BOSTON EDISON

Pilgrim Nuclear Power Station
Rocky Hill Road
Plymouth, Massachusetts 02360

Ralph G. Bird
Senior Vice President — Nuclear

February 20, 1990
BECo Ltr 90-024

Mr. William T. Russell
Regional Administrator, Region I
475 Allendale Road
King of Prussia, PA 19406

Docket No. 50-293
License No. DPR-35

Subject: **Pilgrim Nuclear Power Station Revised Operability Evaluation of Installed Salt Service Water Pumps**

Dear Mr. Russell:

This letter transmits the Pilgrim Nuclear Power Station revised (updated) operability evaluation of the Salt Service Water (SSW) Pumps (Reference BECo Letter No. 90-017, dated January 1° 1990). Our evaluation concludes that the SSW Pumps are operable and the requirements of Technical Specification 3.5.B.1 for the SSW Pumps are met.

Information concerning the condition of the pump material was provided to other licensees via the Nuclear Network on January 18, 1990 and was updated on February 9, 1990 and February 15, 1990.

A copy of the report on the pump material was provided to the Senior Resident Inspector on February 16, 1990.

Please feel free to contact me or Mr. R. N. Swanson of my staff if you have any questions or need additional information regarding the enclosed operability evaluation.

E. W. Davis
for R. G. Bird

RLC/bal

Enclosure: SSW Pump Operability Evaluation, Revision 1

IE01
1/1

Boston Edison Company
Pilgrim Nuclear Power Station

Docket No. 50-293
License No. DPR-35

cc: Mr. M. Fairtile
Licensing Project Manager
Office of Nuclear Reactor Regulation
U.S. Nuclear Regulatory Commission
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11555 Rockville Pike
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Mr. J. R. Strosnider
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Sr. NRC Resident Inspector - Pilgrim Station

BOSTON EDISON COMPANY
OPERABILITY EVALUATION

Revision 1

1. Initiating Document F&MR 90-8/NCR 90-3

2. Affected Item (System, Subsystem, Train, Component, or Device)

   Salt Service Water Pumps (P208B, C, D, E)

   The salt service water pumps are vertical, single stage, deep well pumps manufactured by Goulds Pumps.

3. Specified Function of the Affected Item

   The salt service water pumps supply water at adequate flow and pressure to the RBCCW heat exchangers as an ultimate heat sink for the RBCCW system for all accident and transient conditions.

4. References

   FSAR 10.7
   Technical Specification 3.5.B, 4.5.B
   PDCR 77-44
   Specification M8
   Drawing M8-4
   PDC 90-12

5. Operability Concern

   On 1/11/90, while horizontally transporting the assembled pump (without motor) from the maintenance shop to the intake structure, the bowl/impeller end of SSW pump A was dropped approximately 6 to 12 inches leading to a 360 degree throughwall fracture of the second, 80 inch column section up from the bowl/impeller end. Further investigation indicated that the area of the fracture had reduced material properties (e.g. yield strength, ultimate strength, percent elongation) relative to specification. The operability concern is that remaining pumps in service may have columns having similarly reduced material properties that could affect their operability under design loading conditions.

   Pump A has been fully inspected, tested and returned to service and no operability concerns exist.

6. Operability Evaluation (check one)

   [X] Operable

   [ ] Inoperable

   [ ] Conditionally Operable

7. Basis for Evaluation

The service water system normally operates at approximately 30 psig and uses cold sea water. One train consisting of two pumps is required to satisfy the heat removal requirements for all design basis accidents and transients. Pumps A and B supply Train A, pumps D and E supply Train B and pump C normally acts as a swing pump.

The overall length of the assembled pump is in excess of 42 feet (drawing M8-4). The pump was being transported at each end by slings from two forklifts. The fracture occurred approximately 17 feet from the bowl/impeller end. Analysis of the stresses resulting from this drop indicate loads of approximately 30 ksi from a drop height of 6 inches and approximately 42 ksi from a drop height of 12 inches. Lab tests of samples from the area of the failure indicated ultimate strengths ranging from 23 to 32 ksi. Therefore, a failure was expected due to the drop.

