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Analysis of Ultrasonic Inspection Data for Pilgrim 1 Reactor Nozzle N-2B

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Abstract

The ultrasonic examination data relative to the discontinuity located in the Pilgrim I Reactor Vessel Nozzle N-2B weld was reviewed. The data was obtained during the 1976 in-service inspection. The results of the review of several examinations are tabulated, test conditions discussed, and a conclusion made as to probable flaw size.

ANALYSIS OF ULTRASONIC INSPECTION DATA FOR PILGRIM 1 REACTOR NOZZLE N-2B

K. K. Klindt

INTRODUCTION

The information gained by ultrasonic inspection during the 1976 in-service inspection of Pilgrim 1 Reactor Vessel, Nozzle N-2B, lead to confusing and apparently conflicting results when compared to the 1974 inspection data. These results are reported in Boston Edison's summary of March 3, 1976, to the Nuclear Regulatory Commission (NRC) and are based upon the inspections performed by Southwest Research Institute. An independent analysis of the data obtained by SWRI for 1974 and 1976 was requested by NRC to corroborate Boston Edison's report.

An evaluation of the data was made to determine the answers to three basic questions: (1) Has there been a change in the size of the flaw in the shell-to-nozzle weld at Nozzle N-2B since 1974? (2) Is the change from the ultrasonic calibration block used in 1974 to a new block in 1976 valid? (3) What is the present size of the Nozzle N-2B flaw as determined by the new calibration block?

A modification of the scanning equipment since 1974 consisted of installing a 2-inch extension, with provisions for an additional 1-inch extension, on the arm carrying the two ultrasonic transducers. This should not cause any significant change in the ultrasonic response. The 1/2 inch by 1 inch rectangular transducers used in 1974 were changed to 3/4 inch diameter round transducers in 1976. This may cause some difference in response due to the change in beam geometry, however, the change should be minor and should not have a significant effect on the ultrasonic response from flaws after calibrating on the same calibration block to the same amplitude setting.

CHANGE IN FLAW SINCE 1974

In order to determine whether a change had occurred in the flaw size since the 1974 in-service inspection, the recorded data from that inspection was compared to the appropriate 1976 records. Run No. 11 of the 1976 inspections was designed to duplicate the 1974 inspection including the removal of the scanning arm extension and calibration on the 1974 block. The ultrasonic amplitude and the distance through the metal were recorded on strip charts for both 45° and 60° angle transducers. A copy of the charts for the 60° transducer scanning is shown and discussed on the following pages in Figures 2 through 9. A circumferential weld length of approximately 5 inches is covered in these figures. The distance between the scan paths represented by each figure is 0.649 inch.

In Figure 1, the top chart is for 1974 and the bottom chart is for 1976. The bottom half of each chart is the recording of the ultrasonic signal amplitude. The system is calibrated such that eight lines on the amplitude signal represents 100% DAC which is the maximum response obtained from a 5/16 inch side drilled hole in the calibration block. The top half of each chart is the record of the distance between the transducer and the reflecting surface of the flaw (metal distance). The start point of the scan in 1976 was apparently 3/4 inch farther back from the weld than in 1974. Since, in both examinations, the flaw signal was already present at the start of the scan, only that part of the flaw

