GE Nuclear Energy

TECHNICAL SERVICES BUSINESS
GE Nuclear Energy
175 Curtner Avenue, San Jose, CA 95125

GE-NE-B13-01805-16
DRF 137-0010-8
Class II
February 1996

Evaluation of the Limerick Unit-1 Core Shroud Inspections (Refuel Outage 6)

February 1996

Prepared by:

Marcos L. Herrera, Principal Engineer
Engineering & Licensing Consulting Services

K. Faynshtein

Karina Faynshtein, Engineer
Engineering & Licensing Consulting Services

GE Nuclear Energy
San Jose, CA

IMPORTANT NOTICE REGARDING CONTENTS OF THIS REPORT

Please Read Carefully

The only undertakings of the General Electric Company (GE) respecting information in this document are contained in the contract between PECO Energy Company and GE, and nothing contained in this document shall be construed as changing the contract. The use of this information by anyone other than PECO, or for any purpose other than that for which it is intended under such contract is not authorized; and with respect to any unauthorized use, GE makes no representation or warranty, and assumes no liability as to the completeness, accuracy, or usefulness of the information contained in this document, or that its use may not infringe privately owned rights.

Table of Contents

EXECUTIVE SUMMARY

UT inspection of the H3, H4, H5, and H7 core shroud welds was performed during refuel outage 6 at Limerick Unit-1. Minor indications were observed in the inspected areas of weld H3. Indications were not observed at welds H4, H5, and H7. This report presents the results of the application of the flaw evaluation calculations for the inspected welds. Structural margin is assured if the calculated safety factors, using the flaw evaluation method, exceed the required safety factors. The flaw evaluation methodology was prepared in a previous analysis.

This evaluation used a crack growth rate of 5×10^{-5} in/hr and a NDE uncertainty of 0.4 inch which were added to each flaw end. A twenty-four month operating cycle was assumed for the evaluation. Uninspected areas were assumed to be completely cracked and all indications were assumed to be through-wall. No new crack initiation was assumed. In addition, shroud dead weight, buoyancy, and vertical seismic loads were conservatively neglected. The flaw evaluation indicates safety factors greater than the required safety factors. Thus, structural integrity of the shroud is demonstrated for a minimum of one operating cycle.

1. INTRODUCTION

This report presents the evaluation of the 1996 outage (Outage 6) ultrasonic test (UT) results for the Limerick Unit-1 core shroud. Figure 1-1 shows a schematic of the core shroud. Reference 1-1 presented the L_{min} approach and flaw evaluation methodology for Limerick Unit-1. The UT detected indications (see report sheets in Appendix A) were evaluated per the methodology and procedures presented in Reference 1-1.

The evaluation presented in this report uses the flaw evaluation methodology which is used to calculate the existing safety margin at each inspected weld. Section 1.1 describes the approach to disposition the indications using the flaw evaluation method.

1.1 Flaw Disposition Approach

The approach in dispositioning the flaws in the Limerick Unit-1 core shroud is outlined in this section. This approach is consistent with the approach taken to disposition indications at several other BWR plants since core shroud cracking has been observed and is consistent with the BWR VIP methods in Reference 1-2.

The UT detected flaw lengths used in the flaw evaluation calculations included an uncertainty factor on length sizing. This uncertainty factor includes consideration for NDE technique uncertainty. NDE length uncertainty value of 0.4 inches for NDE method was added to each flaw end in this evaluation (Reference 1-3). This is a very conservative approach, considering the basis and the latest uncertainty data available from the BWR-VIP (Reference 1-4).

There are areas which could not be inspected during the UT inspection due to obstruction by other components. In the calculations presented in this report, all uninspected areas were assumed to contain through-wall flaws along the entire length of the uninspected zone. The estimated crack growth and uncertainty were added to the assumed through-wall flaws in the uninspected zones. This is a conservative assumption based on the UT results for all welds. All indications were found to be part-through-wall.

