AEOD ENGINEERING EVALUATION REPORT*

UNIT: Browns Ferry 1
DOCKET NO.: 50-259
LICENSEE: Tennessee Valley Authority
NSSS/AE: General Electric/Utility

EE Report No.: AEOD/E417
DATE: July 2, 1984
EVALUATOR/CONTACT: C. Hsu

SUBJECT: LOOSENING OF FLANGE BOLTS ON RHR HEAT EXCHANGER LEADING TO PRIMARY TO SECONDARY SIDE LEAKAGE

EVENT DATE: June 20, 1980 (LER 80-049/03X-1)

SUMMARY

Licensee Event Report 80-49 for Browns Ferry 1 describes an event in which a residual heat removal (RHR) heat exchanger was found leaking during a routine operability test. This leakage was detected by a pressure increase in the secondary side of the heat exchanger which indicated a leak of primary coolant into the RHR service water system which discharges to the Wheeler Reservoir. Six additional events found in this review had similar leakage. Three were at Browns Ferry 1, the others at Browns Ferry 2. These were recurrent events. The leaks in two of these events resulted in release of radioactivity into the environment. These radioactive fluid releases were in excess of the technical specification limit. The RHR heat exchangers at these two units are identical and manufactured by Perfex Inc.

The leakage occurred at a gasket joint of the floating head flange in the RHR heat exchanger and was due to loosened nuts at the flange. It was believed that the loosening of nuts was due to flow-induced vibration and/or thermal cycling. These two operational conditions had not been fully considered in the design of these RHR heat exchangers. Flow-induced vibration and thermal cycling could produce a combined loading on the floating head gasket joint such that torque application alone could not provide adequate compression on the gasket to tighten the joint. The stud elongation approach was needed in order to preclude occurrence of nut loosening on the floating head joint.

Generic Safety Issue C-9 listed in the Task Action Plans, which addresses the safety significance of leaks in RHR heat exchangers at BWR plants, has been downgraded in a recent NRC priority ranking plan and dropped from further consideration for resolution. The bases for the risk significance estimate and assumptions for the prioritization of this safety issue are (1) tube failure is the only source of leaks in RHR heat exchangers and (2) in

*This document supports ongoing AEOD and NRC activities and does not represent the position or requirements of the responsible NRC program office.

all BWR plants the RHR SW system is designed to have pressure greater than that of the RHR system in the RHR heat exchanger whenever the heat exchanger is in service. Hence, a leak in the RHR heat exchanger may not necessarily cause radioactivity to release into the environment. However, in the events of this review, the leaks in the RHR heat exchanger were from the floating head joint due to loosened nuts, not tube failures, and the service water pressure was lower than that of primary coolant in the RHR heat exchangers at the Browns Ferry units which are BWR plants. NRR should review the assumptions used for the priority ranking of the Generic Safety Issue C-9 in light of the deviations identified.

This report suggests the following actions:

1. NRR should reconsider the status of Generic Safety Issue C-9. This reconsideration should assess the variation in the assumptions used and determine whether changes would impact the priority ranking of this generic safety issue.

2. IE should consider issuing an Information Notice to stress the use of a stud elongation approach which can provide proper compression to assue tightness of the floating head gasket joint of a RHR heat exchanger subjected to flow-induced vibration and thermal cycling during operation.

INTRODUCTION

This engineering evaluation reviews an event at Browns Ferry 1 described in LER 80-), which involved leakage from the primary to the secondary side of a RHR heat exchanger. The leakage occurred at a gasket joint of the floating head flange and was due to loosened nuts at the flange. A number of similar events involvng leakage in the RHR system were found in a search of the LER data base file. These additional events occurred at Browns Ferry 1 and 2. The events at Browns Ferry 1 were reported in LERs 80-43, 78-23, and 77-01 and the events at Browns Ferry 2 in LERs 80-53, 80-34, and 80-33. These six events were similar to the one at Browns Ferry 1 which was reported in LER 80-49 and involved loosening of flange bolts on the floating head of a RHR heat exchanger which resulted in primary to secondary side leakage.