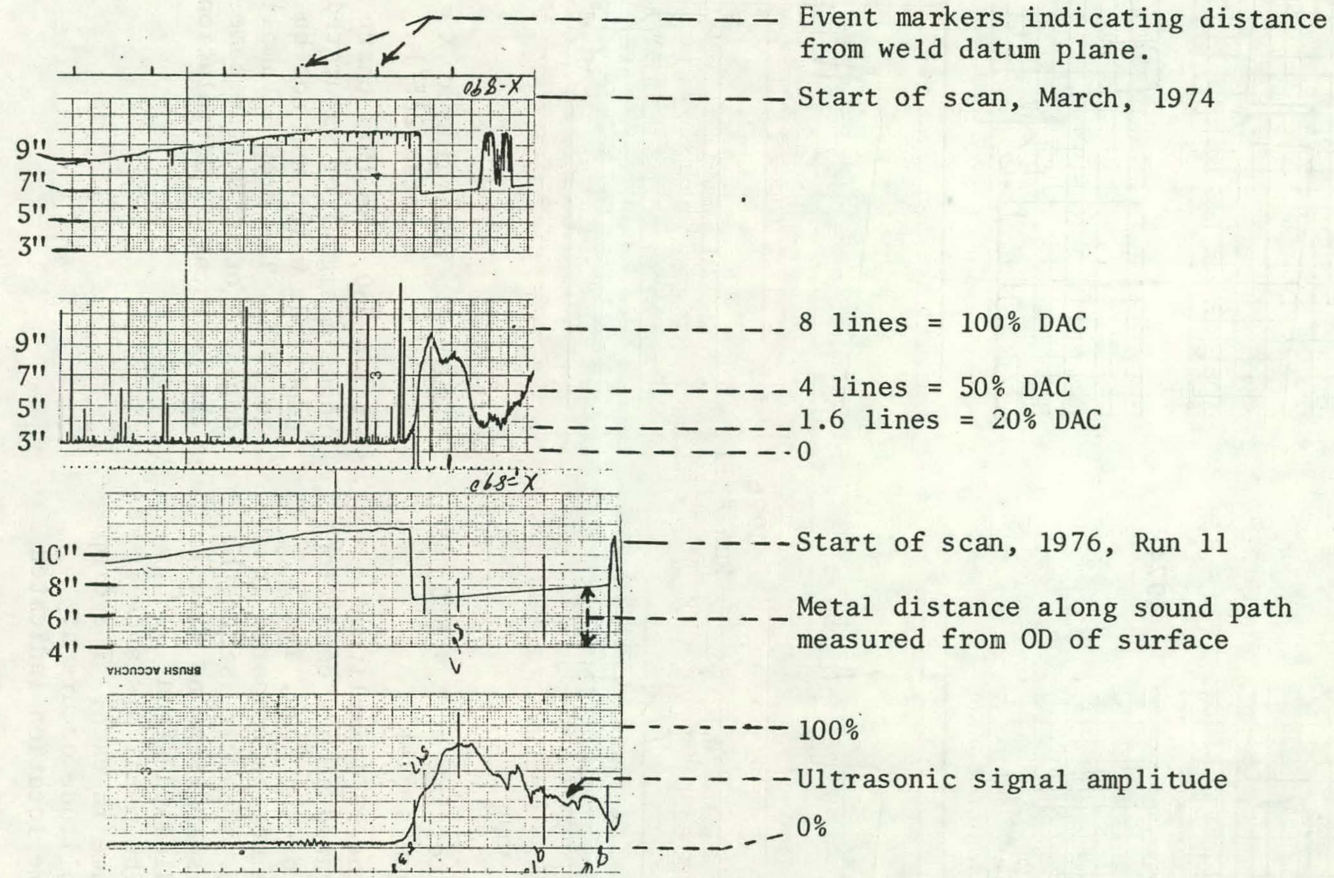
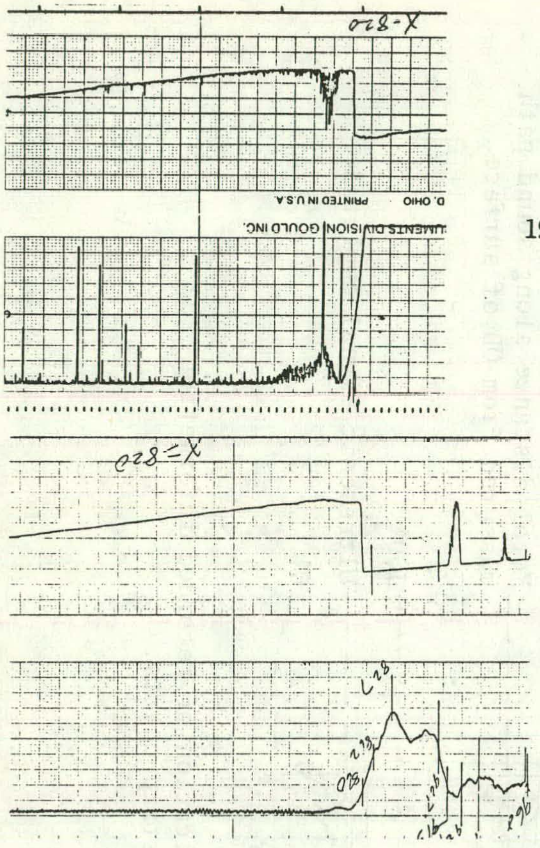


Figure 1. Identification of recorded information on the strip charts.

1974

1976
Run # 11



"A"

Figure 2. Recording at X = 820
counts (281°)

At X = 820, the 1974 amplitude shows a saturated signal condition at the start of the scan, and therefore can not be compared in shape to 1976. However, since the 1976 signal is smaller, no flaw growth is indicated signal amplitude. The metal distance is nearly the same in each. The drop in signal amplitude occurs at about the same location indicated by "A".

