MEM-MNA-296(93)
Rev. 2

EVALUATION OF THE ULTRASONIC TEST RESULTS FROM THE 1993 ISI ON THE UNDERCLAD FLAW INDICATIONS IN THE SEQUOYAH UNIT 1 REACTOR VESSEL NOZZLES

Performed by : R. D. Rishel 7/14/93
R. D. Rishel,
Metallurgical & NDE Analysis

W. H. Bamford 7/16/93
W. H. Bamford,
Structural Mechanics Technology

Verified by : D. Kurek 07/19/93
D. Kurek,
Metallurgical & NDE Analysis

Westinghouse Energy Systems
P.O. Box 355
Pittsburgh, Pennsylvania 15230

Evaluation of the Ultrasonic Test Results from the 1993 ISI on the Underclad Flaw Indications in the Sequoyah Unit 1 Reactor Vessel Nozzles

---

I. OBJECTIVES

The objectives of this effort were to evaluate the ultrasonic test results from the 1993 inservice inspection (ISI) on the underclad flaw indications in the Sequoyah Unit 1 reactor vessel nozzles, and to evaluate whether there has been any change in measured sizes with respect to the 1980 supplemental preservice inspection (PSI) results.

II. SCOPE

The scope of this effort is defined as follows:

(1) Evaluate the ultrasonic sizing methodology used by Southwest Research Institute (SwRI) for the ISI, and relate it to the 1980 PSI sizing methodology.

(2) Evaluate the indications with respect to IWB-3500 and IWB-3600 using the raw data, and discuss the structural integrity.

(3) Explain any changes in the indication sizes as measured in the 1980 PSI and 1993 ISI examinations.

III. EVALUATION OF ULTRASONIC SIZING METHODOLOGY

As part of the 1993 SwRI ISI program related to the Sequoyah Unit 1 reactor vessel nozzle underclad flaw indications it was required to compare the baseline procedures (per the 1980 supplemental PSI examinations) with current ASME Section XI/Regulatory Guide 1.150 procedures (per the 1993 SwRI ISI examinations)[1]. This comparison was performed using a set of underclad cracking test blocks identified in table 1, a similar manual baseline PSI procedure as used in 1980, and an automated ASME Section XI/Regulatory Guide 1.150 ISI examination procedure as used in 1993.

The results of these comparisons in terms of length and depth sizing errors for cracks are indicated in tables 2 and 3, respectively. These same results are shown graphically in figures 1 and 2, respectively. The PSI length sizing technique is a 1/4 maximum amplitude drop method also referred to as -12dB drop. The SwRI length sizing technique is a 1/2 maximum amplitude drop method also referred to as -6dB drop. The data when taken as a whole indicates that the PSI technique tends to oversize such cracks (mean error = 0.23") and the SwRI technique tends to undersize such cracks (mean error = -0.08"). However when the data is presented graphically (figure 1) it is shown that both techniques oversize small flaws, i.e. lengths less than 1", with the SwRI technique being the more accurate. (Note: The underclad flaw indications found in the Sequoyah Unit 1 reactor vessel nozzle bores are less than 1".) The data scatter, though, is somewhat large for the flaws less than 1" long regardless of technique. Thus the most appropriate conclusion is that underclad flaws appear to be oversized in length for either technique when the true lengths are small. This is consistent with ultrasonic test experience and theory on small flaws where the ultrasonic beam is larger than the flaw size.

The PSI depth sizing technique was based solely on a length to width ratio of 3:1, i.e. the depth is 1/3 the length. The SwRI depth sizing technique is based on the use of the SLIC (Shear and Longitudinal Waves, Inspection and Characterization) transducer and a methodology dependent on the recognition of time-based ultrasonic responses from crack extremities. The latter technique is more reliable than amplitude-based or constant length/depth ratio sizing methodologies. The results of the laboratory investigation are indicated in table 3 and graphically shown on figure 2. Thus the conclusion is that the SwRI technique, when it is capable of distinguishing the crack tip reflectors, is a more realistic depth measurement tool.

IV. EVALUATION OF FLAW INDICATIONS WITH RESPECT TO STRUCTURAL INTEGRITY

The underclad flaw indications found in the 1980 PSI examinations and recharacterized in the 1993 ISI examinations have been plotted on the appropriate flaw evaluation charts from the Sequoyah Units 1 and 2 reactor vessel flaw evaluation handbook (WCAP 13668)[2], as shown in figures 3 and 4, for both the inlet and the outlet nozzle bore regions.