The pump column material is an aluminum bronze casting (ASTM B148 C95200) with a required ultimate strength of 65 ksi minimum, yield strength of 25 ksi minimum, and elongation of 20% minimum. A total of four coupons from the area of the fracture were tested. These tests were performed at two separate labs and gave consistent results of significantly reduced strength. The worst coupon gave an ultimate strength of 23.9 ksi and an elongation of 0.5%. Lab tests of four samples from a "good" section of a pump A column indicated tensile strengths ranging from 70 to 85 ksi (ASTM specified at 65 ksi minimum) and yield strengths from 27 to 45 ksi (ASTM specified at 25 ksi minimum). Three of the four samples had elongations of 21 to 34% (ASTM specified at 20% minimum). The fourth sample had an elongation of 16% attributed to a localized crevice/pit. See Table 1 for a detailed description of lab test results.

Two factors are believed to have contributed to the fracture. First, the initial casting process likely produced a susceptible material since metallurgical analysis has identified a eutectoid condition indicating that the required single phase of the material was not achieved. In this initial eutectoid condition, an aluminum-rich phase of the material forms at the grain boundaries. With continued exposure to a corrosive medium (sea water) over several years, the material dealloys as the aluminum is lost. This results in the formation of a low strength, copper-rich network. This eutectoid condition was in a relatively large section in the vicinity of the flange supporting the conclusion that the weakness was introduced by casting and not by some other process (e.g. welding). Metallography has indicated that the fracture area consisted of a substantially interconnected eutectoid region which is significantly more susceptible to dealloying. Metallography also indicated that acceptable material contains the expected microstructure with small amounts of eutectoid (<5%) which is not interconnected and is much less susceptible to degradation. Slow cooling of the casting is believed to cause the eutectoid condition.

Second, weld build-up had been done in the upper flange region of this column to restore a spider bearing support surface which had been worn due to operation. Subsequently, a crack developed in the weld build-up. This crack was a pre-existing flaw approximately 5 inches maximum in length and throughwall. Examination determined that this crack had existed for some time prior to application of the impact load caused by dropping the pump. It was determined that the crack was not the result of fatigue and was not propagating circumferentially during operation. The primary origin of the fracture was at the weld build-up and it propagated rapidly through the low strength, copper-rich network.

Because the material in the area of the break had very low percent elongation, the potential for brittle fracture was considered in this evaluation. For brittle fracture to occur, the material must be susceptible. The likelihood of brittle fracture is affected by the size of the load, the type of load, and whether a flaw exists in the material prior to the load being applied. An existing flaw provides an initiation site for a fracture. The dealloyed condition caused the embrittled-type properties in the failed material making it susceptible to brittle fracture. With the pre-existing flaw and high impact load from the drop, the situation was such that a brittle fracture was likely. However, impact loads of sufficient magnitude are not expected during operating or accident conditions such that a fracture would occur.

A fracture analysis of the material with degraded mechanical properties was performed by Teledyne Engineering Services (see attached letters). This evaluation provides a measure of degraded materials' ability to withstand shock loading with pre-existing flaws. The testing and analysis determined the following critical flaw sizes assuming worst identified degraded material (appropriate factors of safety are applied):

Permissible Crack Length

	Through Wall	Surface (1/4t)	1/2t
Normal (2 ksi)	1-1/4"	235 degree	2.2"
Faulted (10 ksi)	1/4"	0.8"	1/2"
Faulted (6.3 ksi)	0.65"	360 degree	1.1"

These results indicate that under a faulted condition stress of 10 ksi, a 1/4" or greater circumferential throughwall crack or a 0.8" or greater circumferential surface (3/32" deep) crack must exist for the crack to propagate and cause column failure in degraded material. For the maximum calculated stress level of 6.3 ksi, a throughwall crack of 0.65 inches or less or a ½t surface crack of 1.1 inches or less is permissible assuming that the worst identified degraded material conditions existed in the area of the crack. For undegraded material, permissible crack sizes are estimated to be at least four times greater. These flaws would all be readily detectable by visual or liquid penetrant examinations.

