GPU Nuclear

GPU Nuclear Corporation
Post Office Box 480
Route 441 South
Middletown, Pennsylvania 17057-0191
717 944-7621
TELEX 84-2386
Writer's Direct Dial Number:

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Office of Nuclear Reactor Regulation
Attn: J. F. Stolz, Chief
Operating Reactor Branch No. 4
Division of Licensing
U.S. Nuclear Regulatory Commission
Washington, DC 20555

Dear Mr. Stolz:

Three Mile Island Nuclear Station Unit 1 (TMI-1)
Operating License No. DPR-50
Docket No. 50-289
TMI-1 Reactor Coolant Pump Damage

This letter is to respond to the remaining questions asked in your letter of September 21, 1984. On October 12, 1984, we provided you with responses to items 1-3 with respect to the pump shaft, and provided copies of our reference documents, Babcock and Wilcox RDD:84:5183-06:01 "TMI-1 Reactor Coolant Pump Shaft Failure Analysis" and Structural Integrity Associates' "Fatigue and Fracture of TMI-1 Reactor Coolant Pump Shaft Failure." This letter addresses, in order, the remainder of item 3 and items 4-6.

A. Causes of Impeller Damage (Item 3)

As noted in our letter of April 10, 1984, the impeller damage seen in RCP "B" has been attributed to cavitation or flow separation. The cavitation/flow separation damage was confined to the inlet area of the impeller vanes. The local areas of wear are centered 2 to 3 inches from the impeller vane inlet tips on the back or pressure side of the vane. Six of the seven impeller vanes had eroded through in small areas, while the seventh vane showed evidence of erosion but did not break through the vane wall. The vane damage appears to be classical cavitation erosion originating on the back or pressure side of the impeller vanes.

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Cavitation inception work done by McNulty and Pearsall ("Cavitation Inception in Pumps" Journal of Fluids Engineering March 1982) discusses the effect of flow rate on cavitation, the importance of the vane angle incidence during operation, and its relationship to the location of cavitation erosion on the impeller vane. In designing a pump, the optimum vane angle of incidence is selected to minimize vane cavitation for the normal rate of flow expected through the pump. An increase in suction-side vane cavitation occurs at lower flows (increased incidence), and again at higher flows as the angle of incidence become negative and pressure-side cavitation occurs.

The TMI-1, RCP-1B was operated for 1360 hours at low temperatures and pressures (130°F, 315 psig) during system clean-up. Full flow under these conditions is equivalent to 152 percent of the best efficiency flow rate (hot full flow conditions). This operation was consistent with Net Positive Suction Head (NPSH) guidelines provided by the pump manufacturer. It has been determined on the basis of information received from the pump supplier, Westinghouse Electric Corporation, that no test data exists relative to NPSH requirements at flow conditions associated with the 152 percent flow rate. It is evident that the TMI-1 RCP "B" required NPSH at 152 percent of the hot full flow rate is greater than the value predicted by extrapolation from data taken at lower flow rates. Future pump operation at high flow rates (low temperature and pressure), will be restricted to very short periods of time and to use during plant startup, thus minimizing any future cavitation damage.

B. <u>Relationship of Shaft Failure to the Locked Rotor Event</u> (Item 4)

Before responding to your question, GPUN would like to note that all additional evidence available on the rate of fatigue growth of a shaft crack (provided to you in our letter of October 12, 1984) confirms our earlier conclusion that vibration detection will provide ample protection against shaft severance.

Our statement in our letter of April 10, 1984, that a shaft break is bounded by the locked rotor evaluation, is based on the conclusion that, contrary to your hypothesis, reverse flow through the affected loop will be no greater than that predicted for the locked rotor case.

When a shaft break occurs at this location (or any location below the radial bearing), the broken shaft and impeller will drop approximately 3/8 inch and contact the narrowing cross section of the conical diffuser adapter. The lower end of the broken shaft and impeller will remain contained within the pump diffuser section. The weight of impeller and partial shaft (approximately 1900 pounds) is sufficient to keep the impeller down under reverse flow conditions. In this new position with its reduced clearances, the radial load associated with reverse flow cannot rotate the impeller since it contacts the diffuser adapter, the lower impeller labyrinth ring, or the lower thermal barrier ring. Thus the radial loading serves to hold the impeller frozen rather than to rotate it freely.

Both GPUN and Westinghouse have therefore concluded that free rotation of the impeller, leading to an increase in reverse flow, will not occur. Further evidence is provided by the behavior of the Surry reactor coolant pump, which severed its shaft just below the bearing. The impeller dropped down and stopped. Thus GPUN concludes that the FSAR locked rotor analysis does bound this event. The analysis assumes design basis thermal conditions, and predicts a flow reduction from 100 percent to 75 percent in 0.1 seconds, resulting in a minimum DNBR of 1.15. The DNBR design basis limit is 1.0.