As seen in these figures, the indications are all below the limits of the flaw acceptancee standards of paragraph IWB-3500[3] (shown as curve "D" on figures 3 and 4). Therefore they are all acceptable without the need for fracture mechanics evaluation, although the fracture evaluations have been completed and the results are also shown in the figures. The flaws could be much larger and still be acceptable by analysis, as easily seen on the figures.

V. DISCUSSION ON CHANGES IN INDICATION SIZES

Table 4 shows the 1993 ISI data for each underclad flaw indication in the Sequoyah Unit 1 reactor vessel nozzles. Also included are the corresponding data obtained from the 1980 PSI examination.[4,5]

The 1993 indication lengths are longer for the majority of the indications. However, these results do not necessarily mean that the underclad reflectors have grown in length. Significant procedural differences between the 1980 PSI examinations and the 1993 ISI examinations make a direct correlation of data difficult if not unreliable. These include:

- The 1980 PSI examinations were performed manually. Manual examinations are more error prone than the 1993 automated ISI examinations due to operator fatigue, operator discomfort from being in a confined space, and a variety of measurement error sources (coarser measurement devices, coarser measurement procedure, recording errors, and reading errors).

- The 1980 PSI examinations were performed with different ultrasonic test equipment, specifically transducers and instruments, having different characteristics even from that used in the laboratory investigations discussed above.

- As observed in table 2 and figure 1, the error in measuring flaws less than 1" long is highly variable for each technique used in the examinations.

- 'he length sizing in the 1980 PSI examinations was performed on signals having amplitudes ranging from 75 to 355% DAC, and in the 1993 ISI examinations on signals having amplitudes ranging from 6 to 67% DAC.

Experimental evidence exists that indicates that in the reactor vessel bore area shallow flaws tend to grow in length but not in depth when the vessel is subjected to relatively severe thermal shock events, but these are rare events. No experimental results are available on the behavior of these cracks under normal operational loadings. However it is our technical judgement that the underclad flaw indications will not extend in length during future service under normal operational loadings. If one could postulate longer flaws at the same depth, the plotted points, in figures 3 and 4, would simply move to the left ("l" would increase, while "a" would remain the same). It is easily seen from the two flaw evaluation charts that if this were to occur, all the flaws would continue to be acceptable for continued service, and would most likely still be smaller than the acceptance standards of IWB-3500.

In terms of the indication depths, the 1993 ISI measured depths should be considered more accurate than the 1980 PSI depths due to the manner in which they were determined. No correlation between the two sets of data can be performed.

VI. CONCLUSIONS

The following conclusions can be offered through the review of this data.

(1) The length sizing methodology used by SwRI tends to oversize underclad crack reflectors less than 1" long in the sample set available with a large variability. A similar result is obtained using a duplication of the 1980 supplemental PSI length sizing methodology. It is expected that this trend would continue in field implementation.

(2) The depth sizing methodology used by SwRI sizes the underclad crack reflectors in the sample set more accurately than the estimated depths of the 1980 supplemental PSI methodology, and would be expected to reflect a similar type accuracy in field implementation.

(3) The measured 1993 ISI flaw indications satisfy the acceptance standards of the ASME Code Section XI, IWB-3500 and therefore are considered acceptable for continued service.

(4) Correlation of underclad flaw indication sizes between the 1993 ISI and the 1980 PSI examination is difficult due to significantly inherent differences in the inspection procedures. Therefore any judgement on the increased measured lengths in the 1993 ISI examinations is not feasible.

(5) If increased lengths are postulated assuming relatively constant depths, the flaw indications would still be acceptable for continued service.

V. RECOMMENDATIONS

The following recommendation is offered from the review of this data.

(1) The 1993 ISI results should be regarded as the new baseline for any future comparisions since the inspection procedures are expected to more closely compare.

VI. REFERENCES

1. Facsimile Transmittal from Grady Lagleder, SwRI, to Rick Rishel, Westinghouse, on May 26, 1993: SwRI Program on the Underclad Flaw Indications in the Sequoyah Unit 1 Reactor Vessel Nozzles.

2. WCAP-13668 : Handbook on Flaw Evaluation for Sequoyah Units 1 and 2 Reactor Vessels, W. H. Bamford and D. E. Prager, April 1993.

3. ASME Code Section XI, 1977 Edition including the 1978 Summer Addenda.

4. Facsimile Transmittal from David Goetcheus, TVA, to Don Adamonis, Westinghouse, on May 11, 1993: 1993 ISI Data on the Underclad Flaw Indications in the Sequoyah Unit 1 Reactor Vessel Nozzles.

