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HATCH 1 AND 2 EVALUATION OF RCIC TURBINE EXHAUST PRESSURE TRIP FOR LOCA APPLICATION

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CONTENTS

1. SUMMARY

The feasibility of raising the reactor core isolation cooling (RCIC) turbine exhaust pressure trip setpoint was evaluated for Hatch 1 and 2. The objective of changing the setpoint is to increase RCIC availability during small break loss-of-coolant accidents (LOCAs).

In theory, raising the setpoint would allow a longer period of RCIC operation before its turbine is tripped off by high pressure in the primary containment caused by the LOCA. Turbine/pump effectiveness with a higher trip setpoint was considered. Steam leakage rates from the turbine gland seals were determined over a range of backpressures beyond the present setpoint. Various LOCA scenarios were evaluated to determine the potential for extending the domain of RCIC operation. Containment response was evaluated to determine a suitable exhaust pressure trip setpoint.

Both offsite and onsite radiological consequences of operating the RCIC system at higher backpressures were evaluated. Upper-bound calculations for the doses were found acceptable without any hardware modifications. The adverse consequences of operating the RCIC system beyond the present setpoint when not needed were also considered and found acceptable. It is concluded that raising the RCIC turbine exhaust pressure setpoint can be accomplished with existing RCIC system hardware. This change will further enhance the in-depth protection of Hatch 1 and 2 against small break LOCAs, and, therefore, an increased setpoint is recommended.

2. INTRODUCTION AND BACKGROUND

A study has been performed to evaluate the feasibility of raising the RCIC exhaust pressure trip setpoint for Hatch 1 and 2 and to evaluate possible solutions to design or operational problems which might arise as a result of the modification. This report is the result of that study.

The RCIC System is designed to maintain sufficient water in the reactor pressure vessel to cool the core and maintain the nuclear boiler in the standby condition in the event that the vessel becomes isolated from normal feedwater makeup flow. The RCIC System as originally designed was not intended to be operational during LOCA conditions. Even though this system is not required for satisfactory core cooling during an accident, its additional reactor water makeup capacity would make a positive contribution to safety, especially if degraded emergency core cooling system (ECCS) conditions were assumed to exist. During many postulated LOCA conditions, containment pressure will exceed the current exhaust pressure trip setpoint of 25 psig. RCIC availability would be enhanced by raising the turbine exhaust trip setpoint, thereby allowing the RCIC to run longer during a LOCA. For large breaks the reactor pressure decreases so rapidly that little or no RCIC flow would be delivered before the turbine would be tripped on low reactor pressure, so the potential benefit would be gained only for small and intermediate break LOCAs.

Operation of the RCIC turbine at higher backpressures will result in increased steam leakage from the gland seals to the RCIC turbine room. Depending on the magnitude, such leakage might be unacceptable from a radiological standpoint and could require hardware modifications in order to change the setpoint. This aspect of the modification therefore required the most study.

3. SCOPE AND EVALUATION METHOD

The RCIC turbine flows and gland seal leak rates are time-dependent parameters which also vary with break size and differing scenarios. Realistic calculations were made for this analysis, as far as practicable, so that sound recommendations could be formulated. However, as necessary, bounding values were used to simplify the analysis, particularly for many of the time-dependent variables. In this manner, the complexity of the calculations was reduced without affecting the conclusions.

The elements of this analysis are characterized as follows:

(a) RCIC system pumping performance and potential gland seal steam leakage rates were determined for backpressures beyond the current setpoint.

(b) Reactor vessel pressure and level response were examined for various scenarios over a spectrum of LOCA break sizes. The outcome was an assessment of potential RCIC operation periods and the expected condition of the fuel to be used in the radiological assessment.

(c) Containment pressure response to various size breaks was reviewed. This defined the potential backpressure for RCIC turbine operation.

(d) Radiological consequences of operating the RCIC System for extended periods at higher backpressure were evaluated. Offsite doses were calculated as well as dose rates in the reactor building and in the RCIC turbine room.

(e) Based on the results, with consideration given to possible hardware or procedural changes, an appropriate setpoint was determined.

To evaluate the total impact of an exhaust pressure trip setpoint change, the logic diagram shown in Figure 3-1 was developed. This diagram indicates the logic process used to generate possible operating modes. Each of these modes was examined, because the consequence of each could be changed with a change in the pressure setpoint.

Raising the turbine exhaust pressure trip setpoint has no effect on turbine performance during normal operation. The change would simply allow continued operation during accident conditions if the backpressure exceeded the present setpoint. The normal operating condition for RCIC is during an isolation of the reactor from the feedwater system. Thus, for this mode (shown as Mode A in Figure 3-1) a setpoint change has no impact because the containment will not be pressurized.*

For large breaks (Mode B) the RCIC turbine is tripped by low reactor pressure before delivering significant flow, and a change in the exhaust pressure trip has no impact. The consequences of Modes C, D, and E, in which sustained RCIC operation is possible, are evaluated in this analysis.