Material allowable stress values were adjusted assuming non-ductile and reduced material properties. Section VIII of the ASME code (UCI-23) requires a safety factor of 10 between the minimum tensile and allowable stress for cast iron which is a brittle material similar to the degraded casting. The lowest of four test specimens from the degraded material had a tensile strength of approximately 23.9 ksi. Thus, the allowable would be 2.39 ksi. However, the loading of concern is primarily bending and the allowable in bending is 1 1/2 times that for tension. Thus, the adjusted allowable value for the degraded material is 3.6 ksi.

Table 2 is a summary of calculated versus allowable stress values for the normal, operating basis earthquake (OBE) and safe shutdown earthquake (SSE) conditions. Results of Table 2 show that the maximum stress levels would be below the code allowables assuming the worst case identified degraded material existed in these pumps. These analyses account for the installed stabilizers and tie-rods (see Figure 1) and the effects of water on mass and damping. Stabilizers have recently been installed on pumps B and C and tie-rods have recently been installed on pump A (all but lowest column) and pumps B, C, D and E (top two columns) to increase margins to allowables. The stabilizers alone improve stress margins by up to 50%. Therefore, even with an assumed loss of design margin, the salt service water system can still perform its safety function for all accidents and transients described in the FSAR. This analysis is consistent with FSAR structural loading criteria. This evaluation has been reviewed by and has the concurrence of Dr. William Cooper, a consulting engineer with Teledyne Engineering Services, as described in the attached letter.

For all design basis accidents except earthquakes, the pump loads seen during the accident are identical to those seen during normal operations. Since pump loads during normal operation are low (1.2 ksi), a low probability SSE would have to occur to significantly challenge the pumps. The probability of an SSE occurring at PNPS between now and mid-April (estimated new column delivery date, i.e. approximately two months) is in the range of 1.6×10^{-4} and 1.6×10^{-5}. The likelihood of an SSE occurring coincident with an accident is even more remote. Since two pumps in the same train are needed to mitigate this event, multiple pump failures must occur to pose a safety problem.

Also, if only one SSW pump fails, a coincident diesel (or other emergency electrical supply) failure must also occur in the other safety train to challenge plant safety. PNPS diesels have a demonstrated reliability of over 99%. An inservice pump must be in a more severely degraded condition than the worst section of pump A (the fractured pump) in order for a failure to be considered possible. All of these factors combined demonstrate a low risk situation.

Extensive field testing was performed on the pump A columns, the inservice B, C, D and E accessible columns, and new columns stored in the warehouse. No other cracking or reduced strength conditions have been identified. Testing was performed in the area where the flange joins the column because this area is most susceptible to slower cooling that leads to eutectoid formation. UT measurements in the areas of post-weld buildup machining indicated some reduction of wall thickness. Assuming safe shutdown earthquake loads, adequate wall thickness was measured using UT. Liquid penetrant testing of the inside diameter of the other columns of pump A revealed aligned porosity, corrosion porosity, and what is believed to be 360° lack of fusion in the upper flange area of one column. This column also had reduced wall thickness at one flange end. These conditions also likely resulted from the weld build-up effort. This column was not returned to service in pump A due to time constraints of the rework involved.

Should a weld-induced cracking condition exist in conjunction with degraded (eutectoid) material, the potential for crack propagation exists if adequate stress is applied. Pump A operated with the significantly degraded material condition and with a substantial weld-induced crack and did not fail in service. Without the degraded material condition, column failure by existing crack propagation due to SSE loads is not expected since the base material will arrest the crack growth. Adequate wall thickness is expected in other pumps based on the pump A inspections.

Improvements have been made in the manufacture of replacement column types 641 and 642 (See Figure 1). These columns are centrifugally cast versus the sand casting used in the failed column. Also, these columns are cast in two smaller pieces which allows for more uniform cooling and reduces shrinkage and porosity concerns that can result from a single piece casting. The two castings are then joined by a circumferential weld at the centerline to provide the finished product. Pumps B, C and D have some columns which have been manufactured using the improved processes. The pump manufacturer knows of no inservice failures of this new design. This better quality casting is recognizable by the circumferential weld at its centerline. These columns were visually verified to be installed in pumps B, C and D as indicated by dots (•) on Figure 1. Heat treating and controlled cooling of the castings will reduce the potential for significantly interconnected eutectoid formation in both centrifugal and sand castings. These treatments have been specified for the new replacement columns.

