INTERIM REPORT

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Responsible NRC Individual and NRC Office or Division:
Dr. Joe Muscara, Metallurgy and Materials Res. Br. RSR

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Prepared for
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Washington, D.C. 20555

INTERIM REPORT

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RSR Contact: Dr. Joe Muscara

PNL Program Manager: F. L. Becker

JULY MONTHLY REPORT

Status of the program is described below by task.

TASK 6: SAMPLE FABRICATION

Welding of the 33-1/2 O.D. A106 ferritic pipe is 50% complete. The revised welding procedure appears to be adequate and no visible indications of cracking have occurred thus far. It is expected that the samples will be delivered early in September.

Thermal cracking of the 10 inch Schedule 80S and 27.5 inch I.D. stainless pipe is in progress. Due to the longer than expected cycle times required to crack the 27.5 inch samples, the samples will not be available until mid-November. This will delay the Round Robin initiation to December 1, 1980.

Recent developments at PNL have shown that highly realistic (similar to service cracks) IGSCC cracks can be grown in 10 inch Schedule 40 304 stainless pipe. Tests are currently in progress to determine if IGSCC cracks of this type can be grown in a 10 inch Schedule 80S welded pipe sample. The results of this test should be known by early September.

TASK 7: MEASUREMENT AND EVALUATIONS

The recent results of the side drilled hole versus notch and flaw aspect raio tests were reported in the April-June quarterly and are not repeated here. Major measurement activities during the month centered on evaluation of cracked samples to be used in the Round Robin.

The schedule delay of the Round Robin has necessitated rescheduling of efforts; this additional time will be used to accelerate the measurement and evaluation program. Tasks presently in the preparation and planning stage include:

1. Investigations to establish a more effective calibration standard and inspection sensitivity.

2. Develop search unit selection criteria for use in conjunction with 1. above.

3. Investigate the influence of austinitic weld metal attenuation on inservice inspection where only one side of the weld is accessible.

4. The influence of surface roughness and surface profile conditions on inspection sensitivity.

In addition to the above, a review is currently being made of inservice inspection requests for relief. It is expected that this review will yield specific questions which could be answered by this program. The results of this review and recommended test programs will be included in the Phase II Analysis Before Test program.

Items which have been identified thus far include:

1. The effect of using an unclad calibration sample for the inspection of clad components.

2. The effectiveness of inspections performed on cast stainless components or pipes. This question should be answered by the upcoming Round Robin inspection.

3. The effectiveness or feasibility of inspections performed on thin wall pipes and vessels (.2 to .4 inch wall thickness). This problem is related to Class 2 systems and may therefore receive a lower priority.

It is expected that this review will be complete by September. Other specific recommendations by the NRC staff or others will be welcomed. We do not expect to initiate effort on these tasks, other than planning, until review and approval of the Phase II Analysis Before Test document is completed.

TASK 8: ROUND ROBIN PREPARATION

The Search Unit Tracking and Recording System (SUTARS) and software were delivered in July. Installation and check out of the software, tape unit and plotter have been delayed due to the lack of the proper interface board for the plotter. Efforts are currently in progress to locate an acceptable interface board.

As stated previously, the Round Robin will be delayed until December. This delay will allow us to fabricate our own IGSCC samples rather than rely on samples which may or may not be available from EPRI. These samples will be much more representative of field conditions, in terms of geometrical conditions and counterbar configurations. A 10 inch Schedule 40 and a 10 inch Schedule 805 pipe are in process at this time. If satisfactory cracks can be produced in the Schedule 805 pipe, the remaining samples required for the Round Robin will be made from the 805 pipe material.

FUTURE PLANS

Preparation for the Round Robin is continuing. Due to the delay in the Round Robin, additional emphasis will be placed on measurement and evaluation activities. It is expected that the SUTARS system will be operational by early September. Sample preparation for IGSCC cracking will be performed during the month of August.

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June 16, 1980

Dr. Joe Muscara
Metallurgy and Materials Research Branch
Reactor Safety Research Division
Nuclear Regulatory Commission
Mail Stop 1130-SS
Washington, D.C. 20555

Subject: Foreign Travel Trip Report, May 27 - June 6, 1980

Dear Joe:

This trip report describes activities conducted and information obtained by F.L. Becker, PNL, on behalf of the NRC, under research program B2289, "Integration of NDE Reliability and Fracture Mechanics," over the period from May 27 to June 6, 1980. The primary objective of the trip was to attend the CSNI Specialists meeting on testing of stainless steel, held in Brussels on May 28-29, 1980. Information gathering visits were also conducted at Association Vancotte (May 27), UKAEA Risley Laboratories (June 1), CEGB NDT Application Center (June 2) and Det Norske Veritas (June 5-6).