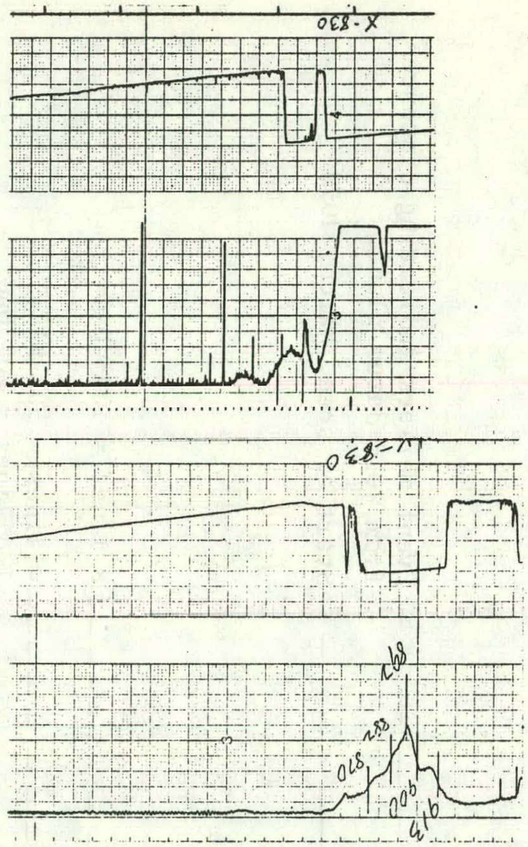
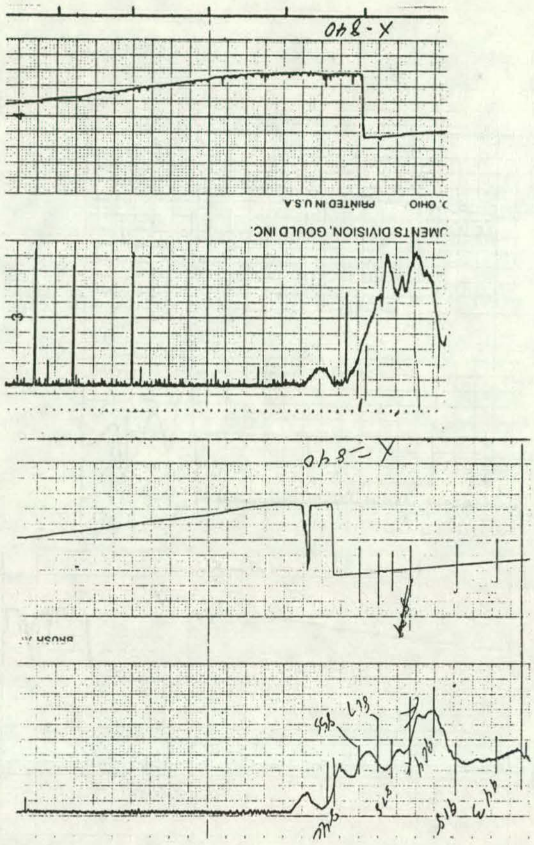


Figure 3. Recording at X = 830
counts (285°)

At X = 830, the 1974 chart again shows a signal of saturated amplitude which can not be compared to 1976. The drop in amplitude does not occur at the same time in the two scans. Correlation is poor.



1974

1976

Run #11

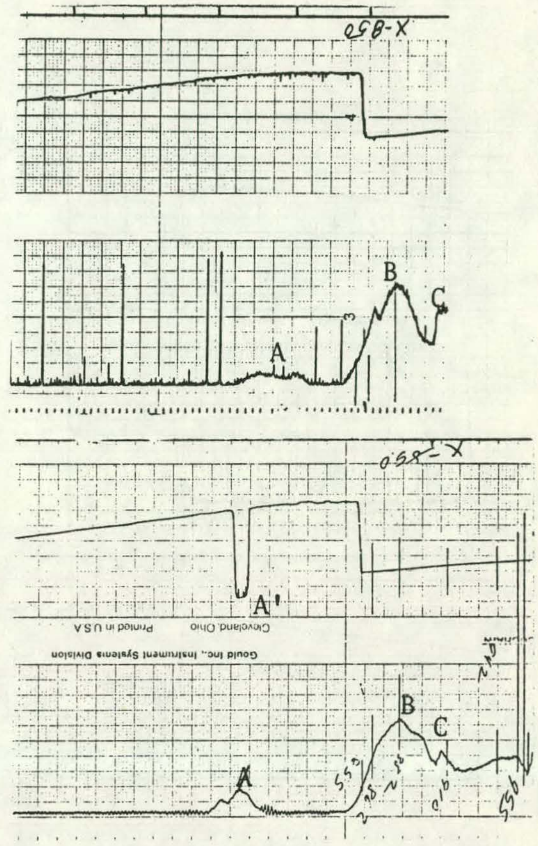
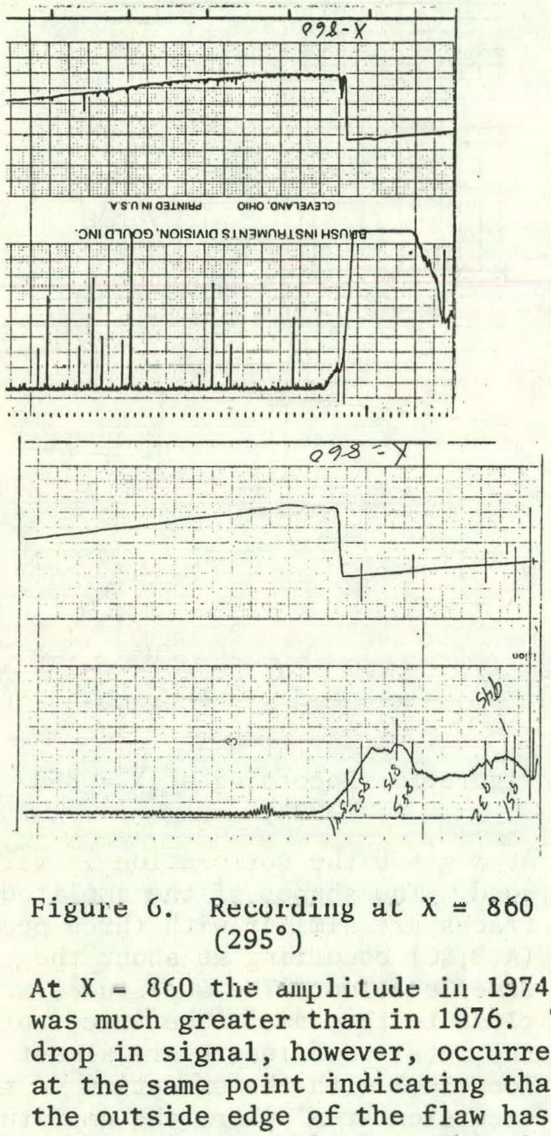