For Mode F with the further degradation to include a failed automatic depressurization system (ADS), no quantification of the total radiological consequences was attempted, as it was beyond the scope of this study. For this scenario the operator must restore normal cooling, high pressure coolant injection (HPCI), or the ADS; or manually depressurize. Increasing the RCIC exhaust pressure setpoint would potentially prolong RCIC operation and provide more time to restore core cooling or to depressurize. While RCIC operation in Mode F is the least likely of those considered, it has the potential for significant benefit. The radiological consequences of the RCIC turbine leakage could well be small relative to the consequences postulated without RCIC, if the operator were unable to restore core cooling or to depressurize the reactor in time to prevent core damage.

The accompanying analysis bounds the radiological consequence of the RCIC turbine leakage. The analysis is not extended to the degraded core domain (Mode F). The next sections describe the analysis performed to bound the consequences of operating in Modes C, D, and E.

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*A potential benefit exists also for an isolation condition during which no containment cooling systems are available.

MODE	COMMENT
A	NORMAL RCIC MODE (ISOLATION)
B	RCIC TRIPPED OFF BY LOW REACTOR PRESSURE
C	HPCI AND RCIC BOTH OPERATE
D	RCIC PROVIDES SUFFICIENT MAKEUP BUT COULD BE TRIPPED ON HIGH EXHAUST PRESSURE
E	RCIC UNABLE TO MAINTAIN LEVEL; ADS INITIATED AT LEVEL 1
F	FURTHER DEGRADED CONDITION; CONSEQUENCES NOT QUANTIFIED IN THIS STUDY

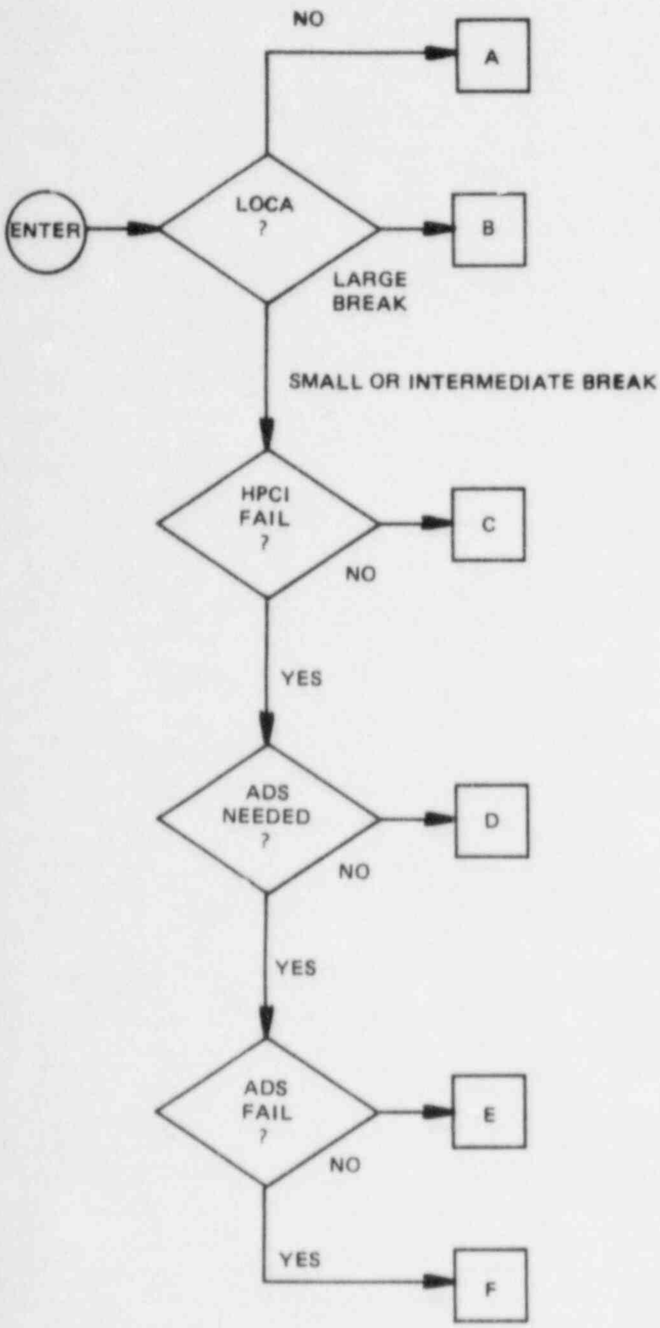

Figure 3-1. Potential Conditions for RCIC Operation

4. RCIC SYSTEM PERFORMANCE AT HIGH TURBINE EXHAUST PRESSURES

The RCIC turbine exhaust pressure trip is currently set at 25 psig. Increasing the trip setpoint would not alter the RCIC System performance under normal circumstances, as noted earlier. The increase would allow operation of the system at containment pressures above the present value. Containment pressures to 50 psig were considered. Two areas of system performance required evaluation for turbine exhaust pressures above the present setpoint.