Information useful to the program was collected at each laboratory and is described within the body of the report. A primary objective of these activities was to establish agreements for cooperation with these organizations. In this regard, the visit to Risley was most beneficial. An outline of the recommended information exchange (under existing working agreements) is outlined in the report under the Risely visit. Agreements with other organizations consisted of exchange of published reports and personal communications. These reports and communications will prove beneficial to the program, as many of the investigations planned for this program may be reduced in scope in light of information which we have received from these organizations.

Association Vancotte, Brussels Belgium, May 27, P. Caussin, J. Cermac

Conversations and hands-on laboratory work with Mr. Cermac concerning coarse grain and centrifugally cast stainless resulted in the following conclusions:

1. The nature of centrifugally cast stainless steel is highly variable, even for one manufacturer.

2. The dual element (1 MHz, 45° L wave) search unit developed by Vancotte is effective for internal defects. However, it is only marginally effective for surface connected defects. (inservice cracks)

3. It was agreed to exchange grain structure micrographs, as well as velocity and attenuation anisotropy data as they become available.

4. A Vancotte probe was given to the program for evaluation. Results of the evaluation will be sent to Mr. Caussin.

5. A sample of our centrifugally cast stainless will be sent to Vancotte for comparison with three other samples presently in their possession.

6. Personal communications to continue to maintain cognizant of latest U.S.-European developments.

In addition to the above, Vancotte is initiating a parametric study of the effects of instrument variations on test results. The enlarged study program will most likely become part of PISC II. A similar study is lanned for this program in FY-1981. Cooperation between the two programs should prove to be mutually beneficial. However, since instruments used in the two countries are markedly different many of the experiments will need to be duplicated.

UKAEA Risley Nuclear Laboratories, Dr. R.W. Nicholes, I.P. Bell

Discussions at Risley centered on possible information exchange agreements between USNRC and the UKAEA. Discussions with Dr. Nicholes outlined their efforts in anticipation of a UK PWR program. These include a technique validation program and the establishment of a test authentication authority. Later discussions with Mr. Bell and his staff concentrated on possible areas of cooperation. A summary of the validation tests and authentication authority are summarized below.

Validation Tests. It is anticipated that a public inquiry concerning the UK decision to imp ement a PWR construction program will be held in the spring of 1982. A concern vital to the success of this program is the demonstration of the effectiveness of NDE procedures in assuring that unacceptably large cracks do not exist in the primary system (vessel and piping). In light of the less than spectacular results of PISC I, the UKAEA has established an accelerated program employing improved techniques (tandem, focused probe, 10 to 20% DAC and improved near-surface configurations), to demonstrate the effectiveness of these improved techniques.

Flaw sizes and locations will be approximately similar to PISC II; that is 10-25 mm defects located on or near the surface. Approximately four plates will be fabricated and three to four inspection teams will perform the tests. It is expected that the trials will be completed by early 1982 and that these improved techniques will demonstrate the required high assurance. No tests are planned for piping systems.

Authentication Authority. The second major step in the establishment of the PWR capability is the creation of an "Authentication Authority". This has been recently authorized. The main duties of the proposed UK Inspection Authentication Agency is shown on the attachment to this report. As can be seen from the attachment, many of the proposed activities are similar to I and E responsibilities. However, they go considerably further, particularly in approving the effectiveness of personnel and test procedures. It is my understanding that the effectiveness of all NDE techniques will be tested before they are accepted for field application.

Suggested Areas of Cooperation. Cooperation in this area should be mutually beneficial stemming from the fact that they (UK) are placing primary emphasis on the pressure vessel, whereas we are placing considerable emphasis on primary piping systems. Suggested areas of cooperation are as follows:

US (NRC) to provide:

1. Information and transfer of technology for producing thermal fatigue cracks.

2. Make information concerning effectiveness of primary piping inspections, including details if requested, available to the UKAEA.

UK (AEA-Risley) to provide:

1. Detail results of validation tests:

   a. progress reports and plans

   b. maximum signal amplitude response for each flaw, team, technique combination

   c. results of evaluation, probability of detection, probability of correct rejection and sizing accuracy.

2. Exchange of information on methods and statistical techniques which will be used for authentication of NDE method effectiveness.

A draft proposal for this cooperative agreement will be written for comment. After review by NRC the draft will be sent to Mr. I.P. Bell at Risley for further comment and revisions, if necessary.

The UK validation data along with PISC I data could be evaluated to determine the effectivenss of current US RPV inspections. Comparison of conventional ASME techniques and improved techniques would:

1. Demonstrate that current techniques and requirements are not adequate.

2. Demonstrate the effectiveness of improved techniques.

3. Provide a basis and justification for improved requirements.

CEGB NDT Application Center, A. Wouldridge, Dr. J. Coffey, Dr. J. Tomlinson

The Central Electricity Generating Board (CEGB) NDT Application Center, Wythenshaw, England, was visited on June 3, 1980. The primary objective of this meeting was to obtain additional information on crack roughness and tightness, as well as information on the influence of surface roughness on detection and sizing accuracy. The effects of anisotropic velocity and attenuation effects in cast austentic material was also discussed.