1.1.1 Flaw Evaluation

The flaw evaluation method takes into account the indication characterization information provided by the UT inspection. Specifically, the azimuthal location of the indications is taken into account when determining the structural safety factor. For purposes of this evaluation, the following conservative assumptions were used:

- All flaws were assumed to be through-wall
- All uninspected areas were assumed to be fully cracked
- A conservative crack growth rate of 5×10^{-5} in/hr was assumed
- NDE uncertainty of 0.4 inch was added to each flaw end
- Crack growth for the analyzed number of cycles was added to each flaw end
- No account was made for new crack initiation

The LEFM calculations were performed using a solution which best approximated the actual distribution of uninspected regions. LEFM calculations were performed only for Welds H3 and H4. These locations are the only welds where the fluence will exceed the threshold value of 3×10^{20} n/cm^2 when LEFM must be considered.

The LEFM solution used to evaluate a given pair of indications (with lengths of 2a and 2b) corresponded to that for three colinear flaws (See Rooke & Cartwright, "Compendium of Stress Intensity Factors", page 136). In this solution, the middle flaw of length 2a was separated from two neighboring flaws, both of length 2b, by a ligament, c. The ligament c corresponds to the actual distance between two uninspected zones for Weld H4, or uninspected zones or flaws for Weld H3. Thus, this solution includes the impact of neighboring flaws of different lengths.

However, in order to better simulate the actual distribution of uninspected zones (or flaws and uninspected zones for H3), a factor was applied which incorporates the affect of more than three colinear flaws. For example, for Weld H4, there are four assumed flaws which correspond to the four uninspected zones. The correction for multiple flaws is taken from Rooke & Cartwright, "Compendium of Stress Intensity Factors", page 140. This corresponds to equi-distant , equi-length flaws. The length used for this evaluation was the longest of the flaw pair being considered. The distance between the two flaws being considered is used as the distance between the equi-length flaws.

It should be noted that this LEFM method is considered conservative given that the inspection of H4 showed no indications in the areas inspected, and only a few minor indications in Weld H3. Thus, the assumption of through-wall cracking is considered to be conservative. It is likely that significantly less than the assumed through-wall indications exist in these uninspected zones given that significant inspection of Welds H4, H5, and H7 showed no indications.

In summary, the LEFM solution was calculated by first determining the stress intensity factor from the three flaw solution for a given pair of uninspected zones or flaws. This solution was modified to include the effect of more than three assumed flaws separated by the actual distance between the flaws and a shell correction factor.

