468
12-23-75
7120-3 plus
Germany + Japan
(4)
plus UC-37

Dr. # 1868

ANCR-1259

UC-37

NRC-3

INSPECTION SYSTEM FOR ZIRCALOY CLAD FUEL RODS

Aerojet Nuclear Company

IDAHO NATIONAL ENGINEERING LABORATORY

Idaho Falls, Idaho — 83401

MASTER

DATE PUBLISHED—OCTOBER 1975

PREPARED FOR THE
ENERGY RESEARCH AND DEVELOPMENT ADMINISTRATION
IDAHO OPERATIONS OFFICE UNDER CONTRACT E (10-1)-1375

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

DISCLAIMER

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, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

DISCLAIMER

Portions of this document may be illegible in electronic image products. Images are produced from the best available original document.

Printed in the United States of America
Available from
National Technical Information Service
U. S. Department of Commerce
5285 Port Royal Road
Springfield, Virginia 22161
Price: Printed Copy \$4.00; Microfiche \$2.25

NOTICE

This report was prepared as an account of work sponsored by the United States Government. Neither the United States nor the Energy Research and Development Administration, nor any of their employees, nor any of their contractors, subcontractors, or their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness or usefulness of any information, apparatus, product or process disclosed, or represents that its use would not infringe privately owned rights.

ANCR-1259

Distribution Under Category:
UC-37
Instruments
NRC-3
Water Reactor Safety Research
Fuel Behavior
TID-4500

**INSPECTION SYSTEM
FOR ZIRCALOY CLAD FUEL RODS**

by

M. E. Yancey
E. H. Porter
H. R. Hansen

AEROJET NUCLEAR COMPANY

Date Published - October 1975

PREPARED FOR THE
U. S. ENERGY RESEARCH AND DEVELOPMENT ADMINISTRATION
IDAHO OPERATIONS OFFICE
UNDER CONTRACT NO. E(10-1)-1375

NOTICE
This report was prepared as an account of work sponsored by the United States Government. Neither the United States nor the United States Energy Research and Development Administration, nor any of their employees, nor any of their contractors, subcontractors, or their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness or usefulness of any information, apparatus, product or process disclosed, or represents that its use would not infringe privately owned rights.

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

ABSTRACT

This report describes the design, development, and performance of a remote scanning system for nondestructive examination of fuel rods. Characteristics that are examined include microcracking of fuel rod cladding, fuel-cladding interaction, cladding thickness, fuel rod diameter variation, and fuel rod bowing. Microcracking of both the inner and outer fuel rod surfaces and variations in wall thickness are detected by using a pulsed eddy current technique developed by Argonne National Laboratory (ANL). Fuel rod diameter variation and fuel rod bowing are detected by using two linear variable differential transformers (LVDTs) and a signal conditioning system. The system mechanical features include variable scanning speeds, a precision indexing system, and a servomechanism to maintain proper probe alignment.

Initial results indicate that the system is a very useful mechanism for characterizing irradiated fuel rods.

CONTENTS

ABSTRACT	ii
I. INTRODUCTION	1
II. DESIGN CRITERIA	3
III. SCANNING SYSTEMS	4
1. AXIAL SCANNING	4
2. ROTARY INDEXING	4
3. SERVO POSITIONING SYSTEM	6
IV. INSPECTION SYSTEM	12
1. LVDT – DIMENSIONAL	12
2. PULSED EDDY CURRENT SYSTEM	12
V. INSPECTION RESULTS	24
1. CALIBRATION STANDARDS	24
2. TYPICAL DATA	24
3. DATA EVALUATION	28
VI. CONCLUSIONS	37
VII. REFERENCES	38
APPENDIX A – DIMENSIONAL DATA FOR DEFECT CALIBRATION STANDARDS	39

FIGURES

1. Sketch of typical LWR fuel rod	2
2. The fuel rod scanning facility	5
3. Scanner drive system	6
4. PEC instrumentation and scanner control system	7

