NUREG/CR-2878 PNL-4373

q_c

Detection of Small-Sized Near-Surface Under-Clad Cracks For Reactor Pressure Vessels

Prepared by T.T. Taylor, S.L. Crawford, S.R. Doctor, G.J. Posakony

Pacific Northwest Laboratory Operated by Battelle Memorial Institute

Prepared for U.S. Nuclear Regulatory Commission

NOTICE

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, or any of their employees, makes any warranty, expressed or implied, or assumes any legal liability of responsibility for any third party's use, or the results of such use, of any information, apparatus, product or process disclosed in this report, or represents that its use by such third party would not infringe privately owned rights.

Availability of Reference Materials Cited in NRC Publications

Most documents cited in NRC publications will be available from one of the following sources:

- The NRC Public Document Room, 1717 H Street, N.W. Washington, DC 20555
- 2. The NRC/GPO Sales Program, U.S. Nuclear Regulatory Commission, Washington, DC 20555
- 3. The National Technical Information Service, Springfield, VA 22161

Although the listing that follows represents the majority of documents cited in NRC publications, it is not intended to be exhaustive.

Referenced documents available for inspection and copying for a fee from the NRC Public Document Room include NRC correspondence and internal NRC memoranda; NRC Office of Inspection and Enforcement bulletins, circulars, information notices, inspection and investigation notices; Licensee Event Reports; vendor reports and correspondence; Commission papers; and applicant and licensee documents and correspondence.

The following documents in the NUREG series are available for purchase from the NRC/GPO Sales Program: formal NRC staff and contractor reports, NRC-sponsored conference proceedings, and NRC booklets and brochures. Also available are Regulatory Guides, NRC regulations in the Code of Federal Regulations, and Nuclear Regulatory Commission Issuances.

Documents available from the National Technical Information Service include NUREG series reports and technical reports prepared by other federal agencies and reports prepared by the Atomic Energy Commission, forerunner agency to the Nuclear Regulatory Commission.

Documents available from public and special technical libraries include all open literature items, such as books, journal and periodical articles, and transactions. *Federal Register* notices, federal and state legislation, and congressional reports can usually be obtained from these libraries.

Documents such as theses, dissertations, foreign reports and translations, and non-NRC conference proceedings are available for purchase from the organization sponsoring the publication cited.

Single copies of NRC draft reports are available free upon written request to the Division of Technical Information and Document Control, U.S. Nuclear Regulatory Commission, Washington, DC 20555.

Copies of industry codes and standards used in a substantive manner in the NRC regulatory process are maintained at the NRC Library, 7920 Norfolk Avenue, Bethesda, Maryland, and are available there for reference use by the public. Codes and standards are usually copyrighted and may be purchased from the originating organization or, if they are American National Standards, from the American National Standards Institute, 1430 Broadway, New York, NY 10018.

3 3679 00059 2958

NUREG/CR-2878 PNL-4373 R5

Detection of Small-Sized Near-Surface Under-Clad Cracks For Reactor Pressure Vessels

Manuscript Completed: January 1983 Date Published: February 1983

Prepared by T.T. Taylor, S.L. Crawford, S.R. Doctor, G.J. Posakony

Pacific Northwest Laboratory Richland, WA 99352

Prepared for Division of Engineering Technology Office of Nuclear Regulatory Research U.S. Nuclear Regulatory Commission Washington, D.C. 20555 NRC FIN B2289



ABSTRACT

The analysis of pressurized thermal shock (PTS) shows it is necessary for nondestructive evaluation to demonstrate high probability of detecting cracks 0.250 inches deep and deeper at the clad/base metal interface.

Ultrasonic techniques developed and used in Europe are evaluated in this paper for their applicability to U.S. reactor pressure vessels for detecting cracks of interest for PTS.

Flaw detectability experiments were carried out by testing the inspection technique's ability to detect artificial flaws under several types of clad, including some Manual Metal Arc (MMA) clad. Both ground and unground clad surfaces were evaluated. Crack sizing tests of the inspection technique were made using a crack tip diffraction technique.

The data reported here indicate that for sufficiently smooth clad surfaces, the dual 70° compressional wave technique is extremely effective for detecting under-clad cracks. In addition, results show that dramatic signal-to-noise improvements can be made by grinding the clad surface. Specifically, an improvement of 10 to 12 dB in signal-to-noise ratio was achieved by smoothing the clad surface roughness from 12.6 x 10^{-3} inches RMS to 5.6 x 10^{-3} inches RMS. The improvement in surface finish allowed sufficient ultrasound to penetrate the clad surface to improve crack detection confidence from low to very high.

TOUDTOON

The malvale of presenteed thermal shock (PIS) shows it all needsary for nondestructive evaluation to demonstrate high probability of detecting cracks 0.250 inches deep and deeper at the cladybase metal interface.

Ditracorid techniques developed and used in Europe are evaluated in this paper for their applicability to U.S. reactor pressure vessels for detecting tracks or interest for 275.

Flaw detectability experiments were carried out by testing the inspection technique's ability to detect artificial flaws under several types of clad. Ancluding some Manual Metal Arc (MMA) clad. Both ground and unground clad surfaces were evalulated. Crack sizing tests of the inspection technique were made using a crack tip differention technique.

The data reported here ladicate that for sufficiently smooth elad surfaces, the dual 70° compressional wave tochnique is extremely effective for detecting under-clud dracks. In addition, results show that dramatic signal-to-noise improvements can be made by griading the clud surface. Specifically, an improvement of 10 to 12 dB in signal-to-noise for to vas achieved by smoothing the clud surface roughness from 12.6 x 10° inches RMS to 5.6 x 10° inches RS. The improvement in acting finites allowed sufficient ultrasound to peneirate the clud surface to improve crack detection confidence from low to very bieh.

EXECUTIVE SUMMARY

It has been postulated that small (0.25 inch deep) cracks beneath the clad of pressure vessel belt line welds could result in vessel failure during a reactor overcooling transient. Nondestructive evaluation must demonstrate a high probability of detecting these small cracks. The cracks of interest lie parallel or perpendicular to the clad lay and within the first one inch of the vessel surface.

European techniques (DeRaad, Engl and Bergh, 1981; Launay et al., 1981) using 70° compressional waves have been shown to be effective in detecting under-clad cracks 3 mm deep or shallower under ideal conditions (smooth clad and cracks predominantly perpendicular to the clad lay). Most circumferential welds in U.S. pressure vessels have been clad using the manual metal arc (MMA) process. This welding process creates rough surfaces that contribute to ultrasonic inspection noise and inhibit inspection effectiveness. This paper reports progress in a program in which the Pacific Northwest Laboratory is evaluating European and other inspection techniques that may be useful for inspecting U.S. pressure vessels.

Flaw detectability experiments were carried out by testing the inspection technique's ability to detect artificial flaws under several types of clad, including MMA clad. Both ground and unground clad surfaces were evaluated. Crack sizing tests of the inspection technique were made using a crack tip diffraction technique.

The data reported here indicate that for sufficiently smooth clad surfaces, the dual 70° compressional wave technique is extremely effective for detecting under-clad cracks. In addition, results show that dramatic signal-to-noise improvements can be made by grinding the clad surface. Specifically, an improvement of 10 to 12 dB in signal-to-noise ratio was achieved by smoothing the clad surface roughness from 12.6 x 10^{-3} inches RMS to 5.6 x 10^{-3} inches RMS. The improvement in surface finish allowed sufficient ultrasound to penetrate the clad surface to improve crack detection confidence from low to very high.

The results of flaw detectability experiments reported in this paper show that few U.S. reactor vessels have been effectively examined for Pressurized Thermal Shock (PTS) type flaws. The conclusions (on page 17) suggest changes to Codes and/or regulatory guides that would improve detection of PTS-type flaws.

EXECUTIVE SUMMARY

It has been postulated that small (0.25 inch deep) cracks beneath the clad of pressure vessel belt line welds could result in vessel failure during a reactor overcooling transfert. Nondestructive evaluation must demonstrate a nigh probability of detecting these small cracks. The oracks of interest lie parallel or perpendicular to the clad lay and within the first one inch of the vessel surface.