Figure 4. Recording at X = 840 (288°)

At X = 840, there is a fair correlation between 1974 and 1976. The rise and fall of the high amplitude part of the signal occurs at about the same location and the part of the signals above 50% DAC is of about equal length. The difference in amplitudes is not large.

Figure 5. Recording at X = 850 (292°)

At X = 850 the correlation is very good. The shapes of the amplitude traces are similar with three peaks (A,B,&C) occurring at about the same location. The amplitudes are close to the same. The traces of the metal path length are almost identical with the exception of the excursion at A' where the amplitude of signal A reached an amplitude sufficient to get into the metal distance gate and produce an output signal.



1974

1976

Run #11

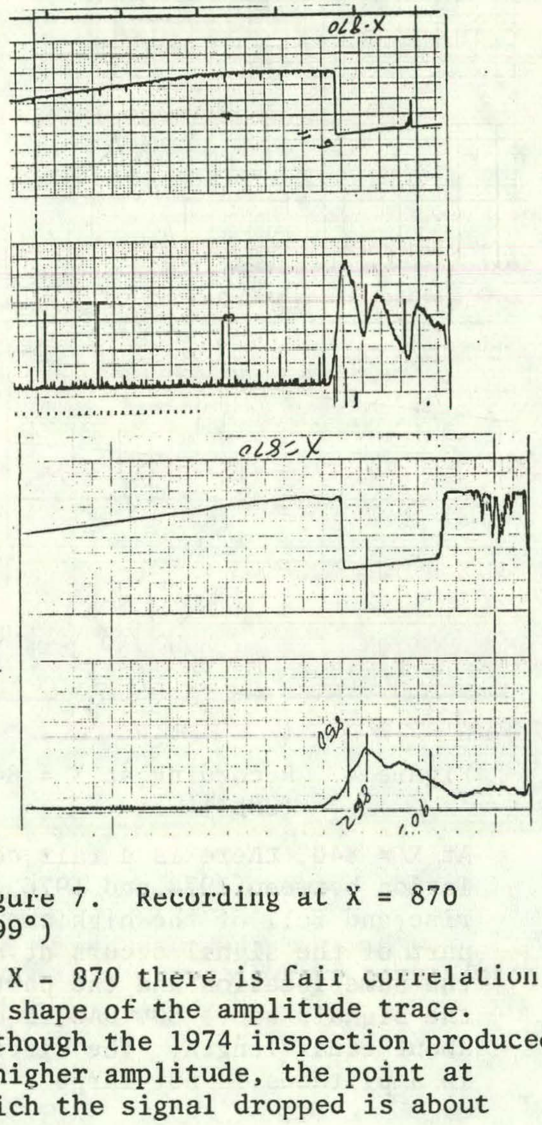
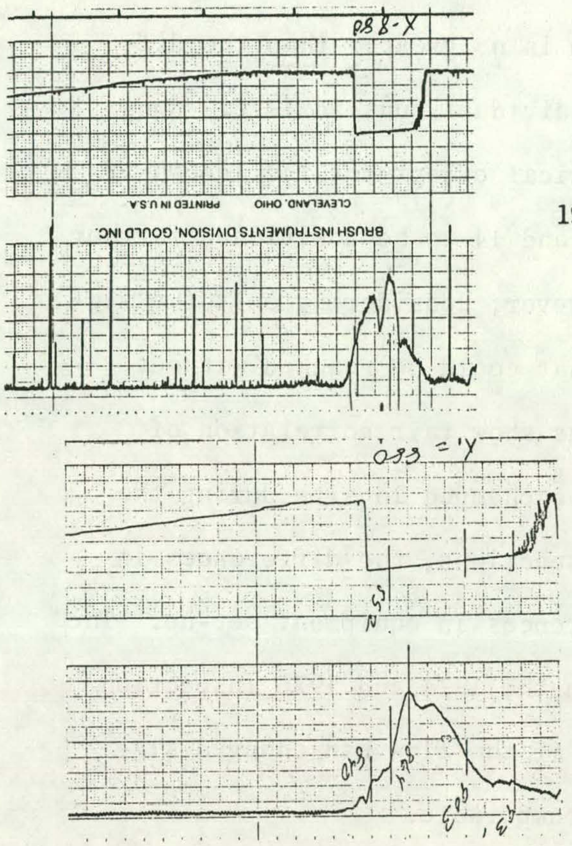