Calculations indicate that the static dead weight loads resulting from the horizontal transport of the pumps are on the order of 5 ksi at the midpoint. The static loads in the columns adjacent to the mid-column of the pump are in the range of 3 to 5 ksi during transport. This is roughly twice the normal operating load. Dynamic effects during transport would have tended to increase these loads somewhat. Therefore, the mid-columns of several inservice pumps have probably experienced loads (during transport for maintenance) that are significantly greater than normal operating loads and a significant percentage of SSE loads. During transport, no failures other than pump A have occurred.

During our investigation, we learned that Pilgrim had one other column failure in 1977 in pump D. Discussions with a consultant at AMPCo (the company that repaired the column) indicate that this failure was due to fatigue. At that time, the pump tripped on high amperage. On troubleshooting, a 360° circumferential failure of the uppermost column was discovered at the upper flange transition. The pump experienced high vibration and was apparently operated after bearing damage had occurred. We believe that the cause for the vibration was flow instabilities which were aggravated during certain pump operating combinations. Design changes to the pump suction end and system operational changes have been implemented which have reduced flow induced vibration. Also, a Boston Edison records search of work on the salt service water system was performed and no other failures of the older design column were found other than the 1977 and 1990 failures. Goulds has reported no other failures of the older design column. Further research indicates that no other aluminum bronze castings exposed to sea water are used in safety-related applications at PNPS.

Operators would become quickly aware of any pump failures by the high current pump trip and low header pressure indications in the control room. High current pump trip led the operators to recognize the 1977 event.

Based on inspection and testing of pump A and inservice pump columns, analysis of pump stresses with stabilizers (pump A without crediting stabilizers) and tie-rods, review of pump maintenance records, and the low likelihood of any seismic loads, the potential for a pump failure due to postulated degraded material and/or cracking is negligible and the pumps are considered operable.

8. **Compensatory Measures/Conditions Required**

The following actions will be taken as prudent measures to verify materials and integrity of the remaining salt service water pumps:

1) Pump A was inspected, tested and returned to service on 2/13/90 at 1734 hours.

2) Remaining pumps (B, C, D and E) will be inspected, tested and returned to service with tie-rods installed on the upper six columns.

   a) Prior to returning these remaining pumps to service, the following inspection plan shall be used and satisfactory results obtained:

   Remaining pumps (B, C, D and E) will be inspected and tested in two phases. The first phase consists of external tests and inspections of all columns followed by tie-rod installation on all but the lowest column before returning each pump to service. The second phase requires pump disassembly for internal tests.

   In the first inspection phase, the following inspections and tests will be performed without disassembling B, C, D and E pumps.

   1) Ultrasonic testing wall thickness measurement in the vicinity of the flanges.

   2) Visual inspection of the outside diameter.

   3) Hardness testing on the outside diameter near the flanges on all areas not tested previously.

   (Target - 3/18/90 early finish)

   b) In the second inspection phase, each pump will be removed and disassembled to perform the following inspections and tests:

   1) Liquid penetrant examination on the outside diameter at the vicinity of the column flanges.

   2) Visual inspection of the inside diameter near the flanges.

   3) Hydro test at 125 psig with a 15 minute holding time.

   4) Liquid penetrant examination on the inside diameter in the vicinity of the column flanges.

3) Columns found to have degraded properties will be systematically replaced with satisfactorily tested columns.

4) If an inservice salt service water pump becomes inoperable while one salt service water pump is tagged out of service for inspection and testing and pump column fracture can not be eliminated as the cause, a 24 hour LCO will be entered.

5) In the longer term, newly ordered columns will replace all columns in each pump. (Target - 6/30/90 early finish)

9. Performed By Thomas White Jr. 2/16/90

Reviewed By [illegible] for WTW 2/16/90 Date ______

Recommends Approval [illegible] Date 2/16/90
(S&SA Division Manager)

Recommends Approval L J Olivier Date 2/16/90
(ORC Chairman)

ORC Meeting Number 90-18

Approved By [illegible] Date 2·16·90
(Plant Manager)