5.	Fuel rod upper locator assembly	8
6.	PEC probe servo positioning system	10
7.	The probe positioning servomechanism	11
8.	Block diagram of the PEC system	14
9.	PEC probe assembly	15
10.	Actual sample point locations	17
11.	Wall thickness probe lift-off crossing point (CP)	18
12.	Defect probe lift-off crossing points (CP)	19
13.	Defect sensitivity versus scanning velocity: (T) transverse defect (L) longitudinal defect	20
14.	Defect sensitivity versus rotational indexing location: (T) transverse defect (L) longitudinal defect	21
15.	Wall thickness calibration standard	22
16.	Surface profile of zircaloy fuel rod	25
17.	LVDT diameter calibration trace	26
18.	Unirradiated LWR fuel rod 952	29
19.	Unirradiated LWR fuel rod 952	30
20.	Irradiated LWR fuel rod 835	31
21.	Irradiated LWR fuel rod 835	32
22.	Data on calibration standard showing outer surface defects prior to scanning LWR fuel rod 835	33
23.	Axial time-averaged power distribution for fuel rod 835	34
24.	Transducer reference data	35
25.	Three-dimensional defect map	36

TABLES

I.	Diameter Calibration Data	27
----	-------------------------------------	----

I. INTRODUCTION

As part of the light water reactor (LWR) safety studies being sponsored by the Nuclear Regulatory Commission (NRC), Aerojet Nuclear Company (ANC) is conducting in-pile tests on irradiated and unirradiated fuel rods. During the tests, the fuel rods are being exposed to a variety of off-normal and accident conditions. The data obtained from these tests are intended to provide the NRC and the nuclear industry with current and factual reactor safety information.

For these tests it is necessary that the fuel rods be completely characterized and contain no unknown defects. Characterizing information is needed both before and after in-pile testing. A pulsed eddy current (PEC) system was incorporated as one part of the system designed to obtain this information. The PEC technique initially was developed at Argonne National Laboratory (ANL)^[1,2,3] for inspection of stainless steel cladding^[4]. This system was adapted for the inspection of zircaloy clad fuel rods. The technique provides a method of (a) detecting microcracks located in the inner and outer surfaces of the cladding, (b) detecting fuel-cladding interaction, and (c) determining cladding thickness. In addition, the system provides information on fuel rod diameter variation and fuel rod bowing. This is accomplished by using two linear variable differential transformers (LVDTs) with the appropriate signal conditioning electronics and a variable speed scanning system with precision indexing capability.

Standards were fabricated for use in calibrating the system. The standards include measurements of transverse and longitudinal defects, wall thicknesses, diameter variations, and rod straightness.

This report describes the design, development, and calibration of the scanning system which was built to provide the needed characterization information. A companion report is being prepared which will describe the results obtained when using the equipment on LWR-type fuel rods^[5].

A typical LWR-type fuel rod to be used in this work is illustrated in Figure 1. As in standard pressurized water reactor (PWR) fuel rods, the cladding is zircaloy-4; the fuel is UO_2 , but the pellet stack height is 35 to 36 inches. Fuel enrichment, gas annulus pressure, and burnup vary among the rods.

Fig. 1 Sketch of typical LWR fuel rod.

II. DESIGN CRITERIA

The following criteria were established as guidelines in developing the system:

- (1) The facility would be remotely operable in a hot cell in order to accommodate preirradiated fuel rods.
- (2) Surface defect measurement capability would permit detection of cracks 0.0062 inch wide by 0.100 inch long; by 0.002, 0.004, and 0.006 inch deep; oriented both longitudinally and transversely; and on both inner and outer surfaces. Sensitivity verification would be obtained from micromachined calibration samples, with replicas available to verify the calibration samples.
- (3) The system would be capable of measuring nominal wall thicknesses ranging from 0.019 to 0.027 inch.
- (4) The system would be capable of measuring diameter increases of 80% with nominal fuel rod diameters as large as 0.5 inch before expansion.
- (5) The system would provide complete inspection of fuel rod surfaces.
- (6) Fuel rod scan velocity would be variable and optimized for the best signal/noise ratio.
- (7) Periodic calibration of all inspection parameters would be possible.

III. SCANNING SYSTEMS

1. AXIAL SCANNING

Figure 2 shows the fuel rod scanning facility. The system was designed to axially scan a vertically-mounted fuel rod. The fuel rod is held in a free-standing position by locators which are mounted in the center of the lower base plate and top plate. The four corner columns provide both guidance and two-dimensional lateral constraint for the traveling center platform. The scanning platform has large sintered bronze bushings which slide vertically on the corner columns. Thus, the centerline of the scanning platform is collinear with the centerline of a straight fuel rod held by the locators.

The scanning motion is achieved by three acme-threaded lead screws rotating in three bronze threaded nuts affixed to the platform. The three lead screws are rotated simultaneously by means of miter gears and horizontal shafts, causing the platform to move up or down. These shafts are in turn rotated by one common input shaft. The three lead screws are located in a triangular configuration such that the centroid of the triangular area formed by the lead screws is coincident with the fuel rod centerline.