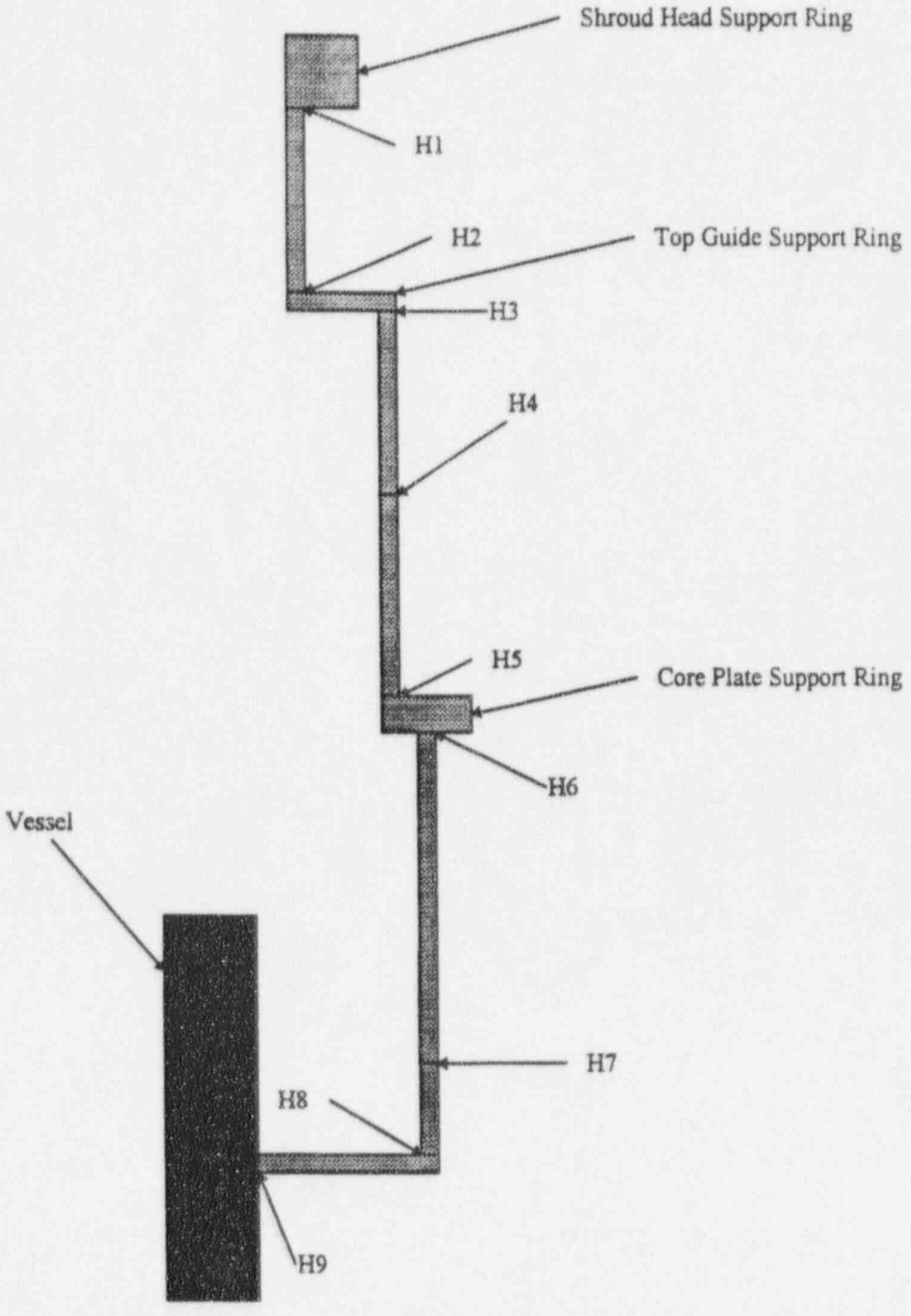

Figure 1-1 Schematic of Core Shroud Welds

1.2 References

1-1 "Determination of Inspection Lengths for the Limerick Unit-1 Shroud," GENE-523-A037-0495, DRF 137-0010-8, July, 1995.

1-2 BWR Core Shroud Inspection and Flaw Evaluation Guidelines, GENE-113-0894, DRF 137-0010-07, Rev. 1, March 1995, Prepared for the BWR Vessel and Internals Project Assessment Subcommittee.

1-3 BWR-VIP Core Shroud NDE Uncertainty & Procedure Standard, November 1994.

1-4 Reactor Pressure Vessel and Internals Examination Guidelines, BWR VIP (BWRVIP-03) Proprietary Report, October 1995.

2. EVALUATION OF UT RESULTS

This section provides the results of the application of the flaw evaluation methodology for the Limerick Unit-1 core shroud circumferential welds. The evaluation was performed using a conservative approach. All uninspected areas were treated as through-wall flaws. Crack growth for one cycle and NDE technique uncertainty were added to the end of each indication. In addition, all indications were treated as being through-wall and deadweight, buoyancy, and vertical seismic loads were conservatively neglected in calculating the primary stresses. UT inspection results indicate that all indications are part through-wall.

Appendix A contains the UT examination reports for welds H3, H4, H5, and H7. All indication lengths, including the uninspected area lengths, were increased by the assumed length uncertainty (0.4 inches on length at each flaw end) plus crack growth for one 24 month operating cycle at each flaw end.

