UNITED STATES
NUCLEAR REGULATORY COMMISSION
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MAINE YANKEE ATOMIC POWER COMPANY
DOCKET NO. 50-309
THERMAL SHIELD MOUNTING SYSTEM REPAIR
SAFETY EVALUATION

BACKGROUND

The 825 MWe Maine Yankee nuclear power plant entered commercial operation in 1972. The nuclear steam supply system fabricated by Combustion Engineering (CE) is quite different than the standard CE two loop design. In the standard design, each loop has one steam generator with two cold legs, each with a 900 RPM reactor coolant pump. In contrast, Maine Yankee is a three loop design with one steam generator and one 1200 RPM reactor coolant pump in each loop. Therefore, the Maine Yankee reactor internals are subjected to hydraulic forcing functions which are different from the standard CE design. The three loop configuration does not provide an axis about which differential flow forces can act on the reactor internals. In addition, the configuration of the Maine Yankee alternating hot and cold leg nozzles is indicated by Maine Yankee Atomic Power Company to contribute to greater flow stability.

The Maine Yankee thermal shield is a cylindrical structure 3.0 in. thick, 152 in. long, made of type 304 stainless steel. It weighs approximately 64,000 pounds. It is outside and concentric with the core support barrel, which contains and supports the reactor core. The purpose of the thermal shield is to reduce the neutron flux and gamma ray heating in the reactor pressure vessel wall.

At the upper end, the shield is supported by nine equally spaced lugs welded to the outer periphery of the core support barrel. A loading bearing 5" diameter support pin with a slot for the support lug provides the interface between the lug and the shield. The thermal shield is positioned radially utilizing positioning pins which are threaded through the shield and butt against the core support barrel. There are nine equally spaced positioning pins on the upper portion of the shield directly beneath each of the support lugs and seventeen equally spaced positioning pins on the lower portion.

Maine Yankee conducted an extensive Precritical Vibration Monitoring Program during hot and cold functional testing in 1972. This experimental program incorporated the use of internal and external accelerometers, pressure transducers, strain gauges and scratch gauges which permitted the recording at specific locations of time dependent accelerations, pressure, strains and maximum relative displacements.

This program provided measurements of the magnitude of core support barrel and thermal shield structural vibrations and hydraulic pressure fluctuations during various modes of reactor operation. This program provides confirmation based upon experimental evidence, that the hydraulic excitations and structural responses of the Maine Yankee reactor internals are within design estimates and are acceptable for all normal steady state and transient flow modes of reactor coolant pump operation.

In 1973, the standard CE design Palisades reactor experienced significant wear of the reactor vessel internal support lugs due to relative motion between the reactor vessel and the internals assembly. In response to this occurrence, Maine Yankee contracted with CE to evaluate the degree of reactor internals vibration using ex-core neutron noise analysis techniques. The results of this evaluation indicated that the signal characteristics were different from Palisades and the magnitudes of the signals were significantly less and not changing over time. Nonetheless, the core support barrel was removed and the vessel flange was inspected for indications of incipient damage as seen at Palisades. The thermal shield was not inspected at this time. Even though there was no indication of excessive motion, Maine Yankee installed an improved core support barrel holddown ring which was determined to be the source of the problem at Palisades.

Additionally, a loose parts monitoring system was installed in the 1974 timeframe to provide on-line monitoring capability to detect loose parts in the reactor coolant system. This system utilized two reactor vessel accoustic sensors (one upper and one lower) and one sensor for each of the three steam generators.

During the 1982 refueling outage, the Maine Yankee reactor internals were again removed from the reactor vessel and inspected as part of the Inservice Inspection Program required after ten years of operation.

The inspection disclosed that the condition of the reactor internals was normal with the following exception. Three of the nine upper thermal shield positioning pins were dislodged from their threaded holes, two being entrapped between the thermal shield and core barrel and the third being caught in the flow skirt located at the bottom of the vessel. The extensive wear on the pins plus the far lower radiation level of the third pin indicated that failure occurred during the first few years of plant operation.

