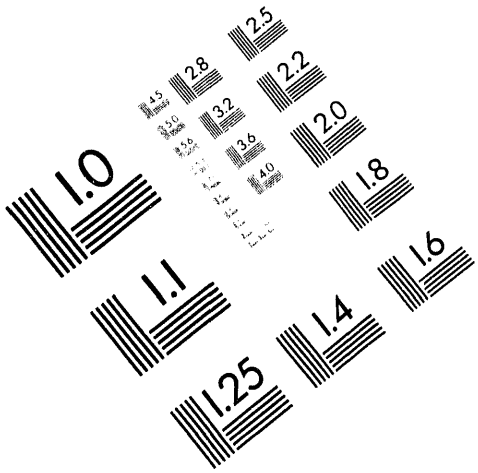

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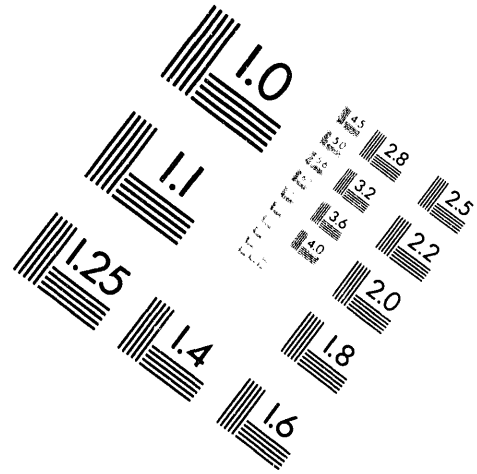

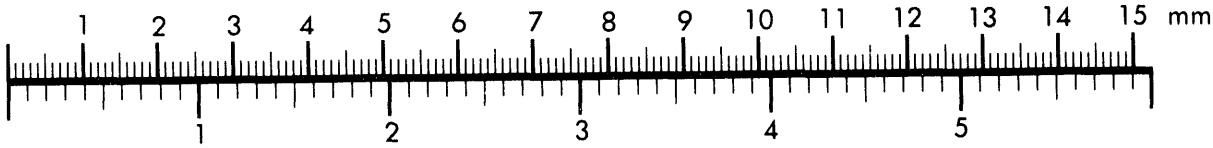

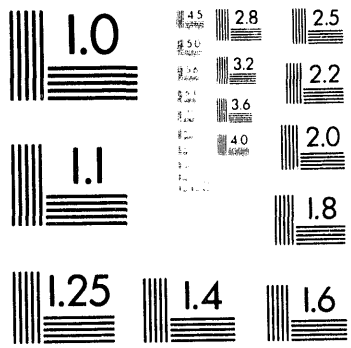

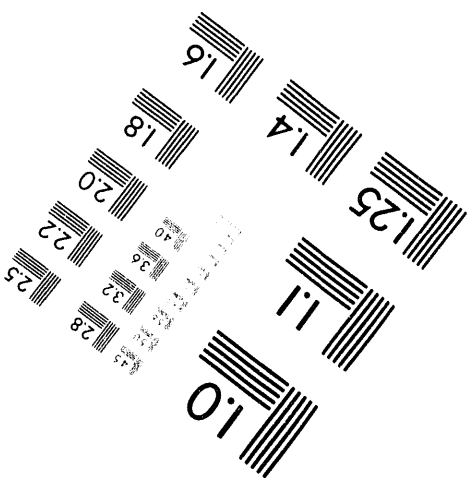

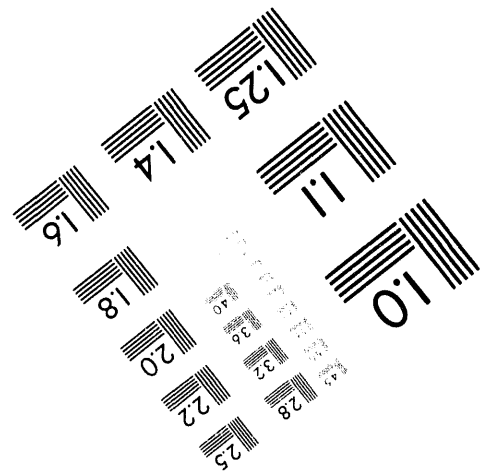

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DESIGN OF PRODUCTION TEST IP-297-A-FP