First, RCIC System pumping performance at various exhaust pressures was considered. For those scenarios of interest in which extended periods of RCIC operation could occur, the reactor pressure would be above 400 psig (these scenarios are described in the following section). At 400 psig or above, there would be no degradation of RCIC performance, and rated flow would be delivered to the reactor. Some loss in capacity would be expected below 400 psig. However, this is not a concern because the alternative being considered provides for continued operation compared to no RCIC flow at all for the current design in this higher turbine exhaust pressure domain.

Second, and more significant, is RCIC turbine gland seal leakage at elevated backpressures and associated radiological effects. Vendor-supplied information was used to conservatively calculate the combined steam leakage at the turbine shaft and at the governor and turbine stop valve stems. This combined steam leakage is shown in Figure 4-1 as a function of turbine exhaust pressure.

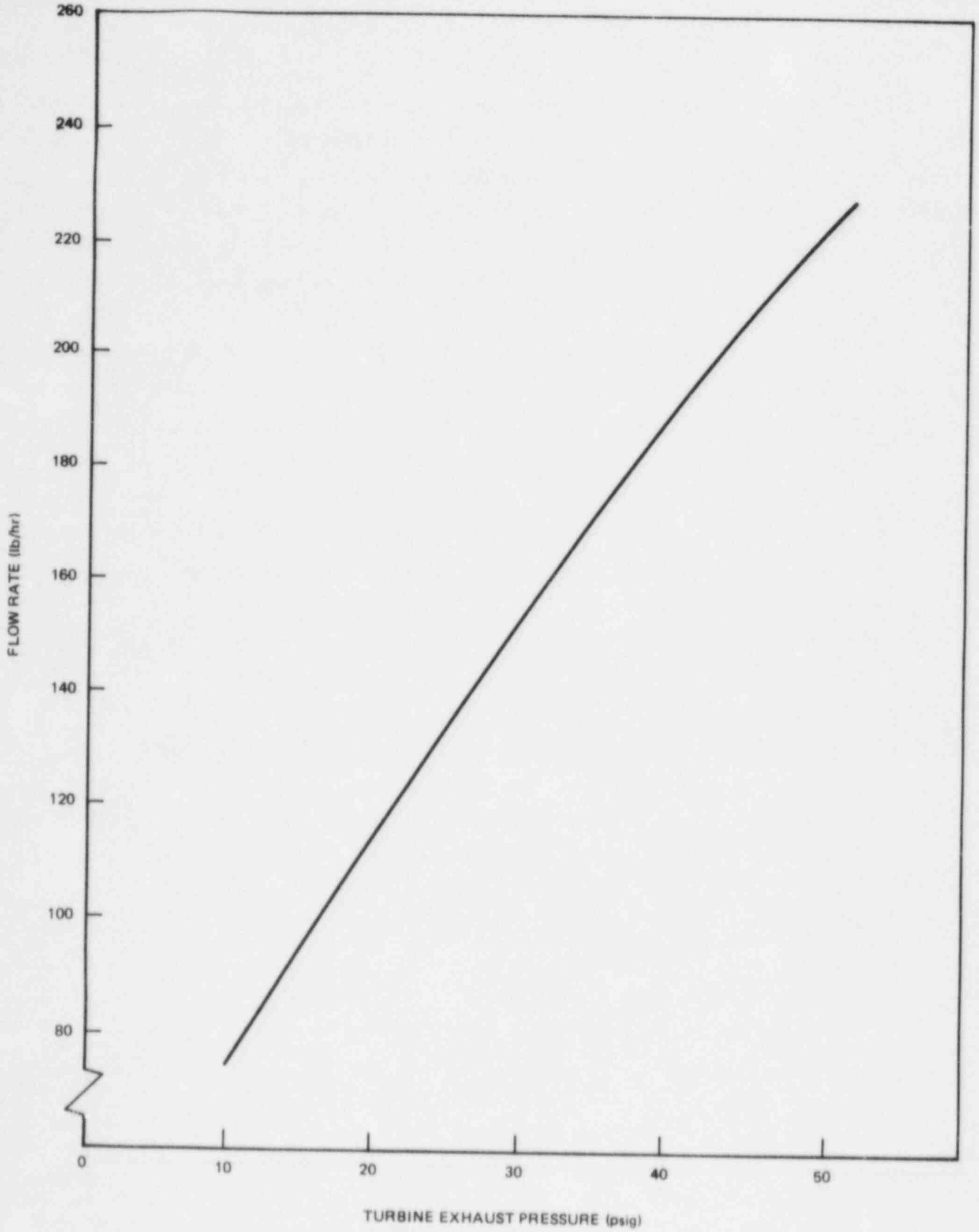

Figure 4-1. Combined RCIC Steam Leakage vs. Turbine Exhaust Pressure

5. ASSESSMENT OF EXTENDED RCIC OPERATION

5.1 POTENTIAL FOR EXTENDED RCIC OPERATION

Reactor pressure and water level response during a LOCA were evaluated over a wide range of breaks from very small to intermediate size. In addition to break size variation, the break flow regime (steam versus liquid) was also considered. Expected reactor fuel conditions were also established. The focus of the study was on scenarios in which the HPCI is postulated to be unavailable, because it is this situation where continued RCIC operation is of most benefit. However, combined operation of HPCI and RCIC was also evaluated.

Cases in which RCIC could operate the longest were those for which the break flow approximately balances the makeup flow. For such a liquid break, reactor pressure would be controlled at about 1100 psi by operation of the safety/relief valves (S/RV). This case is shown as Curve A of Figure 5-1. For smaller breaks RCIC could be manually controlled. If not manually controlled, RCIC would be on during the period when the reactor water level increases from the initiation level to the high level RCIC trip, then off until auto restart upon low level. For such cases, ADS would not be required (this corresponds to Mode D of Figure 3-1).

For liquid breaks in which RCIC alone cannot maintain inventory, RCIC could operate from the time of its initiation until the ADS depressurized the vessel to the low reactor pressure trip for the RCIC turbine. This corresponds to Mode E of Figure 3-1. A typical example in this range is shown as Curve B of Figure 5-1. Pressure response for the largest break of interest in this break size domain is shown as Curve C of Figure 5-1. For larger breaks the period of RCIC operation would be short and the flow delivered to the reactor vessel would be insignificant. Thus, for liquid breaks, RCIC could potentially operate on a continuous basis for an extended time (Curve A), on a continuous basis until tripped by low vessel pressure (Curves B or C), on a continuous basis under manual control, or on an intermittent basis in the auto mode (very small breaks) for an extended period.