Combustion Engineering conducted a preliminary evaluation of the effect of the loss of the pins, based on what was known in 1982, and concluded that the thermal shield support lugs were sufficient to prevent lateral motion of the thermal shield without any of the upper positioning pins. A presentation was made to the staff which justified continued operation without replacement of the three positioning pins on the basis of CE's analysis, the experience during the first ten years of operation with no indication of wear, even though the pins probably fell out early in life, and Maine Yankee's commitment to aggressively monitor core internals motion using the accoustic monitoring system.

In the Spring of 1983, St. Lucie Unit 1, a standard two loop CE plant, inspected their reactor internals during a refueling outage. The thermal shield was found to be in a severely deteriorated condition, which included missing and worn positioning pins, worn and severely damaged support lugs, and cracking in the core support barrel at the lug locations. The thermal

shield was cocked on the core barrel and large fragments were missing. The damage was so severe that St. Lucie elected to remove the thermal shield. This greatly extended the length of the outage. Several months later, the Millstone Unit 2 reactor conducted an inspection of their thermal shield during a refueling outage and found similar damage but not quite as severe as St. Lucie. Milestone Unit 2 also elected to remove their thermal shield during the lengthy outage which ensued. Both St. Lucie Unit 1 and Millstone Unit 2 are CE standard design plants.

DISCUSSION

Hydraulic Differences

In response to this experience at St. Lucie and Millstone Units, Maine Yankee increased the monitoring of the reactor internals and contracted with two independent consultants to provide expertise in this area.

The plant continued to operate to the next regularly scheduled refueling outage because of the ability to monitor the internals and the belief that the reactor coolant system differences between Maine Yankee and the standard CE design accounted for Maine Yankee's successful operation without indications of thermal shield damage.

Although the standard CE NSSS Design reactor internals are very similar in design to Maine Yankee, the reactor coolant system is quite different. Each of the two loops in the standard design includes a large diameter hot leg which carries the hot coolant to the steam generator and two smaller cold legs which returns the coolant to the reactor. Each of the cold legs contain one 900 RPM reactor coolant pump which provides the driving force for the coolant and is ultimately the source of the hydraulic forcing functions which act on the reactor internals. It is important to note that the cold leg nozzles are mirror images of each other and it is easy to envision a line drawn down the center of the vessel about which differential flow forces between the pumps in the two opposing loops can act. Main Yankee's alternating hot and cold leg nozzles provide no such axis of symmetry.

The Maine Yankee reactor coolant system differences from the CE NSSS standard design include three 1200 RPM reactor coolant pumps and three equally spaced cold leg inlet nozzles which are normal to the reactor vessel wall. The cold leg piping contains an elbow just upstream of the reactor vessel inlet nozzle. This elbow skews the velocity distribution of the flow at the reactor vessel inlet nozzle such that it is higher at the right hand edge as viewed from outside the vessel. This inlet velocity distribution, along with the curvature of the outlet plenum wall upon which the flow impinges, coupled with cold leg nozzles which are all oriented in the same direction, imparts a counterclockwise rotational component to the flow entering the vessel.

The hydraulic forcing functions acting on the thermal shield are, therefore, different from the standard CE plant. The three loop Maine Yankee reactor is believed to be inherently more stable in that it does not provide an axis about which differential hydraulic forcing functions can act on the reactor internals.

Inspections

Periodic monitoring of the Maine Yankee reactor internals using both ex-core neutron noise analysis techniques and the Loose Parts Monitoring System indicated that deterioration of the support system was not occuring. A safety evaluation of the consequences of a postulated thermal shield drop was performed and submitted to the Nuclear Regulatory Commission. The evaluation concluded there would be no adverse impact on the health and safety of the public. The ISI video tapes taken during the 1982 outage were reviewed to look for evidence of distress based on the knowledge of failure modes gained at the other plants.