The major points of discussion were the studies on crack tightness, roughness and liquid filled cracks performed by Tony Wouldridge. The results of these studies were very similar to our own, except that the CEGB study included liquid filled cracks and a greater range of roughness, while our study concentrated on a larger number of samples (for statistical purposes) at the extremes of expected roughness. Results of the two independent investigations are in substantial agreement. We, therefore, believe it will not be necessary to perform further experiments on the effects of crack tightness. Minor experiments on crack roughness and liquid filled cracks may need to be performed to extend the current data base.

The second topic of discussion was the effect of surface roughness on the effectiveness of ultrasonic inspection. This study, performed by Dr. John Coffey, resulted in acceptance standards and requirements for grinding of weld crowns. A copy of the report on this subject was received and will be analyzed to determine its usefulness in our investigations. It is expected that the maximum allowable roughness 125 μ in RMS is a value which should be mandatory. Further investigation will be required to evaluate contour specifications and their impact on US practices. Useful discussions were also held on the subject of propagation through austenitic weld metal. These discussions were in agreement with the results presented at the Brussels meeting.

An interesting application of fracture mechanics and NDE reliability was also discussed. This involved a pumped storage hydroelectric project. The procedure required estimation of the largest crack which could be missed during inspection. It was then calculated how long it would take this flaw to grow through wall. The inspection frequency was then set at 1/5 the time for through wall crack growth.

This CEGB organization has also written standards for ultrasonic search unit performance and is in the process of establishing requirements for instrument performance. These requirements are useful, however, I do not believe they sufficiently address the problem of inspection repeatability due to search unit and instrument variability.

CEGB NDT Center personnel are highly qualified and continued communications with this group will be beneficial.

Det Norske Veritas, O. Forli

The primary objective of this visit was to discuss details of a program conducted by Mr. Olav Forli on "Comparison of Radiography and Ultrasonic Testing." The statistical results of Forli's program match closely our predictions for probability of detection. Detail discussions were held concerning the conduct of the program and the reasons for the large spread in the data. We had originally understood that the lack of penetration defects in Forli's program were located at the back surface of the plate. However, it was learned that this was not the case. Double V weld prep was used for all welds and the defects were located near the center of the plate. Forli's data is, therefore, more applicable to fabrication and preservice inspection, as opposed to inservice inspection.

One interesting point revealed in the discussions was that the standard deviation for inspectors who recorded at 50% DAC was much less than those who recorded at 20% DAC.

Forli agreed to send us copies of detailed test results for our analysis. This program is continuing and will provide further information on testing reliability and repeatability.

OECD CSNI Specialists Meeting on Reliability of Ultrasonic Inspection of Austenitic Stainless Steel Components, Brussels, Belgium, May 29-30, 1980

The results of this meeting are too numerous to discuss here (a copy of the agenda is attached) and I would be glad to supply copies of particular papers or discussions of applicable areas with concerned individuals. However, in general, it appears that we are gaining a basic understanding of the physics concerned with propagation in coarse grain austenitic material. It appears that 45° longitudinal wave propagation is the only feasible approach. Most papers dealt with detection of internal fabrication defects. The 45° L wave technique is suitable for internal fabrication defects but is inadequate for surface connected defects due to the mode conversion to shear at a corner reflector. The application of signal averaging and other signal-to-noise ratio improvement techniques appears to be promising.

I would be glad to answer any specific questions concerning papers given at this conference.

Sincerely,

F.L. BECKER
Nondestructive Testing Section

FLB:dd

Attachment

CSNI Specialist Meeting on Reliability of Ultrasonic Inspection of Austenitic Materials and Components, Brussels, 29-30 May 1980 hosted by Association Vincotte

P R O G R A M M E

29th May 1980

9.00 a.m. : Registration

10.00 a.m. : Welcoming address : Mr. J. Geothals
Directeur, Association Vincotte

10.15 a.m. : Chairman - opening remarks : P. Caussin

10.25 a.m. : Session 1 : Fundamentals

Chairmen : K. Goebbels, X. Edelmann

- A. Juva
  The effect of anisotropy of the propagation of ultrasonic waves in austenitic stainless steel
- J.P. Launay, J.J. Olivera, R. Trumpff*
  Contribution to improving ultrasonic testing of thick bimetallic welds

11.20 a.m. : C O F F E E   B R E A K

11.35 a.m. :

- H.A. Crostack
  Some fundamental aspects of testing austenitic steel structures by ultrasonics
- J.L. Rose*, M.J. Avioli, M.E. Lapides
  Utilization of a Fisher Linear Function in IGSCC detection

12.30 p.m. : L U N C H

1.45 p.m. :

- E. Neumann*, M. Roemer, R. Schenk, K. Matties
  On the application of ultrasonic testing techniques for coarse grain austenitic welds.
- D.S. Kupperman
  Overview of Argonne National Laboratory work on Ultrasonic NDE of stainless steel welds.

