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Acceptance Testing of the Eddy Current Probes for Measurement of
Aluminum Hydroxide Coating Thickness on K West Basin Fuel Elements

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Abstract: Acceptance testing was successfully conducted on specially developed eddy current probes for measuring aluminum hydroxide coating thicknesses on N Reactor fuel stored in K West Basin. The results demonstrated in principle the capability to perform these measurements in field applications in K West Basin.

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Christine Hillingham
Release Approval

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**ACCEPTANCE TESTING OF THE EDDY CURRENT PROBES FOR MEASUREMENT
OF ALUMINUM HYDROXIDE COATING THICKNESS
ON K WEST BASIN FUEL ELEMENTS**

1.0 INTRODUCTION

During a recent visual inspection campaign of fuel elements stored in the K West Basin, it was noted that fuel elements contained in sealed aluminum canisters had a heavy translucent type coating on their surfaces (Pitner 1997a). Subsequent sampling of this coating in a hot cell (Pitner 1997b) and analysis of the material identified it as aluminum hydroxide. Because of the relatively high water content of this material, safety related concerns are raised with respect to long term storage of this fuel in Multi-Canister Overpacks (MCOs). A campaign in the basin is planned to demonstrate whether this coating can be removed by mechanical brushing (Bridges 1998). Part of this campaign involves before-and-after measurements of the coating thickness to determine the effectiveness of coating removal by the brushing machine. Measurements of the as-deposited coating thickness on multiple fuel elements are also expected to provide total coating inventory information needed for MCO safety evaluations. The measurement technique must be capable of measuring coating thicknesses on the order of several mils, with a measurement accuracy of 0.5 mil.

Several different methods for quantitatively measuring these thin coatings were considered in selecting the most promising approach. Ultrasonic measurement was investigated, but it was determined that due to the thin coating depth and the high water content of the material, the signal would likely pass directly through to the cladding without ever sensing the coating surface. X-ray fluorescence was also identified as a candidate technique, but would not work because the high gamma background from the irradiated fuel would swamp out the low energy aluminum signal. Laser interferometry could possibly be applied, but considerable development would be required and it was considered to be high risk on a short term basis.

The consensus reached was that standard eddy current techniques for coating thickness measurement had the best chance for success in this endeavor. If proper placement and alignment of the eddy current measurement probe on the coating could be achieved, the thickness of this non-conductive coating over the conductive fuel cladding (Zircaloy 2) should be measurable based on magnetic stand-off aspects. Eddy current devices are routinely used to measure paint coating thicknesses on metal surfaces in this regard.

The purpose of this report is to document the development and acceptance testing of the eddy current system conducted to qualify its use for the measurement of aluminum hydroxide coating thicknesses on fuel stored in the K West Basin.

2.0 PROBE DESIGN

A meeting with Zetec, Inc. (an acknowledged expert company in eddy current applications) was held to discuss development of suitable eddy current probes to measure aluminum hydroxide coating thicknesses on fuel elements under 16 ft of water in the K West Basin. The objectives were to have the capabilities of measuring the coating thickness on the outer surfaces of both outer and inner N Reactor fuel elements, as well as the coating on the inside surface of the outer fuel element. They expressed confidence that suitable probes could be designed and fabricated to meet these objectives.

The proposed probe design for measuring the outer fuel element surfaces is shown schematically in Figure 1. The probe design consists of a nylon shoe or saddle that mates with the outside surface of the fuel element and provides the proper alignment for the spring-loaded eddy current coil located at the inside center of the shoe. Two probes sized to the appropriate diameters would be fabricated for measuring the outside surfaces of both outer and inner fuel elements.

The proposed probe for measuring the inside diameter of outer fuel elements is shown schematically in Figure 2. Spring loaded shoes captured in a nylon body serve to center the probe inside the fuel element bore. One of the spring loaded shoes contains the high frequency eddy current coil.

A contract was let with Zetec, Inc. to procure the eddy current probes and to rent a model MIZ-40 analyzer for processing the eddy current signals. Photographs of the fabricated outer element outside diameter probe and inside diameter probe are shown in Figures 3 and 4, respectively. Each probe is affixed to a 25 ft long wand to facilitate underwater measurements in the basin.