Figure 3 shows a schematic of the total drive system. The input shaft which drives the three lead screws is coupled to a reversing drive which can provide a sudden reversal of the direction of rotation of its output shaft, while the direction of rotation of its input shaft remains constant. This is accomplished by electrically energizing either of two clutch assemblies. The addition of a brake allows the output shaft to be stopped instantly upon deenergizing either of the clutches, while the input shaft continues to rotate.

The SCR-controlled motor permits the scan speed to be varied to optimize the performance of the PEC system. The scanning platform speed may be varied up to 3.33 inches/second in the down direction and up to 2.67 inches/second in the up direction.

2. ROTARY INDEXING

A "Slo syn" rotary indexing table and drive stepping motor with a preset indexer were used to provide rotational positioning and indexing capability. This capability made it possible to axially scan the fuel rod at predetermined intervals and to accurately relocate at the same intervals in order to monitor any change resulting from subsequent testing. The system is capable of changing rotational position in either direction by as little as 0.01 degree and is normally preset for a 10-degree change. The indexing table may also be positioned by a manual switch. The table will rotate until the switch is released. The rotary indexing controller is shown in Figure 4.

The rotary indexing table, with lower fuel rod locator attached, is mounted on the lower base plate. To provide fuel rod indexing capability, an offset tongue and groove

Fig. 2 The fuel rod scanning facility.

Fig. 3 Scanner drive system.

arrangement was used: A machined groove was located in the base of a fuel rod and offset tongue in the lower fuel rod locator assembly.

Figure 5 shows the fuel rod upper locator assembly. This assembly was designed to allow the fuel rod to rotate freely with no lateral motion.

3. SERVO POSITIONING SYSTEM

In order to obtain meaningful and repeatable data, a positioning system capable of maintaining the relative position of the PEC probes to the fuel rod during scanning was necessary. It is required that the distance between the probe surface and the fuel rod surface (lift-off) be maintained within ± 0.005 inch^[7]. Since some fuel rod bowing was expected, it was not possible to mount the PEC probes rigidly to the traveling platform. Also, it was necessary to compensate for changes in fuel rod diameter, so a spring-loaded fixture that holds the probe against the fuel rod would not be satisfactory. Therefore, instead of building a 100% spring-actuated fixture, a system was designed that was actuated on one

Fig. 4 PEC instrumentation and scanner control system.

ANC - A - 4565

Fig. 5 Fuel rod upper locator assembly.

axis by a spring and on the other axis by a servomechanism. This system can compensate for diameter changes as well as bowing because the servomechanism uses the fuel rod centerline for a control reference, whereas a spring-actuated fixture uses the location of the edge of the fuel rod for a reference.

Figure 6 shows a schematic diagram of the servo positioning system. The signals from the two linear variable differential transformers, 180 degrees apart, which monitor locations of the fuel rod surface, are conditioned to provide an output which is proportional to the location of the fuel rod centerline. This output is used as the control signal to the servomechanism which maintains the proper relationship between the PEC probes and the fuel rod. Thus, the position of the PEC probes will be maintained within ± 0.005 inch of the fuel rod centerline.

The servomechanism uses a torque motor with a double-ended shaft, which eliminates the need for gearing. One end of the shaft drives a lead screw with a pitch of 20 revolutions per inch. The lead screw positions the table upon which the PEC probes are mounted. The other end of the shaft drives a 10-turn potentiometer which is used as a feedback element. The combination of a 10-turn potentiometer and a 20-revolution-per-inch lead screw limits the range over which the servomechanism can make corrections to $\pm 1/4$ inch. This range was compatible with the LVDT's full-scale range of $\pm 1/4$ inch. The maximum allowable error of ± 0.005 inch in the positioning of the table is only $\pm 1\%$ of the full-scale range of the feedback potentiometer.

To facilitate the installation of fuel rods during remote operation, a system was designed to retract the LVDTs from the fuel rod surface. Figure 7 shows this mechanism as well as the servomechanism.

Fig. 6 PEC probe servo positioning system.

Fig. 7 The probe positioning servomechanism.