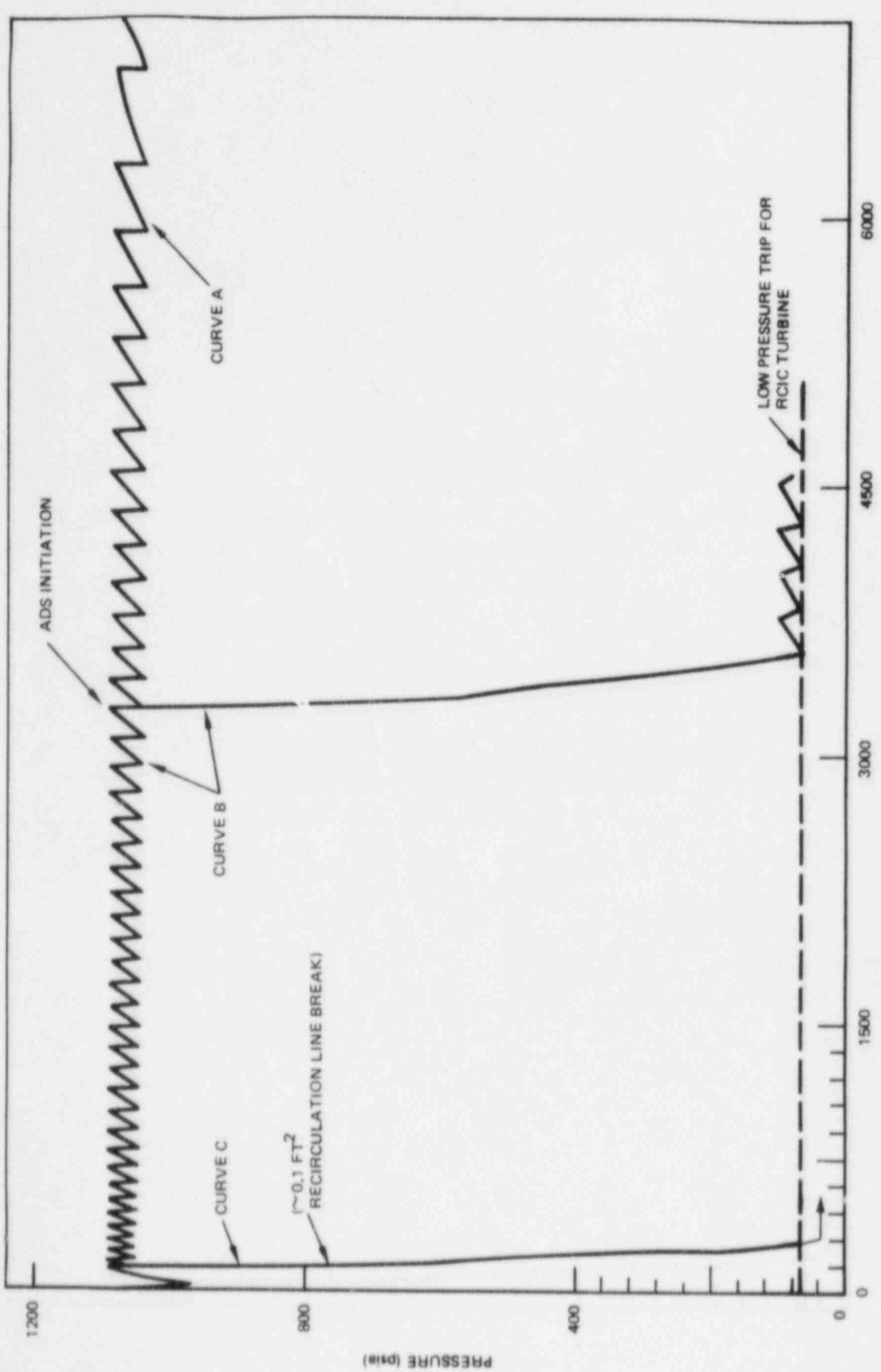

Figure 5-1. Typical Reactor Pressure Response Spectrum for Small and Intermediate Liquid Breaks

