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June 20, 2014
TMI-14-068

10 CFR 50.73

U.S. Nuclear Regulatory Commission
Attn: Document Control Desk
Washington, D.C. 20555-0001

THREE MILE ISLAND NUCLEAR STATION, UNIT 1 (TMI-1)
RENEWED FACILITY OPERATING LICENSE NO. DPR-50
DOCKET NO. 50-289

SUBJECT: LICENSEE EVENT REPORT (LER) NO. 2013-001-01
"Reactor Coolant "B" Cold Leg Drain Line Flaw"

This supplement updates Licensee Event Report (LER) 289/2013-001-00. The supplement revises the LER to include the results from the destructive laboratory analysis and finite element analysis for the reported condition. The corrective actions described in original LER remain valid.

This report is submitted in accordance with 10 CFR 50.73(a)(2)(ii)(A). For additional information regarding this LER contact Mike Fitzwater, Sr. Regulatory Engineer, TMI Unit 1 Regulatory Assurance at (717) 948-8228.

There are no regulatory commitments contained in this LER.

Sincerely,

Mark Newcomer
Plant Manager, Three Mile Island Unit 1
Exelon Generation Co., LLC

MN/mdf

cc: TMI Senior Resident Inspector
Administrator, Region I
TMI-1 Senior Project Manager

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NRR

NRC FORM 366 (01-2014) U.S. NUCLEAR REGULATORY COMMISSION

LICENSEE EVENT REPORT (LER)

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4. TITLE
Reactor Coolant "B" Cold Leg Drain Line Flaw Supplement

5. EVENT DATE			6. LER NUMBER			7. REPORT DATE			8. OTHER FACILITIES INVOLVED	
MONTH	DAY	YEAR	YEAR	SEQUENTIAL NUMBER	REV NO.	MONTH	DAY	YEAR	FACILITY NAME	DOCKET NUMBER 05000
11	07	2013	2013 -	001 -	01	06	20	14	FACILITY NAME	DOCKET NUMBER 05000

9. OPERATING MODE	11. THIS REPORT IS SUBMITTED PURSUANT TO THE REQUIREMENTS OF 10 CFR §: *(Check all that apply)*			
N	[ ] 20.2201(b)	[ ] 20.2203(a)(3)(i)	[ ] 50.73(a)(2)(i)(C)	[ ] 50.73(a)(2)(vii)
	[ ] 20.2201(d)	[ ] 20.2203(a)(3)(ii)	[X] 50.73(a)(2)(ii)(A)	[ ] 50.73(a)(2)(viii)(A)
	[ ] 20.2203(a)(1)	[ ] 20.2203(a)(4)	[ ] 50.73(a)(2)(ii)(B)	[ ] 50.73(a)(2)(viii)(B)
	[ ] 20.2203(a)(2)(i)	[ ] 50.36(c)(1)(i)(A)	[ ] 50.73(a)(2)(iii)	[ ] 50.73(a)(2)(ix)(A)
10. POWER LEVEL	[ ] 20.2203(a)(2)(ii)	[ ] 50.36(c)(1)(ii)(A)	[ ] 50.73(a)(2)(iv)(A)	[ ] 50.73(a)(2)(x)
	[ ] 20.2203(a)(2)(iii)	[ ] 50.36(c)(2)	[ ] 50.73(a)(2)(v)(A)	[ ] 73.71(a)(4)
0	[ ] 20.2203(a)(2)(iv)	[ ] 50.46(a)(3)(ii)	[ ] 50.73(a)(2)(v)(B)	[ ] 73.71(a)(5)
	[ ] 20.2203(a)(2)(v)	[ ] 50.73(a)(2)(i)(A)	[ ] 50.73(a)(2)(v)(C)	[ ] OTHER
	[ ] 20.2203(a)(2)(vi)	[ ] 50.73(a)(2)(i)(B)	[ ] 50.73(a)(2)(v)(D)	Specify in Abstract below or in NRC Form 366A