Browns Ferry 1

LER 80-49/03X-1, dated May 4, 1983, reported that on June 20, 1980, with the unit in steady state full power operation, a routine test of the RHR system for operability revealed that RHR heat exchanger 1-C was leaking. This leakage was detected by a pressure increase in the secondary side of the heat exchanger which indicated a leak of primary coolant into the RHR service water system which discharges to the Wheeler Reservoir. Subsequent disassembly and inspection of the heat exchanger revealed that about 30 percent of the lock nuts on the floating head had loosened, resulting in a leak at the floating head gasket joint. It was believed that loosening of the locking nuts was due to flow-induced vibration and/or thermal cycling. No tube leaks were identified. Locking tabs were installed on all nuts to prevent recurrence of loosening. The heat exchanger was then satisfactorily leak tested prior to return to service. In order to prevent similar occurrences, locking tabs were also installed on all RHR heat exchangers at the Browns Ferry Station.

A similar event occurred on April 11, 1980, in one of the other RHR heat exchangers and was reported in LER 80-43. The unit was operating at 85% power. A routine inspection revealed that RHR heat exchanger 1-A was leaking due to loosened floating head nuts. The cause of nut loosening was thermal cycling and vibration. six of the 52 lock nuts were found to have loosened causing a leak at the gasket joint. The lock nuts had been installed during an earlier modification. Corrective action was to replace the gasket and tighten the flange nuts in accordance with the maintenance instructions for the plant.

LER 78-23, dated July 25, 1978, provides a description of radioactive release to the environment through a RHR heat exchanger due to loosened nuts of the floating head. On July 15, 1978, during normal shutdown, reactor coolant leaked from a RHR heat exchanger into the RHR service water system which discharged to the Wheeler Reservoir. A total of 40 mCi were released. The concentration in the discharge water released was in excess of Technical Specification limits. The heat exchanger was immediately isolated. Inspection disclosed that flow-induced vibration had loosened full-sized locking nuts allowing the floating head gasket to leak. All lock nuts were to be replaced and more sensitive process monitors were to be installed. Other heat exchangers were to be checked for leakage and selected ones were to be inspected for loosened flange nuts.

The event reported in LER 77-01 occurred on January 4, 1977. During cold shutdown, the radiation monitor on the RHR service water discharge line from heat exchanger 1-A showed an increase in radiation levels. A sample test of the service water effluent revealed that the radiation level had exceeded the license release limit. However, because of a communication misunderstanding between the lab analyst and the shift engineer, it was not until the next day when the shift engineer recognized that a radioactive release exceeding the limit had occurred. Heat exchanger 1-A was then removed from service and heat exchanger 1-C was placed in service. The release occurred because of a leak at the floating head gasket due to stud bolts becoming loose in service. The heat exchanger was satisfactorily leak tested in April 1976 and had not been in service since. This, together with documentation of previous sampling whenever the heat exchanger had been in service, confirmed that the leakage was not an existing condition and probably started after the heat exchanger had been in service for one hour on that day. In repairing the leak and replacing the gasket, lock nuts were installed on each stud bolt to preclude future loosening in service. This modification was to be made to all RHR heat exchangers for all three units at the site when they were opened in the future for maintenance or inspection.

Browns Ferry 2

LER 80-053/03X-1, dated May 11, 1981, describes that on December 5, 1980, with the unit in steady state power operation, a leak in RHR heat exchanger 2-C was found during a routine test. The cause was a leak at the floating head gasket joint due to loose nuts. Loosening of the nuts was a result of thermal cycling and vibration. The gasket was replaced, and nuts with locking tabs were installed. The heat exchanger was then satisfactorily tested. Redundant systems were available during this event.

On August 15, 1980, with the unit at full power operation, it was found during a routine test that RHR heat exchanger 2-C was leaking. The event was reported in LER 80-34, dated September 8, 1980. Redundant heat exchangers B and D were operable. About ten percent of the lock nuts and full nuts had loosened due to thermal cycling and vibration. The loosening of these nuts resulted in a leak at the floating head gasket joint. The gasket was replaced and tested and the nut torque was increased from 50 ft-lbs to 225 ft-lbs. A change was initiated to install locking tabs. Later in the day, RHR heat exchanger 2-B was tested and a leak was found at the floating head gasket joint. The event was reported in LER 80-33, dated September 8, 1980. The leak at the gasket joint was attributed to loose flange nuts from thermal cycling and vibration. The licensee corrective action to prevent the nuts from loosening was to add locking tabs to the flange nuts and increase the nut torque.