3.0 CALIBRATION STANDARDS

In order to generate calibration curves of thickness versus signal strength for each of the probes, calibration standards were fabricated. Bar stock of Zircaloy 2 was procured and 18-in. long cylinders were machined to the same diameters as those of the outer and inner fuel elements. A 3-in. deep bore was made in the top of the outer element standard to represent the inner diameter geometry. Once the proper base metal is employed, any non-conducting material can be used to simulate the aluminum hydroxide coating. Color-coded plastic shims were affixed to the outer and inner surfaces of the standards. Since the recovered aluminum hydroxide coating was found to be about 3 mil thick, shim thicknesses of 2, 3, 5, and 10 mil were selected to provide calibration data over the anticipated range of coating thickness. Combined with a bare metal location, a total of five calibration points are thus available to generate the calibration curves.

The fabricated standards with shims attached are shown in Figure 5. The shim bands are 2 in. high with 2 in. of bare metal between each shim. There are also four shims and a bare metal surface in the top bore of the outer element calibrations standard.

4.0 MEASUREMENT OF LABORATORY GROWN ALUMINUM HYDROXIDE COATING

A side activity to the aluminum hydroxide coating brushing campaign has been an attempt by Pacific Northwest National Laboratory staff to simulate this coating growth on Zircaloy 2 coupon specimens in the laboratory on an accelerated basis. While full size specimens would be preferred, available material was limited to small Zircaloy 2 tubing about 0.5 in. diameter x 2 in. long. Several of these coupons were submerged in a bath of NaAlO_2 , with the coupons maintained at a higher temperature than the bath to promote coating deposition. After 940 hours of testing, a coating of about 0.5 mil in thickness (as measured by a mechanical micrometer) covered one of the coupons. Analysis by X-ray diffraction confirmed that the coating was aluminum hydroxide.

Attempts were made to measure the coating thickness on this coupon using the outer diameter probes. While signals obtained for the coated coupon versus an uncoated coupon were of the correct relative magnitude (i.e., weaker signal for the coated coupon), meaningful quantitative measurements could not be attained because the gross geometry mismatches of the probes and coupons made eddy current coil positioning very difficult. However, another eddy current probe provided by Zetec, Inc. was available that was better suited for measuring these coupons. This reference probe is used in conjunction with the other measurement probes as part of a bridge balancing system in the eddy current analyzer. The eddy current coil in this reference probe is situated in a V block configuration, which allowed proper placement of the probe on the small coupons to be achieved.

A simple calibration curve was generated using this reference probe and plastic shims of 0 (bare metal), 1, and 2 mil placed on an uncoated coupon. The measurements were made with the coupon submerged in distilled water. The calibration curve is shown in Figure 6. The coated coupon was then measured in the water bath using the reference eddy current probe, with the result also shown in Figure 6. As indicated, the eddy current measured thickness is 0.45 mil, essentially the same as that measured with the micrometer. This demonstrates that aluminum hydroxide coating thickness on Zircaloy 2 metal can be accurately measured in water by the eddy current probes if correct probe positioning can be achieved.

5.0 DEVELOPMENT TESTING

Checkout testing of the eddy current probes using the calibration standards was performed in the Cold Test Facility (CTF) in the 305 Building. This facility is a K Basin mockup with corresponding water depth and access

grating replications. The calibration standards were positioned on the water basin floor and 25 ft long shafts were attached to each of the measurement probes, with the signal leads affixed to the shafts.

Experience gained in the checkout testing of the probes led to a number of modifications to expedite the measurement process. To obtain a measurable signal, the probe is positioned on the standard (on a shim or bare metal) and then retracted. The signal measured is the peak value with the probe positioned on the standard compared to the null value when it is pulled away. It was found that each time the probe was retracted, the long wand would cause it to wander a considerable distance from the standard, making placement back on the standard very difficult. To remedy this situation, a guide was installed at the top of each standard to capture the probe wand and limit its travel when pulled away from the surface of the standard. Figure 7 shows a measurement being made at a bare metal location on the inner element calibration standard. The capture guide can be seen at the top of the photograph.

Another observation made during checkout testing was that it was difficult to overcome the downward articulation of the probe body when placed on the standard. This was due to the poor leveraging achievable on the end of the 25 ft wands. A set screw was subsequently installed on each outer diameter probe to limit this articulation such that the desired mate-up was more easily achieved upon first contact. The set screw is visible near the bottom of the probe body in Figure 7.

An example of a signal readout is shown in Figure 8. To measure a signal voltage intensity, the cursor at the left of the analyzer screen is positioned such that it encompasses a peak reading on the signal trace as well as the null reading when the probe is retracted away from the surface being measured. When an acceptable signal has been selected on the screen, a processor key is activated and a digital readout of the signal strength is displayed (6.66 volts in Figure 8).