LAB TEST RESULTS

Tensile Specimens

Laboratory	Sample	Sample Location	Ultimate (ksi)	Yield (ksi)	% Elong	Rockwell B
	Specification		65.0	25.0	20%	
SWEC	T1	642D mid	85.4	31.1	34%	66 to 75
SWEC	T2	642D mid	70.0	29	16%	
SWEC	T3	642D mid	84.7	31.1	33%	
SWEC	T4	642D mid	79.5	45	21%	
SWEC	T5	642D fracture	31.9	31.2	<1%	41 to 52
MMR	1	642D fracture	23.9	21.7	0.5%	58
MMR	2	642D fracture	28.7	26.3	1.3%	
MMR	3	642D fracture	28.9	25.9	2.2%	
MMR	4	642D mid	82.0	27.2	35%	
MMR	A	642D flange	78.0	36.9	23%	
MMR	7	642D flange				77.0
MMR	8	642D flange				76.5
MMR	9	642D flange				77.0
MMR	10	642D flange				79.0
MMR	CF1-A	1" from 642D bottom flange	82.0	28.7	33%	
MMR	CF1-A	3 1/2" from 642D bottom flange	75.5	25.1	24%	
Teledyne	Degraded					53 to 56
Teledyne	Undegraded					61 to 69

Chemical Analysis

Test Lab	Sample Location	Copper (%)	Aluminum (%)	Iron (%)	Other (%)
MMR	Specification	88	8.5-9.5	2.4-4	
MMR	Column Tube	89.17	8.35	2.43	.05
MMR	Column Flange	87.22	9.22	3.51	.05
MMR	1 from fracture	89.4	8.1	2.3	
MMR	2 from inner pipe surface away from weld	89.4	7.63	2.8	
MMR	3 from inner surface of pipe where weld was thought to be (probably weld stick material)	91.5	7.2	1.1	

TABLE 2 (Page 1 of 1)

EVALUATION OF PUMP COLUMNS
WITH ASSUMED DEGRADED MATERIAL PROPERTIES*
(PUMPS B, C, D, E)

	TYPICAL PUMP (With Stabilizers & Tie-rods on Top 2 Columns)	
	Max Calc Stress Ksi	Allow Stress Ksi
Normal Operation (NO)	1.2	2.4
OBE + NO	3.9	5.9
SSE + NO	6.3	8.6

* An allowable of 1/10 of the minimum tensile strength of the four degraded test coupons per ASME VIII UCI-23 was used.

NOTE: Stabilizers have been added to pumps B and C. Tie-rods have been added to all but the lowest column of pump A and to the top two columns on pumps B, C, D and E.

TABLE 3 (Page 1 of 3)
FIELD TEST RESULTS

ITEM	TEST	RESULTS	
Pump A			
All columns except fractured column 642D	a) LP of OD within 6" of flange	All acceptable	
	b) Hydrostatic Test	All acceptable	
	c) Flange parallelism to ensure proper axial alignment	All acceptable	
	d) LP of ID within 8" of flange (644 column sent to lab before performing LP)	641	Acceptable
		642A	Acceptable
		642B	Acceptable
		642C	Acceptable
		642E	Scrapped*
	e) VT of ID within 8" of flange	641	Acceptable
		642A	Acceptable
		642B	Acceptable
		642C	Acceptable
		642E	Scrapped*
		644	Acceptable
	f) UT of OD within 6" of flange (644 column sent to lab before performing UT)	641	Acceptable
		642A	Acceptable
		642B	Acceptable
		642C	Acceptable
		642E	Scrapped*
	g) Rockwell B Hardness (644 column sent to lab before testing) (Data taken within 6" of flange)	641	Acceptable
		642A	Acceptable
		642B	Acceptable
		642C	Acceptable
		642E	Acceptable
	h) RT within 6" of flange	641	Acceptable
		642A	Acceptable
		642B	Acceptable
		642C	Acceptable
		642E	Acceptable

* 642E has aligned porosity, corrosion porosity, 360° lack of fusion and a counterbore in the flange area with a reduced wall thickness. This column could be repaired except for time constraints and is therefore being scrapped.

NOTE: Rockwell hardness field test results were checked against lab results and found to be consistent.