Buropean techniques (DeRaad, Engl and Bergh, 1981; Launay et al., (1931) using 70° compressional waves have been shown to be affective in detecting under-clad cracks 3 mm deep or shallaver under ideal conditions (smooth clad and cracks predominactly pergendicular to the blad lay). Most circumfermial welds in 0.8. pressure vessels have been clad using the manual becal ato (MMA), process. This welding process creates rough inhibit inspection effectiveness. This paper reports progress inhibit inspection effectiveness. This paper reports progress inhibit inspection effectiveness. This paper reports progress is a program in which the Pacific Morthwest Inspection holes and evaluating European and other inspection techniques that may be useful for inspecting 0.8, pressure vessels.

Plaw detectability experiments were carried out by testing the inspection technique's ability to detect artificial blaws under several types of clad, including 2NA clad. Both ground and unground clad autises were evaluated. Crack sizing tests of the inspection technique were made using a crack tip diffraction technique.

The data reported here indicate that for sufficiently smooth clad surfaces, the dual 70° compressionel wave technique is exicemely effective for detecting under-clad cracks? In addition, results show that Gramatic signal-to-noise improvements can be made by grinding the clad surface. Specifically an improvement of 10 to 12 dB in signal-to-noise ratio was achieved by smoothing the clad surface roughness from 12.6 Cl0⁻¹ inches RMS to 7.6 x 10⁻² inches RMS. The improvement in surface finish alloved sufficient ultrasound to penetrate the clad birds

The results of flaw detectability experiments reported in this paper show that few U.S. reactor vedeals have been effectively examined for Pressurized Thermal Shock (FTS) type flaws. The conclusions (on page 17) suggest changes to Codes and or cegulaboty guides that would improve detection of PTS-type

CONTENTS

ABST	TRAC	ст.		• •						•	•	•			•	•	•	•	•	•	iii
EXEC	CUTI	VE	SUM	MAH	RY							•									v
INTE	RODU	CTI	ON																		1
FLAV	V DE	TEC	TAB	IL	ITY																2
COMI	PARI ND D	SON	OF EL	PI EMI	ULS	E I TI	ECH	HO	SH	IEA	R	WA •	VE •								12
UNDI	ER-C	CLAD	CR	ACI	K C	HAI	RAG	CTI	ERI	IZA	TI	ON	I		•						13
CON	CLUS	SION	S																		17
LONG	G-TE	ERM	UND	ER-	-CL	AD	CI	RAC	CK	PF	200	GRA	M								18
REFI	EREN	ICES																			19



FIGURES

1.	Probe for Under-Clad Crack Detection 2
2.	Flaw Response from Pressurizer Dropout 4
3.	Relative Amplitude Response of Ground Strip Clad Sample with Under-clad Notches 5
4.	Relative Amplitude Response of Unground Strip Clad Sample with Under-clad Notches
5.	Relative Amplitude Response of Ground Single- Wire Subarc Clad Sample with Under-clad Notches . 6
6.	Relative Amplitude Response of Unground Single- Wire Clad Sample with Under-clad Notches 6
7.	Test Blocks for Background Noise 8
8.	Background Noise Measurements
9.	Surface Condition Before Grinding 10
10.	Surface Condition After Grinding 10
11.	Scatter of Ultrasound through an Unground Clad Surface
12.	Scatter of Ultrasound through a Hand Ground Clad Surface
13.	Scatter of Ultrasound through an Ideal (Smooth) Surface
14.	Crack Tip Diffraction Technique for Sizing Under-clad Cracks
15.	Experimental Sizing Data for 60 ⁰ Longitudinal Wave
16.	Experimental Sizing Data for 45 ⁰ Longitudinal Wave
17.	Sound Path through Clad Surface for Shear Waves . 16
18.	Correlation of Proposed Sound Path to Experi- mental Data



TABLES

1.	Flaw Amplitude Response from Nine Under-Clad Thermal Fatigue Cracks
2.	Estimate of Relative Detectability of Under- Clad Cracks Greater than 6 mm in an Optimized System
3.	Crack Sizing Data for Matrix I Flaws 14



DETECTION OF SMALL-SIZED NEAR-SURFACE UNDER-CLAD CRACKS IN U.S. PRESSURE VESSELS

INTRODUCTION

The belt line welds in the pressure vessels of several U.S. reactors have suffered serious radiation damage. This damage resulted from high copper content in the welds. It has been postulated (Gamble and Strosnider) that under-clad cracks as small as .250 inches in depth could result in vessel failure during an overcooling transient. A combination of conditions would be required for this type of failure to occur. These include: crack existance, high radiation damage, and high pressure (approaching operating pressure) at a low temperature. This generic safety issue is identified as Pressurized Thermal Shock (PTS).

The ability of nondestructive evaluation (NDE) to detect and characterize flaws provides an opportunity to assess the integrity of the inner surface of the vessel. Currently, a specialized technique developed in Germany and France is generally accepted as providing optimum detection resuls (DeRaad, Engl and Bergh; Launay et al.; Becker; Gruber). At the direction of the U.S. Nuclear Regulatory Commission (NRC), the Pacific Northwest Laboratory (PNL) is evaluating the effectiveness of this technique. The objective of this study is to provide NRC with information on how well the technique detects flaws in pressure vessels fabricated in the U.S.

The technique developed in Europe utilizes high-angle (generally greater than 50°) compressional waves. This technique was developed to detect under-clad cracks in light water reactor vessels. Inspection is performed with the search unit in contact with the clad surface (i.e., near surface flaw detection). It has been shown to be effective in detecting under-clad cracks 3 millimeters deep under ideal conditions (smooth clad and cracks predominantly perpendicular to the clad lay). Figure 1a shows the directivity pattern in steel of a 70° zone focused compressional wave emitted from a dual element transducer. The directivity pattern in Figure 1a shows that the peak energy of a 70° zone focused transducer lies between 0.25 in. and 0.5 in. below the surface of the metal, which makes the high-angle compressional waves ideal for detecting defects near the clad/base metal interface. The compressional waves have better penetrating power through clad than shear waves, providing a better signal-to-noise ratio. Commercially available transducers specially designed for under-clad-crack detection incorporate a transmit/receive design that allows the highangle zone focusing (see Figure 1b).



FIGURE 1. Probe for Under-clad Crack Detection: a) Directivity Pattern for 70^o Compressional Wave; b) Send/Receive Design for Commercial Probes.

The PNL evaluation of this technique included an assessment of flaw detectability and initial crack characterization experiments. This evaluation is part of a long-term NRC program designed to identify ultrasonic inspection technology that can reliably detect and characterize cracks beneath the clad of a reactor pressure vessel. This report deals with study results to date. The following report section discusses flaw detectability experiments in which European technique were used to detect artificial flaws under several types of clad. The subsequent section describes crack characterization experiments. Conclusions are followed by a discussion of plans for the long-term program.

FLAW DETECTABILITY

Flaw detectability experiments have been carried out on strip clad, single-wire subarc clad, and manual clad. Both ground and unground surfaces were evaluated. The test blocks used for this evaluation included: a 29.5 in. dia. clad dropout, two 23.6 in. square blocks with strip and single-wire clad with one side ground and the other as deposited, ^(a) and two small samples with ground and unground, manually clad surfaces. The pressurizer dropout contained through-clad notches as well as thermal fatigue cracks under the clad. The two EPRI blocks contained notches under the clad (under-clad notches). The two manually clad samples contained two reference reflectors each and were used to evaluate general noise level.

The measurements reported here were taken using a 2-MHz dual-beam longitudinal (SEL) 70° transducer with .39 x .59 in. elements and focal zone of .67 in. This unit was considered optimal for the clad conditions and thicknesses (.25 to .35 in. tested. All measurements were performed manually.

Measurements of flaw amplitude response from each of the under-clad thermal fatigue cracks (labeled A through I) in the pressurizer dropout sample were compared with the amplitude response from a 1/8 in. dia., flat-bottom reference reflector (Table 1). The flaw amplitude response was measured from two directions (180° apart) as would be done during actual field tests. The amplitude responses were higher than responses from the reference reflector; therefore, these cracks should be easily detectable with this technique even under field conditions.

	Flaw Depth Through			Flaw Res	sponse(b)		
Flaw	Wall (in.)	Direc	ctio	n		Direc	ction 3
A	0.50	+3	dB			+6	dB
В	0.50	+5	dB	Direction	Direction	+5	dB
С	0.25	+6	dB	A	В	+10	dB
D	0.50	+3	dB		/	+5	dB
Е	0.25	+14	dB		Clad	+5	dB
F	0.15	+4	dB	11	1	+8	dB
G	0.50	+1	dB			+2	dB
H	0.75	+6	dB	Flaw		+12	dB
Ι	0.75	+9	dB			+1	dB

TABLE 1. Flaw Amplitude Response from Nine Under-Clad Thermal Fatigue Cracks

(a)Access to these two samples was made possible through J.R. Quinn, Electric Power Research Institute (EPRI), Palo Alto, California.