The stresses used for the flaw evaluation are shown in Table 2-1. These stresses were calculated by conservatively neglecting shroud deadweight, buoyancy, and vertical seismic loads. Limit load safety factors were calculated using the Distributed Ligament Length (DLL) computer program (Reference 2-1).

For the flaw evaluation calculations, the flaw lengths (after proximity criteria application) are input into the DLL computer program which accounts for the azimuthal location of the indications (assumed to be through-wall).

The calculated safety factors for both normal/upset and emergency/faulted conditions are shown in Table 2-2. It can be seen from Table 2-2 that there is sufficient safety margin between the calculated and the required safety factors.

Table 2-1. Primary Membrane and Bending Stresses at the Shroud Welds

Weld Designation	Normal/Upset		Emergency/Faulted	
	P_m (ksi)	P_b (ksi)	P_m (ksi)	P_b (ksi)
H3	0.300	0.935	0.724	1.583
H4	0.300	1.471	0.724	2.411
H5	0.300	2.740	0.724	4.468
H7[1]	0.517	3.746	0.937	6.140

(1) The stresses reported in Reference 1-1 have been changed due to a correction in the inside radius used in the calculation.

The following assumptions were used in calculating the safety factors in Table 2-2:

- All flaws were assumed to be through-wall
- All uninspected areas were assumed to be fully cracked
- A conservative crack growth rate of 5×10^{-5} in/hr was assumed
- NDE uncertainty of 0.4 inch was added to each flaw end
- Crack growth for one cycle was added to each flaw end
- No account was made for new crack initiation

Table 2-2.
Flaw Evaluation Calculated Safety Factors for One Cycle of Crack Growth
(Required SF: 2.77 for Normal and Upset, 1.39 for Emergency and Faulted)

Weld	Limit Load Flaw Evaluation Safety Factor		LEFM[2] Flaw Evaluation Safety Factor	
	Normal/Upset	Emergency/Faulted	Normal/Upset	Emergency/Faulted
H3[1]	16.7	9.1	---	---
H4	12.7	7.3	---	---
H5	7.4	4.4	---	---
H7	5.1	3.1	---	---

(1) Uninspected area from 35.50° to 54.50° and Indication #1 combined due to the proximity criteria. Uninspected areas from 304.50° to 360.00° and 0.00° to 6.10° also combined.

(2) LEFM not performed for one-cycle. See Tables 2-3 and 2-4 for the two cycle and five cycle results, respectively.

2.1 Consideration of Additional Crack Growth

Additional calculations were performed using two and five cycles of crack growth to demonstrate the margin available in the core shroud welds and for the purpose of demonstrating that the reinspection criteria is met.

2.1.1 Two Cycles of Crack Growth

Calculations for two cycles of crack growth (total of two cycles beyond outage 6 UT results) were performed to demonstrate the margin available in the core shroud welds and to demonstrate that L_{min} criteria has been satisfied. Calculations were performed by adding [2(2Δa) + U], where Δa is crack growth at each flaw end for one cycle and U is the length uncertainty. Note that this calculation is for the intent of demonstrating the margin available in the core shroud welds for operation over the next operating cycle. In addition, this calculation demonstrates that the L_{min} criteria of Reference 1-2 has been satisfied. This calculation does not account for any new crack initiation. Table 2-3 provides the results for these calculations. These results also indicate that the minimum required flaw evaluation safety factors are met with the additional operating cycle of crack growth. The following assumptions were used in calculating the safety factors in Table 2-3:

- All flaws were assumed to be through-wall
- All uninspected areas were assumed to be fully cracked
- A conservative crack growth rate of 5×10^{-5} in/hr was assumed
- NDE uncertainty of 0.4 inch was added to each flaw end
- Crack growth for two cycles was added to each flaw end
- No account was made for new crack initiation

Table 2-3. Flaw Evaluation Calculated Safety Factors With Crack Growth Corresponding to Two Operating Cycles (Required SF: 2.77 for Normal and Upset, 1.39 for Emergency and Faulted)