ITEM	TEST	RESULTS
Pump A		
Failed Column (642D)	a) Tensile Tests (see Table 1).	In fracture area, ultimate and yield strength and % elongation significantly below ASTM standard. In middle and other end of column, same properties were within specification.
	b) Rockwell Hardness (see Table 1).	In fracture area, hardness values were below ASTM standard. In middle and other end of column, hardness was within specification.
	c) Metallography	Results support the conclusion of eutectoid condition being present in materials of degraded properties.
	d) Chemical Analyses (see Table 1).	Analyses in area of fracture indicate dealuminization (from corrosion). Middle and other end of column are within specification.
New Columns (In Warehouse)		
2-641s 2-642s	a) LP of OD within 6" of flange	All acceptable
	b) LP of OD within 3" of both sides of circumferential beltline weld	All acceptable
	c) LP of ID within 8" of flange	All acceptable
	d) Hydrostatic Test (manufacturers test)	All acceptable
	e) Rockwell B Hardness within 6" of flanges	All acceptable

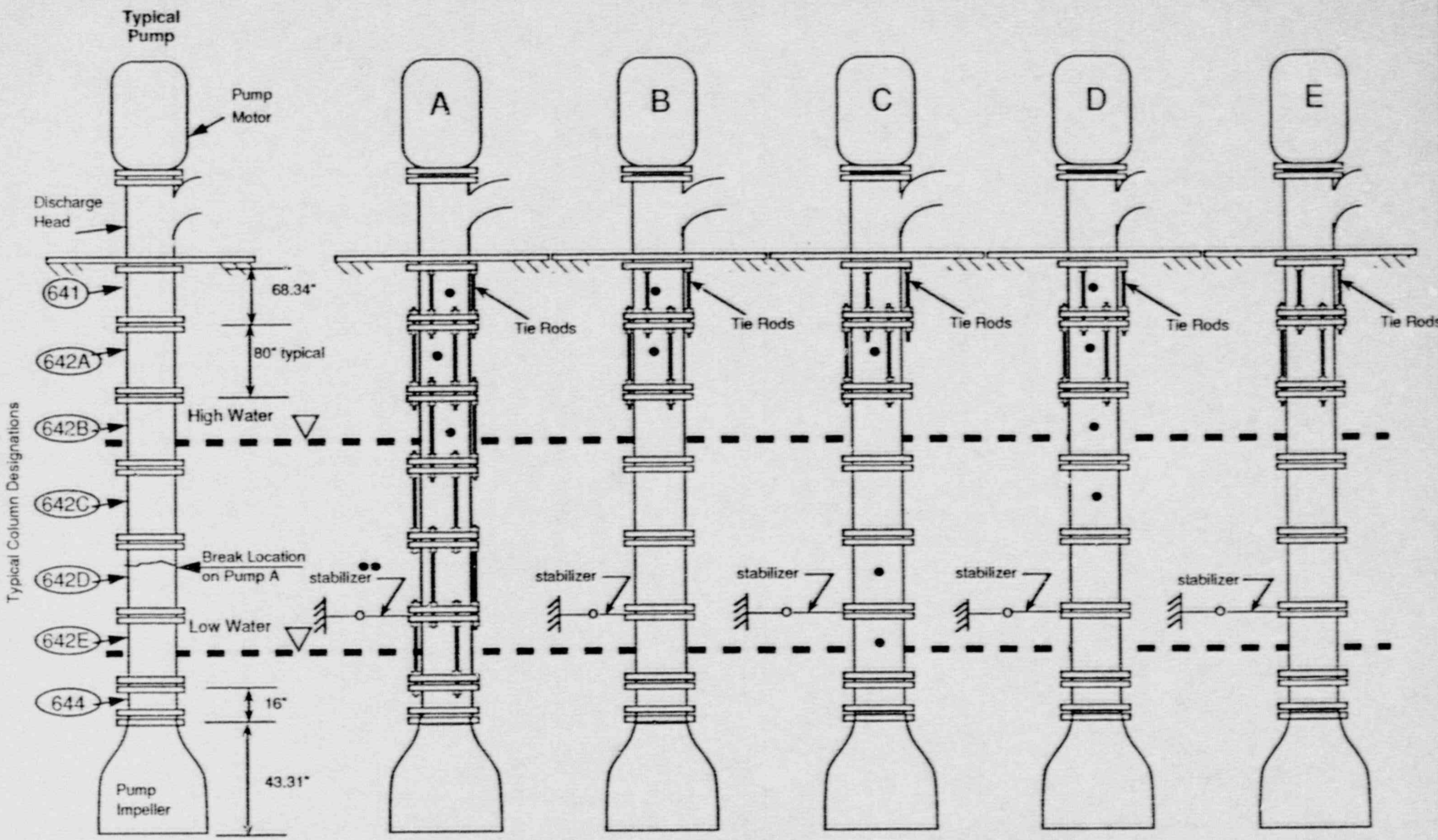
ITEM	TEST	RESULTS
New Columns (In Warehouse)		
1-644	a) Rockwell B Hardness within 6" of flanges	All acceptable
	b) UT wall thickness (.375" minimum)	All acceptable
	c) VT of ID within 8" of flange	All acceptable
	d) VT of OD within 6" of flange	All acceptable