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* Speaker

2.35 p.m. : Session 2 : Instruments and Methods

Chairmen: C.E. Lautzenheiser, J.P. Launay

- B.S. Gray*, R.J. Hudgell, H. Seed
  Longitudinal wave ultrasonic inspection of austenitic weldments.
- M. Igarashi*, T. Shibata, M. Miura
  Ultrasonic testing technique of fuel cladding tubes for FBR - grass echo suppressing techniques
- J.R. Tomlinson*, A.R. Wagg
  Experience of ultrasonic inspections of fillet welds in austenitic steel in Heysham and Hartlepool AGRs

3.50 p.m. : C O F F E E B R E A K

4.05 p.m. :
- S. Kraus*, K. Goebbels
  Improved ultrasonic inspection of austenitic stainless steel components by signal averaging techniques
- G. Gruber
  Multiple-bearing-angle (MBA) crack detector for cladded pipe examination
- V.L. Newhouse*, N.M. Bilgutay, J. Saniie
  Flaw visibility enhancement by split-spectrum processing
- S. Ganapathy
  Ultrasonic imaging technique in nondestructive evaluation

6.00 p.m. : C O C K T A I L P A R T Y - offered by Association Vincotte

7.30 p.m. : Buses to city

30th May 1980

9.00 a.m. : Session 3 : Industrial practice

Chairmen: J.R. Tomlinson, A. Juva

- X. Edelmann
  Application of ultrasonic testing techniques on austenitic welds for fabrication and in-service inspection

- M. Kroll*, E. Fischer, M. Sternischa, H.D. Wallheinke
  Recent experience in the ultrasonic examination of austenitic steel components
- L. Yague de Alvara
  Spanish experiences on stainless steel UT inservice inspection in nuclear plants

10.15 a.m. : COFFEE BREAK

10.30 a.m. :
- J.P. Launay*, J.C. Lecomte, P. Martin, A. Thomas
  Detection of underclad defects by nondestructive testing
- T. Saitoh*, S. Takashi
  Sizing of cracks perpendicular to stainless steel weld overlay

11.30 a.m. : Visit to the laboratories

12.30 p.m. : LUNCH

1.45 p.m. : Session 4 : Reliability

Chairmen : I. Bell, J. Muscara

- S. Sandberg
  Survey of ultrasonic testing in austenitic weld materials
- G. Artoniola, D. Laterza, G. Torrida*
  Ultrasonic examination of stainless steel E.B. welds by an immersion technique
- P. Caussin*, J. Cermak, D. Verspeelt
  Factors affecting the reliability of the ultrasonic examination of austenitic components
- C.E. Lautzenheiser*, W.C. Hegaughey, W.T. Flash
  Detectability of intergranular stress corrosion cracking using field-proven ultrasonic technique
- F.L. Becker
  Ultrasonic inspection reliability for primary piping systems

4.00 p.m. : COFFEE BREAK

4.15 p.m. : Panel Session

Chairman : P. Caussin

Panelists : X. Edelmann, K. Goebbels, J.P. Launay, C.E. Lautzenheiser, J. Muscara, J.R. Tomlinson

5.30 p.m. : Closure of Meeting

5.45 p.m. : Buses to city and airport

INTEGRATION OF NONDESTRUCTIVE EXAMINATION RELIABILITY AND FRACTURE MECHANICS[(a)]

F.L. Becker, Program Manager
S.H. Bush, Project Manager
F.A. Simonen, Project Manager

S.R. Doctor
G.B. Dudder
P.G. Heasler
G.P. Selby

SUMMARY

Primary emphasis during the past quarter was directed toward sample preparation for the round robin and measurement of the impact of inspection sensitivity changes resulting from the 1977 Code revision. It is presently expected that the round robin will be de.ayed from August, 1980 to December, 1980, due to delays in sample preparation. The reduction in inspection sensitivity resulting from the 1977 Code revision was measured to be from 6 to 16 dB over the range from .4 to 2.4 inch wall thicknesses. Recommendations for corrective measures are in preparation.

INTRODUCTION

The primary piping systems of nuclear power plants are inspected inservice according to the rules of the ASME Boiler and Pressure Vessel Code, Section XI (Rules for Inservice Inspection of Nuclear Power Plant Components). These inspections are performed periodically on a sampling of pipe joints. Ultrasonic techniques are normally used for these inspections.

The Integration of NDE Reliability and Fracture Mechanics Program has been established to determine the reliability of current inservice inspection techniques and to develop recommendations which will assure a suitably high inspection reliability. The objectives of the program include the following:

Determine the reliability of ultrasonic inservice inspection (ISI

(a) RSR Fin. Budget No. B2289-0; RSR Contact: Dr. J. Muscara

performed on commercial, light water reactor primary piping systems.)

