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THE NONDESTRUCTIVE EXAMINATION
OF G AND H LOTS FFTF FUEL CLADDING

J. Ryden, Jr
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May 1970

AEC RESEARCH &
DEVELOPMENT REPORT

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BNWL-1359

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THE NONDESTRUCTIVE EXAMINATION
OF G AND H LOTS FFTF FUEL CLADDING

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May 1970

IN3 '70

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Printed in the United States of America
Available from
Clearinghouse for Federal Scientific and Technical Information
National Bureau of Standards, U.S. Department of Commerce
Springfield, Virginia 22151
Price: Printed Copy \$3.00; Microfiche \$0.65

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ABSTRACT

An inspection for defects, using ultrasonic techniques, has been performed on 2744 ft of small diameter stainless steel tubing (G and H Lots). The intended use for this tubing was as reactor fuel cladding in fuel performance studies for the Fast Flux Test Facility (FFTF).

The ultrasonic pulse-echo inspection mode was used to detect and reject defects equal to or greater than 8% of the wall thickness in depth. Statistical control techniques were used to maintain the precision of the tester to a known value. This provided a test of high reliability and a greater assurance that defects of rejectable size were actually rejected.

Although the two lots had the same metallurgical composition, they were fabricated differently. The H Lot tubes were fabricated in a conventional manner. The G Lot received extra treatment and care in the fabrication in an attempt to reduce the number of rejectable defects. The test results verified that G Lot did have fewer defects; i.e., 8% for G Lot versus 15% for H Lot.

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THE NONDESTRUCTIVE EXAMINATION OF G AND H LOTS FFTF FUEL CLADDING

J. Ryden, Jr. and E. F. Perrizo

INTRODUCTION

The nondestructive examination of G and H Lots FFTF fuel clad tubing for defects has been performed. This report presents a description of the equipment, techniques and quality control program used, as well as test, statistical, and metallographic results. Appendix A includes testing specifications and cladding description.

SUMMARY

An ultrasonic pulse-echo technique was used to inspect 2744 ft of FFTF developmental fuel cladding for defects. Verification and control of the tester performance was made by use of a statistical control procedure that was followed throughout the testing. The defect reject size was based on the tester responses from electric-discharge-machined (EDM) notches that were oriented both axially and circumferentially on both tube surfaces. Defects were rejected that produced tester indications equal to or greater than that obtained from 1.2 mil deep by 5 mil wide by 30 mil long EDM notch. The test system's precision was such that there was a 0.95 certainty that the above size defects were rejected 95% of the time.

SYSTEM DESCRIPTION

GENERAL

A photograph of the complete tube testing facility is shown in Figure 1. It consists of system electronics, transducers, recorder and tubing transport system.

FIGURE 1. Ultrasonic Tube Testing Facility

The electronic units are built into a Tektronix Oscilloscope plug-in chassis. The oscilloscopes are used for displaying the signal train and gating pulses.

The transducers are mounted on fixtures inside the water tank. Micrometer adjustments allow the transducers to be accurately aligned to the tube surface.

The recorder has two channels and is used to record the defect responses. One channel is for the transverse defects, and the other is for the axial defects.

The transport system provides an accurate helical scan along the tube length. A synchronous motor provides a tube rotation of 1450 rpm. The water tank, containing the transducers, is translated the length of the tube by a motor driven lead screw.

ELECTRONICS

Two modified NORTEC NDT-100 ultrasonic testers, one for each transducer, were used. The function of these units was to repetitively pulse the transducers, amplify and process the return echoes for display on a strip chart recorder. Since the basic testers consisted of only a pulser and receiver, gating and integrating circuits were designed and incorporated in the units. Figure 2 shows a block diagram of the modified unit. The operation is as follows. The pulser supplies a sharp spike pulse to the transducer at a fixed repetitive rate. The signals from the transducer are amplified by the amplifier and then displayed on the oscilloscope CRT. This same signal train is also coupled to the Flaw Gate which has two modes of operation: Direct and Surface Gate

FIGURE 2. Electronics Block Diagram

Follower. In the Direct mode, the time position of the gating pulse is fixed. In the Surface Gate Follower mode, the position of the gating pulse remains a fixed amount of time behind the front surface signal. Thus, if the tube to transducer distance varies, so will the gating pulse and the flaw signals will always occur within the gating pulse. The Delay and Gate Pedestal Generator circuits provide the necessary signals for the positioning of the flaw gate. The output of the flaw gate contains only the defect signals. This output is coupled to a peak reader circuit which processes the signals for display on a strip chart recorder.