(b)Sensitivity Standard: 1/8 in. dia., flat-bottom reference reflector.

Figures 2 through 6 show the relative signal amplitudes for: a 1/8 in. dia., flat-bottom hole (FBH) at the interface, an ASME-type through-clad notch, thermal fatigue under-clad cracks, under-clad notches, the base line noise, and indications from within the clad. The base line is the level which would yield a nearly continuous recording. Occasional clad indications arise from the clad itself and are particularly prevalent when signal propagation is perpendicular to ungound clad. These clad signals have been measured and will be addressed later.



FIGURE 2. Flaw Response from Pressurizer Dropout.

The samples in Figures 2 through 4 each exhibit similar responses and good signal-to-noise ratios. Calibration gain was within +2 dB for each of the three samples. The signal-to-noise ratio for the ground single-wire clad of Figure 5 is slightly less, but satisfactory. An additional gain of 6 dB was required for calibration of the sample in Figure 5 over that used for the samples in Figures 2 through 4. An additional gain of 14 dB was required for calibration of the unground single-wire clad of Figure 6.



FIGURE 3. Relative Amplitude Response of Ground Strip Clad Sample with Under-clad Notches (sample provided by EPRI).



UNDER CLAD

NOTCHES

20



- FIGURE 5. Relative Amplitude Response of Ground Single-Wire Subarc Clad Sample with Under-clad Notches (sample provided by EPRI).
- FIGURE 6. Relative Amplitude Response of Unground Single-Wire Clad Sample with Under-clad Notches (sample provided by EPRI).

6

The flaw detectability measurements just described show a marked dependance on surface condition (i.e., "as welded" versus ground). To provide an estimate of inspectability under noisy clad conditions, noise level measurements were made on manually clad test blocks.

The test blocks used for the noise level measurements are shown in Figure 7. Both blocks were clad using stainless steel, single-wire, manual metal arc welding and contain a 1/8 in. dia., flat-bottom hole. The block shown in Figure 7a was "as welded" and the block in Figure 7b was lightly hand ground.

Noise level measurements were made on both samples by adjusting the response from a 1/8 in. dia., flat-bottom-hole to 80% of full screen height. A time exposure photograph was taken of background noise generated while scanning perpendicular to the clad in a defect-free area of the clad specimens.

This technique, while perhaps crude, provides a method for recording peak background noise. A measure of peak background noise is important because an operator must be able to differentiate signals of interest from inherent background noise.

Figure 8 illustrates the results of ultrasound energy backscattered from two conditions of surface finish. Figure 8a shows large amounts of backscattered ultrasound energy resulting from a rough "as clad" surface; this condition makes signal interpretation very difficult for examination personnel. Light hand grinding can reduce backscattered energy 10 to 12 dB as shown in Figure 8b.

A measurement of surface roughness was also performed to quantify the "improvement" of surface condition with grinding. These measurements were taken using a linear variable differential transformer (LVDT) that was attached to a stylus and moved across the surface of the test block both parallel and perpendicular to the clad. Figures 9 and 10 show the results of these measurements. The change in surface roughness measurements from 0.012 in. RMS for the as-welded surface to 0.006 in. RMS for the hand-ground surface reduced backscattered energy 10 to 12 dB.

To understand why surface roughness has such a dramatic effect on background noise, a simple computer program was developed that used Snell's Law to trace the path of the ultrasound. The program cannot be used to model the ultrasound beam, but is very useful for showing trends in the ultrasonic beam scatter. Since the program can trace ultrasonic rays through an arbitrary surface condition, surface profile mea-





Background Noise for Hand-Ground Condition

FIGURE 8. Background Noise Measurements.



surements of the "as-welded" condition and hand-ground surface were plotted to show the relative scatter of sound for each condition.

Figure 11 shows the scatter of ultrasound when penetrating an as-welded clad surface. Figure 12 shows the scatter of ultrasound when penetrating hand-ground surface.



FIGURE 11. Scatter of Ultrasound through an Unground Clad Surface.





For comparison, Figure 13 shows the penetration of ultrasound through an ideally smooth surface. The plots dramatically illustrate that the welded surface increases scatter of the ultrasound considerably. This scattering of the ultrasound



FIGURE 13. Scatter of Ultrasound through an Ideal (Smooth) Surface.

results in decreased energy in the area of interest, thereby reducing the sensitivity of the inspection. This would also explain the decrease in the signal-to-noise ratio for the aswelded clad conditions.

COMPARISON OF PULSE ECHO SHEAR WAVE AND DUAL ELEMENT TECHNIQUES

Since the implementation of Regulatory Guide 1.150, several shear wave techniques have been proposed or used for underclad crack inspection. To assess the effectiveness of these techniques, comparison studies were performed.

Under optimum conditions of ground clad, 60° and 70° contact shear wave (PE) techniques were compared with contact dual element longitudinal probe techniques. The test involved use of 12 cracks observed from both sides, thus allowing 24 observations. Nine of the test cracks were thermal fatigue type cracks and the remaining cracks were produced by hydrogen cracking. All cracks had an extended depth of 12 mm below the clad/base metal interface with a 3:1 aspect ratio. The comparison test involved measurement of flaw detectability and flaw amplitude response.

All techniques were calibrated using a 1/16 in. diameter side-drilled hole (SDH). The results of the comparison test are shown in Table 2 below.

TABLE 2. Crack Detection Performance

	70 ⁰ Shear <u>Single</u>	60 ⁰ Shear Single	45 ⁰ Long. Dual	60 ⁰ Long. Dual	70 ⁰ Long. Dual
Number of Cracks Not Detected	7	6	0	0	0
Number of Cracks Detected	17	18	24	24	24
Average Amplitude of Detected Cracks (Relative to DAC)	-5.8 dB	-8.5 dB	-7.7 dB	+1.2 dB	+2.7 dE

Both shear wave pulse echo techniques not only failed to detect a quarter of the flaws, but provided very poor flaw amplitude response and signal-to-noise ratio. The dual element longitudinal wave techniques performed much better. The 45° dual element longitudinal techniques provided poor amplitude response; however, the improved signal-to-noise ratio allowed all flaws to be detected. The 70° dual element longitudinal technique proved to be the best performer. Using this technique, all flaws produced responses above the 1/16 in. SDH reference level.

UNDER-CLAD CRACK CHARACTERIZATION

Characterization of a crack after detection provides estimates of crack size (both length and depth) so appropriate engineering decisions can be made for crack disposition.

Crack sizing via the crack tip diffraction technique (see Figure 14) was investigated for underclad cracks. Ultrasound energy is reflected from both the face of the crack and diffracted from both the top and bottom tips. This sizing technique involves detecting ultrasound energy diffracted from the bottom of the crack tip. The 12 cracks used in the comparison test previously described were sized using crack tip diffraction with both 45° and 60° dual element probes. Crack depths (Cp) were calculated from sound path measurements using the formula

$$Cp = \cos(\theta) \times M_{p}$$
.

where $\boldsymbol{\theta}$ is the inspection angle and M_p is the sound metal path.



FIGURE 14. Crack Tip Diffraction Technique for Sizing Underclad Cracks.

In addition, under-clad nocthes of known depth were also sized. The results of the crack sizing experiments are shown in Table 3. The results of the notch sizing experiments.

TABLE 3. Crack Sizing Data for Matrix I Flaws.

Crack Descri	ption	Depth Ave.	Std Dev.
Туре	Orientation	(inches)	S
Hydrogen cracking		.673 .675	.102
Thermal fatigue through clad		.768 .680	.181 .073
Thermal fatigue		.763 .765	.060 .051
	<u>600 Siz</u>	ing	
Hydrogen cracking		.713 .723	.180 .229
Thermal fatigue through clad	11 <u>1</u>	.903 .690	.167 .048
Thermal fatigue	Ļ	1.033	.311

45° Sizing

14

The 60° dual element probe provided very good correlation to theory for both cracks and notches when compared with actual defect size (Figure 15). The 45° probe shows a good correlation between sound beam path measurements and defect size. However, the experimental results indicate the cladding is affecting the propagation path of the 45° longitudinal wave for the notches resulting in consistently undersizing them as shown in Figure 16.