Using fracture mechanics analysis, determine the impact of NDE unreliability on system safety and determine the level of inspection reliability required to assure a suitably low failure probability.

Evaluate the degree of reliability improvement which could be achieved using improved and advanced NDE techniques.

Based on material, service and NDE uncertainties, formulate recommended revisions to ASME Section XI and Regulatory Requirements needed to assure suitably low failure probabilities.

The scope of this program is limited to inservice inspection of primary piping systems. The results and recommendations are also applicable to Class II piping systems. Programs currently in progress concerning inspection reliability of pressure vessels are also being monitored and evaluated.

TECHNICAL PROGRESS

The progress and major accomplishments of the past quarter are described below by task.

TASK 6: SAMPLE FABRICATION

Two major activities are in progress as a part of this task. These include sample fabrication and sample cracking. The ten inch schedule 80S, 304 stainless and 27.5 inch I.D. cast stainless samples have been welded and are currently being cracked by the thermal fatigue process. The A106 carbon steel pipes were delivered in late April, 1980 and welding initiated in early May. After completion of one weld and partial completion of the second weld, numerous cracks were detected near the weld fusion line. Chemical analysis indicated a high carbon content for the material (.4%, .35 allowed maximum). The cracking was attributed to lack of sufficient preheat and low interpass temperatures which would be unsuitable for material with this high carbon content. The welding procedure has been revised to provide the necessary preheat and post weld heat treatment. The samples have been remachined and welding, using the improved procedure, is in progress. It is expected that the welded samples will be delivered by September 1, 1980.

Thermal fatigue cracking of the ten inch diameter schedule 80S stainless steel and 27.5 inch I.D. cast stainless pipes is in progress. Two of the six required ten inch pipes have been completed (five cracks) and two of the 16 required cracks in the 27.5 inch cast have been completed.

Parameter development test on the 27.5 inch cast material has shown that cracks as deep as 1.0 inch can be grown reliably. The crack shown in Figure 1 was grown in a welded 27.5 inch cast stainless sample in 21 days. With the currently available fatigue stations (four), it is expected that the cast stainless specimens will be completed by October 1, 1980, and the 33 inch diameter ferritic samples will be completed by mid-November, 1980. This schedule would allow initiation of the round robin tests by December 1, 1980. Alternatives to shorten this schedule are currently being investigated.

TASK 7: MEASUREMENT AND EVALUATION

Two measurement programs are currently in progress. These include measurement of the reduction in inspection sensitivity resulting from the use of notch calibration reflectors as opposed to side drilled holes and the influence of flaw aspect ratio on signal response.

Calibration Sensitivity

The 1977 Revision, Summer 1978 Addenda of the ASME Code Section XI, Appendix 3 revised the calibration reflector from a side drilled hole (1974 Revision) to a notch reflector of depth $d = 0.104t - 0.009t^2$ for ferritic steel piping and 10% of wall thickness (t) for austenitic piping. A measurement program was developed to determine the impact on test sensitivity of this Code revision.

The measurement program to determine the impact of the change in calibration reflectors, consisted of approximately 540 measurements on 34 piping calibration standards. The standards (from a BWR reactor presently under construction) ranged in wall thickness from .237 to 2.343 inches, and in diameter from four to 30 inches. Twenty-six of the samples were ferritic and eight were stainless steel. The samples contained both side drilled holes and notch reflectors according to the applicable codes. Measurements were performed using 0.25, 0.5 and 1.0 inch diameter, 2.25 MHz search units using 45° and 60° shear wave contact shoes. The .25 inch search unit was used for thicknesses up to

.75 inch. The 1.0 inch search unit was used for thicknesses greater than .75 inch and the 0.5 inch unit was used over the total range. A Sonic Mark I flaw detector was used for the measurements. A Nortec 131D flaw detector was used for verification on four of the samples.

The measurements were performed by establishing a distance amplitude correction (DAC) curve for the side drilled holes and measuring the notch response relative to the DAC curve. For 45° shear waves, the principal angle used for piping inspection, the measured results are shown in Figure 2. The notches produce higher reflected amplitudes than the side drilled holes. A calibration performed using the notches (1977 Code) will, therefore, provide a less sensitive inspection than the side drilled hole calibration (1974 Code). The reduction in inspection sensitivity is dependent on pipe wall thickness ranging from -6 dB (a factor of 2) at .4 inch to -16 dB (a factor of 6.3) at a wall thickness of 2.4 inches. The error bars on the measured curve of Figure 2 are the $\pm 2\sigma$ error bars for the measurements (σ equals 2 dB).