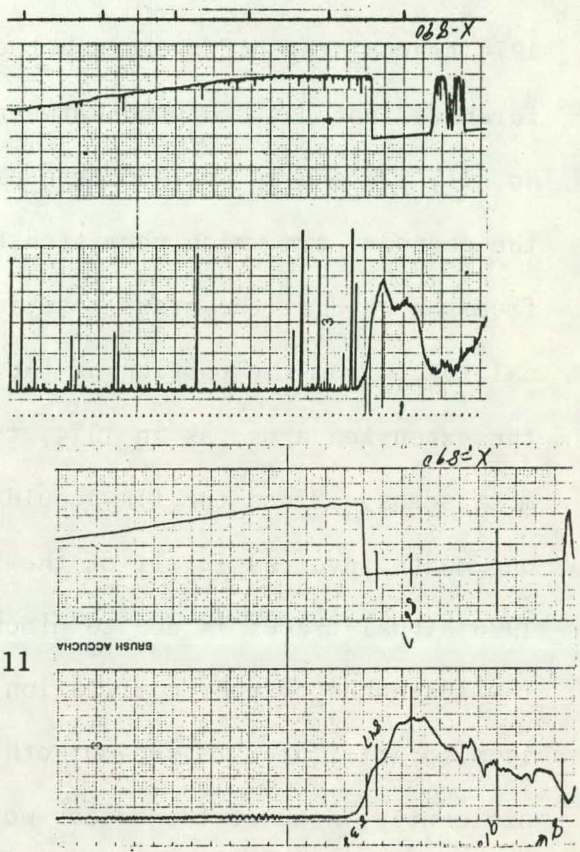
Figure 6. Recording at X = 860 (295°)

At X = 860 the amplitude in 1974 was much greater than in 1976. The drop in signal, however, occurred at the same point indicating that the outside edge of the flaw has not moved perceptively. This is also shown by the metal distance trace.

Figure 7. Recording at X = 870 (299°)

At X = 870 there is fair correlation of shape of the amplitude trace. Although the 1974 inspection produced a higher amplitude, the point at which the signal dropped is about the same.





1974

1976

Run # 11

Figure 8. Recording at X = 880 (302°)

At X = 880, both the shape and amplitude of the signal are similar showing good correlation between 1974 and 1976.

Figure 9. Recording at X = 890 (306°)

At X = 890, fair correlation exists. The shape of the signal traces compare favorably at the left edge of the peak as the sound beam passes over the top of the flaw nearest the outside surface of the vessel is recorded. The two traces are oriented so that identifying features in the main part of the flaw are vertically aligned.

Although all of the 1976 traces do not correlate with all of the 1974 traces, the differences between them is no greater than the differences that can be found between the individual runs in 1976. Runs No. 11, 12, and 14 in 1976 were all identical except for the length of the scanning arm which permitted Runs 12 and 14 to be positioned farther from the weld at the start position. However, considering only the signal trace from the portion of the weld that could be reached without the extension arms, as in 1974, these runs show fair correlation of most scans. Since the flaw could not have changed in size during the one month involved in all of the 1976 inspections, the differences in 1976 signal traces is due to minor differences in equipment set-up. The few instances of poor correlation bwtween the 1974 and 1976 inspection is also attributed to set-up; otherwise, if the flaw had changed significantly, none of the traces would be comparable.

More positive evidence of no-flaw-growth since 1974 is presented in Table 1. The smallest number of the "Depth from OD" column represents the distance from the top of the flaw to the outside surface of the vessel. This distance has remained the same within inspection accuracy tolerances since 1974. By examining the strip chart recordings one can see the differences are due to a shift of the 50% amplitude points along the length of the scan rather than a change in the metal path length.

This examination of the strip charts of 1974 and 1976 leads to the conclusion that no significant change in flaw size has occurred since 1974.

VALIDITY OF 1976 CALIBRATION BLOCK, PIL-5A

The 1974 in-service inspection of Pilgrim 1 Reactor Vessel was performed with ultrasonic equipment calibrated on a reference block designated PIL-5. This block was from a material of the same P-Number as the vessel steel as required by the 1971 ASME Code. The ultrasonic attenuation properties of the calibration block were high compared to nuclear reactor vessel grade steel. This necessitated an unduly high instrument gain during calibration and greater than normal signals from any flaw detected.