THE EFFECT OF AUTOCLAVE FILM DAMAGE ON THE INCIDENCE OF GROOVE PITTING ON X-8001 ALLOY FUEL JACKETS

BY

R. E. Hall

and

W. H. Hodgson

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DESIGN OF PRODUCTION TEST IP-297-A-FP, THE EFFECT OF AUTOCLAVE FILM DAMAGE ON THE INCIDENCE OF GROOVE PITTING ON X-8001 ALLOY FUEL JACKETS

Introduction

The recent increase in the incidence of groove pitting on X-8001 clad fuel elements in the old reactors apparently refutes the earlier hypothesis that surface segregation of the secondary phase of this alloy was the primary cause of the unique, preferential attack sustained during irradiation. Components received within the past fifteen months have exhibited essentially none of the segregation. On the other hand, recent evidence suggests that localized penetration of the autoclave film on X-8001 may influence groove attack. The implications of this hypothesis include the necessity of special handling to preserve the autoclave film integrity or possibly elimination of the film altogether.

Either certain conditions or properties of the X-8001 alloy or unusual autoclave conditions intermittently produce non-uniform autoclave films. If some of these film conditions are a result of non-uniform alloy structure in the cans, they may contribute to the groove pitting attack. This report presents the design of a test to compare the scratched and non-uniform autoclave films with uniform unscratched controls under special irradiation conditions to compare the incidence of groove pitting.

Objective

The objective of this test is to evaluate the hypothesis that autoclave film damage contributes to groove pitting of X-8001 alloy clad fuel elements.

Summary of Test

The initial test of sixteen charges containing test elements having three non-uniform autoclave film conditions, and the standard control elements, in a latin square configuration, will be irradiated in new tubes in an old reactor under special flow conditions to 800 MWD/T exposure goal. The need for subsequent testing will be based on the results of this test.

Basis

The persistence of peculiar groove pitting which appears intermittently on X-8001 aluminum alloy-clad fuel elements in the old reactors continues to be a major problem. Radiometallurgical examination of many fuel elements having these pits has

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never revealed evidence of intergranular corrosion; rather, the corroded surfaces appear to have had mechanical work performed on them. Several mechanisms for this type of attack are proposed. These include: a) segregation of alloying constituents on the cladding surface; b) formation of a brittle oxide film which may be mechanically damaged by flowing water[1]; c) "cavitation" like attack on the surface of downstream pieces because of high water temperature - low vapor-pressure relationship; and d) mechanical damage to the autoclave film resulting in sacrificial corrosion in the damaged area. These latter "grooves" appear to be the result of scratches, but may be caused by other mechanical damage to the film.

An in-reactor test[2] to reproduce the "grooving" phenomena was interrupted by a failure which necessitated discharge of the entire test at about 50 percent of goal exposure. Coincidental with the in-reactor test, arrangements were made with the vendor for increased "scalping" of the bloom stock from which X-8001 alloy components were fabricated, to reduce observed nickel segregation. The apparent relief of the groove-pitting problem, which coincided with increased utilization of the segregation-free components, resulted in a de-emphasis of testing programs to reproduce the groove-pitting phenomena. Subsequent experience has shown that in spite of the improvement in jacket surface fabrication, decrease in the incidence of groove pitting may have been a result of lower tube outlet temperatures and that once again it is a serious corrosion problem in the old reactors. Recent experience in D, DR and H Reactors has indicated that groove pitting may be associated with side failures (although conclusive proof is missing, the presence of groove pitting in the vicinity of the failure point on three recent failures in these reactors could be circumstantial evidence.) In addition, a production test[3] to evaluate core stability, recently discharged from DR Reactor contained pieces with both longitudinal and transverse pits which appear to support the hypothesis that groove pitting may be initiated by damage to the oxide film.