Weld	Limit Load Flaw Evaluation Safety Factor		LEFM Flaw Evaluation Safety Factor	
	Normal/Upset	Emergency/Faulted	Normal/Upset	Emergency/Faulted
H3[1]	16.0	8.73	3.71[2]	1.99[2]
H4	12.3	7.0	2.99[3]	1.69[3]
H5	7.1	4.2	---	---
H7	4.9	3.0	---	---

(1) Uninspected area from 35.50° to 54.50° and Indication #1 combined due to the proximity criteria. Uninspected areas from 304.50° to 360.00° and 0.00° to 6.10° also combined.

(2) Limiting condition given by combination of Indication #5 and uninspected area from 304.5° to 6.1°.

(3) Limiting condition given by combination of uninspected zones between 124.12° to 186.1° and 215.55° to 235.6°.

2.1.2 Five cycles of Crack Growth

Additional calculations were also performed to demonstrate the margin available to meet reinspection criteria. Calculations were performed for a total of five cycles of operation by adding [5(2Δa) + U]. Note that this calculation is for the intent of demonstrating the margin available in the core shroud welds for reinspection criteria. This calculation does not account for any new crack initiation. Table 2-4 provides the results for these calculations. These results also indicate that the minimum required flaw evaluation safety factors are met with five operating cycles of crack growth. The following assumptions were used in calculating the safety factors in Table 2-4:

- All flaws were assumed to be through-wall
- All uninspected areas were assumed to be fully cracked
- A conservative crack growth rate of 5×10^{-5} in/hr was assumed
- NDE uncertainty of 0.4 inch was added to each flaw end
- Crack growth for five cycles was added to each flaw end
- No account was made for new crack initiation

Table 2-4. Flaw Evaluation Calculated Safety Factors With Crack Growth Corresponding to Five Operating Cycles (Required SF: 2.77 for Normal and Upset, 1.39 for Emergency and Faulted)

Weld	Limit Load Flaw Evaluation Safety Factor		LEFM Flaw Evaluation Safety Factor	
	Normal/Upset	Emergency/Faulted	Normal/Upset	Emergency/Faulted
H3[1]	13.8	7.5	3.7[2]	1.98[2]
H4	10.9	6.3	2.81[3]	1.59[3]
H5	6.3	3.8	---	---
H7	4.5	2.8	---	---

(1) Uninspected area from 35.50° to 54.50° and Indication #1, #2, and #3 combined due to the proximity criteria. Uninspected areas from 304.50° to 360.00° and 0.00° to 6.10° also combined.

(2) Limiting condition given by combination of Indication #4 and uninspected area from 124° to 186.1°.

(3) Limiting condition given by combination of uninspected zones between 124.12° to 186.1° and 215.55° to 235.6°.

2.2 References

2-1. BWR Core Shroud Distributed Ligament Length Computer Program, GE-NE-523-113-0894, Supplement 1, September 1994.

3. SUMMARY AND CONCLUSIONS

UT inspection of the core shroud welds was performed during the 1996 winter outage (Outage 6). This report presents the flaw evaluation results for the inspected core shroud circumferential welds. The primary membrane and bending stresses conservatively neglected the shroud deadweight, buoyancy, and vertical seismic loads.

The evaluation assumes all UT detected indications are through-wall even though UT confirmed that they are only part through-wall. No new crack initiation was assumed in the analysis. By exceeding the required safety factors using the flaw evaluation methodology, the ASME Code Section XI safety margins are demonstrated to be satisfied.

The flaw evaluation method uses linear elastic fracture mechanics (LEFM) and limit load concepts to determine acceptable through-wall indication lengths. For the Limerick Unit-1 core shroud, only welds H3 and H4 were evaluated using LEFM.

The flaw evaluation also uses the ASME Code Section XI criteria for combining flaws based on the proximity of indications. In addition, a second method for including the interaction between neighboring indication tips was considered for the LEFM allowable flaw size calculation.