This review indicated that incipient damage had not been present in 1982. Even though all evidence indicated that damage was not occuring, the licensee of Maine Yankee prudently decided to pull the core support barrel during the next outage to thoroughly inspect the thermal shield and replace the three missing pins. Maine Yankee decided to develop a replacement thermal shield positioning pin which would be similar and functionally equivalent to the

original pins. CE was tasked with designing the replacement pin and the means for its installation. CE was also tasked with developing a method for measuring pre-load on the remaining pins in order to better assess the overall tightness of the support system. Plans were made to inspect the entire thermal shield support system during the 1984 refueling outage, and replace the three missing pins.

The conceptual pin development effort resulted in a decision to install a three piece replacement pin described later in this report. Two separate parallel development efforts resulted from the first; one to develop tooling to machine the thermal shield to accept the replacement pins and the other to develop tooling to deliver and install the pins. Both efforts were complex and difficult. The machining system not only had to be capable of operating remotely in an underwater high radiation environment, but it had to be very precise and capable of machining stainless steel to tolerances of ± 5 mils. The pin installation tooling development effort required the development of six separate tools and the means for delivering each to a location approximately 8.0 ft. under water. These too had to have remote operating features because of the high radiation environment in which they were required to operate. The inspection and repair were successfully completed during the 1984 refueling outage.

An inspection plan was developed which provided for an underwater visual inspection of the outer surface of the thermal shield with emphasis on the support system in order to identify an indications of damage or distress. The inspection was concentrated on the areas around each of the support lugs because no damage was found at other CE plants outside this area. In addition, plans were made to document the condition of the remaining six upper and 17 lower positioning pins.

A detailed inspection of the nine support lugs and 26 positioning pin locations was conducted using underwater closed circuit television cameras (CCTV), and remote handling equipment.

The cameras utilized were capable of resolving a line 7 mils in width. The inspection teams were comprised of one Maine Yankee inspector and one Combustion Engineering inspector who had inspected damage at other CE plants. The CCTV camera was positioned in close proximity to the thermal shield for the outer surface inspection and was inserted into the annulus between the thermal shield and core support barrel to inspect the condition of the positioning pins. The thermal shield and support structure appeared to be undamaged, or close to the original condition. Other than the three missing positioning pins discovered during the 1982 outage, no additional differences from the original condition were seen. The inspection demonstrated that the condition of the thermal shield support system had not changed from that observed during the 1982 ten year Inservice Inspection.

Repairs

The scope of the repair consisted of the following key elements:

- Replacement of the three missing (V, X, Y) with a replacement pin which was essentially equivalent to the original design.
- Assessment of the condition of the included pin (W) and replacement if necessary.
- Assessment of the condition of the thermal shield radial positioning pins using the novel preload testing concept developed by Combustion Engineering.

The replacement positioning pin is a simple design which duplicates the function of the original pin. The replacement pin components were designed and fabricated of 304 stainless steel by Combustion Engineering.

The replacement design consists of the following three sub components:

- Threaded inner collar
- Positioning pin
- Outer locknut

The thermal shield was machined at pin locations V, X, and Y to accept the components of the replacement pin. Inside and outside counterbores were machined to provide seating surfaces for the inner collar and outer locknut.

Although difficulties were experienced, Combustion Engineering successfully installed the three replacement positioning pins at locations V, X, and Y. These pins were preloaded to approximately 5,000 pounds.

Preload testing was commenced following replacement of the first positioning pin. Original upper and lower pins were tested for preload, but the results were inconclusive. However, preload testing was used successfully during the installation of the three replacement pins. To better determine the condition of the positioning pins, an alternate method, light gap testing, was developed to detect whether the pins were in fact in contact with the core support barrel.

Small diameter CCTV cameras were positioned either along side (upper pins) or directly above (lower pins) the positioning pins, opposite a bright light source. The light source was moved opposite the camera in attempts to detect light at the interface between the positioning pins and the stellite wear pad on the core support barrel. No gaps were detected at the five remaining upper pins which could be tested. One pin, pin "R", could not be tested due to mechanical interference. Gaps were detected at 11 of the 17 lower positioning pins. Attemps were made to quantify the size of the gaps using a mockup and five and ten mil feeler gauges attached to long handled tools. These methods proved inconclusive.