Note: LP is inconclusive for item 644 which has an unmachined rough cast surface.

PIECE	TEST	RESULTS
In-Situ		
B, C, D, E SSW Pumps	a) Rockwell B. Hardness (at lower flanges of 641 column and upper flange of 642A column)	Pump B Acceptable C Acceptable D Acceptable E Acceptable
	b) Visual verification of location of new design columns (including those that are submersed)	See Figure 1 for locations.

SALT SERVICE WATER PUMPS

Key to Pump Column Designations & Pump Column Layouts



● Indicates columns installed since 1987

●● Pump A Stabilizer: 2 of 3 legs are currently installed but are not credited in analyses because they are only fully effective for all loading directions if all 3 legs are installed.

Figure 1

ENGINEERING SERVICES

130 SECOND AVENUE

WALTHAM, MASSACHUSETTS 02254-9195

(617) 890-3350 TWX (710) 324-7508

January 19, 1990
7257-1

Mr. R. V. Fairbank
Manager - Nuclear Engineering Department
Boston Edison Company
25 Braintree Hill Office Park
Braintree, MA 02184

Subject: Operability Evaluation of Salt Water Service Pumps

Dear Mr. Fairbank:

Teledyne Engineering Services (TES) has reviewed the material property information and the draft reports for the subject evaluation, with particular consideration of the structural design criteria applied.

Based on this review, TES concurs with the criteria used in the structural evaluation, specifically including: the analysis methods used to determine the applied stresses; the use of the as-measured material properties; the factors applied to the measured properties in order to determine allowable stress values (use of a nominal factor of safety of 10 on the ultimate tensile strength, a multiplying factor of 1.5 because the limiting stresses are primarily bending, and the multiplying factors of 2.0 for OBE and 2.4 for SSE); and, the conclusions with respect to structural integrity based on the above listed items.

We particularly want to comment on the procedure and factors used to determine the allowable stresses. The data indicate that the material properties adjacent to the flange are degraded from expected values. Not only are the yield and tensile strengths lower than normal for this material, but the ductility is significantly reduced. The degraded material approaches the characteristics of the cast irons considered in Part UCI of Section VIII of the ASME Boiler and Pressure Vessel Code. Therefore, we consider it appropriate to use the factors on the material properties of the rules of UCI (the values of 10 and 1.5) rather than the much more liberal factors applied by the Code to this material in the normal more ductile condition. Having made this correction, we consider it correct to continue to apply the normal Section III, Class 3 factors for the Service Level C and Service Level D conditions (the values 2.0 and 2.4). Finally, we note that the lowest measured value of the tensile strength has been used as the basis of these calculations, and that the next lowest value is 20% higher. This, plus the alleviating factors which would be demonstrated in a more detailed analysis and the fact that the slight overstress condition exists in only one column, contribute to our opinion that reasonable assurance of structural integrity has been demonstrated.