12. LICENSEE CONTACT FOR THIS LER

FACILITY NAME	TELEPHONE NUMBER *(Include Area Code)*
Michael Fitzwater, TMI Unit 1 Regulatory Assurance Engineer	(717) 948-8228

13. COMPLETE ONE LINE FOR EACH COMPONENT FAILURE DESCRIBED IN THIS REPORT

CAUSE	SYSTEM	COMPONENT	MANU-FACTURER	REPORTABLE TO EPIX	CAUSE	SYSTEM	COMPONENT	MANU-FACTURER	REPORTABLE TO EPIX

14. SUPPLEMENTAL REPORT EXPECTED	15. EXPECTED SUBMISSION DATE	MONTH	DAY	YEAR
[ ] YES *(If yes, complete 15. EXPECTED SUBMISSION DATE)* [X] NO				

ABSTRACT *(Limit to 1400 spaces, i.e., approximately 15 single-spaced typewritten lines)*

On November 7, 2013 TMI-1 was in refueling shutdown mode during planned outage T1R20. While conducting planned ISI of the reactor coolant "B" cold leg drain line, a flaw in the pipe weld was discovered. The flaw was located in a 2 inch drain line elbow to pipe weld (designated as weld RC-289). The flaw did not meet acceptance standards and was reported as a non-emergency degraded condition. Extent of condition and ISI scope expansion was performed. The flawed section containing RC-289 was cut out and replaced. A destructive laboratory examination and finite element analysis (FEA) was performed on the removed pipe section. The root cause of the crack is unknown but believed to be the result of geometry induced focusing of lower levels of stress, not capable of inducing cracking alone, but when combined at a geometric feature such as a lack of fusion (LOF) at a natural notch, initiated the crack. The lower energy requirements of propagation then governed the crack growth. Based on the FEA results, instrumentation of the "B" cold leg drain line is recommended to determine the true source of the crack initiating stress. If the crack source can be found with this data and stopped, actions will be created to eliminate the source of cracking. Otherwise proactive replacement may be warranted.

The submittal of this LER constitutes reporting to the NRC in accordance with 10 CFR 50.73 (a)(2)(ii)(A).

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A. EVENT DESCRIPTION

Plant Conditions before the event:

Babcock & Wilcox – Pressurized Water Reactor – 2568 MWth Core Power
Date/Time: November 07, 2013 / 13:02 hours
Power Level: 0%
Mode: Refueling Shutdown

Event:
On November 07, 2013, TMI-1 was in a refueling shutdown status for the T1R20 planned refueling and maintenance outage. During a planned Inservice Inspection (ISI) volumetric examination of the reactor coolant "B" cold leg drain line, a flaw in the pipe weld was discovered. The flaw is located in a 2 inch drain line elbow to pipe weld (designated as weld RC-289).

The flaw was determined to not meet acceptance standards under ASME Section XI, IWB-3600, "Analytical Evaluation of Flaws" with the RCS strength boundary considered degraded requiring report under 10 CFR 50.72(b)(3)(ii)(A) as a non-emergency degraded condition. The eight hour report was made at 13:02 on November 07, 2013 documented under EN# 49512.

TMI-1 reactor coolant system (RCS) has two Once Through Steam Generators (OTSG) [AB/HX]* with four Reactor Coolant Pumps (RCP - two in OTSG Loop "A" and two in OTSG Loop "B"), and includes piping and instrumentation. Each RCP [AB/P]* suction line (28 inch diameter) has a 2 inch drain. Each drain line contains two manual valves in series routed to a header connected to the suction of the Reactor Drain Pump [WD/P]*.

The 2 inch drain lines for the "A," "B," and "D" suction lines are connected to 1.5 inch nozzles (with inconel safe ends) by 1.5 inch by 2 inch reducing 90 degree elbows. The "C" suction leg drain is through a 2.5 inch diameter RCS letdown line that taps off of the bottom of the suction leg.