C. Pressure Boundary Integrity (Item 5)

The statement from our April 10, 1984 letter that you question is a paraphrasing of ANSI N18.2, the standard to which reactor coolant pumps are designed. The ANSI Standard states:

> "The reactor coolant pressure boundary together with its protection systems shall be designed so that sudden stopping of one reactor coolant pump (Condition IV) due to seizure or other similar cause will not result in failure of the reactor coolant pressure boundary."

Obviously, the most limiting case from the standpoint of creating a pressure transient must be a very abrupt stop. This is the locked rotor transient. Babcock and Wilcox analysis (Midland FSAR) predicts a 50 psi pressure spike and confirms that this will not affect the primary pressure boundary. In analyzing this transient, credit is taken for a reactor trip at 1.5 seconds on RCS flow. GPUN does not plan to supplement this information.

The only deviation from the locked rotor event is that the upper end of the shaft is no longer attached to the impeller after shaft severance. After the load is lost, this part of the motor shaft can turn freely. Under these conditions, the pump is predicted to perform as described below.

1. Reduction in RCS flow rate would automatically trip the reactor and an increase in pump vibration would initiate operator actions leading to a manual pump trip.

2. For a break below the radial bearing, the shaft section above the severance is constrained by geometry limits to remain in place.

3. Shaft failure below the pump radial bearing would not result in shaft vibration levels high enough to cause abnormal leakage of the pump seals.

4. The motor and motor fly wheel integrity is not compromised.

Given this information, we confirmed in our letter to you that the pump continued to meet its design basis. Further evidence that such behavior is expected is the performance of the Surry RCP after a complete break just below the bearing. The pressure boundary remained intact throughout the event.

D. <u>Safety Significance of Impeller Damage</u> (Item 6)

The localized impeller wear seen on the "B" RCP is considered to be of no safety significance whatever, as it is not present to an extent which can be described as "significant" from a standpoint of pump performance. Further, the "B" impeller was replaced along with the "B" shaft. However, Westinghouse, the pump manufacturer, predicts that even if the impellers in service had damage to the extent seen in the now-replaced "B" RCP impeller, no measurable change in flow rate would be seen.

In evaluating the effect of cavitation wear on flow, both the size and location of the worn areas are considered. On the "B" RCP impeller, the damage was limited to localized areas near the vane inlet tips. The pressure gradient between the suction side and pressure side of each impeller vane is relatively low near the inlet tip. No metal extrusion or deformation was noted at the point of maximun vane erosion, confirming that suction-to-discharge-side differential pressure and resultant flows are low. A through-wall area of wear has considerably less affect here than it would near the mid-point of the blade, where higher differential pressures would drive greater flow through the damaged areas. In addition, the through-wall areas of wear were quite small compared to the total vane area. Thus, head and flow losses would not be expected to be appreciable.

GPUN also evaluated the ability of an impeller damaged to the extent of the "B" RCP impeller to maintain its integrity through continued operation. In designing a pump impeller, the impeller vane thickness is determined by the loads imposed and by the streamline curvature necessary for casting and smooth hydraulic flow at normal flow rates. The loads are greatest at the largest vane diameter (the impeller discharge). At the inlet tip, loads are lower. The design wall thickness in the area which experienced cavitation damage (only a few inches from the inlet tip) is thus much greater than necessary to carry the required loads. GPUN has concluded that ample material remains to carry these loads, even after small local areas experience metal loss due to cavitation wear. Therefore, the integrity of the impeller will not be expected to be compromised.

Although damage similar to the "B" RCP impeller damage is not considered significant, it should also be noted that such damage is not believed to be present in the other pumps. As we described in our letter of April 10, 1984, all three pumps were inspected visually by inserting a camera into the cold leg. No through-vane cavitation damage was seen. Although there may be some unseen metal loss from the under sides of the vanes, any cavitation damage that may exist is clearly to a lesser extent than was present in the "B" pump. We characterized it in our April letter as "superficial." In addition, since cold, single-pump operation is to be limited to very short periods of time and to startups (See Section A of this letter), no appreciable development of new or enlarged wear areas is expected.

Confirmation that flow rates are acceptable will be obtained through full flow testing during the startup program. As you are aware, such testing is a required portion of the surveillance program, to be performed at 100 percent power following each refueling outage. Such testing is a comparison with pre-existing data, and can only be validly performed at that power level. Thus GPUN has no flow test data to provide at this time. However, it has been observed that flow rates during periods of precritical pump operation have not been unusually low. Extrapolation to full flow conditions does not predict reduced pump performance.

You have also asked for any further information that supports our statement that the pump damage has no safety significance. In Items 3-6, you have requested additional information on each of the supporting arguments from our April 10 discussion that led to that conclusion. Thus, we feel that complete and ample information is already being provided to allow you to conclude, as we did in April, that the pump damage cannot be viewed as a safety concern either for the present cold shutdown operation or for future power operation. GPUN does not plan to provide any additional discussion beyond response to your specific questions.

Sincerely,

RJ Toole for

H. D. Hukill
Director, TMI-1

MJG:dls

cc: R. Conte
W. Hazleton
H. Silver