DISCUSSION

These seven reports illustrate recurrent problems of loosening nuts on internal floating head flanges of RHR heat exchangers. The loosening of nuts has caused gasket joints to leak resulting in release of radioactive reactor coolant to the enviroment. The cause of loosening nuts on the floating head flange apparently was a combination of flow-induced vibration and thermal cycling resulting from operation of the RHR system. Flow-induced vibration in a shell and tube type heat exchanger may be induced by shell side flow, tube side flow, or fluid flow fluctuation. The most frequently encountered source of vibration is from shell side fluid flow. Shell side flow may produce excitation forces which could cause destructive tube vibration, inducing high bending moments on floating head bolts. Existing predictive correlations are inadequate to insure that any given design will be free of such damage. The vulnerability of a heat exchanger to flow-induced vibration depends on the flow rate, tube and baffle materials, unsupported tube span length, tube field layout, shell diameter, and inlet/outlet configuration. Because of the uncertainties or unknowns involved, the manufacturer will not necessarily attempt to analyze for vibration unless specifically requested by the licensee and with sufficient information provided in the purchasing specification. Heat exchangers normally should not be subjected to abrupt temperature fluctuations. Hot fluid normally should not be suddenly introduced when the unit is cold, nor cold fluid suddenly introduced when the unit is hot. Frequent operability testing and abbreviated operation of the RHR system may introduce a large number of sudden temperature changes in a RHR heat exchanger which could cause stress oscillation of tightened bolts on the floating head.

Our discussions with the manufacturer revealed that information regarding the flow-induced vibration was not specified in the specification. Therefore, the impact of flow-induced vibration has not been fully considered as a loading condition in the bolting design for the inner floating head joints. As for the design condition of thermal cycling, the condition of temperature change was considered as a steady state concern rather than a transient state in the analytical design. No testing program was conducted to demonstrate design adequacy of these two operational conditions. It is evident that the loosening of nuts on the floating head may be attributed to inadequate specification of operational conditions.

Generally, in bolted gasket flange joints, the residual compression on the gasket necessary to prevent leakage depends on how effective the initial compression has been in forming intimate contact with the flange joint faces. Initial compression is the compression on the gasket before internal pressure is applied. The effect of applying the internal pressure is to decrease the compression on the contact surfaces since part of the bolt tension is used to support the pressure load. Tests show that a residual compression on the gasket of only one to two times the internal pressure, with the pressure acting, may be sufficient to prevent leakage where the joint is not subjected to bending or to large and rapid temperature changes. With occurrence of flow-induced vibration and thermal cycling in the RHR heat exchanger during operation, the floating head joint encounters both bending moments and transient temperature service conditions. To withstand both of these disturbing influences, a larger residual compression on the gasket is required to achieve a leak-free bolt joint. The amount of increase needed in compression depends on the impact of both vibration and thermal cycling on bolt loads at the joint. Since it is difficult to determine the overloading due to these two severe service conditions, the licensee apparently was not successful in their early attempts to apply a proper compression on the gaskets of the floating head joints in order to prevent recurrence of the gasket leaking even though the locking tabs were used to secure the nuts in place.

In an effort to preclude recurrence of the loosening bolts on the floating head joint, which is an existing design deficiency of bolting, the licensee performed an extensive investigation on floating head stud tensioning. The investigation concluded that torque application alone could not provide adequate compression on the gasket to tighten the floating head joint. It appeared that a stud elongation approach rather than a prescribed torque value could be used to ensure tightness of the joint. The licensee's conclusions were: (1) the 750 ft-lb torque applied to the nuts did not exert consistent uniform seating stress to the existing gaskets, (2) there was a possibility of exceeding stud yield tension if the torque was increased above 750 ft-lbs unless stud elongation was monitored, and (3) RHR heat exchanger floating heads should be reassembled using stud elongation as the acceptance criterion rather than torque value. Accuracy of the elongation measuring device was to be ± .001 in. or less to assure proper stress levels and to detect any relaxation of stress over operating periods. The report recommendations were to: (1) develop an elongation measuring tool and stud end design capable of measuring elongation with a repeatable accuracy of ± 0.001 in., (2) perform 100% baseline measurement on the next convenient heat exchanger to verify stressed and unstressed stud elongation measurement of 0.025 ± 0.002 in., (3) remeasure elongation after a minimum of one shutdown cooling cycle comparing measurements to the original stressed condition, (4) reassemble RHR heat exchanger 2-D and 2-C using lock tabs and .025 ± 0.002 inches stud elongation, and (5) revise the heat exchanger test procedures to reflect the above recommendations.