A prolongation from a plate, identified as Luken's Heat No. C-2945, reportedly used in the fabrication of Pilgrim 1 Reactor Vessel, was found and a section was obtained from which to make a new calibration block. Six 5/16 inch holes were drilled into the block in accordance with ASME Code, Section XI, requirements. This block was designated PIL-5A.

The two blocks were compared ultrasonically. The response from a 5/16 inch side drilled hole, 3.5 inches from the surface, was approximately 12 dB greater in amplitude from the new block than from the old block with the same instrument settings. Boston Edison has made a complete study with adequate documentation to characterize both blocks showing distance-amplitude correction and the ultrasonic beam spread for the transducers used.

An inspection performed with an instrument calibrated on the new block would have only 1/4 the sensitivity as an instrument calibrated on the old block. This would result in flaw signals appearing with only 1/4 the amplitude originally measured. No doubt exists that fewer recordable flaw signals would be found with the new block calibration. Validation of the new block as appropriate for use on Pilgrim 1 vessel was essential prior to approval of the 1976 inspection results.

In order to verify that this new calibration block was from a plate used in Pilgrim 1 Vessel, Boston Edison was asked to supply the plate manufacturer's certification on Luken's Heat C-2945 from their documentation file on Pilgrim 1 Vessel. They did not supply this certification but they did supply Combustion Engineering's Mill Order No. and the location in which the plate was installed in the vessel. From this information the appropriate documentation was found in NRC's report file of the test specimens for Pilgrim 1 fabrication. The Luken's certification and Combustion Engineering's reports verify that the new block and the reactor vessel shell came from the same steel.

The use of the new test block is appropriate for the ultrasonic inservice inspection of Pilgrim 1 Reactor Vessel. It is in accordance with 1974 ASME Code, Section XI, Appendix I, Par. I-3121, which states that the block material shall be from the components to be inspected. The 1974 Code also has requirements regarding heat treatment, cladding, and surface finish which this block does not comply with; however, the 1974 Code is not mandatory for this vessel and the lack of the 2 hours post weld heat treatment and the use of a machined rather than rolled surface is probably insignificant. Certainly cladding could have no effect since this ultrasonic inspection does not utilize a bounce from the inside surface. However, cladding deposited on the block in the same manner as the vessel cladding might enable Boston Edison to make a longitudinal beam comparison of attenuation of the back reflections from both the block and the vessel. This would provide a qualitative rather than a quantitative result but would further validate the calibration block.