5. Facsimile Transmittal from David Goetchus, TVA, to Rick Rishel, Westinghouse, on July 13, 1993: Corrections to 1993 ISI Data on the Underclad Flaw Indications in the Sequoyah Unit 1 Reactor Vessel Nozzles.

TABLE 1 :
UNDERCLAD CRACKING TEST BLOCK FLAWS USED IN THE LABORATORY COMPARISON OF THE 1980 SUPPLEMENTAL PSI AND THE 1993 ISI TECHNIQUES

BLOCK IDENTIFICATION	CRACK LENGTH (IN.)	CRACK DEPTH (IN.)	ASPECT RATIO
W-A-1	1.25	.23	5.4:1
W-A-2	.65	.11	6.0:1
W-A-3	1.63	.31	5.3:1
W-B-1	1.25	.23	5.4:1
W-B-2	.65	.11	6.0:1
W-B-3	1.63	.31	5.3:1
PS-1	.25	.11	2.3:1
PS-2	.58	.25	2.3:1
PS-3	.76	.33	2.3:1
APPENDIX VIII - 1A	1.43	.14	10.2:1
APPENDIX VIII - 1B	1.95	.14	13.9:1
APPENDIX VIII - 2A	1.93	.68	2.8:1
APPENDIX VIII - 2B	1.98	.68	2.9:1

SOURCE : Southwest Research Institute, Reference 1

TABLE 2 : LABORATORY COMPARISON OF LENGTH SIZING METHODOLOGIES

BLOCK ID.	MANUAL PSI TECH. AMPL. (%DAC)	AUTO. ASME/RG 1.150 TECH. AMPL. (%DAC)	ACTUAL LENGTH (IN.)	MANUAL PSI TECH. LENGTH MEAS. ERROR(1)	SwRI TECH. LENGTH MEAS. ERROR(2)
W-A-1	566	35	1.25	-0.22	-0.23
W-A-2	631	37.5	0.65	0.82	0.55
W-A-3	669	48.5	1.63	0.86	-0.13
W-B-1	318	25.5	1.25	-0.35	-0.55
W-B-2	238	46	0.65	0.82	0.45
W-B-3	355	37	1.63	-0.03	-0.24
PS-1	596	24.5	0.25	0.25	0.10
PS-2	450	26	0.58	0.48	0.32
PS-3	358	22.5	0.76	0.64	0.14
1A	312	28.5	1.43	-0.06	-0.26
1B	362	34	1.95	-0.02	-0.35
2A	197	39	1.93	-0.43	-0.83
2B	262	28.5	1.98	0.20	0.02
MEAN ERROR				0.23	-0.08

NOTE (1): Lengths taken at 1/4 maximum amplitude.
NOTE (2): Lengths taken at 1/2 maximum amplitude.

SOURCE : Southwest Research Institute, Reference 1

TABLE 3 :
LABORATORY COMPARISON OF DEPTH SIZING METHODOLOGIES

BLOCK ID.	ACTUAL DEPTH (IN.)	MANUAL PSI TECHNIQUE ERROR[1]	SwRI SLIC TECHNIQUE ERROR
W-A-1	0.23	0.11	0.01
W-A-2	0.11	0.38	0.08
W-A-3	0.31	0.52	0.05
W-B-1	0.23	0.00	0.02
W-B-2	0.11	0.19	0.23
W-B-3	0.31	0.02	0.09
PS-1	0.11	0.05	0.03
PS-2	0.25	0.10	0.10
PS-3	0.33	0.13	0.09
1A	0.14	0.31	0.05
1B	0.14	0.50	0.03
2A	0.68	-0.18	0.06
2B	0.68	0.04	-0.05

	MEAN ERROR	0.17	0.06

Note (1): Estimated by using length divided by three.

