instrument taps and sample connections are of less than 3/4-inch diameter, protection of the core following the rupture of these lines is afforded by the charging pumps.

3.4 Conclusions

Evaluated in the light of current technology, the design of the proposed ECCS meets our functional limits on temperature, core damage, and clad-water reaction for the entire break spectrum. In addition, the design provides protection for up to 3/4-inch breaks without ECCS action, and the ECCS can prevent clad perforations for breaks of less than 4.0 inches in diameter. However, we continue to stress the need for (1) further research and developement concerning clad perforations and their affect on core cooling, and (2) experimental confirmation of ECCS design conservatism.