Pin "W" or the "included pin" is located between pins "V", "X" and "Y". Evidence from other CE plants that had sustained thermal shield damage showed that if impacting had occurred, the pins could no longer be rotated due to thread damage. The decision was made to attempt to tighten and load pin "W", and in so doing, test a method which could be utilized on the lower pins.

This was accomplished by machining the locking bar from the pin and rotating the pin with tools developed on site. The pin was successfully rotated and preloaded to approximately 4,600 pounds. The pin was tested for preload approximately 12 hours later with the same results. The interface between the pin and the thermal shield was drilled to accept a stainless steel sel-lock spring which was used to stake the pin and prevent it from rotating. The skating spring was successfully delivered and inserted.

This action completed the repair of the upper pins. It was also significant in that it demonstrated that the threads on the pin and in the thermal shield were still in excellent condition and that tightening original pins was a viable option. This also provided evidence that impacting had not occurred during the initial eleven years of operation. The decision was made to attempt a similar repair on a lower pin. Pin "C" was selected because it was known to be not in contact with the core support barrel based on the light gap test results. The plan for repairing pin "C" was as follows:

- o Remove the lock bar on pin "C".

- o Develop tooling to tighten pin "C" and quantify the gap.

- o Remove pin "C" for purposes of observation.

- o Develop tools to install a new pin "C" of original design if threads were found to be in good condition.

Work on the lower pins proved to be significantly more difficult than the upper pins due to being further underwater. The upper pins are approximately 8.0 ft. under water while the lower pins are at a depth of 18 ft.

Despite these added difficulties, Pin "C" was successfully rotated. The amount of rotation was approximately 3/4 to one full turn which equates to a 47 to 63 mil gap. This gap was larger than anticipated based on initial interpretation of the evidence from the light gap test. The original pin was then successfully removed and a new pin successfully installed in its place. The removed pin was inspected and the threads were determined to be in excellent condition, providing further evidence that impacting had not occurred. The newly installed pin was torqued tight and additional lower pin work was planned.

The expanded scope of work on the lower pins included tightening sufficient pins to achieve a pair of pins either in contact or loaded in each quadrant. During tightening, the amount of rotation of each pin would be quantified. The goal of the lower pin work was to fix the thermal shield to the core support barrel in two orthogonal directions.

During this phase of the program, seven pins, in addition to pin "C", were tightened. This resulted in 8 of the 17 lower pins loaded, with four additional pins in contact with the core barrel or with gaps too small to detect with the light gap test. Following tightening, the eight pins were staked using the same technique previously described for pin "W". The eight pins which were successfully tightened had the following as-found gaps based upon pin rotation:

Pin	Approximate Gap mils
C	47-63
F	8
G	4
K	21
L	26

Pin	Approximate Gap mils
N	*
P	8
Q	19

* Unable to quantify amount of rotation from CCTV videotape.

A final light gap test was performed on all lower pins. Only pins A, D, E, J and M had detectable gaps.

The thermal shield repair program achieved the original goal of replacing the three missing upper positioning pins. The upper pins are either loaded, in contact with the core support barrel, or have undetectable gaps. The lower pin repair program was also very successful. The radial support provided by the lower positioning pins is much improved and the lower region is fixed to the core support barrel in two orthogonal directions. In summary, the as-left condition of the thermal shield support system is a significant improvement over the as-found condition. Since the inspection showed that the thermal shield appeared undamaged and was in, or close to, the original condition, the repair was determined to be sufficient to return to power operation and continue with the reactor internals monitoring program. Details of the inspection results and repair program were presented to the staff on May 15, 1984 prior to return to power operation.

Future Monitoring

The next planned inspection of the thermal shield will occur during the 1988-89 refueling outage or when the core support barrel is next removed, or sooner if the monitoring program indicates an inspection is warranted.