Theoretical calculations were performed according to Ermolov, 1972 and Werneyer, 1977, to assure that the measured results in Figure 2 were reasonable. These calculations, shown in Figure 2 as "Theory", are in close agreement with the measured results. The calucations were performed for the far field conditions which are satisfied for thicknesses greater than 1.0 inch. However, the differences below one inch are not great. It should be noted that the theoretical curve has not been adjusted to fit the data, but is the actual dB difference predicted by the theory. The agreement is remarkable.

For 60° shear wave inspection, there was not a statistically significant difference between the side drilled hole and the notch calibration sensitivies. However, the side drilled hole calibration was qualitatively slightly less sensitive. This difference between 45 and 60° shear wave inspection results from mode conversion at the notch reflector. Reflection from the side drilled hole is always at normal incidence and no mode conversion takes place. For a notch or right angle reflector, two reflections occur; one at the incident and one at the complementary angle, as sound is reflected from the back surface and the notch surface. At 45°, both reflections are above the critical angle for longitudinal mode conversion and the sound is totally reflected. At 60° incidence, the complementary angle is 30°, which is below the angle of total relfection. At 30° only approximately 15% of the energy is reflected as a shear wave with the remainder being mode converted to a longitudinal wave, which does not return to the search unit.

Three variables in the experiment not yet discussed include: material, search unit diameter and instrument. Eight of the samples were stainless steel (maximum size, 24 inch diameter, 1.140 inch wall). Since this experiment measures the relative amplitudes of reflectors in the same sample, we would not expect major differences due to material type. This was indeed the case. However, the stainless samples did show slightly more scatter due to point-to-point differences in material attenuation. The overall trend, however, was consistent with the ferritic samples. No statistically significant trend difference was noted for changing transducer diameter as long as the correlations were applied within their applicable ranges (up to .75 inch thickness for the 1/4 inch search unit and greater than .75 inch thickness for the 1.0 inch search unit). Spot checks with the Nortec instrument showed no appreciable differences from results obtained with the Sonid Mark I instrument.

In summary, it can be said that calibration for 45° shear wave inspection will be from 6 to 16 dB less sensitive using the notch relfectors (1977 Code) as opposed to side drilled holes (1974 Code). The theoretical calculations agree with the measured results and can in the future be used as a basis for comparison.

Impact on Inspection Reliability of Inspection Sensitivity

The depth of calibration notches specified in Appendix III - 3430 (Section XI, 1977 Revision) are on the same order as allowable planar indications specified in Tables IWB-3514-2 and -3 for inservice examination (Section XI, 1977 Revision). The calibration sensitivity established by Appendix III is not sufficiently sensitive to detect unacceptably large flaws due to the following:

1. The reporting level is set at 100% DAC (primary reference level).
2. The "ideal" calibration reflector (notch) is longer than the flaws required to be detected.
3. The maximum allowable flaw sizes for preservice examination are smaller than the calibration reflector.
4. Cracks occurring inservice are not "ideal" reflectors and will, due to their roughness, tightness and orientation, yield lower reflected amplitudes than ideal reflectors (notches).

Measurements and evaluations previously reported, Hooper 1979, and Hooper 1980, indicate that the influence of the factors listed previously could be as large as 12 dB. It is, therefore, unrealistic to expect inservice cracks to yield reflected amplitudes exceeding 100% DAC (1977 Code). Based on the above, it is our contention that the reduction in test sensitivity, shown in Figure 2, resulting from acceptance of the 1977 Code through Summer, 1978, is not justifiable.

Inspection of Machined Flaws of Varying Aspect Ratios

Under another NRC-sponsored ultrasonic ISI research program* our laboratory has acquired specimens of four types of reactor pipe, each containing several machined defects. Inspection of these samples permits us to observe the combined influence of several parameters influencing flaw detectability.

The four types of pipe are:

4" diameter, 0.237" wall thickness, carbon steel

12" diameter, 0.688" wall thickness, 304 stainless steel

20" diameter, 1.031" wall thickness, carbon steel

20" diameter, 1.031" wall thickness, 304 stainless steel

The machined reflectors include I.D. and O.D. 1977 ASME, Section XI calibration end-mill notches and a 1974 ASME side drilled hole. The other reflectors are EDM notches of three different aspect ratios and angles of orientation (from vertical), for a total of nine EDM defects per pipe sample. The three flaw angles are 0° (vertical), 15° and 25°. These angles were selected for their poor reflection characteristics, based on our earlier results from inspection of angled flaws in flat plates. The three aspect ratios are 0.5 (semi-circular), 0.25, and 0.05. The notch depths are those defined as maximum allowable, as a function of aspect ratio, in Tables IWB-3514-2 and -3.

Inspection of these machined defects was carried out using two ultrasonic instruments, frequently employed in reactor ISI: a Sonic Mark I and a Nortec 131D. Three transducers were used: 1/4", 1/2" and 1", 2.25 MHz Areotech Gamma units. Inspections were performed at 1/2 V 45°, 3/2 V 45° and 1/2 V 60°

*RSR Fin. Budget No. B2157; RSR Contact: Mr. George Johnson/Mr. Martin Hum beam paths. Reflection amplitudes were recorded as dB relative to the end-mill notch DAC required by the 1977 version of ASME Section XI.