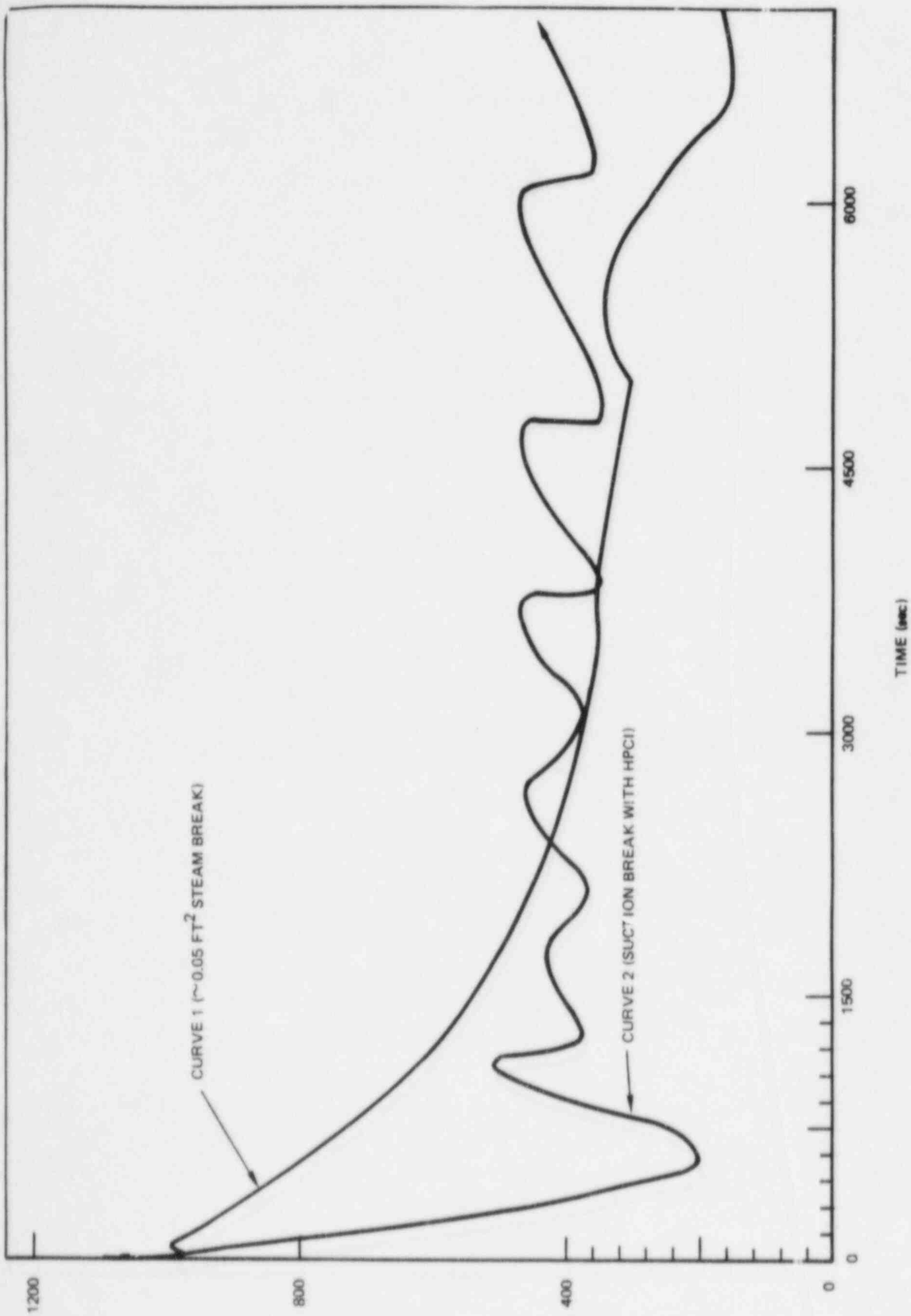

Figure 5-2. Typical Reactor Pressure Responses for Special Case LOCAs with RCIC Operating

For the steam break in which the RCIC flow essentially balances the liquid boil-off (Curve 1, Figure 5-2), the reactor pressure slowly decays and would not initiate a low pressure RCIC trip for two to three hours. For smaller steam breaks, RCIC flow exceeds the makeup requirement and could be manually operated similar to the small liquid breaks. This steam break size domain also falls into Mode D of Figure 3-1.

For larger steam breaks, the pressure decay would be more rapid, and RCIC could not provide sufficient makeup to maintain reactor water level. In this case, RCIC operation would be terminated earlier by low reactor pressure caused by the larger break flow. Thus, for steam breaks, RCIC can potentially operate continuously for a period up to several hours, or intermittently or in a manual mode for an extended period.

Another scenario considered is one in which HPCI is available and both HPCI and RCIC operate (Mode C of Figure 3-1). Again, the case of longest continuous RCIC operation is defined when the makeup is approximately equal to the break flow (Curve 2 of Figure 5-2). Here again, smaller breaks result in intermittent operation, and larger breaks trip RCIC on low reactor pressure. For situations in which HPCI can maintain level by itself, it may be desirable to secure the RCIC system to minimize RCIC turbine steam leakage. (This situation is discussed in detail in Section 9.)

From this analysis two bounding cases were considered further. Each case has the potential for continuous operation of the RCIC System for an extended time period. In the first case, the reactor pressure is maintained at a high value which maximizes the RCIC turbine leakage flow. In the second case, the reactor pressure falls to about 400 psi where turbine steam leakage would be lower but the initial rapid depressurization would maximize the fission gas release from the fuel. Although this second case is considered less likely than the first, it was selected for the study because it has the potential to be a bounding case.

5.2 EXPECTED FUEL CONDITION