SOURCE : Southwest Research Institute, Reference 1

TABLE 4 :
ULTRASONIC TEST DATA ON THE SEQUOYAH UNIT 1 REACTOR VESSEL NOZZLE UNDERCLAD FLAW INDICATIONS, 1980 SUPPLEMENTAL PSI EXAMINATION AND 1993 ISI EXAMINATION

NOZ. ID.	IND. ID.	PSI %DAC MAX.	ISI %DAC	PSI LENG. (IN.)(1)	ISI LENG. (IN.)(2)	PSI DEPTH (IN.)(3)	ISI DEPTH (IN.)
1I	1	125	17	0.25	0.61	0.083	0.14
1I	2	178	38	0.375	0.70	0.125	0.24
1I	3	75	ND	0.25	----	0.083	----
1O	1	75	ND	0.25	----	0.083	----
1O	2	178	37	0.25	0.40	0.083	0.25
1O	3	125	31	0.25	0.62	0.083	0.20
1O	4	316	17	0.375	0.40	0.125	0.19
1O	5	316	ND	0.312	----	0.104	----
2I	1	251	32	0.375	0.50	0.125	0.12
2I	2	282	25	0.312	0.49	0.104	0.20
2I	3	75	ND	0.375	----	0.125	----
2I	4	251	10	0.25	0.69	0.083	0.11
2I	5	200	8	0.50	0.70	0.167	0.20
2I	6	282	67	0.375	0.40	0.125	0.09
2I	7	159	ND	0.25	----	0.083	----
2I	8	200	18	0.625	0.61	0.208	0.20
2I	9	141	18	0.625	0.61	0.208	0.20
2I	10	316	44	0.50	0.50	0.167	0.17
2I	11	282	22	0.312	0.50	0.104	0.20
2I	12	178	12	0.375	0.60	0.125	0.15
2I	13	159	ND	0.25	----	0.083	----
2I	14	251	34	0.375	0.57	0.125	0.18
1I	15	282	42	0.312	0.50	0.104	0.22

2I	16	125	ND	0.25	----	0.083	----
2I	17	178	23	0.25	0.60	0.083	0.10
2I	18	100	ND	0.25	----	0.083	----
2I	19	95	ND	0.25	----	0.083	----
2I	20	141	ND	0.25	----	0.083	----
2I	21	200	25	0.375	0.60	0.125	0.22
3I	2	224	25	0.4375	0.42	NG	0.11
3I	1	80	ND	0.312	----	0.104	----
3O	1	159	12	0.375	NG	0.125	NG
3O	2	159	8	0.375	NG	0.125	NG
3O	3	200	10	0.50	NG	0.167	NG
3O	4	125	14	0.375	NG	0.125	NG
3O	5	100	ND	0.50	----	0.167	----
3O	6	100	ND	0.50	----	0.167	----
3O	7	251	ND	0.50	----	0.167	----
3O	8	125	10 ~~67~~	0.375	NG	0.125	NG
3O	9	141	ND	0.375	----	0.125	----
3O	10	75	6	0.25	NG	0.083	NG
3O	11	100	ND	0.25	----	0.083	----
3O	12	200	9	0.375	NG	0.125	NG
3O	13	200	7	0.25	NG	0.083	NG
3O	14	178	ND	0.375	----	0.125	----
3O	15	178	11	0.375	NG	0.125	NG
3O	16	200	9	0.25	NG	0.083	NG
3O	17	200	10	0.375	NG	0.125	NG
3O	18	178	27	0.375	0.59	0.125	0.13
3O	19	251	23	0.50	0.60	0.167	0.24
3O	20	282	22	0.50	0.59	0.167	0.10
3O	21	200	9	0.25	NG	0.083	NG
3O	22	251	14	0.25	NG	0.083	NG
3O	23	224	13	0.50	NG	0.167	NG
4I	2	112	ND	0.25	----	0.083	----

4I	4	200	24	0.281	0.49	0.094	0.16
4I	5	80	9	0.25	0.49	0.083	0.09
4I	1	141	ND	0.375	----	NG	----
4I	3	100	ND	0.25	----	NG	----
2O	1	100	7	0.4375	NG	NG	NG
4O	1	125	ND	0.375	----	NG	----

NOTE (1): Lengths taken at 1/4 maximum amplitude.
NOTE (2): Lengths taken at 1/2 maximum amplitude.
NOTE (3): Estimated by using length divided by three.
NG : Not given.
ND : Not detected.
---- : No data.