Very truly yours,
TELEDYNE ENGINEERING SERVICES

W. E. Cooper

W. E. Cooper, PE
Consulting Engineer

J. C. Tsacoyeanes

J. C. Tsacoyeanes
Consulting Engineer

TELEDYNE
ENGINEERING SERVICES

February 2, 1990
7257-2

Mr. R.V. Fairbank
Manager - Nuclear Engineering Department
Boston Edison Company
25 Braintree Hill Office Park
Braintree, MA 02184

Subject: Pilgrim Salt Service Water (SSW) Pump Columns - Fracture Toughness Testing

Dear Mr. Fairbank:

Teledyne Engineering Services has performed fracture toughness tests on the SSW Pump A failed column material Specimen material was obtained from column samples in the possession of Massachusetts Material Research, Inc. The results reported herein are for three-point bend specimens machined from material adjacent to the fracture surface at three circumferential locations. Nominal dimensions of the specimens are 3/8" x 3/8" x 1.54". The procedures of ASTM E-399, "Standard Test Method for Plane-Strain Fracture Toughness" were used recognizing that the dimensions and nature of the material would preclude full compliance with the E-399 validity requirements.

Specimens were machined with a straight through notch on the side corresponding to the outside diameter of the column and precracked by fatigue. Therefore, crack extension during the bend test would progress through material with the greater degree of de-aluminizing.

Test results are summarized below:

Specimen	K_I (KSI $\sqrt{in}$)
T2	9.0
T3	9.8
T5	9.7

All bend tests were performed with specimen temperature at 32F. As expected, none of the above tests satisfied all of the validity requirements of E-399. An additional specimen, T1, failed during precracking at an approximate value of 8.6 KSI $\sqrt{in}$. A preliminary value for material considered to be undegraded is estimated at approximately 22 ksi$\sqrt{in}$. This is based on a single specimen which fractured during precracking.

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Hardness measurements obtained on the tested specimens are tabulated below for both degraded and undegraded material.

	Degraded	Undegraded
Rockwell B	56,56,53,55	69,61
Brinell	88,88,85,86	110,95

As requested, we have approximated permissible crack sizes based on a fracture toughness value,KIC of 9.0 ksi$\sqrt{in}$ and two crack configurations as follows:

(1) a through wall circumferential crack

(2) a surface crack of 3/32 inch depth and of elliptical shape. (The depth is based on Section III postulated crack size of 1/4 thickness for non-ductile failure evaluation.)

Crack sizes for the above are calculated for stress levels of 2 ksi (Normal Conditions) and 10 ksi (Faulted Conditions). In addition, the appropriate safty factors of $\sqrt{10}$ and $\sqrt{2}$, respectively are applied. The permissible crack sizes are tabulated below:

	Permissible Crack Length	
	Through wall	Surface
Normal	1-1/4"	360 degree
Faulted	1/4"	0.8"

Very truly yours,

TELEDYNE ENGINEERING SERVICES

J C Tsacoyeanes

James C. Tsacoyeanes
Engineering Manager

JCT/msb

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February 15, 1990
7257-3

Mr. R.V. Fairbank
Manager - Nuclear Engineering Department
Boston Edison Company
25 Braintree Hill Office Park
Braintree, MA 02184

Subject: Pilgrim Salt Service Water (SSW) Pump Columns

Dear Mr. Fairbank:

The attachment (TES Letter 7257-2) transmitted to you on February 2, 1990 reported the results of our testing program on the SSW Pump A failed column material. Also included in the letter were the calculated permissible crack sizes based on the fracture toughness value of 9.0 ksi $\sqrt{in}$ and two crack configurations as follows:

(1) a through wall circumferential crack

(2) a surface crack of 3/32-inch depth (one-quarter thickness) and of elliptical shape.

Subsequent to that work, BECO requested that TES perform similar calculations for a surface crack of one-half the column thickness. We have completed those calculations and have tabulated below the results along with the previously calculated results.

Permissible Crack Length

	Through Wall	Surface 1/4 T	Surface 1/2 T
Normal (σ=2ksi)	1-1/4"	235 degrees	2.2"
Faulted (SSE):			
(σ=10ksi)	1/4"	0.8"	0.5"
(σ=6.3ksi)	0.65"	360 degrees	1.1"

TELEDYNE
ENGINEERING SERVICES

Note that the value of 235 degrees above was previously reported as 360 degrees. The new value incorporates the additional condition of limiting the net-section stress to a value not greater than the allowable stress value for Normal Operation of 2.4 ksi.

Very truly yours,

TELEDYNE ENGINEERING SERVICES

J. C. Tsacoyeanes

James C. Tsacoyeanes
Consulting Engineer

JCT/msb