To date, full data has been taken for all samples except the 20" stainless steel pipe section, which will be left out of the observations and conclusions that follow.

The primary observation is that beam spread seems to be the key to angled-flaw detection, as observed earlier in studies on flat plate samples. Data taken using the Nortec instrument are usually higher in amplitude and fluctuate less with flaw angle changes, than data taken using the Sonic unit. The operating frequency of the Nortec unit is some 200 KHz lower than that of the Sonic, leading to more beam spread. Also, less angle sensitivity and generally higher amplitudes are produced by the smaller of a pair of transducers, viz. the transducer with more beam spread. These observations are in agreement with earlier studies of angled flaws in flat plates, when it was shown that the best combination of high amplitude and low fluctuation with angle was achieved using low frequency (1.5 MHz) dual search units with 3/8" square sending and receiving transducers.

A second observation in support of earlier flat plate studies is that 60° inspection performs better than 45° inspection for nonvertical flaws. This is because the mode conversion from the calibration notch is at its maximum for a 60° beam, causing a high calibration gain setting. When a nonvertical flaw is inspected, the mode conversion is reduced or absent, so at 60° beam angle there is more opportunity for the flaw to exceed the notch amplitude and, therefore, become reportable. Using a large transducer takes most advantage of this effect. The reflected beam from a nonvertical flaw may not exit the metal at its entry point (transducer location), but in some cases (most notably for a 15° flaw) the beam exit is close enough to the beam entry point that a large transducer may receive it while a small one might not.

Detection of the vertical flaws was best achieved by 45° inspection. Inspection using both beam angles is indicated for higher detection probability.

Increasing pipe wall thickness seems to have a negative effect on reflection amplitudes. The 4" pipe data show very little amplitude change as a function of flaw angle, while the 20" pipe data fluctuate considerably. This is attributed to two effects. First, the flaws in the 4" pipe are about 0.6 λ deep, where λ represents the acoustic wavelength. The 20 inch pipe flaws are about 1.9 λ deep. The higher depth causes the reflected beam to be more collimated, meaning that the area of emergence on the pipe surface will be small. Second, in a thick wall, the reflected beam has farther to travel to reach the surface. Clearly, if the reflected beam does not retrace the path of the incident beam, then the farther it travels the greater the separation will be between insertion and emergence points. For the four inch pipe, the wide-spread reflected beam does not have enough room to deviate much from the incident beam path. When it reaches the surface, the reflected beam illuminates an area which is at least partially but probably mostly eclipsed by the transducer, producing a high amplitude signal. For the 20 inch pipe, the collimated reflected beam has more space in which to diverge from the incident beam path. Therefore, we have a reflected beam illuminating a small area of the pipe surface which may be far from the search unit, and, therefore, low amplitude and more variation of amplitude with varying flaw angle.

Comparison of aspect ratios yields few surprises. A longer flaw generally produced an equal or higher amplitude than a similar shorter flaw. There are some exceptions--the longest flaw in a few cases reflecting less than the medium length flaw--which at this time, defies confident explanation, but usually the expected occurs and a flaw of greater area produces greater amplitude.

Nonvertical flaws of less than maximum length and vertical semicircular flaws proved rarely reportable (100% DAC) in 45° inspection. The best results are achieved using the 1/4" search unit. Many of the data fall below 50% DAC and are, therefore, not even recordable. Almost all the data lies above 20% DAC; none are below 10% DAC.

Impact of Machined-Flaw Data on Inspection Reliability

Inspection of machined notches of varying angle and aspect ratio in pipe specimens indicates poor recording and reporting probability. The flaws are of maximum allowable (minimum rejectable) depth, and inspections were carried out using an ASME Section XI, 1977 DAC.

Major conclusions are:

60° beam inspection will detect nonvertical flaws more reliably than 45° inspection. 45° inspection is generally better for 0° flaws. Use of both beam angles is indicated.

Detection probability of nonvertical flaws is enhanced by high beam spread, which may be achieved by low frequency and/or low transducer size.

Nonvertical flaw orientation becomes more of a problem as pipe wall thickness increases. In inspection of thin wall pipe, countermeasures may not be necessary.

Reliable detection of nonvertical flaws, especially flaws of high aspect ratio (short flaws), will require an increase in inspection sensitivity through changes in claibration reflector and/or recording and reporting levels.

The data set will be completed by completion of the inspection of the 20 inch stainless pipe specimen. Also, these samples will be inspected with a 1.5 MHz dual search unit in hopes of reducing detectability dependence on flaw orientation. In addition, the spectra of beams reflected from certain flaws will be examined to check our theory that low frequencies enhance nonvertical flaw detection.