TUBING TRANSPORT SYSTEM

The transport system provides the basic helical scan over the length required for 100% ultrasonic inspection of the tubing. The equipment, illustrated in Figure 3, provides the test scan while accurately maintaining the required tube to transducer alignment.

With the tank at the end position, the tube to be tested is placed between the mandrels and grasped on the inside surface by expandable rubber chucks. The tubing is then rotated by a synchronous motor coupled to the mandrel. A second motor is coupled to a lead screw which drives the test tank in either direction. Entry ports at the sides of the water tank provide access for the tube being tested. Rubber "o" rings, mounted in bearings, fit snugly around the tube and contain the water. To reduce the tendency of some tubes to vibrate when rotated at 1450 rpm, tube stabilizers are mounted 18 in. apart on the main frame. The stabilizers are designed so that they open and close upon the passing of the tank. While the tubing is rotated, the test tank is translated from its start position, over one mandrel, to its finish position over the other mandrel. The tested tube is then ready to be exchanged for an untested tube. An exchange can take place in less than 60 sec.

(a) TUBING TRANSPORT SYSTEM

(b) TEST TANK

FIGURE 3. Tubing Transport System Cross Section

DESCRIPTION OF ULTRASONIC TECHNIQUE

An ultrasonic pulse-echo technique was used to inspect the cladding. Two transducers were used, one oriented to detect transverse defects, and the other oriented to detect axial defects as illustrated in Figure 4.

FIGURE 4. Ultrasonic Transducer Positions

Initially, numerous different types of transducers and modes of ultrasonic wave propagation were investigated. The best results were obtained with a round, unfocused transducer in the transverse test, and a medium spherically focused transducer in the axial test. The complete testing parameters are given in Table 1.

TABLE 1. Ultrasonic Test Parameters

Transverse Test Transducer	8 MHz, flat-faced 125 mil diameter ceramic
Axial Test Transducer	10 MHz, spherically focused ceramic
Transverse Transducer Angle	16°
Axial Transducer Offset	40 mils
Pulse Repetition Rate	6000 pps
Tube Rotation	1450 rpm
Relative Tube Translation Rate	9 in./min

CALIBRATION STANDARD

In accordance with the testing specifications (see Appendix A), a calibration standard was fabricated. Notches were induced by the electric-discharge-machining (EDM) method in a defect-free tube. A drawing of the standard and the measured notch depths are shown in Figure 5. All notches were specified to be 30 mils long by 5 mils wide. Three different depths, for each orientation and location, was desired for calibration purposes. Since the EDM process is not accurate enough to produce the exact desired depth, all notches were replicated and the dimensions measured with a microscope.

QUALITY CONTROL PROCEDURES AND TECHNIQUES

A statistical control program was followed throughout the testing of the tubing. The purpose of this program was to verify that the tester precision stayed within known limits.

A prerequisite to the start of the inspection was the knowledge of the tester's short and long term drift. This was determined by inspecting the calibration standard with the tester 5 times in succession at 1 hr intervals over an

A. CALIBRATION STANDARD

NOTCH	DEPTH (MILS)	NOTCH	DEPTH (MILS)
TRANSVERSE 1	1.73	AXIAL 1	1.20
TRANSVERSE 2	2.56	AXIAL 2	2.32
TRANSVERSE 3	4.02	AXIAL 3	4.00
TRANSVERSE 4	1.02	AXIAL 4	1.65
TRANSVERSE 5	1.84	AXIAL 5	2.99
TRANSVERSE 6	4.36	AXIAL 6	5.86

B. MEASURED NOTCH DEPTH

FIGURE 5. Calibration Standard Drawing and Measured Notch Depth

8 hr period. By use of statistics, the variance of the amplitudes of the tester response from each standard notch was calculated. This was done for both a short-term and long-term basis. The short-term variance was indicative of the precision and the long-term was a measure of the instrument's drift.