During T1R20 the "B" RCP cold leg suction drain elbow was examined using ultrasonic technology. At the weld designated as weld RC-289, an indication was found within the weld that initiated at the inside diameter (ID) and progressed approximately 66% through wall, toward the outside diameter (OD). The defect was confirmed using phased array technology. Per the ultrasonic examination, the wall thickness at the defect was 0.460 inch and the defect was 0.280 inch in depth leaving a remaining ligament of 0.180 inch (180 mils). Destructive analysis later found the flaw to be approximately 35% through wall, with the weld thickness at 0.361 inches and a crack depth of 0.126 inches.

ASME Section XI 2004, subsection IWB, paragraph IWB-3514-2 requires the acceptable flaw depth to be less than 12 ½% of measured wall thickness. The maximum wall loss that would have been allowable at this location was 0.0575 inches (57.5 mils). Based on 0.280 inches (280 mils) of wall loss measured via the initial ultrasonic examination, the crack was greater than the code allowable limit requiring removal. Based on exceeding paragraph IWB-3514-2 limits, the fitting was replaced. The removed fitting was

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shipped to B&W for destructive analysis to determine the failure mechanism. A new fitting was welded in place. The weld that replaced RC-289 was performed under shop conditions and was radiographed. No indications were noted from the installation Non-Destructive Examination (NDE).

In 1995, B" RCP cold leg suction drain elbow weld RC-187 was found cracked through-wall and reported via LER 1995-003-00 (also discussed in below section "E. Previous Occurrences"). The fitting and weld RC-187 was replaced by a new fitting with designated weld RC-289 during T1R11 (1995).

TMI station inspected the cold leg drain elbows in T1R14 (2001) and reported a "geometry" indication at the bottom of weld RC-289. A "geometry" finding is an indication attributed to a change in the geometry of a weld as opposed to a flaw, for example, changing wall thickness from a weld to a pipe or weld protrusion into the flow path at the root pass. The geometry indication was reviewed against the radiographs performed during T1R11 (1995) since replacing the elbow (with weld RC-289). There were differences in the geometry at the bottom of the weld that could have accounted for the geometry finding therefore no further actions were taken by the NDE technician or Amergen (owner of TMI in 2001).

TMI station inspected the cold leg drain elbows again in T1R18 (2009) and reported a "geometry" indication at the top of weld RC-289. The geometry indication was reviewed against the radiographs performed during T1R11 (1995). There were differences in the geometry at the top of the weld that could have accounted for the geometry finding therefore no further actions were taken. It is possible that this 2009 geometry finding was actually an early detection of the crack that was found in T1R20 (2013).

Due to the similarities between the RC-187 and the RC-289 failures, a Finite Element Analysis (FEA) examining the geometry of the fitting was conducted. The FEA examined the combination of component geometry and other stresses such as thermal swirl fatigue in conjunction with pressure, residual axial weld stress, RCs thermal anchor movement, and the lack of fusion weld defect site. Both the 1995 and 2013 defects are believed to have failed due to a concentration of stresses that were maximized at the upper side of the weld on the ID.

LER 2013-001-00 reported the condition found on weld RC-289 during outage T1R20. This supplement LER is based on the root cause investigation report that was revised to include the results of the destructive analysis and Finite Element Analysis (FEA) on the "B" cold leg drain line elbow (and designated weld RC-289).

B. CAUSE OF EVENT

The apparent root cause for RCS weld RC-289 crack found in T1R20 was that a resultant stress, composed of multiple smaller stresses focused by weld geometry, initiated a crack in RC-289. This crack was driven through the weld by stresses from plant heatup, cooldown, and thermal fatigue.

The destructive analysis report found the defect to span 35% of the wall thickness at that point in the fitting. (The fitting thickness varies over the range where the fitting size changes from 2 inch to 1 ½ inch thus the specific point of the defect has a thickness unique to that axial location. The weld was

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found to be 0.361 inch thick at the crack and the defect was approximately 35% of that thickness or 0.126 inch. The crack occurred at the joint top which is described as the 0° location.