Results of the flaw evaluation indicate safety factors which are greater than the required safety factors. Thus, structural integrity of the shroud is demonstrated for a minimum of one operating cycle.

APPENDIX A

UT Inspection Reports for Welds H3, H4, H5, and H7

GE Nuclear Energy

LGS
Limerick Unit 1 RO6 Shroud UT Project 1CKSC February 1996

Shroud Weld H-3 Indication Data

Total Scan Length Examined (Deg.)	197.20°	Thickness (in.)	2.00"
Total Scan Length Examined (in.)	358.46"	Circumference (in.)	660.72"
Percentage of Weld Length Examined	54.78%	Inches per Degree	1.81"
Percentage Flawed of Examined Weld Length	4.03%	Degrees per Inch	0.55°
Percentage Flawed of Total Weld Length	2.21%		
Total Flawed Length (Deg.)	7.96°		
Total Flawed Length (In.)	14.37"		

Ind. No.	Start Deg.	End Deg.	Length Deg.	Length In.	Length Trans	Depth Max.In.	Depth Trans	Depth Pos.Deg.	Percent Thickness	Indication Location*	Scan Type	Multiple Scan
1	54.50	57.15	2.65	4.79	45s	0.37	60L	56.12	18.5	Lowerl/D	2s	N
2	61.91	63.50	1.59	2.87	45s	0.20	60L	63.00	10.0	Lowerl/D	2s	N
3	68.50	70.56	1.06	1.92	45s	<0.20	60L	70.06	<0.10	Lowerl/D	2s	N
4	112.74	113.80	1.06	1.92	45s	<0.20	45s	13.25	<0.10	Lowerl/D	2s	N
5	270.85	272.44	1.59	2.87	45s	0.22	60L	271.40	11.0	Lowerl/D	2s	N

Indication Comments:

* In reference to the weld
Indication depth is measured from initiation surface, either I.D. or O.D., as applicable. Indication length as noted in inches refers to O.D. measurements, regardless of whether the indication is I.D. or O.D.

Areas Not Examined by All 3 Transducers (Azimuth References): 162.80 *Total Degrees Not Examined*

0.00	to	6.10	for	6.10
36.50	to	54.50	for	18.00
124.00	to	186.10	for	62.10
215.50	to	235.60	for	20.10
304.50	to	360.00	for	55.50

Explanation of Limitations:

Limitations: Core Spray Downcommers, Guide Rods, LPCI Lines and Lifting Lugs

Additional Comments:

None

Prepared by: [signature] Date: 2-17-96 Reviewed by: [signature] Date: 2-17-96

GE Nuclear Energy

LGS
Limerick Unit 1 R06 Shroud UT Project 1CKSC February 1996

Shroud Weld H-4 Indication Data

Total Scan Length Examined (Deg.)	202.34°	Thickness (in.)	2.00"
Total Scan Length Examined (in.)	366.74"	Circumference (in.)	650.72"
Percentage of Weld Length Examined	56.21%	Inches per Degree	1.81"
Percentage Flawed of Examined Weld Length	0.00%	Degrees per inch	0.55°
Percentage Flawed of Total Weld Length	0.00%		
Total Flawed Length (Deg.)	0.00°		
Total Flawed Length (in.)	0.00"		

Ind. No.	Start Deg.	End Deg.	Length Deg.	Length In.	Length Trans	Depth Max.In.	Depth Trans	Depth Pos.Deg.	Percent Thrnwall	Indicatio Location	Scan Type	Mulitple Scan

None

Indication Comments:

* In reference to the weld
Indication depth is measured from initiation surface, either I.D. or O.D., as applicable. Indication length as re d in inches refers to O.D. measurements, regardless of whether the indication is I.D. or O.D..