As a consequence of reactor vessel depressurization, radioactive fission gas can leak through cladding defects generated during normal operation (the so-called "spiking" release). The greatest spiking release occurs when there is a rapid depressurization and the differential pressure between the cladding interior and exterior surfaces is highest. Therefore, for all the cases considered above, fuel damage is not expected as a consequence of the accident, and the "spiking" release would be the controlling source of activity released to the reactor coolant. For the highly degraded case where both HPCI and ADS fail and RCIC cannot maintain inventory by itself, fuel perforations could occur. This situation corresponds to Mode F of Figure 3-1 and is not quantitatively evaluated.

6. DETERMINATION OF MAXIMUM PRESSURE SETPOINT

Containment pressure response to LOCA events was examined to determine the maximum pressure setpoint for the RCIC turbine exhaust trip; or to determine, for a given setpoint, for what range of break sizes RCIC could continue operation without being tripped.

The containment pressure response to a LOCA is a function of many parameters including break size and location. Once the suppression chamber pressure transient is established, the RCIC turbine exhaust line friction, other irreversible losses, and the head imposed by the submergence of the exhaust pipe in the suppression pool must be added when considering the setpoint selection.

Existing suppression chamber pressure response calculations for small and intermediate breaks typical of those in Final Safety Analysis Reports were reviewed for Hatch 1 and 2. Turbine exhaust line losses and submergence heads were added to obtain the pressure at the turbine exhaust. For Hatch 1 and 2, the maximum turbine exhaust pressures range from 40 to 44.5 psig. The peak pressures are break size and break regime (steam or liquid) dependent but typically are reached in the order of 10 to 20 minutes for the range of break size for which extended RCIC operation is of benefit. These calculated pressures tend to be high because of the conservatism in the suppression chamber pressure response calculations. Raising the RCIC trip setpoint to 50 psig for Hatch 1 and 2 should preclude high turbine exhaust pressure trips for these LOCAs. The acceptability of this value from the radiological standpoint is discussed in the following section.