TABLE 1 - ULTRASONIC DETERMINATION OF FLAW SIZE AND LOCATION, NOZZLE N-2B

Beam Angle	60° Nominal Inspection Angle												45° Nominal Inspection Angle											
Transducer Shoe	Curved										Flat		Curved										Flat	
Calibration Block	Old Block P11-5								New Block P11-5A				Old Block P11-5								New Block P11-5A			
Arm Extension	0		0		2		3		2		2		0		0		2		3		2		2	
Inspect.	March 1974		1976 Run #11		1976 Run #14		1976 Run #12		1976 Run #16		1976 Run #15		March 1974		1976 Run #11		1976 Run #14		1976 Run #12		1976 Run #16		1976 Run #15	
Location	Depth From OD	Flaw 50%-50%	Depth From OD	Flaw 50%-50%	Depth From OD	Flaw 50%-50%	Depth From OD	Flaw 50%-50%	Depth From OD	Flaw 50%-50%	Depth From OD	Flaw 50%-50%	Depth From OD	Flaw 50%-50%	Depth From OD	Flaw 50%-50%	Depth From OD	Flaw 50%-50%	Depth From OD	Flaw 50%-50%	Depth From OD	Flaw 50%-50%	Depth From OD	Flaw 50%-50%
	?-3.4	?			3.5-3.3	0.2			--	--	--	--												
280°							4.2-3.3	0.9																
			3.4-3.3	0.1			4.2-3.3	0.9																
281°																	3.7-3.4	0.3						
	?-3.3	?	3.5-3.3	0.2	4.3-3.3	1.0	4.2-3.2	1.0	3.5-3.4	0.1									3.7-3.2	0.5				
282°			3.6-3.2	0.4			4.2-3.2	1.0											3.5-3.2	0.3				
			3.5-3.2	0.3			4.2-3.2	1.0									3.7-3.4	0.3	3.5-3.4	0.1				
283°	?-3.6	?			3.7-3.3	0.4			3.4-3.3	0.1														
			--	--			4.4-3.3	1.1											3.5-3.4	0.1				
284°			3.6-3.4	0.2			4.3-3.3	1.0											3.5-3.2	0.3				
																	3.7-3.4	0.3			3.4-3.4	0.1		
	?-3.2	?	3.4-3.3	0.1	4.0-3.3	0.7	4.3-3.3	1.0	3.5-3.2	0.3									3.8-3.2	0.6				
285°																								
			--	--			4.1-3.2	0.9											3.9-3.2	0.7				
286°			3.6-3.6	0.1			4.5-3.2	1.3									3.7-3.2	0.5	3.5-3.2	0.3	3.4-3.3	0.1		
	?-3.3	?			4.2-3.2	1.0			3.4-3.3	0.1	--	--												
			3.4-3.3	0.1			4.5-3.2	1.3											3.7-3.4	0.3				
287°																								
			?-3.4				4.2-3.3	0.9											3.7-3.4	0.3				
288°																	3.7-3.4	0.3			3.5-3.4	0.1		
	?-3.3	-	3.8-3.2	0.6	4.3-3.2	1.1	4.2-3.2	1.0	3.4-3.4	0.1	--	--							3.7-3.4	0.3				
289°			?-2.2				4.6-3.2	1.4											3.7-3.4	0.3				
			?-3.4				4.7-3.3	1.4									3.7-3.4	0.3	3.5-3.4	0.1	--	--		
290°	?-3.3	?			4.6-3.3	1.3			4.1-3.7	0.4	4.1-3.6	0.5												
			?-3.6				4.5-3.4	1.1											3.5-3.4	0.1				
291°			?-3.7				4.5-3.4	1.1											3.7-3.4	0.3				
																	3.7-3.4	0.3			3.4-3.4	0.1		
	?-3.3	?	?-3.4		4.5-2.5	2.0	4.5-2.5	2.0	--	--	--	--							3.5-3.4	0.1				
292°																								
			?-3.2				4.5-3.3	1.2											3.7-3.4	0.3				
293°			3.5-3.3	0.2			4.5-3.2	1.3									3.7-3.4	0.3	3.7-3.4	0.3	--	--		
	?-3.3	?			4.2-3.2	1.0			3.5-3.3	0.2	--	--												
			3.5-3.3	0.2			4.4-3.2	1.2											3.7-3.4	0.3				
294°																								
			3.5-3.2	0.2			4.5-3.2	1.3											3.4-3.4	.1				
																	--	--			--	--		
295°	?-3.3	?	3.5-3.3	0.2	4.0-3.2	0.8	4.3-3.2	1.1	3.6-3.3	0.3	--	--							3.5-3.4	0.1				
296°			3.5-3.2	0.3			4.6-3.2	1.4											3.5-3.4	0.1				
			?-3.6				4.4-3.2	1.2									3.7-3.4	0.3	3.7-3.4	0.3	--	--		
297°	3.5-3.3	0.2			4.5-3.4	1.1			--	--	--	--												
			?-3.3				3.9-3.3	0.6											3.7-3.4	0.3				
298°			3.7-3.3	0.4			3.6-3.3	0.6											3.7-3.4	0.3				
																	3.7-3.4	0.3			--	--		
	3.6-3.4	0.2	--		3.7-3.3	0.4	4.2-3.4	0.8	--	--	--	--							3.7-3.4	0.3				
299°																								
			?-3.4				4.3-3.4	0.9											3.7-3.4	0.3				
300°			?-3.3				4.3-3.4	0.9									--	--	3.7-3.5	0.2	--	--		
	3.6-3.5	0.1			4.2-3.3	0.9			--	--	--	--												
			?-3.6				4.3-3.4	0.9											--	--				
301°																								
			?-3.6				4.2-3.6	0.6											3.8-3.7	0.1				
																	--	--			--	--		
302°	3.5-3.4	0.1	3.7-3.4	0.3	4.5-3.4	1.1	4.5-3.4	1.1	--	--	--	--							3.7-3.6	0.1				
			?-3.4				4.6-3.4	1.2											3.7-3.5	0.2				
303°																								
			?-3.4				4.5-3.4	1.1									3.7-3.5	0.2	3.7-3.5	0.2	--	--		
304°	?-3.4	?			4.6-3.4	1.2			--	--	--	--												
			3.6-3.4	0.2			4.4-3.4	1.0											3.7-3.5	0.2				
305°			3.8-3.7	0.1			4.6-3.4	1.2											3.7-3.5	0.2				
																	3.7-3.5	0.2			--	--		
	?-3.4	?	3.7-3.4	0.3	4.6-3.4	1.2	4.6-3.5	1.1	--	--	--	--							3.7-3.5	0.2				
306°																								
			--	--			4.2-3.5	0.7											3.7-3.5	0.2				
307°			--	--			3.6-3.4	0.2									3.7-3.5	0.2	3.7-3.6	0.1	--	--		
	?-3.3				4.0-3.4	0.6			--	--	--	--												
			--	--																				
309°	3.5-3.3	0.2			4.1-3.4	0.7			--	--	--	--												
																	--	--			--	--		

FLAW DIMENSION PERPENDICULAR TO THE SURFACE

The ultrasonic examination of the flaw in nozzle N-2B can be performed only from the outside surface of the vessel and only from the shell side of the weld. This limits the examination basically to one direction, although both 60° and 45° angle scans were used. The welds were scanned with an automated mechanical system and the data was recorded on video camera and on strip charts showing the signal amplitude and the distance to flaw as a function of the physical location of the transducers.