Areas Not Examined by All 3 Transducers (Azimuth References): 157.66° Total Degrees Not Ex mined

0.00°	to	6.10°	for	6.10°
25.55°	to	54.50°	for	18.95°
124.12°	to	186.10°	for	61.98°
215.55°	to	235.60°	for	20.05°
304.52°	to	346.15°	for	41.63°
351.05°	to	360.00°	for	8.95°

Explanation of Limitations:

Limitations: Core Spray Downcommers, Guide Rods, LPCI Lines and Lifting Lugs

Additional Comments:

None

Prepared by: _____ Date: 2-17-96 Reviewed by: _____ Date: 2-17-96

GE Nuclear Energy

LGS
Limerick Unit 1 R0e Shroud UT Project 1CX5C February 1996

Shroud Weld H-5 Indication Data

Total Scan Length Examined (Deg.)	202.34°	Thickness (in.)	2.00"
Total Scan Length Examined (in.)	366.74"	Circumference (in.)	650.72"
Percentage of Weld Length Examined	56.21%	Inches per Degree	1.81"
Percentage Flawed of Examined Weld Length	0.00%	Degrees per Inch	0.55"
Percentage Flawed of Total Weld Length	0.00%		
Total Flawed Length (Deg.)	0.00"		
Total Flawed Length (In.)	0.00"		

Ind. No.	Start Deg.	End Deg.	Length Deg.	Length In.	Length Trans	Depth Max.In.	Depth Trans	Depth Pos.Deg.	Percent Thruwall	Indication Location*	Scan Type	Multiple Scan

None

Indication Comments:

* In reference to the weld
Indication depth is measured from initiation surface, either I.D. or O.D., as applicable. Indication length as noted in inches refers to O.D. measurements, regardless of whether the indication is I.D. or O.D..

Areas Not Examined by All 3 Transducers (Azimuth References): 157.66" Total Degrees Not Examined

0.00"	to	6.10"	for	6.10"
35.40"	to	54.50"	for	19.10"
124.12"	to	186.00"	for	61.89"
215.40"	to	235.50"	for	20.10"
304.52"	to	346.55"	for	42.03"
351.55"	to	360.00"	for	8.45"

Explanation of Limitations:

Limitations: Core Spray Downcommers, Guide Rods, LPCI Lines and Lifting Lugs

Additional Comments:

None

Prepared by: [signature] Date: 2-17-96 Reviewed by: [signature] Date: 2-17-96

GE Nuclear Energy

LGS
Limerick Unit 1 RO6 Shroud UT Project 1C03C February 1996

Shroud Weld H-7 Indication Data

Total Scan Length Examined (Deg.)	196.88°	Thickness (in.)	2.00"
Total Scan Length Examined (in.)	344.91"	Circumference (in.)	630.67"
Percentage of Weld Length Examined	54.69%	Inches per Degree	1.75"
Percentage Flawed of Examined Weld Length	0.00%	Degrees per Inch	0.57"
Percentage Flawed of Total Weld Length	0.00%		
Total Flawed Length (Deg.)	0.00"		
Total Flawed Length (in.)	0.00"		

Ind. No.	Start Deg.	End Deg.	Length Deg.	Length In.	Length Trans	Depth Max.In.	Depth Trans	Depth Pos.Deg.	Percent Thruwall	Indication Location*	Scan Type	Multiple Scan

None

Indication Comments:

* In reference to the weld
Indication depth is measured from initiation surface, either I.D. or O.D., as applicable. Indication length as note in inches refers to O.D. measurements, regardless of whether the indication is I.D. or O.D..

Areas Not Examined by All 3 Transducers (Azimuth References): 183.12 Total Degrees Not Examined

0.00	to	6.10	for	6.10
35.40	to	54.50	for	19.10
123.35	to	185.10	for	62.15
215.40	to	235.60	for	20.20
304.43	to	360.00	for	55.57

Explanation of Limitations:

Limitations: Core Spray Downcommers, Guide Rods, LPCI Lines and Lifting Lugs

Additional Comments:
None

Prepared by: _____ Date: 2-15-96 Reviewed by: _____ Date: 2-16-96