Due to the remote nature of the measurement process involved, optimum placement of the probe on the surface being measured is not always achieved. Typically this produces a comparatively weaker signal, which with experience can be recognized as such. The objective in obtaining a set of good readings is to record a relatively tight grouping of the highest and cleanest signals at any one measurement location. This sometimes requires multiple sets of measurements to be taken and analyzed before an acceptable data set is collected.

Numerous calibration curves were generated during the checkout phase of testing. Examples are shown in Figures 9, 10, and 11 for the outer element outside diameter probe, outer element inside diameter probe, and inner element outside diameter probe, respectively. It is apparent that there was a shift in the probe calibrations over a period of time, particularly for the outside diameter probes. The calibration curves for the most part are parallel to one another, particularly for thicknesses less than 5 mil as expected for K Basin measurements. However, the eddy current coil response voltage appears to drift downward with time. Self diagnostic testing of the MIZ-40 analyzer confirmed that it was functioning properly. The calibration shift may be due

to nylon components of the probes slowly adjusting to the effects of submersion in deionized water. It is evident that periodic calibration checks in the field will be required to ensure accurate data is being collected. It was noted that the calibration drift during any one day was quite small, on the order of 0.1 or 0.2 volts. The frequency of calibration checks in the field will depend on observed drift behavior, but it is anticipated that beginning and end of shift checks should suffice.

6.0 ACCEPTANCE TESTING

Acceptance testing of the eddy current measurement probes was performed on June 17, 1998. The testing was conducted in accordance with the traveler included in the test plan (Bridges 1998). A copy of the traveler, including required signatures/initials, is included as Appendix A. The data sheet used to record the data during the acceptance testing is also included at the end of this appendix.

Calibration curves were generated for each of the three probes, and are shown in Figures 12, 13, and 14. The calibration curves obtained during the acceptance testing were basically identical to those generated in checkout runs performed two weeks earlier for each of the probes. This suggests that the signal drift discussed in the previous section may have saturated. Periodic calibration checks will nonetheless be performed in K West Basin to monitor for any change in calibration and adjust for it should it recur.

As part of the acceptance test procedure, a blind shim was selected after each calibration run and measured to check on whether the required 0.5 mil accuracy could be achieved. The blind shim measured was unknown to the technician operating the analyzer. The results of the blind shim measurements are also included in Figures 12, 13, and 14. As indicated, the thickness of the shim was correctly interpreted within the 0.5 mil accuracy for all the probes.

7.0 CONCLUSION

The results of the development and acceptance testing on the eddy current probes have demonstrated in principle the capability to measure aluminum hydroxide coating thicknesses on K West Basin fuel elements.

8.0 REFERENCES

- Bridges, A. E., 1998, *Test Plan for Techniques to Measure and Remove Coating from K West Basin Fuel Elements*, HNF-2440, Rev.0, Duke Engineering & Services Hanford, Inc., Richland, Washington.
- Pitner, A. L., 1997a, *Visual Examinations of K West Fuel Elements*, HNF-SD-SNF-TI-046, Rev. 0, Duke Engineering & Services Hanford, Inc., Richland, Washington.
- Pitner, A. L., 1997b, *K Basin Fuel Subsurface Examinations and Surface Coating Sampling*, HNF-SD-SNF-TI-060, Rev. 0, Duke Engineering & Services Hanford, Inc., Richland, Washington.

Figure 1. Schematic of Outside Diameter Probe Design.

Figure 2. Schematic of Inside Diameter Probe Design.

Figure 3. Photograph of Outer Element Outside Diameter Probe.

Figure 4. Photograph of Outer Element Inside Diameter Probe.

Figure 5. Eddy Current Calibration Standards.

Figure 6. Thickness Measurement on Laboratory Coated Coupon.

Figure 7. Underwater Measurement of a Calibration Standard.

Figure 8. Example of Signal Readout.

Figure 9. Calibration Curves for the Outer Element Outside Diameter Probe Produced During Checkout Testing.

Figure 10. Calibration Curves for the Outer Element Inside Diameter Probe Produced During Checkout Testing.

Figure 11. Calibration Curves for the Inner Element Outside Diameter Probe Produced During Checkout Testing.

Figure 12. Calibration Curve for the Outer Element Outside Diameter Probe Produced During the Acceptance Testing.

Figure 13. Calibration Curve for the Outer Element Inside Diameter Probe Produced During the Acceptance Testing.

Figure 14. Calibration Curves for the Inner Element Outside Diameter Probe Produced During the Acceptance Testing.