7. RADIOLOGICAL CONSIDERATIONS

The combined RCIC steam leakage characteristics given in Figure 4-1 were used as the basis for assessing potential radiological effects. The design condition for normal operation is 10 psig at the turbine exhaust, with the trip setpoint at 25 psig. For this analysis the calculated doses from the steam leakage were based on operating at a discharge pressure of 50 psig. Note also that the calculated doses are for the radiological effects of steam leakage at the turbine gland seal and at the governor and turbine stop valve stems only and do not include the radiological effects from other pathways (e.g., break flow or S/RV flow), which are contained by the primary containment.

Consistent with the expected conditions for the type of accidents under consideration, no fuel failures were assumed. Consequently, the controlling source term for this analysis is the "spiking" release of iodine and noble gases resulting from the differential pressure across the fuel cladding. In order to bound the radiological consequences of the spectrum of small and intermediate break accidents, it was assumed that all the spiking activity is released to the reactor coolant at time zero. The following additional conservative assumptions were made:

(a) The RCIC turbine would be operated continuously for 10 days after the break.

(b) The combined steam leakage rate corresponds to a maximum exhaust pressure of 50 psig. This bounds the peak exhaust pressure for all the events considered for Hatch 1 and 2.

(c) The removal of activity from the reactor pressure vessel through any other path, such as leakage through the break or steam flow to the S/RVs, is neglected.

Both onsite and offsite radiological effects caused by radionuclides in the combined steam leakage were evaluated. For the offsite dose calculations, the following assumptions were judged to be reasonable:

(a) Activity released by the combined steam leakage is uniformly mixed in the reactor building air volume.

(b) Reactor building air is removed at the rate of two air changes per day through the standby gas treatment systems (SGTS).

(c) The SGTS filter efficiency for iodines is 90%.

With these mixing and transport assumptions, thyroid inhalation and whole-body gamma doses were calculated for exclusion area and low population zone distances using meteorological conditions less favorable than the Hatch site from an atmospheric dispersion point of view.*

The results of these calculations are summarized by the enveloping values in the table below. The dose limits of 10CFR100, which are applicable to a design basis (large break) LOCA, and 10CFR20, which are applicable to abnormal operating events are shown for comparison.

	2-hr Dose at Exclusion Area Boundary (millirem)	30-Day Dose at Low Population Zone (millirem)	10CFR100 Limits (Design Basis LOCA) (millirem)	10CFR20 Limits (Abnormal Transients) (millirem)
Thyroid	<0.5	<1	300,000	∿1000
Whole-Body	<5	<0.5	25,000	500

Because the bounding doses tabulated above are orders of magnitude less than even the 10CFR20 limits, it is concluded that the offsite dose consequences of the increased combined steam leakage are acceptable for the conditions under consideration.

Several onsite situations were evaluated including an initial evacuation time from the RCIC turbine room, re-entry to the reactor building, and re-entry to the RCIC turbine room at the peak concentration times. Once again, upper

*Atmospheric dispersion (χ/Q) values used were 1.4×10^{-3} sec/m^3 for the exclusion area boundary and 4×10^{-5} to 5.4×10^{-6} sec/m^3 (time-dependent) for the low population zone.

bound assumptions were made to maximize the calculated dose rates. These included the assumption that all released activity remained in the compartment (room or building) being analyzed. For the initial evacuation of the RCIC turbine room, the doses calculated for an assumed 10 minutes residence time were about 2-1/2 Rem thyroid dose and 1/2 Rem whole-body gamma dose. These upper bound doses are well within the quarterly occupational limits of 10CFR20, which are 7-1/2 Rem thyroid and 1-1/4 Rem whole-body.

Noble gas and iodine activity in the reactor building would increase for a time as the turbine continued to operate and then eventually decrease because of the continuing removal of air from the building and radioactive decay. The potential impact of the combined steam leakage on the accessibility of the building if re-entry should be required was estimated by using the peak post-accident reactor building activity. The maximum thyroid dose rate was calculated at about 13 Rem/hour without breathing protection. Regulatory Guide 8.15 shows protection factors up to 10^4 for certain types of self-contained breathing apparatus. Thus, personnel with adequate breathing protection could re-enter and remain for substantial periods of time.