IV. INSPECTION SYSTEM

1. LVDT – DIMENSIONAL

The LVDT signals were also conditioned to provide the fuel rod diameter deviation and centerline deviation to a Brush 260 recorder. The difference between the two output signals is proportional to the diameter of the fuel rod. One-half the sum of the two input signals is proportional to the location of the fuel rod centerline. The amount of deviation in centerline and diameter variations as shown on the Brush recordings can be determined by

$$\frac{\Delta D}{d} = \frac{S}{G \times L} \quad (1)$$

where

- ΔD = the amount of centerline or diameter variation (inches)
- d = a division^[a] on Brush recording
- S = Brush recorder sensitivity (mV/division)
- G = Gain of appropriate output amplifier in the servo positioning system
- L = LVDT output sensitivity (mV/inch)

Both of the LVDTs had an output sensitivity of 20.0 V per inch of displacement. The diameter deviation output amplifier had a gain of 4.34 and the centerline deviation output amplifier had a gain of 2.60.

2. PULSED EDDY CURRENT SYSTEM

The pulsed eddy current system uses a series of current pulses passing through a field coil to induce eddy currents in the specimen under investigation. The induced eddy currents are influenced by the specimen's characteristics – permeability, conductivity, wall thickness (WT), surface defects, and the distance between probe and specimen (lift-off). The resulting eddy currents produce a pulsed magnetic field which induces a voltage pulse in the pickup coil. The induced voltage of the pickup coil contains information concerning the specimen's

[a] "Division" always refers to the smallest division on the Brush recordings unless otherwise indicated.

surface defects and wall thickness. The wall thickness and defect information are extracted from the induced voltage pulse using a time-sampling technique wherein a gating pulse of approximately 0.1 microsecond is used to sample small increments of the induced voltage pulse. The location of the gating pulse, i.e., the sampling point (SP) location, is adjustable over the entire time duration of the induced voltage pulse. Only outer surface defect information appears in the early portion of the voltage pulse, while both outer and inner surface defect and wall thickness information appear toward the end of the voltage pulse.

The system as developed by Argonne National Laboratory (ANL)^[7] consists of two nearly independent sections, one a wall thickness measuring system and the other a defect-detection system. Separate probes are used for each system. Figure 8 shows a simplified block diagram of the PEC system. The wall thickness measuring section has a thyatron pulse generator which supplies a pulse of current to the WT field coil. A pickup coil senses the resulting signal which is then conditioned by the time-sampling technique. The location of the sampling gates may be varied to achieve a sample point with optimum sensitivity to wall thickness. The pulse generator and sampling gate circuit are controlled by a master clock which has a repetition rate of about 1 kHz. The add/subtract network provides the capability for additional signal conditioning of the wall thickness data.

The defect-detection section also contains a thyatron pulse generator which supplies a current pulse to the defect field coil. The induced voltage of the pickup coil is amplified and then conditioned by the time-sampling technique to allow separation of the inner and outer surface defects and to optimize the system's sensitivity to these defects. Since the sample point containing inner surface defect information also contains outer surface defect information, it was necessary to use the add/subtract network to remove the outer surface defect information, thus obtaining two signals with separate outer and inner surface defect data. The filters are designed to enhance the system's sensitivity to small defects.

Figure 9 shows the probe mounting fixture and the orientation of both the defect and wall thickness probes. The mounting fixture also contains a small bearing which is used to provide 0.004- to 0.005-inch spacing between the probes and the fuel rod. A leaf spring is attached to the mounting fixture to keep the small bearing against the fuel rod should bowing occur. The details of the probe design are discussed in the ANL report^[7]. The defect probe has been designed to be predominantly sensitive to longitudinal defects.

The PEC system was designed with front panel test points for monitoring the induced voltages of the wall thickness and defect pickup coils. Using an oscilloscope, the actual location of the sample point can be identified by a small "blip" appearing on the waveform. These sample points are adjusted for maximum sensitivity to the desired variable, i.e., wall thickness, inner surface defects or outer surface defects, and minimum sensitivity to the undesired variables, including probe lift-off. The sample point locations were adjusted while scanning the defect and wall thickness calibration standards described in Section V-1. Sample point SP 2-1 was adjusted for maximum sensitivity to the outer surface defects while being insensitive to inner surface defects. Sample point SP 2-2 was adjusted for maximum sensitivity to inner surface defects, which also resulted in some outer surface

Fig. 8 Block diagram of the PEC system.