The floating head flanges are inside the shell of the RHR heat exchanger with no direct visual access for leak inspection. Therefore, loosening of bolts could go undetected and lead to the release of radioactivity into the environment in the event of malfunction or failure of the radiation monitoring system. Additionally, the nut loosening has developed in a very short period of time and, if this occurs, it will enhance further loosening in a relatively short time span. Hence, the periodic system operability test may not be capable of providing assurance that leaking at the floating head would not develop in a subsequent operation of heat exchanger. Loosened bolts could cause leaking at the gasket joint. Since the primary coolant pressure is greater than the service water pressure in the RHR heat exchangers at the Browns Ferry units, the floating head gasket leak could cause primary coolant flow into the service water system and render the RHR system inoperable. The leakage from primary to secondary side will not only impair the integrity of the primary pressure boundary, but also allow radioactivity release into the environment or an unrestricted area and constitute a potential hazard to the public safety and health.

The Generic Safety Issue C-9 (Ref. 1) relating to leaks in RHR heat exchangers at BWRs has been downgraded in a recent NRC plan of prioritization on generic safety issues (Ref. 2). Because of its low priority ranking assigned in the work of prioritization, this generic safety issue was dropped from further consideration for resolution. In the priority determination, the assumptions and risk estimates are based on (1) the leak in a RHR heat exchanger is due to tube failure only, (2) the service water pressure is greater than the primary coolant pressure in the RHR heat exchanger, (3) a pressure control system always maintains the service water pressure greater than the primary coolant pressure so that in the event of tube failure or leakage there would be no leakage of radioactive fluid into the environment. In conjunction with the above items, the conclusion was that the availability of RHR for long -term core cooling capability remains high since the probability of tube failure is low and the tube leakage flow rate is also low in comparison to the full flow.

However, in the events of this review, the leaks occurred at the floating head gasketed joints of RHR heat exchangers. The leaks at the gasket joints were due to loosened nuts, not a tube failure, and the service water pressure was lower than the primary coolant pressure in the RHR heat exchangers at the Browns Ferry units which has three BWR plants. Therefore, in this case a leak in the RHR heat exchanger would cause leakage of primary coolant into the service water system which would result in release of radioactive fluid into the environment. Additionally, a search of the LER data base files resulted in the identification of three events which occurred at Hatch 2 involving failures of pressure control valves in the service water pressure control system. The failures resulted in partial or total loss of the RHR system function. These three events were reported in LERs 82-85, 81-98 and 78-46, and also were cited in an AEOD Engineering Evaluation Report (Ref. 3). Among these three events, two events resulted in loss of operation in one of the two trains of the RHR system and one event resulted in loss of operation in both trains. Thus, it appears that the failure of the pressure control system will increase not only the probability of primary to secondary side leakage in the RHR heat exchangers but also the probability of loss of the RHR system function which would reduce the availability of long-term core cooling capability provided by the RHR system. In view of these items, it may be appropriate to evaluate these deviations from the original assumptions so as to determine what their impact may be on the stated priority ranking of C-9.

FINDINGS AND CONCLUSIONS

Based on the preceding discussion and related followup activities in this evaluation, the following findings and conclusions are provided:

1. Recurrent problems have been evident concerning leaking floating head gaskets on the RHR heat exchanger at two units (Browns Ferry 1 and 2). It was believed that flow-induced vibration and thermal cycling caused loosening of the lock nuts resulting in gasket leakage.

2. The RHR heat exchangers at these two units are identical and manufactured by Perfex Inc. The design specification of the heat exchangers was provided by General Electric (the reactor supplier) to the manufacturer.

3. Browns Ferry station has three BWR plants in which the service water pressure is less than the primary coolant pressure in the RHR heat exchanger during RHR system operation. Therefore, a leak in the floating head gasket of the RHR heat exchanger would result in leakage of primary coolant into the service water system and then into the environment.

4. Seven events have occurred at Browns Ferry 1 and 2. The leaks in two of these events resulted in the release of radioactivity into the environment. The concentrations in these releases were in excess of the plant limits.

5. Among these seven events which occurred at Browns Ferry 1 and 2, the leakage of two events was discovered during RHR system operation under plant shutdown conditions and the other five were found during routine operability tests of the RHR system.

6. Flow-induced vibration and thermal cycling are the common failure mechanisms that caused the nuts to loosen in these events. It appears that these two severe operational conditions have not been fully considered in the bolting design of the floating head joint in the RHR heat exchangers.