A P P E N D I X A

TEST TRAVELER FOR THE ACCEPTANCE TEST OF THE EDDY CURRENT PROBES

TEST TRAVELER			Page <u>1</u> of <u>4</u>	Number	
Job Description: ACCEPTANCE TEST FOR EDDY CURRENT PROBES			Work Order No. E57645	Prepared by:	
Operation Number	Test Instruction	Ref., Dwg., Proc. Spec.	Completion Sign/Stamps	Date	Notes
1.0	Pre-operational Checkout		Q NA T <i>RP</i> N NA E <i>QXP</i> O NA	4-18-98 6/18/98	
1.1	Stamp or write "TEST CONTROL COPY" on entire test traveler and attachments.		Q NA T <i>RP</i> N NA E <i>QXP</i> O NA	6-18-98 6/18/98	
1.2	Conduct the "pre-job briefing" of operations, including a review of all procedures, drawings, and other engineering documents required to complete the test.		Q NA T <i>RP</i> N NA E <i>QXP</i> O NA	4-18-98 6/18/98	
1.3	Verify that the performance criteria is included as Attachment 1 of this traveler.		Q <i>RP</i> T <i>RP</i> N NA E <i>QXP</i> O NA	4/18/98 6-18-98 6/18/98	

Q = QC Inspector, T = Technician, N = NDE Inspector, E = Engineer, and O = Other

E = Engineer A.L. Pitzer QXP
 T = Technician LT Pederson RP
 Q = QA J.F. Whit #

TEST TRAVELER (Continuation Sheet)		Page <u>2 of 4</u>	Number		
Operation Number	Test Instruction	Ref., Dwg., Proc. Spec.	Completion Sign/Stamp	Date	Notes
2.0	Calibration Checks: Verify that all instruments and equipment have current calibration stickers.		Q <u>✓</u> T <u>RP</u> N <u>NA</u> E <u>RP</u> O <u>NA</u>	6/18/98 6-18-98 6/18/99	Rental equipment Expires July 20/98
3.0	Issue and verify the equipment list (Attachment 2).		Q <u>NA</u> T <u>RP</u> N <u>NA</u> E <u>RP</u> O <u>NA</u>	6-18-98 6/18/99	
4.0	Complete and verify the test layout/schematic (Attachment 3).		Q <u>NA</u> T <u>RP</u> N <u>NA</u> E <u>RP</u> O <u>NA</u>	6-18-98 6/18/99	
5.0	Set up the test equipment per the test layout/schematic.		OK ARP CE?	6/18/98	

Q = QC Inspector, T = Technician, N = NDE Inspector, E = Engineer, and O = Other

TEST TRAVELER (Continuation Sheet)		Page <u>3</u> of <u>4</u>	Number		
Operation Number	Test Instruction	Ref., Dwg., Proc. Spec.	Completion Sign/Stamp	Date	Notes
6.0	Perform Eddy Current Probe Test(s) (Attachment 1).				
6.1	Position Eddy Current Probe on Calibration Standard. Activate Eddy Current Probe, initiating the test, per instruction from Test Cognizant Engineer. Record observations on data sheets.		Q <u>JK</u> T <u>JKP</u> N <u>NA</u> E <u>QZP</u> O <u>NA</u>	6/18/98 6-18-98 6/18/98	
6.2	Move Eddy Current Probe to another axial location on the Calibration Standard, activate the probe, and record observations. Repeat this step until directed to stop by Test Cognizant Engineer.		Q <u>JK</u> T <u>JKP</u> N <u>NA</u> E <u>QZP</u> O <u>NA</u>	6/18/98 6-18-98 6/18/98	
6.3	Repeat Step 6.1 and 6.2 for other Eddy Current Probes and Calibration Standards.		Q <u>JK</u> T <u>JKP</u> N <u>NA</u> E <u>QZP</u> O <u>NA</u>	6/18/98 6-18-98 6/18/98	

Q = QC Inspector, T = Technician, N = NDE Inspector, E = Engineer, and O = Other

TEST TRAVELER (Continuation Sheet)		Page <u>4</u> of <u>4</u>	Number		
Operation Number	Test Instruction	Ref., Dwg., Proc. Spec.	Completion Sign/Stamp	Date	Notes
7.0	Verify that all steps in this traveler have been completed.		QC V RJA N NA E JXP O NA	6/18/98 6-18-98 6/18/98	
List of Required Attachments:					
1. Performance Criteria 2. Equipment List 3. Test Layout/Schematic					

Q = QC Inspector, T = Technician, N = NDE Inspector, E = Engineer, and O = Other

HNF-2887, Rev. 0

ATTACHMENT 1

PERFORMANCE CRITERIA FOR EDDY CURRENT THICKNESS
MEASUREMENT PROBES ACCEPTANCE TEST

1. Demonstrate capability for proper placement of eddy current probes in/on calibration standards simulating inner and outer fuel elements.
2. Establish proper setup of eddy current analyzer (MIZ-40) to obtain meaningful measurement signals.
3. Confirm measurement accuracy of 0.0005 in. for various shim thicknesses on calibration standards for each of the eddy current probes.
 - A. Generate a calibration curve for each probe.
 - B. Place the probe against a blindly chosen shim (i.e., the person reading the probe signal does not know which shim is chosen).
 - C. The person reading the eddy current analyzer determines the thickness by:
 - Determining the proper eddy current signal
 - Reading the shim thickness from the calibration curves.