Fig. 9 PEC probe assembly.

defect sensitivity. Using the add/subtract network and the signal from channel output 2-1, the outer defect information was eliminated from channel output 2-2 leaving only inner surface defect information. The background noise level of channel output 2-1 was higher than background noise of channel output 2-2, and there was a possibility that small inner surface defect signals in channel output 2-2 could be lost in the background noise resulting from the subtraction. Therefore, an additional sample point, SP 2-3, was used to obtain an output signal containing both inner and outer surface defect information with a low background noise level. Since sample points SP 2-1 and SP 2-2 were slightly sensitive to probe lift-off, sample point SP 2-3 was also set for minimum sensitivity to probe lift-off. The wall thickness sample point, SP 1-3, was adjusted for wall thickness sensitivity with minimum probe lift-off sensitivity.

Figure 10 contains a set of photographs showing the actual sample point locations used. Sample points SP 2-3 and SP 1-3 were set for minimum lift off effects, using an unirradiated LWR fuel rod. These sample point locations were determined by identifying lift-off crossing points (CP), i.e., points of minimum lift-off sensitivity^[8]. Figure 11 shows the lift-off crossing point for wall thickness probe lift-off of 0.0000, 0.0036, 0.0072, and 0.0108 inch. The photo in Figure 11 (b) had the sensitivity of the vertical axis increased to better pinpoint the crossing point. The lift-off crossing points shown in Figure 12 are for defect probe lift-offs of: 12(a) - 0.0000, 0.0036, 0.0072, and 0.0108 inch; 12(b) - 0.0000, 0.001, 0.002, 0.003, and 0.004 inch; and 12(c) - 0.0000 and 0.0036 inch.

Tests were also conducted to determine the effects of scanning velocity and rotational indexing location on the system defect sensitivity, using the defect calibration standards described in Section V-1. Figure 13 shows the inner and outer defect sensitivity of the PEC system with the scan velocity varied from 1.49 inches/second to 2.48 inches/second for the 0.0061-inch-deep defect. The amplitude of the defect indication increased as a function of increased scan velocity. It was also noted that the background noise was lower during the down scan; therefore, this direction was used for the fuel rod scanning. The PEC system response to the 0.002- and 0.004- inch defects varied in the same manner as shown for the 0.0061-inch defect, although their maximum amplitudes were correspondingly less. It was determined that a scan velocity of 1.82 inches/second would provide an adequate defect sensitivity. Figure 14 shows the PEC system sensitivity to a 0.0061-inch defect as the rotational indexing was varied ± 5 degrees. Since the longitudinal and transverse defects were not in exact alignment, there was a difference in the variation of the longitudinal and transverse defect signals as a function of rotational indexing. It was concluded that a 10-degree rotational increment would provide adequate surface coverage for defect detection.

Figure 15 shows the PEC system wall thickness calibration data with a sketch of the calibration standard and the average wall thickness measurements. The wall thickness of the internally machined calibration standard varied as shown in Figure 15. The variations in the recorded data corresponded to the wall thickness variations. The gradual roll-off which occurred near the center of the calibration data resulted from the wall thickness probe averaging the abrupt transition. The roll-off at each end of the calibration data was caused

Fig. 10 Actual sample point locations

Fig. 11 Wall thickness probe lift-off crossing point (CP).

Fig. 12 Defect probe lift-off crossing points (CP).

Outer Surface
100 mV/div

Inches/second

Inner Surface
100 mV/div

2.48

2.15

1.82

1.49

Fig. 13 Defect sensitivity versus scanning velocity: (T) transverse defect, (L) longitudinal defect. Defect size: 0.100 in.(l) x 0.0065 in.(w) x 0.0061 in.(d).

Outer Surface

100 mV/div

T

L

Inner Surface

100 mV/div

T

L

+5°

T

L

0°

T

L

T

L

-5°

T

L

Fig. 14 Defect sensitivity versus rotational indexing location: (T) transverse defect, (L) longitudinal defect. Defect size: 0.100 in.(l) x 0.0065 in. (w) x 0.0061 in.(d).

Fig. 15 Wall thickness calibration standard.

by the aluminum spacers used to join the various standards. The wall thickness probe provides an average indication of wall thickness variations beneath the probe. Concerning the use of a prepared calibration standard, the ANL report^[7] states "It should not be expected, however, that this type of standard, which has a relatively smooth inner surface, will allow a reliable prediction of wall thinning in an irradiated fuel element. If the wall thinning in the fuel element has been produced by a process that creates an irregular inner-jacket surface, or if metallic fission products have accumulated within the field of the probe, the pulsed eddy-current equipment can be relied upon only to indicate the existence of an abnormality and its location." Although a drift problem was noted in the wall thickness measurements over long scanning periods, useful information on short-term (single scan) wall thickness variations can still be obtained.