The failure analysis determined the crack was an ID initiated fatigue crack. The FEA found that the stress levels were all below the values that would precipitate a crack initiation. The conclusions drawn from the original root cause investigation remain valid and the actions created under the original root cause remain in effect.

The crack initiated at a shallow Lack Of Fusion (LOF) feature, 0.009 inches (9 mils) deep, located at the notch created from the root pass weld tie to the pipe. This LOF feature was below the threshold of detection for radiography and was not visible on the construction radiograph. A LOF of this magnitude is not considered unusual and would not have failed the weld. However, the LOF did function to concentrate or focus the existing stresses at this location hence the crack propagates from the base of the LOF.

The crack was found to be tight, straight, and transgranular with little branching evident. This crack morphology is consistent with fatigue failure. The LOF site acted as the initiator for focusing stresses. A 10 mil LOF was also found on the elbow root pass at the 200° location. No cracking was found at that radial location.

The crack face was found uniformly oxidized, indicating a similar age. The similar age points to either a single event or a series of events closely related in time followed by a long period of incubation. Plant heatup or cool down evolutions would fall into this category, as well as plant trips. The crack surface also indicated striations which are indicative of cyclic related stresses. No beach marks were found on the crack surface. Beach marks were attributed to the plant heat-up and cool-down cycles during the previous (1995) flaw evaluation. The lack of beach marks indicates that plant heat-up and cool-down cycles did not drive the crack growth.

Schedule 160 Type 316 Stainless steel should perform over the full life of the plant. This has occurred, up to date, in the "A" and "D" cold leg drains despite two failures in the "B" cold leg drain. Some unique circumstance related to the "B" cold leg or a higher total force resulting in greater weld stress has cracked at this location and was found in 1995 and again in 2013. Actions taken in 1995 have not proven successful in preventing the crack from re-occurring.

The flaw found in 2013 was at the same location of a previously identified geometric indication (during T1R18 in 2009). The geometric indication was not thoroughly described and characterized in the NDE report. Additionally no Exelon review of the data report was conducted. As there was no geometric indication at this location noted during the pre-service examination (1995) nor during a follow-up exam (2001) it is believed the indication in 2009 may have been a flaw of a smaller size.

Both the 1995 and 2013 defects are believed to have failed due to a concentration of stresses that were maximized at the upper side of the weld on the ID. The initiation stress may be different from the propagation stress. A thorough evaluation of an exhaustive list of the stresses involved was completed. The exhaustive list of stresses is as follows:

1.) Weld internal stresses (can be relieved by post weld heat treatment)

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2.) RCS cold leg growth in the downward and horizontal directions pushing the pipe against a hard stop
3.) Thermal stresses from heat up and cool down of the piping
4.) Thermal stresses from swirl introduction of rapid heat up and cool down cycles, called Thermal Fatigue
5.) Stresses from internal pressure, called Hoop Stress.
6.) Stresses from the pull of gravity on pipe and fittings between the supports, called Bending Moment
7.) Stresses that come from vibrations of a reactor coolant pump start and steady state running conditions
8.) Stresses that come from transient loading, such as standing on the pipe or placing lead shielding on the pipe.
9.) Stresses that come from an unknown acceleration, such as an earthquake or a sudden shift in coolant density due to a reactor trip.

Stresses predicted before and after the modifications performed in 1995 indicate that the stress reducing effect of the modifications was significant and supports the expectation that RC-289 would not fail in the future. Since RC-289 did fail again, the presence of one or more stresses of significant magnitude is clear.

There appears to be a strong possibility that the "stress" driving the crack initiation is a composite of multiple stresses added together. The sum or resultant stress from the available stresses, combined with a stress focusing location of the abrupt weld geometry, appear to be the source of the crack initiation. Physical landmarks on the crack surface (from RC-187) appear to conclude that the crack is propagated by the normal heatup and cooldown evolutions as well as the thermal fatigue cycling induced by RCS swirl into the drain line.