Wooldridge (1982) has shown that the grain structure of stainless steel cladding tends to act as a waveguide for 45° shear. Since clad grains tend to be oriented normal to the ferritic base metal, this means that 45° shear ultrasound propagates in the manner shown in Figure 17. If the propagation model that Wooldridge used for 45° shear is applied to the 45° longitudinal wave data, the mathematical model in Figure 17 can be applied. The results of this assumption are shown in Figure 18, which shows an excellent correlation.











FIGURE 16. Experimental Sizing Data for 45° Longitudinal Dual,







FIGURE 18. Correlation of Proposed Sound Path to Experimental Data (each axis has units in inches).

The experimentation performed is not intended to show that the modelling done for shear waves applies to longitudinal waves. Rather, it shows that stainless steel clad does affect the propagation path of longitudinal ultrasound in steel. Further work is planned to develop a model based on elastic constraints and grain orientation to explain our experimental data.

CONCLUSIONS

Based upon the work performed to date on the vessel application task, the following conclusions can be drawn:

- Few U.S. reactor vessels have been effectively examined for PTS-type flaws, based on comparison testing between U.S. standard practice and European techniques.
- For future inservice inspection of U.S. reactor pressure vessels, a 1/16 inch diameter side-drilled hole or 1/8 inch diameter flat bottom calibration reflector should be added to existing vessel calibration blocks for examination of the clad/base metal region.

- The ASME Code Section XI and/or Regulatory Guide 1.150 should be revised to specifically address inspection of the clad/base metal portion of vessels. The revision(s) should include examination requirements based upon inspection techniques currently employed in Europe.
- All clad vessel surfaces should be characterized before inspection to ensure adequate examination sensitivity.
- Minor preparation of clad surfaces may be necessary to ensure effective examination for PTS-type flaws.

LONG-TERM UNDER-CLAD CRACK PROGRAM

To quantify the ability of NDE to detect and size under-clad cracks, a long-term program has been initiated at the Pacific Northwest Laboratory. This program is designed to assess current ultrasonic inspection technology, inspection teams, and inspection procedures for determination of their adequacy to reliably detect and characterize under-clad cracks. Where inadequacies are identified, solutions will be evaluated. The solutions that resolve inadequacies will be recommended for inclusion into the appropriate pressure vessel inspection Codes.

The first task is to evaluate the under-clad crack fabrication techniques. Phase 1 contains the specimens with which six different cracking methods will be used to create the under-clad cracks. Ultrasonic measurements of Phase 1 will provide a comparison of the different cracking methods. Since no experience exists for under-clad cracks in American vessels, the most ultrasonically conservative cracking method will be used.

Phase 2 will be used to evaluate the effects of different clad types and roughness. This is extremely important so that the test sensitivity for a given inspection can be properly established. The clad roughness will be quantified in terms of a surface profile and backscattered noise. Inspection variables such as transducer frequency, size, and angle will be evaluated for the effects of clad conditions.

For future inservice inspection of 0.8. reactor breasure vessels, a 1/16 inch diameter side-drilled hele or 4/8 inch diameter flat bottom calibration reflector should be added to existing vessel calibration blocks for crahination of the clad/base metal region

REFERENCES

Becker, F.L. 1982. "Near Surface Detection in Nuclear Pressure Vessels." In Proc. 5th Int. Conf. on NDE in the Nuclear Industry. Conference held at San Diego, California, May 1982.

DeRaad, J.A., G. Engl, and H. Bergh. 1981. "Inside Ultrasonic Inspection of Innernozzle Radius Corners of Nuclear Pressure Vessels - Contact and Immersion." In Proc. 4th Int. Conf. on NDE in the Nuclear Industry. Conference held at Lindau, West Germany, May 1981.

Gamble, R.M. and J. Strosnider, Jr. June 1981. An Assessment of the Failure Rate for the Beltline Region of PWR Pressure Vessels During Normal Operation and Certain Transient Conditions. NUREG-0778, U.S. Nuclear Regulatory Commission.

Gruber, G.J. 1982. "Near Surface Detection and Sizing of Unclad Cracks in Nuclear Cracks in Nuclear Reactor Vessels by Ultrasonic Multiple-Beams Technique." In Proc. 5th Int. Conf. on NDE in the Nuclear Industry. Conference held at San Diego, California, May 1982.

Launay, J.P. et al. 1981. "Nondestructive Evaluation of Underclad Defects." In Proc. 4th Int. Conf. on NDE in the <u>Nuclear Industry</u>. Conference held at Lindau, West Germany, May 1981.

Wooldridge, A.B., D.J. Allen and D. Denby. June 1982. "Predicting and Minimising the Adverse Effects of Austenitic Cladding on Ultrasonic Inspection of PWR Primary Circuit Components." CEGB Report No. NWR/SSD/82/0072/R.

REFRRENORS

Booker, P.L. 1982. "Near Surface Detection in Muclear Pressure Vessels." In Proc. 5th Int. Conf. on MDF in the Muclear Jadestry. Conference held at San Diego: California, May 1982.

DoRaad, J.A., G. Engl, and B. Bergh, 1981. "Inside Ultrasonic Inspection of Innernozzie Radius Corders of Muclear Pressure Vessels - Contact and Immersion." In Proc. 4th Int. Conf. on EDE in the Muclear Industry. Conference held at Lindau, Sect Gormany, May 1981.

Camble, R.M. and J. Strosnider, Jr. June 1981. An Assessment of the Failure Rate for the Boltline Perion of FWR Pressure Vessels Duting Normal Operation and Certiin Transient Conditions. NuREG-0778, D.S. Nuclear Regulatory Commission.

Gruber, G.J. 1982. "Near Surface Detection and Sizing of Uselad Cracks in Niclear Gracks in Nuclear Heactor Vessels by Ultrasonic Multiple-Beams Technique." In <u>Proc. 5th Int. Conf. ou NDE</u> in the Nuclear Industry. Conference beld at San Diego, Calitornia, Vay 1982.

Ladnay, J.P. et al. 1981; "Nondestructive Evaluation of Underslad Defects." In Proc. 4th Int. Conf. on NDE in the Nuclear industry. Conference beld at Lindau, West Germany, May 1987.

Wooldridge, A.B., D.J. Alien and D. Denby. June 1983. "predicting and Minimising the Adverse Effects of Austenitic Cladding on Ultrasonic Inspection of PWR Primary Circuit Components," cross Report No. NNI/650(82/0072/8.

NUREG/CR-2878 PNL-4373 R5

DISTRIBUTION

No. of Copies

> U.S. Nuclear Regulatory Commission Division of Technical Information and Document Control 7920 Norfolk Avenue Bethesda, MD 20014

R.F. Abbey, Jr. Office of Nuclear Regulatory Research Nuclear Regulatory Commission Washington, DC 20555

S. Fabric Office of Nuclear Regulatory Research Nuclear Regulatory Commission Washington, DC 20555

D. A. Hoatson Office of Nuclear Regulatory Research Nuclear Regulatory Commission Washington, DC 20555

W. V. Johnston Office of Nuclear Regulatory Research Nulcear Regulatory Commission Washington, DC 20555

10 J. Muscara Materials Engineering Branch Engineering Technology Division Nuclear Regulatory Commission Mail Stop 5650NL Washington, DC 20555 No. of Copies

> R. D. Schamberger Office of Nuclear Regulatory Research Nuclear Regulatory Commission Washington, DC 20555 H. H. Scott Office of Nuclear Regulatory Research Nuclear Regulatory Commission Washington, DC 20555 R. Van Houton Office of Nuclear Regulatory Research Nuclear Regulatory Commission Washington, DC 20555 B. D. Liaw Materials Engineering Branch Division of Engineering Nuclear Regulatory Commission Mail Stop 318 Washington, DC 20555

> Martin R. Hum Materials Engineering Branch Division of Engineering Nuclear Regulatory Commission Mail Stop 318 Washington, DC 20555

> Flix B. Litton Materials Engineering Branch Division of Engineering Nuclear Regulatory Commission Mail Stop 318 Washington, DC 20555

No. of Copies

> Warren S. Hazelton Materials Engineering Branch Division of Engineering Nuclear Regulatory Commission Mail Stop 318 Washington DC 20555

> W. J. Collins Office of Inspection and Enforcement Nuclear Regulatory Commission Washington, DC 20555

> Bob Herman Office of Inspection and Enforcement Nuclear Regulatory Commission Washington, DC 20555

Glen A. Walton Region I Office of Inspection and Enforcement Nuclear Regulatory Commission 631 Park Avenue King of Prussia, PA 19406