V. INSPECTION RESULTS

1. CALIBRATION STANDARDS

A simulated zircaloy fuel rod was fabricated containing three surface-defect calibration standards, each approximately six inches long, and two wall thickness calibration standards. One of the latter was an unmodified length of clean, unirradiated zircaloy fuel rod cladding. The other was a length of zircaloy tubing which was internally machined to give two additional variations in wall thickness. Each of the defect calibration standards contained a longitudinal and a transverse defect on both the inner and outer surfaces. These defects were prepared by electron discharge machining and had the following nominal dimensions: 0.100 inch long by 0.0062 inch wide with depths of 0.002, 0.004, and 0.006 inch. Replicas of each defect were obtained, and the exact defect dimensions as supplied by the vendor are shown in Appendix A. The basis for the defect size and orientation was derived from ASTM and RDT standards^[6,9,10].

Figure 16 shows an outer surface profile obtained using the Clevite Surfanalyzer System 360 on a companion piece of zircaloy fuel rod cladding. Similar variations occurred on the inner surface of the cladding, resulting in a uniform wall thickness. This profile variation was detected in both the defect and wall thickness data during initial calibration of the PEC system. Lift-off effects resulting from this surface profile were minimized in the wall thickness data from channel output 1-3 and inner and outer surface defect data from channel output 2-3 by use of the crossing points.

In order to calibrate the LVDT dimensional system for centerline variation, a model fuel rod was fabricated with a uniform diameter of 0.391 inch and straight to within 0.0102 inch total indicator reading. This model fuel rod was rough-machined from Invar 36, stress relieved, hard-chrome plated, and finish-ground to the required diameter. By scanning this model fuel rod in the scanning facility, a chart trace was obtained which contains the error in the system straightness. Any variation from the model fuel rod data will be considered as fuel rod centerline variation. The simulated zircaloy fuel rod containing the wall thickness calibration standard was modified by surface machining to provide a diameter calibration standard. Figure 17 shows the diameter calibration data of the modified standard. The numerical diameter data shown in Figure 17 were provided by the ANC Calibration Laboratory. The amount of deviation can be determined by use of the equation shown in Section IV-1. As shown in Table I, the calculated diameter variations agreed with the measured diameters within about 1%.

2. TYPICAL DATA

Figures 18 through 22 show data obtained from scanning an unirradiated LWR-type fuel rod 952 at 0 and 180 degrees, an irradiated LWR-type fuel rod 835 at 120 and 300

ALIF.

PRINTED IN U.S.A.

CLEVITE CORPORATION/GAGII

Fig. 16 Surface profile of zircaloy fuel rod.

GAIN - 4.2

Sensitivity - 50 mV/div

Orientation - 0°

0.38395 0.38695

0.3946 0.3972 0.38955

Fig. 17 LVDT diameter calibration trace.

TABLE I
DIAMETER CALIBRATION DATA

<u>Measured Diameter Variation (Inch)</u>	<u>Calculated Diameter Variation (Inch)</u>	<u>Diameter Variation Difference (Inch)</u>	<u>Percent Error</u>
0.00300	0.00297	0.00003	1.00
0.00765	0.00773	0.00008	1.04
0.00260	0.00258	0.00002	0.77

degrees, and a scan of the calibration standard, made just prior to scanning fuel rod 835, which shows the outer surface defects. The calibration standard was later modified to provide diameter calibration data as shown in Figure 17. The scan velocity was 1.82 inches/second with a chart speed of 25 mm/second.

The unirradiated fuel rod had a surface flaw at 0 degrees. Visual examination indicated this was not a defect similar to the defect standards but rather a small gathering of metal resulting from a surface scratch. The signal indication was mainly a result of probe lift-off. Since the channel, which was sensitive to both outer and inner defects, was adjusted for minimum sensitivity to probe lift-off, only a small indication was obtained on that channel. The cyclic variation which appears on the outer and inner surface defect data corresponds to the surface profile shown in Figure 16. There was essentially no change in the wall thickness or diameter of fuel rod 952. The centerline data indicated some rod bowing. By increasing the recorder sensitivity for the fuel rod diameter data, it would be possible to show more detailed diameter variations.