Approximate calculations based on the peak post-accident noble gas inventories and conservative geometric assumptions indicate whole-body gamma dose rates on the order of 0.5 Rem/hour. It is concluded that both inhalation dose rates and whole-body gamma dose rates associated with the increased combined steam leakage into the reactor building are sufficiently low that personnel re-entry following the accident would be feasible for reasonable periods of time (∿1/2 to 1 hour).

Re-entry into the RCIC turbine room for a limited period of time may be desirable (e.g., if needed to restart the RCIC turbine after shutdown). Using similar bounding assumptions, an analysis of this re-entry at the peak concentration times was made. At the peak iodine concentration, the calculated thyroid dose rate is about 1000 Rem/hour without breathing protection. For the time of the highest concentration of noble gases, the calculated whole-body dose rate is about 10 Rem/hour. Provided that adequate breathing protection were used to reduce the thyroid dose rate, re-entry to the RCIC turbine room for a short time period (∿0.1 hr) could be made to perform an essential function.

In summary, extended operation of the RCIC turbine at 50 psig backpressure is acceptable from a radiological standpoint. Offsite doses would be orders of magnitude below 10CFR20 limits, and onsite exposures could be controlled within 10CFR20 quarterly occupational limits.

8. OTHER CONSIDERATIONS

RCIC is designed and qualified for continuous operation for 12 hours. The design water temperature range is 40 to 140°F on a continuous basis, and operation with water temperature up to 170°F is permissible for short periods of time. For the LOCA situations postulated, considerably longer operation periods would be possible. Furthermore, suppression pool temperatures could exceed 140°F for LOCA scenarios in which some degradation of pool cooling capability is assumed. Extended operation under such (low probability) conditions could cause RCIC pump damage. This possibility should be considered (as it is in the Emergency Procedure Guidelines) if RCIC is operated at high suppression pool temperatures with or without LOCA.

The potential for significant containment dynamic loads associated with steam condensation at the RCIC turbine exhaust discharge device in the suppression pool was evaluated. For temperatures at about 150°F or above, condensation instabilities could occur if steam mass fluxes are sufficiently high ($\sim$40 lb/sec-ft^2 or above). Approximate calculations for the RCIC spargers indicate maximum fluxes in the range of 6-7 lb/sec-ft^2. Thus, Wurgassen-type steam condensation instabilities would not be expected.

For the degraded situation of Mode F it is desirable to continue RCIC operation as long as possible despite potential RCIC pump damage or steam condensation instabilities. Such continued operation provides additional time for the operator to restore core cooling capability.

9. ADVERSE CONSEQUENCES

No adverse consequences resulting from raising the RCIC turbine exhaust pressure setpoint under normal RCIC operation were identified. Adverse consequences result, however, for the postulated condition where high containment pressure is reached and RCIC operates when it is not needed. In this situation sufficient reactor water level is maintained through cyclic or continuous operation of HPCI and RCIC so that ADS is not activated for an indefinite period. For this case RCIC could operate when not needed and result in doses which would not occur if it were not operating. If no setpoint change were made, these doses would be lower because the lower turbine exhaust pressure setpoint would cause an earlier RCIC turbine trip. Even though the calculated doses are acceptably small (bounded by the above calculations), release of activity in the RCIC turbine room is not desirable. Furthermore, continued operation of RCIC when not needed could potentially limit RCIC turbine room access and reduce the RCIC availability if needed later. For the hypothetical case in question (i.e., LOCA where both HPCI and RCIC operate), it would be desirable to secure RCIC after it is determined that it is not needed to maintain reactor inventory.

A second situation with possible adverse consequences is that of a small break without HPCI where extended RCIC operation with the higher exhaust pressure setpoint could delay or defer ADS relative to the lower setpoint. If it were determined that continued operation in that mode was less desirable radiologically than depressurizing the vessel, RCIC operation could be terminated. As seen by the low calculated doses resulting from RCIC steam leakage, the timing of such a determination would not be critical.

10. CONCLUSIONS AND RECOMMENDATIONS

10.1 CONCLUSIONS

(a) The proposed RCIC turbine exhaust pressure trip setpoint increase would increase RCIC availability during small and intermediate break LOCAs.

(b) RCIC continues to provide a backup to HPCI over a range of small breaks and would provide more time for an operator to recover other systems if either HPCI and/or ADS were unavailable.

(c) The radiological effects of operating RCIC for periods up to 10 days at turbine exhaust backpressures up to 50 psig are acceptable relative to 10CFR20 limits without any hardware changes to mitigate the increased steam leakage.

(d) The adverse consequences of increasing the turbine exhaust pressure setpoint are acceptable.

10.2 RECOMMENDATIONS

(a) The RCIC turbine exhaust pressure trip setpoint should be increased to 50 psig for Hatch 1 and 2.

(b) No hardware changes are recommended other than those needed to implement the setpoint change.

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