Alan R. Herdt Region II Office of Inspection and Enforcement Nuclear Regulatory Commission Suite 3100 101 Marietta Street NW Atlanta, GA 30303

Dr. V. Goel Office of Standards Nuclear Regulatory Commission Washington, DC 20555

Lou Frank Office of Standards Nuclear Regulatory Commission Washington, DC 20555

No. of Copies

R. W. Weeks Materials Science Division Argonne National Laboratory Argonne, IL 60439

F. Shakir Department of Metallurgy Association of American Railroads 3140 S. Federal Chicago, IL 60616

Mr. L. J. Anderson, B2402 Dow Chemical Company Texas Division P.O. Drawer K Freeport, TX 77541

L. Agree Electric Power Research Institute 3212 Hillview Avenue P.O. Box 10412 Palo Alto, CA 94304

B. R. Sehgal Electric Power Research Institute 3212 Hillview Avenue P.O. Box 10412 Palo Alto, CA 94304

W. L. Pearl Nuclear Water & Waste Technology P.O. Box 6406 San Jose, CA 95150

M. A. Wolf Department of Atmospheric Sciences Oregon State University Corvallis, OR 97330

D. O. Harris Science Applications, Inc. 5 Palo Alto Square, Suite 200 Palo Alto, CA 94304

SM-ALC/MMET Attn: Capt. John Rodgers McClellan AFB, CA 95652 No. of Copies

> Mr. Jerry Whittaker Union Carbide Company Oak Ridge National Laboratories Y-12 Oak Ridge, TN 37830

Dr. Sotirios, J. Vahaviolos Western Electric, ERC P.O. Box 900 Princeton, NJ 08540

Mr. M. C. Jon Western Electric, ERC P.O. Box 900 Princeton, NJ 08540

P. Caussin Vincotte 1640 Rhode-Saint-Genese BELGIUM

ACE Sinclair Research Division Berkeley Nuclear Laboratories Berkeley Gloucestershire, CL 13 9 PB U.K.

Don Birchon Admiralty Materials Laboratory Holton Health Poole Dorser, ENGLAND 020-122-2711

I. P. Bell Risley Nuclear Labs UKAEA Risley Warrington Cheshire U.K.

M. J. Whittle NDT Application Centre C.E.G.B. Scientific Services Timpson Road Manchester M23 9LL U.K.

No. of Copies

O. Forli Det Norske Veritas Veritasveien, 1 P.O. Box 300 N-1322 Hovik NORWAY

K. Gott Studsvik Energiteknic AB S-611 82 Nykoping SWEDEN

P. Holler Institut fur Zerstrarangs Frere Prufverfahren Univ. Geb. 37 D-6600 Saarbrucken WEST GERMANY

X. Edelman Sulzer Brothers Ltd Dept. 1513, NDT CH-8401 Winterthur SWITZERLAND

ONSITE

50 Pacific Northwest Laboratory

M. C. Bampton S. H. Bush L. Charlot R. A. Clark S. L. Crawford R. L. Dillon S. R. Doctor (27) A. J. Haverfield P. G. Heasler P. H. Hutton L. T. Pedersen S. G. Pitman G. J. Posakony G. P. Selby F. A. Simonen A. M. Sutey T. T. Taylor Technical Information (5) Publishing Coordination SH (2)

Copies

Mr. Jerry Mhittakar union Carbide Company Cat Ridge Mational Gaberatories 7-12

> Dr. Sotirios, J. Vahaviolos Westrin Birctric, ERC P.O. Box 900 Princerco, NJ 98540

> > Mr. M. C. Jon Western Electric, RRC P.O. Box 900 Princeton, NJ 08540

P. Caussin Vincotte 1640 Rhode-Saint-Genese BELGLUM

NOB Sinclair Demarch Division Berkeley Muclear Laboratoties Sarieley Cloucestershire, CL 13 9 PB

Don Sirchon Admirally Materials Laboritor Molton Health Poole Dorber, EMGLAND 030-122-2711

> L. P. Bell Rieley Mucient Loos DRAEA Rieley Marrington Cheshire

4. J. Multis GT Application Centre C.E.G.B. Scientific Services Fimpson Boad Anchester M23 9LL

coples

0. Forll Def Norske Veritas Veritasvelen, 1 P:0. Box 300 N-1322 Bovis NOrway

K. Gott Btudavik Bnereiteknic A 8-611 82 Nykoping SWEDEN

PL Holl

Institut für Seratearangs Frace Prufverlahten Univ. Geb. 37 D-6600 Saarbrucken WEST GERMANY

> X. Sdelman Gulzer Brothers Ltd Dept. 1513, NDT CH-8401 Winterthur SWITZERLAND

ONSTITE

50 Pacific Northwest Laboratory

N. C. Sampton
B. Buah
I. Chatlot
R. A. Clark
R. L. Crawford
R. Doctor (2)
R. Doctor (2)
A. J. Haverfield
B. G. Heasler
G. P. Federsen
G. P. Selby
F. T. Taylor
T. T. Taylor