In Figure 20, the scan of the irradiated LWR fuel rod 835 at 120 degrees shows an outer surface defect indication (A) and an area of apparent surface corrosion (B) located approximately 9.6 to 12.6 inches from the bottom of the fuel rod. The wall thickness data also indicate wall thinning (C) in the area of the surface corrosion. This corrosion area corresponds to the fuel rod area which was subjected to the maximum time-averaged axial power distribution as shown in Figure 23. Because of the spacing between the wall thickness probe and the defect probe, the wall thickness data indicating wall thinning occurred slightly later in time on the chart trace. The major portion of the indicated centerline deviation resulted from a mismatch between the indexing slot located in the base of the fuel rod and the indexing tab of the holding fixture.

Figure 24 shows the transducer orientation and location relative to the fuel rod. In the 0 degree orientation, the LVDTs are located at 0 and 180 degrees, while the PEC probes are located at 270 degrees. This orientation is meaningful in reviewing the data since the defect and wall thickness data shown in the traces are displaced 90 degrees from the diameter and centerline data.

3. DATA EVALUATION

Complete examination of a single fuel rod yielded 37 traces similar to those shown in Figure 20. The ANC Materials Technology Branch performed a detailed evaluation^[5] of this data. In order to display the surface defect information in a meaningful manner, a three-dimensional mapping technique was used to show defect size variation and location. Figure 25 shows a defect map prepared by the Materials Technology Branch. The defect indication observed by the PEC system was resolved to be primarily spacer grid wear marks and corrosion on the outer surface. Metallographic examination was performed on several fuel rods in order to verify the data obtained using the PEC system. The results of the metallographic examination indicated that defects were present in all of the suspect areas. No defects were found outside of the PEC indicated regions. Cladding thickness variation was generally less than 0.001 inch; however, a few high burnup fuel rods had up to 0.003-inch variation. The PEC wall thickness measurements correlated well with the micrometer measurements.

The LVDT data indicated that fuel rod bowing varied from negligible to 0.012 inch, while only slight diametrial variations (less than 0.0005 inch) were recorded.

Fig. 18 Unirradiated LWR fuel rod 952. Orientation - 0 degrees.

Fig. 19 Unirradiated LWR fuel rod 952. Orientation - 180 degrees.

Fig. 20 Irradiated LWR fuel rod 835. Orientation - 120 degrees.

Fig. 21 Irradiated LWR fuel rod 835. Orientation - 300 degrees.

Fig. 22 Data on calibration standard showing outer surface defects prior to scanning LWR fuel rod 835.

Fig. 23 Axial time-averaged power distribution for fuel rod 835.

Zero Degree Transducer Orientation

Vertical Transducer Location ANC-A-5305

Fig. 24 Transducer reference data.

Fig. 25 Three-dimensional defect map.

VI. CONCLUSIONS

The final system design meets all the design criteria. The initial results indicate that the characterization facility is a very valuable tool for examining the inner and outer cladding surfaces for small defects and for monitoring the wall thickness, diameter, and centerline variations of fuel rods. Metallographic examination verified the results of the PEC system. A scanning velocity of 1.82 inches/second with 10-degree rotational indexing provides adequate resolution and surface coverage for defect detection.

In scanning numerous fuel rods, it was noted that the wall thickness data had a zero drift problem which required continued zeroing of the recorder. However, the system still provided valuable short-term wall thickness data.

VII. REFERENCES

1. C. J. Renken, *Progress Report on Nondestructive Testing by Electromagnetic Methods*, ANL-6414 (July 1962).
2. C. J. Renken, *A Pulsed Electromagnetic Test System Applied to the Inspection of Thin-Walled Tubing*, ANL-6728 (March 1964).
3. T. H. Busse, D. R. Wood, N. S. Beyer, *Nondestructive Inspection of EBR-II Fuel Jacket Tubing Using Electromagnetic Techniques*, ANL-7334 (May 1967).
4. R. R. Asamoto, R. F. Bacon, A. E. Conti, G. P. Wozadlo, *Evaluation of Irradiated Fuel Rods with Pulsed Eddy Current*, GEAP-13928 (December 1972).
5. W. C. Francis et al, *Nondestructive Examination of Irradiated Fuel Rods by Pulsed Eddy Current Technique*, To be released.
6. *Nondestructive Examination*, RDT Standard F 3-6T, paragraph 5(c).
7. C. J. Renken and A. Sather, *Pulsed Eddy Current Test System for Hot Cell Use: Manual of Operation*, ANL-7973 (November 1972).
8. D. L. Waidehich and S. C. Huang, "The Use of Crossing Points in Pulsed Eddy Current Testing", *Materials Evaluation*, 30(1) (1972) pp 20-24.
9. *Special Requirements for Metal Products*, RDT Standard F 3-37T, paragraph 5.1.5 (a) and (z).
10. *Standard Specification for Wrought Zirconium and Zirconium Alloy Seamless and Welded Tubes for Nuclear Service*, ASTM B353-71, paragraph 11.2.