SOURCE : TVA, Reference 4

Source : Southwest Research Institute (May 1993)

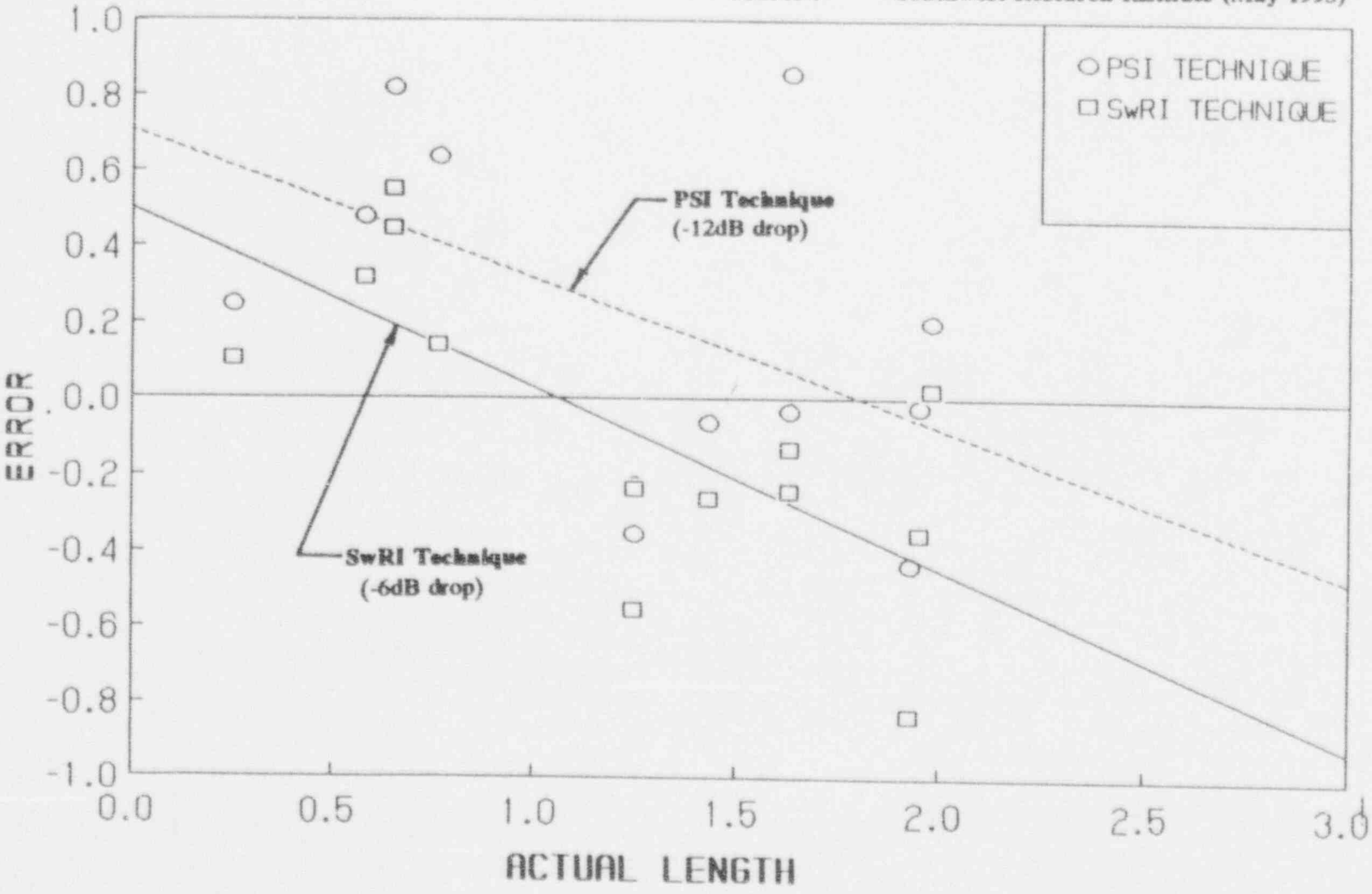


FIGURE 1 : Comparison of Flaw Length Sizing Errors Using the 1980 (PSI) and 1993 (SwRI) Length Sizing Methodologies (-12dB, and -6dB drop, respectively)

Source : Southwest Research Institute (May 1993)