-isid

17777 US. NUCLEAN REQUISION NUEEP/CR-2878 911 BIBLIOGRAPHIC DATA SHEET NUEEP/CR-2878 4 THE AND SUBTILE (Add Yourn No., Kaproprint) Detection of Small-Sized Near-Surface Under-Clad Cracks NUEEP/CR-2878 7. AUTHORISI 3. RECIPENTS ACCESSION NO. 3. RECIPENTS ACCESSION NO. 7. AUTHORISI 5. DATE REPORT COMPLETED 1. Record Number Add No. 9. PERFORMING ORGANIZATION NAME AND MALING ADDRESS (Include Zip Code) DATE REPORT ISSUED 9. PERFORMING ORGANIZATION NAME AND MALING ADDRESS (Include Zip Code) DATE REPORT ISSUED 10. SOURCEAR REGULATORY Commission NUEEP/CR-2878 11. CONTRACT NO. PERIOD COVERED (Include Zip Code) U.S. Nuclear Regulatory Commission NUEEP/CR-2878 12. SPONSORING ORGANIZATION NAME AND MALING ADDRESS (Include Zip Code) NUE PROJECT/TASK.WORK UNIT NO. 12. SPONSORING ORGANIZATION NAME AND MALING ADDRESS (Include Zip Code) NUE PROJECT/TASK.WORK UNIT NO. 13. SUPPLEMENTARY NOTES 1. CONTRACT NO. 14. LEAR FROAT PERIOD COVERED (Include Zip Code) 15. SUPPLEMENTARY NOTES 14. (Leare Ment) 14. ABSTRACT (200 words or mail TO completer acting the pressure verse carried out by testing the cindece Code Code (Include Several) 15. SUPPLEMENTARY NOTES	NRC FORM 335		1. REPORT NUMBER (Assigned by DDC)				
BiblioGRAPHIC DATA SHEET PIL-4373 A THE AND SUPER Leady Owner, Supervised Detection of Small-Sized Near-Surface Under-Clad Cracks 2. Iteer Token's 7. Authonsis 3. RECIPENTS ACCESSION NO. 3. RECIPENTS ACCESSION NO. 7. Authonsis 5. Date Report Complete 3. RECIPENTS ACCESSION NO. 9. FREGORMING ORGANIZATION NAME AND MALING ADDRESS (Include Zip Code) Date Report Complete 182 9. FREGORMING ORGANIZATION NAME AND MALING ADDRESS (Include Zip Code) Date Report Complete 193 12. SPENSORING ORGANIZATION NAME AND MALING ADDRESS (Include Zip Code) U. PROJECTITASK.WORK UNIT NO. 1933 12. SPENSORING ORGANIZATION NAME AND MALING ADDRESS (Include Zip Code) U. FROME TIME 1933 13. TOP Contines Complete Time Technology 0. THE REPORT SUBED 10. PROJECTITASK.WORK UNIT NO. 13. SPENSORING ORGANIZATION NAME AND MALING ADDRESS (Include Zip Code) 10. ONTRACT NO. 11. CONTRACT NO. 13. TOP CONCERNET REGULATOR NAME AND MALING ADDRESS (Include Zip Code) 10. PROJECTITASK.WORK UNIT NO. 11. CONTRACT NO. 13. TOP OF REPORT The Including Signal Concernet Sig	(7.77) U.S. NUCLEAR REGULATORY COMMISS	SION	NUREG/CR-2878 PNL-4373				
4. THE AND SUBTITIE (And Yourne Mo., "Approximate") 2. (Leare Falence) 2. (Leare Falence) 3. RECIPIENT'S ACCESSION NO. 7. AUTHORISI 5. DATE REPORT COMPLETED 7. AUTHORISI 5. DATE REPORT COMPLETED 9. PERFORMING ORGANIZATION NAME AND MAILING ADDRESS (Include Zip Code) DATE REPORT ISSUED PACIFIC NORTHWEST LABORATORY 1983 12. SPONSORING ORGANIZATION NAME AND MAILING ADDRESS (Include Zip Code) DATE REPORT ISSUED VI.S. NUCLEAR Regulatory Commission 10. FROJECTITASK/WORK UNIT NO. U.S. NUCLEAR Regulatory Commission 10. FROJECTITASK/WORK UNIT NO. U.S. NUCLEAR Regulatory Research VI. Incontract NO. Washington, D.C. 20555 14. (Leare duel) 13. TYPE OF REPORT PERIOD COVERED Unclume duel) Topical Report 14. (Leare duel) 14. SUPPLEMENTARY NOTES 14. (Leare duel) 15. SUPPLEMENTARY NOTES 14. (Leare duel) 16. ASTRACT DOD words of well The surger for their use on U.S. reactor pressure versel clad, including some Main 17. DEVIDENCIARE TO MORES INCLEAR COLLIAR	BIBLIOGRAPHIC DATA SHEE						
Pur Reactor Pressure Vessels 3. RECIPIENT'S ACCESSION NO. 7. AUTHORISI S.L. Crawford, S.R. Doctor, T.T. Taylor Morember 11982 9. PERFORMING ORGANIZATION NAME AND MAILING ADDRESS (include Zup Code/) Datte REPORT COMPLETED Morember 11982 9. PERFORMING ORGANIZATION NAME AND MAILING ADDRESS (include Zup Code/) Richland, WA 99352 Datte REPORT ISSUED Morember 10. Datte REPORT ISSUED 12. SPONSORING ORGANIZATION NAME AND MAILING ADDRESS (include Zup Code/) I. Contract No. 10. HOULECTTASK/WORK UNIT NO. 13. NECREAR FERIOR ORGANIZATION NAME AND MAILING ADDRESS (include Zup Code/) I. CONTRACT NO. 10. HOULECTTASK/WORK UNIT NO. 14. SUPPLEMENTARY NOTES 10. FROME 10. FROME 10. FROME 10. FROME 15. SUPPLEMENTARY NOTES 14. (Leave damk) 11. CONTRACT NO. 11. ONTRACT NO. 15. SUPPLEMENTARY NOTES 14. (Leave damk) 11. CONTRACT NO. 16. ABORT COMPANY NOTES 14. (Leave damk) 11. CONTRACT NO. 16. BEPORT TO MORE WE MAIL TO provide confidence in the integrity of a reactor during an over cooling transient, it necessary for nondestructive evaluation to demonstrate high probabilities of detecting cracks located 6.0 mm deep and deeper at the pressure vessel clad surface. The cracks 500 and used in Europer contidence inchique were made using a crack tip diffraction techni	4. TITLE AND SUBTITLE (Add Volume No., if appropriate) Detection of Small-Sized Near-Surface Und	der-Clad Cracks	2. (Leave blank)				
7. AUTHORISI S. D. CTAWFORD, S.R. DOCTOR, T.T. Taylor S. DATE REPORT COMPLETED 9. PERFORMING ORGANIZATION NAME AND MAILING ADDRESS (Incluse Zip Code) DATE REPORT ISSUED PACIFIC NOTTHE SET LABORATORY DATE REPORT COMPLETED Richland, WA 99352 DATE REPORT COMPLETED 12. SPONSORING ORGANIZATION NAME AND MAILING ADDRESS (Incluse Zip Code) DATE REPORT ISSUED Division of Engineering Technology 0 Fried Control (Incluse Zip Code) U.S. NUClear Regulatory Commission II. CONTRACT NO. Division of Engineering Technology 11. CONTRACT NO. Office of Nuclear Regulatory Research III. CONTRACT NO. Washington, D.C. 20555 III. CONTRACT NO. IS. SUPPLEMENTARY NOTES 14. (Leve Simil) 16. Super Confidence in the integrity of a reactor during an over cooling transient, it necessary for nondestructive evaluation to demonstrate high probabilities of detecting transcinet, it necessary for nondestructive evaluation to the clad ay. Ultrasonic techniques develop and used in Europe and deeper at the pressure vessel clad surface. The cracks of and a negoral during an over cooling transient, it necessary for nondestructive evaluated in this paper for their use on U.S. reactor pressure vessels. Flaw detectability experiments were carried out by testing the inspection technique seeses and any detectability experiments were carried out by testing the inspection technique. The data reported here indicate that for sufficiently smoth clad surfaces, the 70° compresion the surface co	Fur Reactor Pressure Vessels	3. RECIPIENT'S ACCESSION NO.					
S.L. Crawford, S.R. Doctor, T.T. Taylor Morth grade Morth grade 12.89 9. PERFORMING ORGANIZATION NAME AND MAILING ADDRESS (Include Zip Code) DATE REPORT ISUED Richland, WA 99352 DATE REPORT ISUED 12. SPONSORING ORGANIZATION NAME AND MAILING ADDRESS (Include Zip Code) DATE REPORT ISUED 12. SPONSORING ORGANIZATION NAME AND MAILING ADDRESS (Include Zip Code) D. (Lever Mark) 13. Type of Regulatory Commission Division of Engineering Technology Office of Nuclear Regulatory Research Incontract Washington, D.C. 20555 13. Type of RePort PENIOD COVERED (Include Zip Code) 14. (Lever diank) Incontract Washington, D.C. 20555 13. Type of RePort PENIOD COVERED (Include Zip Code) 15. SUPPLEMENTARY NOTES Incontract Washington, D.C. 20555 16. ABSTRACT 200 words or Mul To provide confidence in the integrity of a reactor during an over cooling transient, it necessary for nondestructive evaluation to demonstrate high probabilities of detecting cracks located 6.0 mm deep and deeper at the pressure vessel clad surface. The cracks of interest may be parallel or perpendicular to the clad lay. Ultrasonic techniques develog and used in this paper for their use on U.S. reactor pressure vessels. Flaw detectability to detect artificial flaws under several types of clad, including some Man. Metal Arc (MMA) Clad. Both ground and unground clad surfaces were evaluated. Crack siz tests of the inspection technique were made using a crack tip diffraction technique. The data reported here indicate that for sufficiently smoth clad surfaces, the 70° com	7. AUTHOR(S)	5. DATE REPORT COMPLETED					