APPENDIX A

DIMENSIONAL DATA FOR DEFECT CALIBRATION STANDARDS

THIS PAGE
WAS INTENTIONALLY
LEFT BLANK

METCUT
RESEARCH
ASSOCIATES
INC.

3980 ROSSLYN DRIVE, CINCINNATI, OHIO 45209
Teletype: 810-461-2840 Telephone: (513) 271-5100

Client: Aerojet Nuclear Company
Purchase Order No. 38244
Standard No. 1331-21216-1 Date: July 18, 1974
Tube Size 0.391" O.D. 0.023" Wall 6.10" Long
Material _____ Heat No. _____
Specification _____

Certification of notch dimensions by means of replication
with GE RTV Liquid Silicon Rubber

No.	Measured Length	Measured Width	Measured Depth	Location	Type
1	0.100"	0.0062"	0.0023"	I. D.	Long.
2	0.100"	0.0064"	0.0022"	O. D.	Long.
3	0.099"	0.0060"	0.0020"	O. D.	Trans.
4	0.100"	0.0062"	0.0023"	I. D.	Trans.
5					
6					
7					
8					

William J. Stross
William J. Stross, Supervisor
Materials Testing Laboratory

Chester E. Armstrong, Jr.
Chester E. Armstrong, Jr.
Laboratory Technician

METCUT
RESEARCH
ASSOCIATES
INC.

3980 ROSSLYN DRIVE, CINCINNATI, OHIO 45209
Teletype: 810-461-2840 Telephone: (513) 271-5100

Client: Aerojet Nuclear Company
Purchase Order No. 38244
Standard No. 1331-21216-2 Date: July 18, 1974
Tube Size 0.391" O.D. 0.023" Wall 6.10" Long
Material _____ Heat No. _____
Specification _____

Certification of notch dimensions by means of
replication with GE RTV Liquid Silicon Rubber

No.	Measured Length	Measured Width	Measured Depth	Location	Type
1	0.100"	0.0062"	0.0039"	I. D.	Long.
2	0.100"	0.0065"	0.0041"	O. D.	Long.
3	0.101"	0.0062"	0.0042"	O. D.	Trans.
4	0.100"	0.0062"	0.0037"	I. D.	Trans.
5					
6					
7					
8					

William J. Stross
William J. Stross, Supervisor
Materials Testing Laboratory

Chester E. Armstrong, Jr.
Chester E. Armstrong, Jr.
Laboratory Technician

METCUT
RESEARCH
ASSOCIATES
INC.

3980 ROSSLYN DRIVE, CINCINNATI, OHIO 45209
Teletype: 810-461-2840 Telephone: (513) 271-5100

Client: Aerojet Nuclear Company

Purchase Order No. 38244

Standard No. 1331-21216-3

Date: July 18, 1974

Tube Size 0.391" O.D. 0.023" Wall 6.10" Long

Material _____ Heat No. _____

Specification _____

Certification of notch dimensions by means of
replication with GE RTV Liquid Silicon Rubber

No.	Measured Length	Measured Width	Measured Depth	Location	Type
1	0.100"	0.0065"	0.0062"	I. D.	Long.
2	0.100"	0.0065"	0.0061"	O. D.	Long.
3	0.101"	0.0064"	0.0061"	O. F.	Trans.
4	0.100"	0.0064"	0.0059"	I. D.	Trans.
5					
6					
7					
8					

William J. Stross
William J. Stross, Supervisor
Materials Testing Laboratory

Chester E. Armstrong, Jr.
Chester E. Armstrong, Jr.
Laboratory Technician

DISTRIBUTION RECORD FOR ANCR-1259

External

306 - NRC-3, Water Reactor Safety Research Fuel Behavior

170 - UC-37, Instruments - TID-4500, R63

2 - H. J. C. Kouts, NRC

Internal

1 - Chicago Patent Group - ERDA
9800 South Cass Avenue
Argonne, Illinois 60439

3 - A. T. Morphey, Classification and Technical Information Officer
ERDA-ID
Idaho Falls, Idaho 83401

1 - R. J. Beers, ID

1 - P. E. Litteneker, ID

1 - R. E. Swanson, ID

1 - V. A. Walker, ID

1 - R. E. Wood, ID

31 - INEL Technical Library

20 - Author

Total Copies Printed - 538