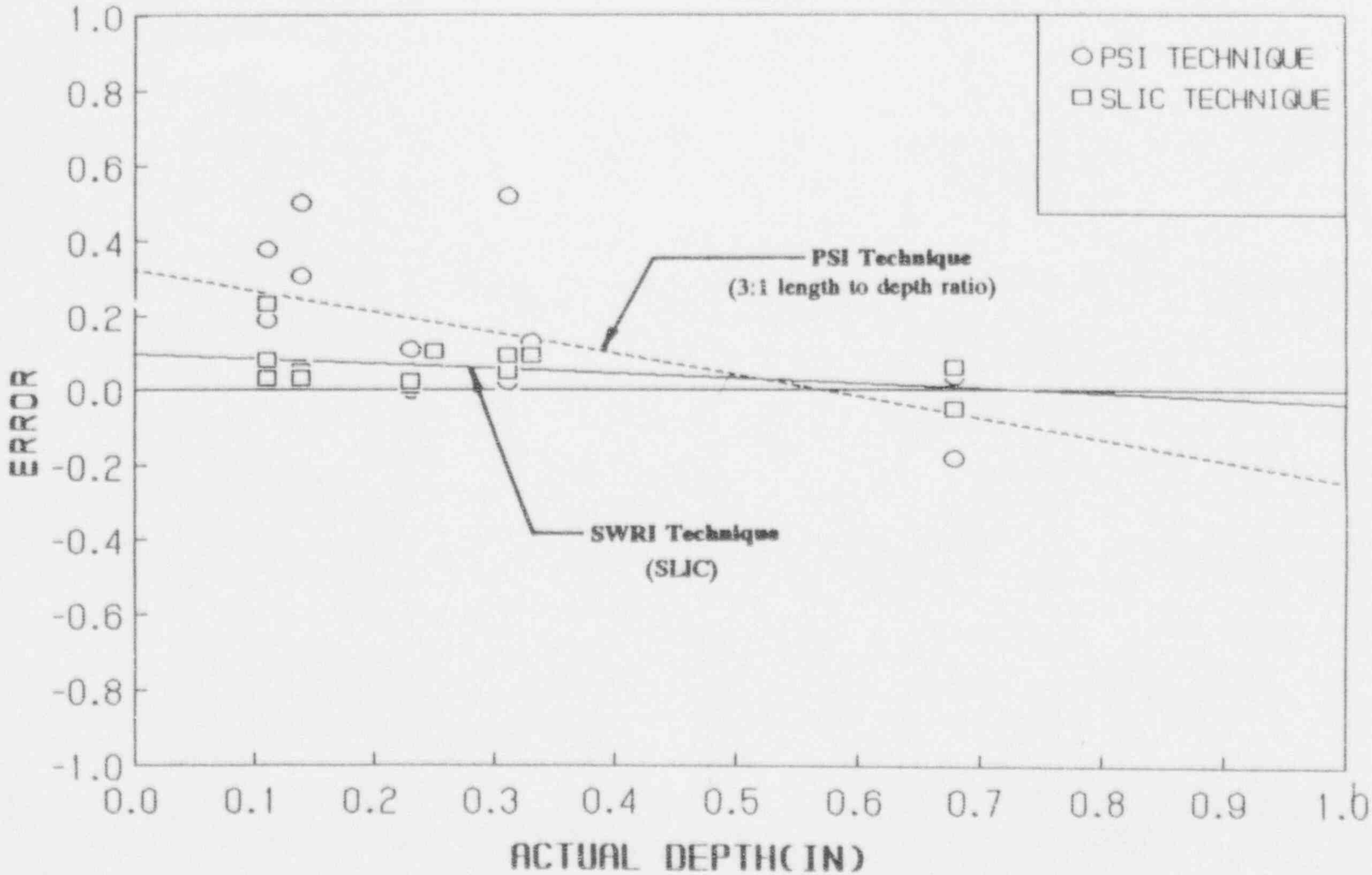