TASK 8: ROUND ROBIN PREPARATION

Preparations for the round robin inspection are proceeding. Sample preparation (see Task 6) is currently the major delay. Contractual negotiations with inspection agencies is in progress. The test protocol has been written and will be sent to the inspection agencies for comment. The SUTARS (Search Unit Tracking and Recording System) instrument has been delivered and system installation and check out is in progress.

FUTURE PLANS

An attempt will be made to shorten the projected delay due to sample preparation. Efforts are continuing to define the impact of decreased inspection sensitivity resulting from the 1977 Code revisions and the formulation of recommendations for correcting this problem area. A revised program schedule and redirection of effort will be redefined during the month of August.

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FIGURE 1. Thermal Fatigue Crack; 6.75 Inch Deep, 2.5 Inch Long, in a Welded Cast Stainless Steel Pipe Sample.

REDUCTION IN ULTRASONIC INSPECTION SENSITIVITY
77 CODE RELATIVE TO 74 CODE
CLASS 1 AND 2 PIPING

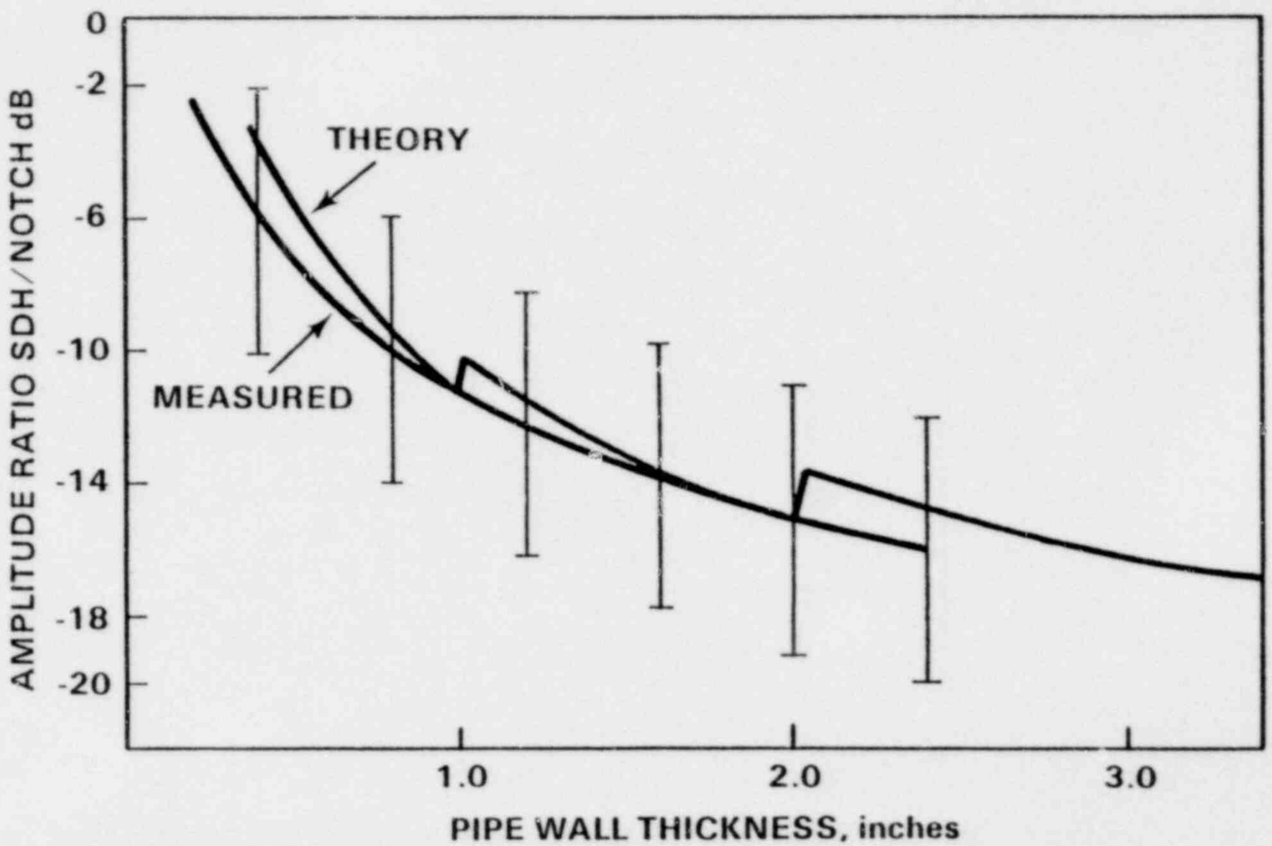

FIGURE 2. Measured and Theoretical Reduction in Ultrasonic Inspection Sensitivity Resulting From Calibrations According to 1977 Code (notch) Relative to 1974 Code (side-drilled holes-SDH). Error Bars ($\pm$ 4 dB) Are the 2σ Measurement Error Bounds.