A calibration curve was then plotted of the measured notch depths versus the statistical means of the tester response amplitudes, as obtained from the short term variance. This plot, along with the tester precision data, enabled the reject level to be set so that the testing specification could be met.

Control of the tester was maintained throughout the inspection by use of control charts. The testing procedure required that the calibration standard be inspected two consecutive times before initiation of production testing and at approximately each hour thereafter. The range and average for each of the nominal 1 mil deep notches were calculated. These notches were the circumferential inside and outside notches, and the axial inside and outside notches. The average and range for each notch were then plotted on their respective control charts. These values had to be within statistically determined limits or the tester was out of control. An out-of-control situation required corrective action and all tubes had to be retested since the last satisfactory run of the standard.

TESTING PROCEDURE

Extreme care was exercised during the inspection to prevent damaging the tubes. The tubes were shipped in individual cardboard containers. They remained in these containers until they were inspected. Then only one tube at a time was removed from its container. This extra precaution did not add significantly to the testing time.

TEST RESULTS

The 2744 ft of tubing consisted of 392 7-ft long tubes. Of these, 255 tubes were designated G Lot and the remaining 137 tubes were designated H Lot.

The G Lot tubes had been fabricated using special procedures and processes. The H Lot tubes had been processed in a normal fashion. The purpose of using the special procedures on G Lot was to determine if a higher yield of nondefective tubes would result. Table 2 summarizes the test results. The G Lot tubes did in fact have fewer defects. In addition to defects, some of the tubes presented a background noise level higher than the reject level. According to the testing specifications, these were also rejects. However, for analysis purposes, a separate category is shown in the table. Again, G Lot had a fewer number in this category. The exact cause of this noise was not definitely determined, although several of these tubes had a larger grain size than the others.

TABLE 2. Test Results

<u>Lot</u>	<u>Number of Tubes Inspected</u>	<u>Tubes with Rejectable Defects, %</u>	<u>Tubes with Noise Level too High, %</u>	<u>Total % of Tubes with Rejectable Defects and with Noise Level too High</u>
G	255	7.8	7.0	14.9
H	137	15.0	23.0	38.0

The defects consisted mostly of cracks, laps, and gouges. Figures 6 and 7 show two typical defects.

Tube No. G-304

10X

Tube No. G-304

200X

FIGURE 6. Typical Defect from G Lot

Tube No. H-122

10X

Tube No. H-122

200X

FIGURE 7. Typical Defect from H Lot

ACKNOWLEDGEMENTS

The authors express their appreciation to W. F. Stevenson and A. C. Callen who constructed the statistical control program, to R. J. Lobsinger who represented the tubing user, and to T. J. Davis for assistance in some of the circuit design.

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APPENDIX A
TESTING AND CLADDING SPECIFICATIONS

APPENDIX A

TESTING AND CLADDING SPECIFICATIONSTESTING SPECIFICATIONS

The requirements to be met in the inspection of the cladding are as follows:

- All tubes are to be 100% inspected.
- All defects are to be rejected which produce indications equal to or greater than that produced by electric-discharge-machined notches, oriented circumferentially and axially, on both the inner and outer tube surfaces having dimensions of 0.0012 in. deep by 0.030 in. long by 0.005 in. wide. The test system's precision must be controlled to the extent that there is to be a 0.95 certainty that the above sized defects are rejected 95% of the time.

CLADDING DESCRIPTION

The cladding was purchased to the following specifications:

- Type 316 stainless steel
- 0.250 in. OD $\pm$ 0.001 in.
- 0.218 in. ID $\pm$ 0.001 in.
- Fully annealed
- Grain size after anneal, less than ASTM 6
- Seven-foot lengths.

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