Photographs of pieces from the charges in which ruptures occurred in D and Dr Reactors show various degrees of groove pitting may be present on a single piece. There appeared to be large, deep (20-30 mils) filmed-over, pits adjacent to tear-drop shaped pits of shallow to medium depth (0-20 mils) having one side shiny (to the downstream side) or the entire surface shiny, showing active corrosion (or erosion) was taking place at the time of discharge. In addition to the above, most pieces had at least one long (1 to 6 inches) groove which had clean exposed surfaces indicating active corrosion. Failures at the older reactors have generally occurred only in new

1. F. H. Krenz, "CORROSION OF ALUMINUM-NICKEL TYPE ALLOYS IN HIGH TEMPERATURE AQUEOUS SERVICE," Corrosion 13, 575t-81t (1957).

2. HW-54010, "PRODUCTION TEST IP-124-A, INVESTIGATION OF CONDITIONS LEADING TO THE SEVERE PITTING OF M-388 ALLOY SLUG JACKETS," N. R. Miller, December 3, 1957 (Secret).

3. HW-59222, "PRODUCTION TEST IP-220-A-4-FP, EVALUATION OF THE DIMENSIONAL INSTABILITY OF CORE BLANK HEAT-TREATED URANIUM," R. E. Hall, February 11, 1959 (Secret).

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tubes wherein the reduced top annulus provided the necessary flow and temperature conditions to cause groove pitting; however, a failure in an old tube in H Reactor (installed in 1956) which exhibited groove pitting, possibly de-emphasized the new tube as an essential cause.

In summary, in spite of improved jacket surfaces from additional scalping operations, the groove pitting of X-8001 aluminum alloy-jacketed fuel elements continues. The postulated mechanism has been revised to include as suspected causes brittle or damaged oxide film, unusual flow and temperature conditions, and normal corrosive mechanisms.

Flow tests under extreme temperature conditions are underway in mock-up facilities; however, it remains that the final, conclusive testing must be done in-reactor. Since the conversion to X-8001 aluminum alloy jackets has reached a point where over seventy percent of I & E fuel elements in old reactors are clad in the nickel aluminum alloy, it is desirable to determine the cause or causes of the phenomena and take necessary steps to eliminate or reduce the hazard of groove pitting of X-8001 alloy cladding. To provide the necessary experience, this test is proposed to attempt to determine the cause of these phenomena and possibly infer means of eliminating groove pitting. Further, since the source of groove pitting has not been pinpointed, this program will include a series of sub-tests designed to evaluate the most probable sources. Currently in the old reactors, the use of water-mixing pieces to reduce tube corrosion may show if the high top annulus temperature is a primary cause and if water-mixing pieces may be used to prevent groove pitting.

The appearance of transverse grooves to a depth of 0.038 inch on recently discharged X-8001 clad PT elements strongly suggests a primary influence of minor damage to the autoclave film, such as scratches or gouges. These transverse grooves have not been noted on C-64 clad elements.

Fabrication of Test Material

1. Fuel Elements

   Fuel elements for this test will be eight-inch natural OIIN I & E, clad in X-8001 aluminum alloy jacketing material. All components are to meet all requirements of Fuel Element Process Specifications.[4]

2. Assembly

   All fuel elements shall be fabricated in accordance with the Fuel Element Process Specifications.

4. HW-47029, "PROCESS SPECIFICATIONS, FUEL ELEMENT MANUFACTURING PROCESSES, FUELS PREPARATION DEPARTMENT." (Confidential)

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3. Quality of Material

All standard quality control measures will be applied in the fabrication of fuel elements. After autoclave, a sharp tool will be used to mark the test elements. These marks, although serious enough to be considered a cause of rejection on standard fuel elements, are considered essential for this test. These are discussed in detail in the "Testing" section of this report.