Comparing the period of time from beginning of plant life to 1995 (RC-187 crack) and, the period from 1995 to 2013 (RC-289 crack) shows the number of thermal cycles was reduced, however the number of Effective Full Power Years (EFPY) was greater. Greater EFPY in less time has produced a crack that is 65% (34% by initial NDE) shorter in depth. Since crack propagation is not linear, the crack depth difference is less distinctive. The EFPY contribution seems to have compensated for the reduction in Thermal Cycles. Therefore, it appears that the source of the propagation is a combination of the heatup and cool downs (thermal cycles) and the number of thermal fatigue cycles which is a function of EFPY. The physical attributes of the crack from the destructive lab analysis for weld RC-187 support this conclusion. The source of the initiation is thought to be a resultant of the existing stresses but is actually unknown.

The destructive failure analysis (for RC-289) indicates the defect is "*an ID initiated fatigue crack at the pipe side weld root*". The LOF feature acted to coalesce the existing stresses and enabled crack initiation. Cyclic stresses propagated the crack as evidenced by the striations. The number of observed striations were greatly reduced from the RC-187 failure and there were no beach marks. These two observations indicate that the actions taken in 1995 were effective in reducing or eliminating some stress inducing events. It is believed that the stresses from heat up and cool down (beach marks) were eliminated and the stresses from the swirl induced thermal fatigue were reduced (reduced number of striations). The source of the crack associated with the 1R20 outage, and

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probably the 1995 crack, is unknown but is believed to be the result of geometry induced focusing of lower levels of stress. These stresses are not capable of inducing cracking alone but when combined at a geometric feature such as the LOF at a natural notch they initiated the crack. The lower energy requirements of propagation then governed the crack growth. Based on the FEA results it is recommended that TMI station instrument the B RCS cold leg with strain gauges and thermocouples to determine the stress source set and relative magnitudes that are responsible for initiating the crack. The true source of the crack initiator can only be determined with this data.

C. ANALYSIS / SAFETY SIGNIFICANCE

If the crack propagated to through wall condition, as in 1995, a very small coolant leak in the area of 30 drops per second (measured during 1995 failure) would develop. This leak would be detectable through reactor building instrumentation and the reactor coolant leak rate calculation. The material properties of the stainless steel used are elastic enough to provide a leak before break presentation, which was the presentation demonstrated in 1995.

A shear failure of the "B" RCS cold leg drain line is bounded by the TMI-1 accident analysis for a small break loss of coolant accident (SBLOCA) described in the TMI-1 Updated FSAR section 14.2.2.4. The cold leg drain line break size is applicable to the small SBLOCA category for which all the cases analyzed concluded: "For the small SBLOCA cases analyzed, the RCS pressure did not depressurize sufficiently to allow LPI flow to enter the reactor vessel. In each case, at the time the analysis was ended, the core was completely recovered, the downcomer level was increasing, and the HPI flow was sufficient to absorb the decay heat and wall metal heat contributions. These conditions confirmed that the (High Pressure Injection) HPI flow, while inadequate to prevent partial core uncovering, was adequate to ensure long-term cooling." Procedures and operator training (including plant replica simulator training) are routinely conducted to provide confidence that such an event would be handled without endangering the health and safety of the public.

There was no actual breach of the RCS that resulted in leakage for this event. There were no actual adverse safety consequences or safety implications that resulted from this event and this event did not affect the health and safety of the public.

D. CORRECTIVE ACTIONS

Determine the source of the stress that is initiating the crack through the application of the following testing: Strain gauges, thermography, temperature measurement, and laser scanning.

If the crack source can be found and stopped, actions will be created to eliminate the source of the cracking.

If the crack source cannot be determined, actions will be created to determine if proactive replacement is warranted.