9. PERFORMING OBGANIZATION NAME AND MAILING ADDRESS (Include Zip Code) DATE REPORT ISUED Pacific Northwest Laboratory Name Richland, WA 99352 6. Reme Wank! 12. SPONSORING ORGANIZATION NAME AND MAILING ADDRESS (Include Zip Code) 8. Reme Wank! U.S. Nuclear Regulatory Commission 10. PROJECT/TASKNORK UNIT NO. U.S. Nuclear Regulatory Commission 11. CONTRACT NO. Division of Engineering Technology 11. CONTRACT NO. Washington, D.C. 20555 PIN B2289 13. TYPE OF NEPORT PERIOD COVERED (Include dam) Topical Report 14. (Leve olenk!) 15. SUPPLEMENTARY NOTES 14. (Leve olenk!) 16. ABSTRACT 200 mode w Mu! TO provide confidence in the integrity of a reactor during an over cooling transient, it necessary for nondestructive evaluation to demonstrate high probabilities of detecting cracks located 6.0 mm deep and deeper at the pressure vessel clad surface. The cracks of interest may be parallel or perpendicular to the clad lay. Ultrasonic techniques develog and used in Suropa ere evaluated in this paper for their use on U.S. reactor pressure vessels. Flaw detectability to detect artificiently smorth clad surfaces were evaluated Crack sizi tests of the inspection technique were made using a crack tip diffraction technique. The data reported here indicate that for sufficiently smorth clad surfaces, the 70° compression eves sional wave technique is extremely effective for detecting under-clad cracks. In additit oresults how	S.L. Crawford, S.R. Doctor, T.T. Taylor	December 1982					
Pacific Northwest Laboratory Richland, WA 99352 MONTH Pebruary Pebruary 1983 I2. SPONSORING ORGANIZATION NAME AND MAILING ADDRESS (Include Zie Code) 8. (Lever Mank) I2. SPONSORING ORGANIZATION NAME AND MAILING ADDRESS (Include Zie Code) 10. PROJECT.TASKIWORK UNIT NO. U.S. Nuclear Regulatory Commission Division of Engineering Technology Office of Nuclear Regulatory Research Mashington, D.C. 20555 10. DONTRACT NO. Topical Report PENDO COVERED (Include date) Topical Report PENDO COVERED (Include date) 16. ABSTRACT 200 words or null To provide confidence in the integrity of a reactor during an over cooling transient, it necessary for nondestructive evaluation to demonstrate high probabilities of detecting cracks located 6.0 mm deep and deeper at the pressure vessel clad surface. The cracks of used in Europe are evaluated in this paper for their use on U.S. reactor pressure vessels. Flaw detectability experiments were carried out by testing the inspection technique sels. Flaw detectability experiments were carried out by testing the inspection technique. The data reported here indicate that for sufficiently smooth clad surfaces, the 70° compres- sional wave technique is extremely effective for detecting under-clad cracks. In additic results show that dramatic signal-to-noise improvements can be made by grinding the clad surface. Specifically, a reduction in noise level of 10 to 12 3B was achieved by improvi the surface. Specifically, a reduction in noise level of 10 to 12 dB was achieved by improvi the surface. Specifically, a reduction from 0.012 in. TMS to 0.006 in. FMS. This reduction in noise moves the crack detectability confidence level from low to very high.	9. PERFORMING ORGANIZATION NAME AND MAILING ADDRE	SS (Include Zip Code)	DATE REPORT ISSUED				
	Pacific Northwest Laboratory Richland, WA 99352	February 1983					
8. (Leave Dank) 12. SPONSORING ORGANIZATION NAME AND MAILING ADDRESS (Include Zip Code) U.S., Nuclear Regulatory Commission Division of Engineering Technology Office of Nuclear Regulatory Research Washington, D.C. 20555 13. TYPE OF REPORT Topical Report 15. SUPPLEMENTARY NOTES 16. ABSTRACT (200 words or Inst) TO provide confidence in the integrity of a reactor during an over cooling transient, it necessary for nondestructive evaluation to demonstrate high probabilities of detecting To provide confidence in the integrity of a treactor during an over cooling transient, it necessary for nondestructive evaluation to demonstrate high probabilities of detecting and used in Europe are evaluated in this paper for their use on U.S. reactor pressure vessels. all subjection technique were made using a crack tip diffraction technique. The data reported here indicate that for sufficiently smooth clad surfaces were evaluated. Crack sizitests of the inspection technique were made using a crack tip diffraction technique. The Surface condition by a factor of two from 0.012 in. RMS to 0.006 in. RMS. This reduction in noise moves the crack detectability confidence level for to 12 dB was achieved by improvi the surface condition by a factor of two from 0.012 in. RMS to 0.006 in. RMS. This reduction in noise moves the crack detectability confidence level from low to very high. 17. KEY WORDS AND DOCUMENT ANALYSIS 17a DESCRIPTORS 17b. IDENTIFIERS.OPEN.ENDED TERMS 19. SECURI			6. (Leave blank)				
12. SPONSORING ORGANIZATION NAME AND MAILING ADDRESS (Include Zip Code) ID. PROJECT/TASK/WORK UNIT NO. U.S., Nuclear Regulatory Commission ID. PROJECT/TASK/WORK UNIT NO. Division of Engineering Technology ID. ONTRACT NO. Office of Nuclear Regulatory Research FENIOD COVERED (Inclusive daws) Washington, D.C. 20555 FENIOD COVERED (Inclusive daws) Topical Report ID. SUPPLEMENTARY NOTES 15. SUPPLEMENTARY NOTES 14. (Lewe daws) 16. ABSTRACT 200 words or Heal To provide confidence in the integrity of a reactor during an over cooling transient, it necessary for nondestructive evaluation to demonstrate high probabilities of detecting cracks located 6.0 mm deep and deeper at the pressure vessel clad surface. The cracks of interest may be parallel or prependiculat to the clad lay. Ultrasonic techniques develog and used in Europe are evaluated in this paper for their use on U.S. reactor pressure vessels. Flaw detectability experiments were carried out by testing the inspection technique. The data areported here indicate that for sufficiently smooth clad surfaces, the 70° compressional wave technique is extremely effective for detecting under-clad cracks. In additic results show that dramatic signal-to-noise improvements can be made by grinding the clad surface. Specifically, a reduction in noise level of 10 to 12 dB was achieved by improvi the surface condition by a factor of two from 0.012 in. RMS to 0.006 in. RMS. This reduction in noise moves the crack detectability confidence level from low to very high. 17. KEY WORDS AND DOCUMENT ANALYSIS 17a DESCRIPTORS 1			8. (Leave blank)				
U.S. NUClear Regulatory Commission Division of Engineering Technology Office of Nuclear Regulatory Research Mashington, D.C. 20555 11. CONTRACT NO. 13. TYPE OF REPORT PERIOD COVERED Unclusive dams! Topical Report 14. (Leve dams!) 16. ASSTRACT 200 works or less! 14. (Leve dams!) 16. ASSTRACT 200 works or less! 14. (Leve dams!) 16. ASSTRACT 200 works or less! 14. (Leve dams!) 16. ASSTRACT 200 works or less! 14. (Leve dams!) 16. ASSTRACT 200 works or less! 14. (Leve dams!) 16. ASSTRACT 200 works or less! 14. (Leve dams!) 16. ASSTRACT 200 works or less! 14. (Leve dams!) 16. ASSTRACT 200 works or less! 14. (Leve dams!) 16. ASSTRACT 200 works or less! 14. (Leve dams!) 16. ASSTRACT 200 works or less! 14. (Leve dams!) 16. ASSTRACT 200 works or less! 14. (Leve dams!) 16. ASSTRACT 200 works or less! 15. SUPPLEMENTARY NOTES 18. AVAILABILITY STATEMENT 14. (Leve dams!) 19. VOLVER 200 Person 14. (Leve dams!) 10. DENTIFIERS: OPEN ENDED TERMS 17. DESCRIPTORS 11. CONTIFICATION 17. NOLVER 2000 PERSON 11. CONTIFICATION CONTIFICATION CONTIFICANDED 17. NOLVER 2000 PERSON <td>12. SPONSORING ORGANIZATION NAME AND MAILING ADDRI</td> <td>ESS (Include Zip Code)</td> <td>10. PROJECT/TASK/WORK UNIT NO.</td>	12. SPONSORING ORGANIZATION NAME AND MAILING ADDRI	ESS (Include Zip Code)	10. PROJECT/TASK/WORK UNIT NO.				
Office of Nuclear Regulatory Research FIN B2289 Washington, D.C. 20555 PERIOD COVERED Unclusive dates! Topical Report PERIOD COVERED Unclusive dates! Topical Report 14. (Leave Dark!) 16. ABSTRACT 200 words or Mail 14. (Leave Dark!) 16. ABSTRACT 200 words or Mail 14. (Leave Dark!) 16. ABSTRACT 200 words or Mail 14. (Leave Dark!) 16. ABSTRACT 200 words or Mail 14. (Leave Dark!) 16. ADSTRACT 200 words or Mail 14. (Leave Dark!) 16. ADSTRACT 200 words or Mail 16. ADSTRACT 200 words or Mail 16. ADSTRACT 200 words or Mail 16. ADSTRACT 200 words or Mail 17. Depreted Period 14. (Leave Dark!) 18. ADVALUE 14. (Leave Dark!) 19. PERIOD COVERED Inclusive dates! 10. ADSTRACT 200 words or Mail 10. ADSTRACT 200 words or Mail 14. (Leave Dark!) 10. ADSTRACT 200 words or Mail 16. ADSTRACT 200 words or Mail 10. ADSTRACT 200 words or Mail 14. (Leave Dark!) 11. The period Could and the person of the person of Could and Surfaces. The cracks of Interstring the clad Surfaces, the 70° compressional wave technique is extremely effective for detecting under-clad cracks. In addition results show that dramatic signal-to-noise improvements can be made by grinding the clad Surfaces or Dout 10. No	U.S. Nuclear Regulatory Commission		11. CONTRACT NO.				