The video presentation of one of the inspection runs was viewed for general familiarization of the appearance of the signals received. Copies of the appropriate strip charts from both 1974 and 1976 were obtained for close analysis. All of the information obtainable from the recordings can not be reduced to tabular form; however, the essential information necessary to arrive at an estimated flaw size is presented in Table 1. Values in the table were taken at the 50% signal amplitude locations.

Considering first the information contained in 1976 Runs #15 and #16, since these are the only examinations in which the new calibration block was used, flaw size is arrived at as follows:

1. The 60° angle of run #16, "Flaw" column, shows a flaw thickness varying from 0.1 inch to a maximum of 0.4 inch at nozzle circumferential location of 290°. (All values in the table are considered significant to tenths of an inch only.

2. The rectangle which would circumscribe the flaw as recorded in Run #16, 60° angle, would have the outer side at 3.2 inches and the inner side at 4.1 inches from the outside surface of the vessel. This describes a through wall rectangular dimension of 0.9 inch. The circumferential length of the rectangle extends from 281° to 295° for a total length of 2.6 inches.
3. The 45° angle of Run #16 shows a flaw size no greater than that described by the 60° angle, and the location of the flaw falls within the limits described in 2. above.
4. Run #15, 60° angle, shows a flaw signal of recordable amplitude at only one location at a nozzle circumferential angle of 290°. The flaw through-thickness location is between 3.6 inches and 4.1 inches for a thickness of 0.5 inch. This location is also contained within the limits described in 2. The 45° angle examination did not produce any signals of a recordable level.

Therefore, when the flaw is described by the 50% signal amplitude limits for recordable indications as specified by the ASME Code, Section XI, it can be circumscribed by a rectangle 2.6 inches long by 0.9 inch through-wall thickness, located with the top side 3.2 inches from the outer surface of the vessel. This flaw characterization is based only upon information obtained when the new calibration block, PIL-5A, was used and does not take into consideration any of the numerous signals less than 50% amplitude.

When the ASME Code requirements are exceeded and indications of less than 50% DAC are taken into consideration it becomes obvious that the discontinuity in the weld is much longer than 2.6 inches. Run #12 in Table 1 shows that a condition exists within the weld such that indications are received continuously from 280° to 307°, or 5.0 inches. Indications on the strip chart recordings beyond the limits of Table 1 show that the discontinuity is present for almost 7 inches; the discontinuity may become intermittent at the extreme ends and is very small.

The thickness of the flaw is less easily determined because of the examination from basically one direction. This necessitates the use of signal amplitude and transducer travel as the only means for judging the through-wall size. Because of beam spread, flaws appear larger than their true dimension when a 50% signal amplitude is used as the limits for measuring transducer travel, providing the flaw is a good reflector in the direction of the ultrasonic beam. Conversely, if the flaw orientation is such that it does not reflect back toward the transducer, or only a partial reflection is received, the signal may be less than 50% of the calibrated level for an extensive flaw thickness. This makes the one-directional method of examination have a high degree of uncertainty. Comparing both the size and shape of the flaw signal from Nozzle N-2B to the signal from a 5/16-inch drilled hole shows that they are quite similar at many locations. At other locations, the distance through which the flaw signal is present compares favorably with that from the 5/16-inch hole but the amplitude is not as high. At still other locations there appear to be two distinct separate points from which reflections are received, indicating either two separate flaws or a single flaw that "turns" in such a manner that reflections are received from only two regions. This two-signal condition exists for only short distances intermittently along the length of the discontinuity.

If all of the isolated points of reflection, including those with less than 50% DAC amplitude, are considered as one flaw they would require a rectangle with a height of about 1.5 inches. These points are not of sufficient size, however, to recommend that they be considered as a part of the characterized flaw at this time. They should be considered for observation in future inspections.

CONCLUSION

The analysis of the data from the ultrasonic inspection of Nozzle N-2B in Pilgrim 1 Reactor Vessel leads to the following conclusions:

1. The flaw in the nozzle between circumferential angles 280° and 307° has not increased in size a detectable amount since 1974.
2. The new calibration block PIL-5A is appropriate for the ultrasonic examination of Pilgrim 1 Reactor Vessel and should be used in future inspections.
3. The flaw size, based upon examination using the PIL-5A calibration block and the ASME Code specifications, should be characterized as 0.9 inches in the through-wall dimension by 2.6 inches long, located with its near side 3.2 inches from the outer surface of the vessel wall.

4. Future inspections should be performed in such a manner that the small indications can be kept under observation. This may be done by conducting the inspection at 6 dB gain above the calibration level. The extent of the inspection should cover all the circumferential length covered in 1974.

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