7. Flow-induced vibration could produce high and uneven bending moments on the bolts around the floating head gasket joint. These additional loadings will result in nonuniform seating stress on the gasket of floating head joint. Sudden temperature changes concurrent with the thermal cycling could cause stress oscillation of tightened bolts on the floating head such that the stress could be reduced below the level needed to prevent loosening of the bolts.

8. A higher compression on the gasket is needed to prevent leakage from a floating head joint subject to bending or to large and rapid temperature changes during service conditions. The compression needed is difficult to determine due to the lack of understanding of the mechanics of gasket action and insufficient information about the impact of flow-induced vibration and thermal cycling on the floating head joint.

9. In the early attempts, the licensee was unable to prevent recurrence of the leakage even though the nut torque was increased to more than four times the original design value and then the nuts were secured in place with locking tabs. The recurrence of nuts loosening may be due to relaxation of bolt stress as a result of thermal cycling during the operation of the RHR system.

10. The licensee determined that torque application alone could not provide adequate compression on the gasket to ensure a leak-free bolt joint and recommended (a) a stud elongation approach to

assure proper stress level and to detect any relaxation of stud stress, (b) to verify stress level, elongation should be remeasured after a minimum of one shutdown cooling cycle and the measurements should be compared with the original stressed condition, and (c) develop an elongation measuring tool and stud end design capable of measuring elongation with a repeatable accuracy of ± 0.001 inches.

11. A review of the NPRDS Data Base file for failure of the Perfex heat exchanger identified several plants, other than Browns Ferry, that also use Perfex heat exchangers in their RHR systems. These plants are Brunswick 2, Peach Bottom 2 and 3, Monticello and Dresden 3 (as far as we know, the service water pressure was higher than the primary coolant pressure during RHR system operation). Leakage through floating head gasketed joints had occurred in the heat exchangers at Peach Bottom 3 and Monticello units. The leakage at Peach Bottom 3 was due to loosened nuts and that at Monticello may be related but the information is insufficient to determine a specific cause.

12. Based on discussions with NRR technical staff, we believe other plants may be similar to the Browns Ferry station in that the service water pressure is lower than the primary coolant pressure in the RHR heat exchanger during RHR system operation, even though we are not able to quantify the number of such plants.

It is evident that flow-induced vibration and thermal cycling are the causes of loosened nuts on the floating head. The impact of these two operational conditions had not been fully considered as a loading condition in the bolting design for the floating head joint. The loosening of bolts was attributed to this deficiency. Flow-induced vibration could produce uneven bending moments on the bolts around the floating head joint and thermal cycling could cause stress relaxation of tightened bolts. It appears that as a result of the combined effects of these two loadings on the floating head joint, torque application alone could not adequately exert consistent uniform seating stress to the gasket to assure a leak-free joint. Contrary to the assumption used in the priority determination for Generic Safety Issue C-9, the service water pressure is lower than the primary coolant pressure in the RHR heat exchangers at the Browns Ferry units such that a leak in the RHR heat exchanger would result in the release of radioactivity into the environment.

In view of the above, we suggest the following actions:

1. NRR should reconsider the priority ranking of "dropped" for Generic Safety Issue C-9 because some of the assumptions and estimates on which this priority determination was based do not appear to be valid. Specifically, as indicated in this evaluation, the Browns Ferry units do not have service water pressure higher than primary coolant pressure in their RHR heat exchangers. For such designs, radioactive releases to the environment would occur

in the event of leakage. Additionally, an AEOD engineering evaluation report, E411 (Ref. 3), cited instances in which a plant had degradation or loss of the RHR system function as a result of failure of the pressure control system.

2. IE should consider issuing an Information Notice to address the use of a stud elongation approach to assure a proper stress level and to detect relaxation of stud stress in the floating head gasket joint of RHR heat exchangers. Such actions should be considered since several plants have this same type of equipment installed in the RHR systems. This concept may also be useful to the flange joint tightening technique with possible broad applications to other equipment subjected to loading conditions of bending moments and thermal relaxations at a gasketed flange joint.

REFERENCES

1. USNRC, "Task Action Problem Description (Categories B, C, and D)," USNRC Report NUREG-0471, June 1978.

2. USNRC, "A Prioritization of Generic Safety Issues," USNRC Report NUREG-0933, "Task Action Plan Items," November 1983.

3. AEOD Engineering Evaluation Report "Failure of Anti-Cavitation Device in Residual Heat Removal Service Water Heat Exchanger Outlet Valve," AEOD/E411, May 1984.