Washington, D.C. 20555 FIN B2289 13. TYPE OF REPORT PERIOD COVERED (Inclusive dates) Topical Report 14. (Leave dates) 15. SUPPLEMENTARY NOTES 14. (Leave dates) 16. ABSTRACT 200 words or insol 14. (Leave dates) 16. ABSTRACT 200 words or insol 14. (Leave dates) 16. ABSTRACT 200 words or insol 14. (Leave dates) 16. ABSTRACT 200 words or insol 14. (Leave dates) 16. ABSTRACT 200 words or insol 14. (Leave dates) 16. ABSTRACT 200 words or insol 14. (Leave dates) 16. ABSTRACT 200 words or insol 14. (Leave dates) 17. Increase and y be parallel or perpendicular to the clad lay. Ultrasonic techniques develop 14. (Leave dates) 18. AVAILABILITY STATEMENT 14. (Leave dates) 14. (Leave dates) 19. SECURITY CLASS (700 words or insol 170. DESCRIPTORS 19. SECURITY CLASS (700 more)	Office of Nuclear Regulatory Research						
13. TYPE OF REPORT TERIOD COVERED (Inclusive dates) Topical Report 14. (Leave plank) 15. SUPPLEMENTARY NOTES 14. (Leave plank) 16. ABSTRACT (200 words or less) 14. (Leave plank) 17. Decoded 6.0 mm deep and deeper at the pressure vessel clad surface. The cracks of interest may be parallel or perpendicular to the clad lay. Ultrasonic techniques develop and used in Europe are evaluated in this paper for their use on U.S. reactor pressure vessels. Flaw detectability experiments were carried out by testing the inspection technique vertaets of the inspection technique were made using a crack tip diffraction technique. The data reported here indicate that for sufficiently smooth clad surfaces, the 70° compressional wave technique is extremely effective for detecting under-clad cracks. In addition for using a crack. Specifically, a reduction in noise level of 10 to 12 dB was achieved by improvit the surface condition by a factor of two from 0.012 in. RMS to 0.006 in. RMS. This reduction in noise moves the crack detectability confidence level from low to very high. 17. NEY WORDS AND DOCUMENT ANALYSIS 17a DESCRIPTORS 18. AVAILABILITY STATEMENT 19. SECURITY CLASS (70m report)	Washington, D.C. 20555		FIN B2289				
TOPICAL Report 15. SUPPLEMENTARY NOTES 16. ABSTRACT (200 words or Mas) To provide confidence in the integrity of a reactor during an over cooling transient, it necessary for nondestructive evaluation to demonstrate high probabilities of detecting cracks located 6.0 mm deep and deeper at the pressure vessel clad surface. The cracks of interest may be parallel or perpendicular to the clad lay. Ultrasonic techniques develop and used in Europe are evaluated in this paper for their use on U.S. reactor pressure vessels. Flaw detectability experiments were carried out by testing the inspection technique's ability to detect artificial flaws under several types of clad, including some Mann Metal Arc (MMA) clad. Both ground and unground clad surfaces were evaluated Crack sizi tests of the inspection technique were made using a crack tip diffraction technique. The data reported here indicate that for sufficiently smooth clad surfaces, the 70° compressional wave technique is extremely effective for detecting under-clad cracks. In additic results show that dramatic signal-to-noise improvements can be made by grinding the clad surface. Specifically, a reduction in noise level of 10 to 12 dB was achieved by improvi the surface condition by a factor of two from 0.012 in. RMS to 0.006 in. RMS. This reduction in noise moves the crack detectability confidence level from low to very high. 17. KEY WORDS AND DOCUMENT ANALYSIS 17a DESCRIPTORS 18. AVAILABILITY STATEMENT 19. SECURITY CLASS (The more) 18. AVAILABILITY STATEMENT 19. SECURITY CLASS (The more)	13. TYPE OF REPORT	PERIOD COV	ERED (Inclusive dates)				
15. SUPPLEMENTARY NOTES 14. (Leave Diank) 16. ABSTRACT (200 words or /ess) To provide confidence in the integrity of a reactor during an over cooling transient, it necessary for nondestructive evaluation to demonstrate high probabilities of detecting cracks located 6.0 mm deep and deepr at the pressure vessel clad surface. The cracks ooi interest may be parallel or perpendicular to the clad lay. Ultrasonic techniques develop and used in Europe are evaluated in this paper for their use on U.S. reactor pressure vessels. Flaw detectability experiments were carried out by testing the inspection technique's ability to detect artificial flaws under several types of clad, including some Mann Metal Arc (MMA) clad. Both ground and unground clad surfaces were evaluated Crack sizi tests of the inspection technique were made using a crack tip diffraction technique. The data reported here indicate that for sufficiently smooth clad surfaces. In additic results show that dramatic signal-to-noise improvements can be made by grinding the clad surface. Specifically, a reduction in noise level of 10 to 12 dB was achieved by improving the surface condition by a factor of two from 0.012 in. RMS to 0.006 in. RMS. This reduction in noise moves the crack detectability confidence level from low to very high. 17. KEY WORDS AND DOCUMENT ANALYSIS 17a DESCRIPTORS 18. AVAILABILITY STATEMENT 19. SECURITY CLASS (7bm mpure)	Topical Report						
16. ABSTRACT [200 words or less] To provide confidence in the integrity of a reactor during an over cooling transient, it necessary for nondestructive evaluation to demonstrate high probabilities of detecting cracks located 6.0 mm deep and deeper at the pressure vessel clad surface. The cracks of interest may be parallel or perpendicular to the clad lay. Ultrasonic techniques develop and used in Europe are evaluated in this paper for their use on U.S. reactor pressure ves sels. Flaw detectability experiments were carried out by testing the inspection techni- que's ability to detect artificial flaws under several types of clad, including some Mann Metal Arc (MMA) clad. Both ground and unground clad surfaces were evaluated Crack sizi tests of the inspection technique were made using a crack tip diffraction technique. The data reported here indicate that for sufficiently smooth clad surfaces, her 70° compres- sional wave technique is extremely effective for detecting under-clad cracks. In addition results show that dramatic signal-to-noise improvements can be made by grinding the clad surface. Specifically, a reduction in noise level of 10 to 12 dB was achieved by improvin the surface condition by a factor of two from 0.012 in. RMS to 0.006 in. RMS. This reduct tion in noise moves the crack detectability confidence level from low to very high. 17. KEY WORDS AND DOCUMENT ANALYSIS 17a DESCRIPTORS 18. AVAILABILITY STATEMENT 19. SECURITY CLASS (7bm mpure) 10: NG SETENCED	15. SUPPLEMENTARY NOTES		14. (Leave blank)				
17. KEY WORDS AND DOCUMENT ANALYSIS 17a. DESCRIPTORS 17a. DESCRIPTORS 17b. IDENTIFIERS/OPEN-ENDED TERMS 18. AVAILABILITY STATEMENT 19. SECURITY CLASS (This repur): 121. 140. OF 7 HOED	cracks located 6.0 mm deep and deeper at interest may be parallel or perpendicula and used in Europe are evaluated in this sels. Flaw detectability experiments we que's ability to detect artificial flaws Metal Arc (MMA) clad. Both ground and un tests of the inspection technique were mm data reported here indicate that for suf sional wave technique is extremely effect results show that dramatic signal-to-noil surface. Specifically, a reduction in noise the surface condition by a factor of two tion in noise moves the crack detectabil	the pressure ves r to the clad lay paper for their re carried out by under several ty nground clad surf ade using a crack ficiently smooth tive for detectin se improvements c oise level of 10 from 0.012 in. R ity confidence le	sel clad surface. The cracks of Ultrasonic techniques develop use on U.S. reactor pressure ver testing the inspection techni- pes of clad, including some Mani aces were evaluated. Crack siz tip diffraction technique. The clad surfaces, the 70° compres- ing under-clad cracks. In addition an be made by grinding the clad to 12 dB was achieved by improv MS to 0.006 in. RMS. This reduce evel from low to very high.				
17b. IDENTIFIERS/OPEN-ENDED TERMS 18. AVAILABILITY STATEMENT 19. SECURITY CLASS (This reports 121, 140, OF 9 HOES)	17. KEY WORDS AND DOCUMENT ANALYSIS	17a. DESCRIPT	ORS				
Unclassified	176. IDENTIFIERS/OPEN-ENDED TERMS 18. AVAILABILITY STATEMENT	19. SE CUF Unclas	RITY CLASS (This report) 21. NO. OF THUES Ssified				
Unlimited 20. SECURITY CLASS (This page) 22. PRICE	Unlimited	20. SECUE	ASSITIED 22. PRICE				

2

NRC 50RM 335 (7 77)