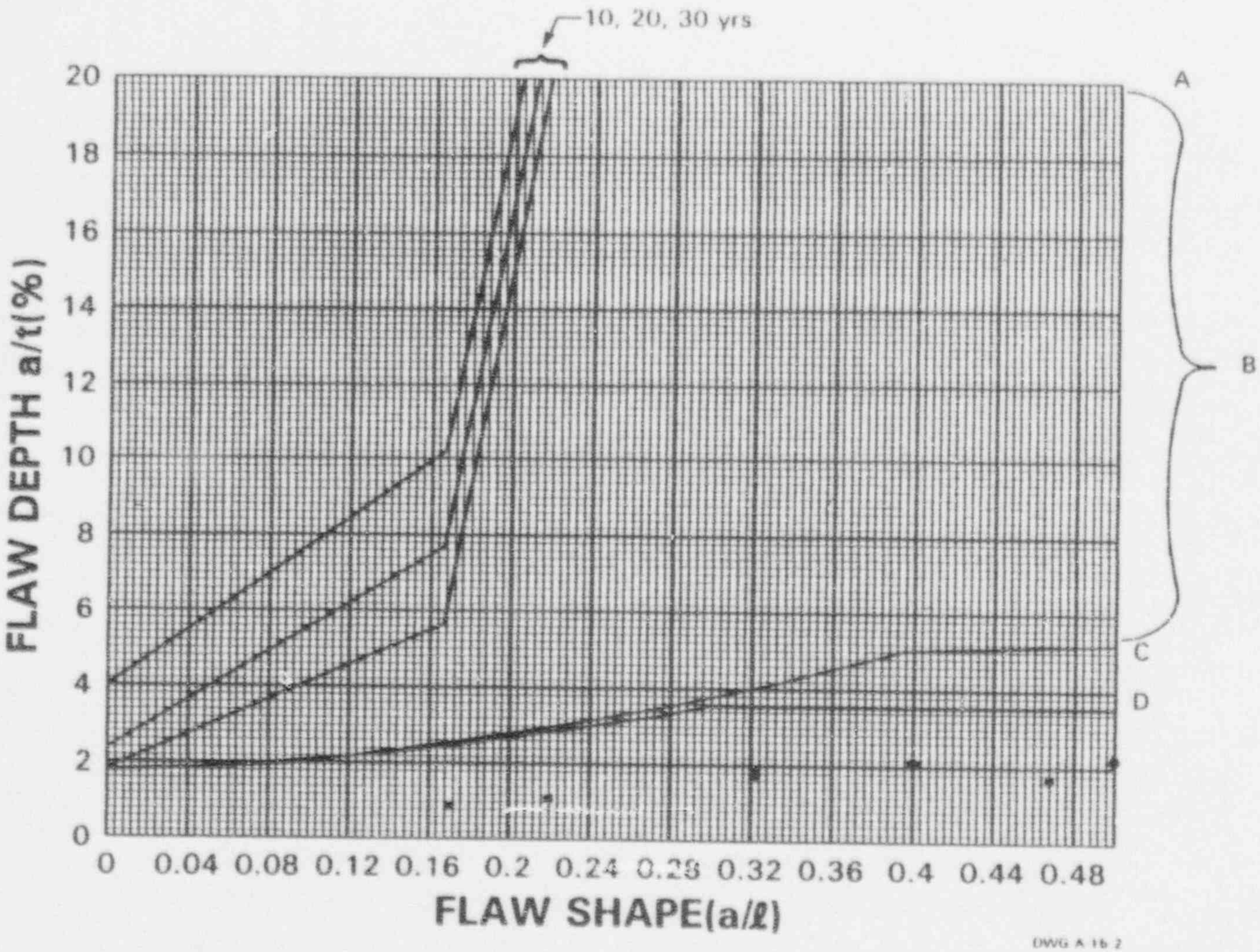