ATTACHMENT 2

EQUIPMENT LIST FOR EDDY CURRENT PROBES ACCEPTANCE TEST

Outer element calibration standard

Inner element calibration standard

Reference assembly block

Underwater camera and VCR

MIZ-40 analyzer

Outer element outer surface measurement probe and cable

Outer element inner surface measurement probe and cable

Inner element outer surface measurement probe and cable

Reference assembly measurement probe and cable

Handling rods for measurement probes

Logbook/data sheets

ATTACHMENT 3

LAYOUT SCHEMATIC FOR EDDY CURRENT PROBES ACCEPTANCE TEST

TEST CONTROL COPY

ACCEPTANCE TEST

ACCEPTANCE TESTING OF THE EDDY CURRENT PROBES FOR MEASUREMENT OF ALUMINUM HYDROXIDE COATING THICKNESS ON K WEST BASIN FUEL ELEMENTS

Date	Time	Std*	Shim	Readings (V)		Avg (V)	Mils
6/18/98	7:55	0/0	0	7.03, 6.98, 7.04, 7.04, 7.01		7.02	
"	7:58	"	2	5.93, 5.87, 5.90, 5.90, 5.90		5.90	
"	8:01	"	3	5.52, 5.62, 5.65, 5.69, 5.70		5.64	
"	8:07	"	5	4.85, 4.86, 4.93, 4.92, 4.91		4.89	
"	8:10	"	10	3.18, 3.10, 3.11, 3.07, 3.06		3.12	
"	8:19	"	3	5.44, 5.44, 5.42, 5.44, 5.44		5.43	3.5
6/18/98	8:27	0/1	0	7.60, 7.60, 7.61, 7.45, 7.43		7.54	
"	8:35	"	5	5.80, 5.84, 5.82, 5.77, 5.80		5.81	
"	8:41	"	3	6.56, 6.41, 6.54, 6.57, 6.46		6.51	
"	8:45	"	2	6.87, 6.89, 6.84, 6.95, 6.90		6.90	
"	9:00	"	2	6.91, 6.93, 6.90, 6.93, 6.91		6.92	1.8
"	9:15	"	10	4.06, 4.10, 4.03, 4.08, 4.08		4.07	
6/18/98	9:20	I	0	6.11, 6.14, 6.16, 6.08, 6.15		6.13	
"	9:24	"	2	5.06, 5.07, 5.01, 5.11, 5.09		5.06	
"	9:27	"	3	4.63, 4.62, 4.69, 4.61, 4.62		4.63	
"	9:29	"	5	3.89, 3.92, 3.88, 3.83		3.88	
"	9:32	"	10	2.49, 2.45, 2.49, 2.41, 2.50		2.47	
"	9:35	"	5	3.95, 3.87, 3.93, 3.96		3.93	4.7

*0/0 = Outer/Outside

0/1 = Outer/Inside

I = Inner

RXP
SOPC
6/18/98J. Hill
DSC
3.4 6/18/98RPA
LH/C
Exp. Log.
6-18-98Held to
retest

Blind

Blind

Blind

DISTRIBUTION SHEET

To	From	Page 1 of 1
Distribution	SNF Characterization Project	Date 08/19/98
Project Title/Work Order		EDT No. 620813
Acceptance Testing of the Eddy Current Probes for Measurement of Aluminum Hydroxide Coating Thickness on K Basin Fuel Elements		ECN No.

Name	MSIN	Text With All Attach.	Text Only	Attach./ Appendix Only	EDT/ECN Only
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P. J. MacFarlan	H0-40	X
B. J. Makenas	H0-40	X
A. L. Pitner (5)	H0-40	X
A. M. Segrest	R3-11	X
J. A. Swenson	R3-11	X
SNF Project File	R3-11	X

Informatics

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Central Files	A3-88	X
DPC	A3-89	X

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J. R. Thielges	L6-38	X

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A. J. Schmidt	K2-12	X