Five new Loose Parts Monitoring System sensors were installed during the most recent refueling specifically to improve the system's capability of monitoring the reactor internals. Three channels were added to the upper head while two were added to the lower head. Three magnetically mounted accelerometers are located on the upper head just above the holddown studs and centered between the hot and cold leg nozzles of each loop. Two lower head accelerometers are mounted on incore instrumentation tubes. This provides improved monitoring capability over last cycle when only two channels were available; one upper sensor mounted on the safety injection line to loop three and one lower sensor on one of the incore instrument tubes. These two channels are still installed in order to provide the means for correlating cycle 7 data with current cycle data. In addition, they provide installed backup capability.

The five reactor vessel channels provide audio output either to headphone or for tape recording purposes. In addition, each channel provides input to an impact monitor chassis. One impact monitor is provided for each of the five reactor vessel channels. The system is currently set up so that an impact alarm locks in when six (6) events exceeding the system threshold

are seen by any combination of channels during a three second period. This limits the number of false alarms due to electronic noise spikes which may be common to all five LPMS channels. The outputs from three channels are inputs to a digital transient recorder which is capable of capturing events. The transient recorder continuously looks at the three channels and locks in the information when triggered by a lock-in alarm from the impact monitor chassis. The data is then printed in strip chart form. Periodic monitoring of the LPMS is performed by the Maine Yankee shift engineers. This includes printing out random traces daily and monitoring the system during routine periodic CEA exercises to check the system response with a known noise source.

The Cycle 8 monitoring program utilizes both the Loose Parts Monitoring System previously described and spectral neutron noise analysis from the four ex-core power range detectors. Trending will be provided by making relative comparisons between periodic spectral analyses specifically looking for anticipated loosening thermal shield signatures.

The planned neutron analysis program is as follows:

o Baseline ex-core neutron noise spectral analysis obtained during startup for the current fuel cycle at approximately 50 percent power and soon after reaching approximately 100 percent power.

- o Monthly ex-core neutron noise analysis for three months and then quarterly for the balance of cycle 8.

- o Ex-core neutron noise monitoring for subsequent fuel cycles will be performed at beginning, middle and end of each cycle.

The frequency of analysis will be adjusted as appropriate in the event of either adverse trending in the neutron noise spectral analysis or if significant LPMS activity implying loosening of the thermal shield is observed.

Ex-core neutron noise analyses have been completed on data recorded on June 24, 1984 (30% power) and June 29, 1984 (50% power). Comparisons between this data and that from Cycle 7 show key differences in the signature characteristics. Cycle 7 monitoring indicated slight growth in a 9.5-11.5 hz region which is believed to be a possible early indication of thermal shield support structure loosening. The spectral peak in the 9.5-11.5 hz region does not exist in the cyle 8 data. Maine Yankee's consultant is of the opinion that the elimination of this peak is the result of tightening of the thermal shield support structure.

Additionally, the spectral peak in the 4.5-6.5 hz region, which is attributed to second mode fuel element vibration and core support barrel beam mode vibration, has decreased. The changes noted are consistent with a tightened system.

Conclusions

The licensee has concluded, based upon his evaluation of the thermal shield inspection and repair program that:

- The thermal shield and support system appeared undamaged and was in, or close to, the original condition during the 1984 inspection;

- the missing three upper radial positioning pins were successfully replaced;

- eight lower radial positioning pins were successfully tightened;

- reactor internals monitoring capability has been greatly improved through addition of five dedicated reactor vessel sensors;

- identifiable changes in ex-core neutron noise spectral analyses indicates that the core support barrel/thermal shield system is tighter which confirms the success of the repair and provides a basis for future monitoring; and

- the success of the repair program provides assurance that the health and safety of the public will not be endangered by Maine Yankee operation.

EVALUATION/CONCLUSION

The staff has reviewed the information submitted by the licensee and concurs with his conclusions. The modification to the licensees inservice inspection program that were mutually agreed upon are stated in the text herein. Specifically, this modification consists of shortening the next examination period for the internals. The improvements in both the loose parts monitoring and ex-core neutron noise analysis add confidence that should severe degradation occur, it would be detected in timely fashion and appropriate remedial action can be taken.

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