Additional actions from the root cause analysis:

- Take measurements on the safe end on the "B" Cold Leg drain and determine if a future elbow can be replaced without work on the safe end
- Revise procedure to require 100% review of all NDE examinations that meet the following criteria:

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a. Component can't be isolated
b. High safety significance
c. Geometry not previously reported

- Change the frequency of examination of the RCS cold leg drains from every 4 years to every 2 years beginning in 2017

E. PREVIOUS OCCURENCES

Previous Events	Previous Event Review
TMI-1 LER 1995-003-00 Reactor Coolant Leak Due To A Cracked Weld In A Cold Leg Drain Line	**Summary:** On September 9, 1995 a through wall leak was discovered at TMI on a reactor coolant cold leg drain line while the plant was in the process of cooling down for a refueling outage. The leak was estimated at 20 drops per second while the Reactor Coolant System (RCS) was at 2,000 psig and 535 °F. The failure was concluded to be cause by fatigue during metallurgical analysis. The crack initiated in the ID from an initial flaw and grew over through wall from thermal stratification and cycling caused by turbulent penetration of the RCS into the stagnant drain line. The flaw was located at top dead center (TDC) of the pipe weld. The failure occurred on the "B" drain line in the weld between the 2" schedule 160 horizontal piping and the 1.5" x 2" Schedule 160 reducing elbow. The piping and the elbow were both 316 stainless steel. The top of the ID of the horizontal piping run (flaw location) is 14.3 inches (10.7 diameters) below the RCS piping ID. The horizontal line extends for 7 feet with a horizontal bend before the first isolation valve. The line was not insulated at the time of the leakage. A rigid vertical support was located a few feet from the elbow. Subsequent examination determined the flaw was 0.55" on the OD (7 to 33 degrees from the top of the pipe) and 2" on the ID (-13 to 122 degrees from the top of the pipe). The crack initiated in the ID from the heat affected zone in the pipe wall and grew through wall through the weld. It was noted during analysis that there was a notch present at the flaw initiation site. The flaw started in a section of metal undergoing intergranular attack (3 mils deep) and propagated in a transgranular manner. There were 41 beach marks believed to be associated with plant heat up/cool down cycles, of which there were 42 since plant startup in 1974. Additionally striations were observed with a spacing of 0.2 μm (8 μin), corresponding to 44,000 striations through wall. Additionally damage was noted on the vertical rigid supports due to thermal growth of the RCS downward. The stress at the weld was determined to be 38 ksi without consideration of the thermal stratification stresses. It was determined that the "B" drain line had a positive slope from the elbow during operation allowing hot water penetrating from the RCS into the horizontal piping to move upward in the horizontal section towards the valve and colder water to flow to the weld. This condition did not exist in the other drain lines. The drain line was replaced with the same components as the original construction

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with the exception of the addition of insulation to prevent heat loss and modification of supports to reduce stresses from thermal growth and remove the positive slope of the drain line.

Applicability:
The cracked weld found during the 2013 outage is the replacement weld from the 1995 through wall crack. The 2013 crack is in the same location as the 1995 crack was with the exception that the 2013 crack was not through wall and smaller on the ID, indicating that the flaw was found earlier in its growth cycle.

The main differences between the two flaws is that in the case of the 2013 flaw, the line was insulated and vertical supports had been removed to reduce stresses due to thermal growth and to remove a positive slope from the elbow through the horizontal piping segment. The original 1995 construction weld was made in the shop with a consumable insert; the 2013 weld was made in the shop with an open butt weld. Though the stresses due to thermal growth were reduced by removal of vertical supports, an increase in weld stresses and stress concentration is believed to be present due to the unusual geometry in the location of the weld.

It is believed a high stress state is created in the weld due to thermal movement of the RCS coupled with the increased stress concentration in the open butt weld. The drain line slopes upwards to the first isolation valve as it did in 1995 (the slope is believed to be less prominent in the current state), and thermal fatigue is the mechanism that grew the weld through wall.

* Energy Industry Identification System (EIIS), System Identification (SI) and Component Function Identification (CFI) Codes are included in brackets, [SI/CFI] where applicable, as required by 10 CFR 50.73 (b)(2)(ii)(F).