FIGURE 2 : Comparison of Flaw Depth Sizing Errors Using the 1980 (PSI) and 1993 (SwRI) Depth Sizing Methodologies (3:1 length to depth ratio, and SLIC, respectively)



LEGEND

A - The 10, 20, 30 year acceptable flaw limits.

B - Within this zone, the surface flaw is acceptable by ASME Code analytical criteria in IWB-3600

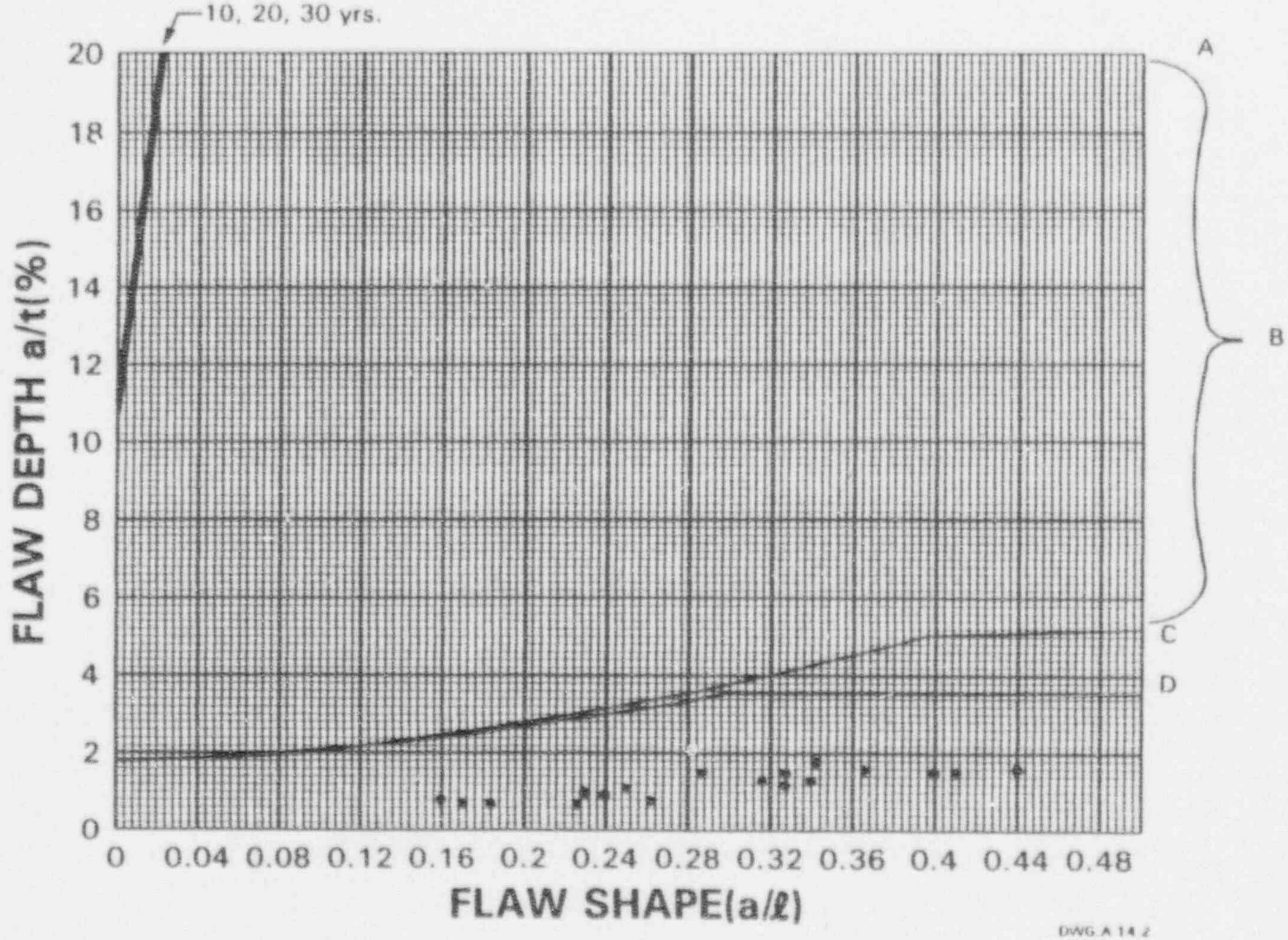
C - ASME Code allowable since 1983 Winter Addendum

D - ASME Code allowable prior to 1983 Winter Addendum

Figure A-15.2 Evaluation Chart for Outlet Nozzle Bore Region

X Inside Surface	X Surface Flaw	X Longitudinal Flaw
__ Outside Surface	__ Embedded Flaw	__ Circumferential Flaw

FIGURE 3 : Flaw Evaluation Chart for Flaw Indications Found in the Sequoyah Unit 1 Outlet Nozzle Bore Region (Source: Westinghouse WCAP-13668)



LEGEND

A - The 10, 20, 30 year acceptable flaw limits.

B - Within this zone, the surface flaw is acceptable by ASME Code analytical criteria in IWB-3600

C - ASME Code allowable since 1983 Winter Addendum

D - ASME Code allowable prior to 1983 Winter Addendum

Figure A-14.2 Evaluation Chart for Inlet Nozzle Bore Region

_X_ Inside Surface   _X_ Surface Flaw   _X_ Longitudinal Flaw
___ Outside Surface   ___ Embedded Flaw   ___ Circumferential Flaw

FIGURE 4 : Flaw Evaluation Chart for Flaw Indications Found in the Sequoyah Unit 1 Inlet Nozzle Bore Region (Source: Westinghouse WCAP-13668)

ENCLOSURE 2

TVA Commitments

1. TVA will revise the Unit 1 in-service inspection (ISI) program (Surveillance Instruction 114.1) by March 9, 1995, to include an augmented inspection requirement of the Unit 1 reactor vessel nozzles for underclad cracks. The augmented examination technique will be at least as sensitive as that used to conduct the examination during the Unit 1 Cycle 6 refueling outage. The Unit 1 Cycle 6 examination will serve as a baseline examination for the augmented examination that will be performed at the end of the second 10-year ISI interval for Unit 1.

2. TVA will submit to NRC the results of the augmented examination of the Unit 1 reactor vessel nozzles. These results will be submitted within six months from the end of the second 10-year ISI interval for Unit 1.