4. Quantity of Material

For the initial test, to evaluate the effects of scratches and non-uniform film, 576 X-8001 clad OIIN I & E fuel elements will be required. These are to consist of the following categories:

a. One hundred forty-four (144) having uniform autoclave film.
b. One hundred forty-four (144) having non-uniform autoclave film, and
c. Two hundred eighty-eight (288) pieces to complete the charges on the upstream ends.

Quantities of fuel elements for subsequent testing will depend on the size of the test required.

5. Standard Controls

The standard controls will consist of the 72 fuel elements from the group having a uniform film and which will not be scrached. These elements will be further defined under the "Testing" section which follows.

Testing

1. Pre-irradiation Testing and Measurements

Groove pitting appears on fuel elements in the downstream half of the charge, in the high coolant temperature zone. Therefore, to evaluate causes of this condition, only the downstream half of each charge will contain test elements. The test and control elements will be grouped into the following categories.

	AUTOCLAVE FILM CONDITION	
Surface Condition	Uniform	Non-uniform
Scratched	Code A 72 Pieces	Code C 72 Pieces
Non-scratched	Code B 72 Pieces (Standard Controls)	Code D 72 Pieces

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a. Scratches will be applied in the selected pattern (see attached sketch) using a sharp corrundum tool. Penetration will be less than 0.004 inch.

b. Charges will be made up in latin square arrangement as one charge in each of the following configurations.

ABCD...thru 16 pieces	CADB...thru 16 pieces
BCDA...thru 16 pieces	ADBC...thru 16 pieces
CDAB...thru 16 pieces	DBCA...thru 16 pieces
DABC...thru 16 pieces	BCAD...thru 16 pieces
BACD...thru 16 pieces	ADCB...thru 16 pieces
ACDB...thru 16 pieces	DCBA...thru 16 pieces
CDBA...thru 16 pieces	CBAD...thru 16 pieces
DBAC...thru 16 pieces	BADC...thru 16 pieces

The remainder of each charge will be made up of the 288 non-selected fuel elements. Each selected piece will be marked with the code letters and position number as well as all pieces in each charge having the series number.

c. i) All pieces will be measured for warp, length and diameter.
ii) The selected pieces in positions 1 thru 16 will be weighed and photographed with the slit camera to record surface conditions prior to irradiation. The slit camera pictures will be indexed on the code letter on the base of each selected piece and by a rectangular slot cut in the male contour and on the base adjacent to the outer edge (see attached sketch).

2. Irradiation

The initial test of 16 charges containing test and control elements in a latin square configuration will be irradiated in new tubes in an old reactor under special flow conditions to 800 MWD/T exposure goal. The set of conditions selected for this test will represent conditions under which groove pitting has occurred, as nearly as possible. Thus, based on past experience, there is a reasonable probability that groove pits will appear on some, if not all, of the downstream pieces in this test. Since it is possible that water-mixers affect the incidence of groove pitting, it will be necessary to preclude use of mixers in these charges.

3. Post Exposure Examination

a. All fuel elements from this test will be visually examined for surface conditions. Those pieces exhibiting groove pitting are to be photographed with the slit camera, indexed in such a way that the post-irradiation photographs may be compared with the pre-irradiation photographs.

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b. Pre-measured fuel elements will be measured for diameter, warp and weight changes.
c. All fuel elements will be weaseled to permit calculation of specific power and specific exposure.

Test Audit

Notebook HW-63122 will be needed to record all laboratory data pertaining to this test. Any unusual incidents, whether or not they seem important at the time, are to be recorded in the notebook.

The appendix of the report contains a list of items to be used as a guide for preparation of the notebook.

Test Limitations and Hazards

Since the mechanism for generation of groove pits is not fully understood, the possibility exists that groove pitting may not appear on any pieces from this test. If this condition occurred, this test must be considered inconclusive, yet the results are expected to point out probable conditions necessary to produce groove pitting in further testing.

R. E. Hall
Process and Reactor Development
Irradiation Processing Department

W. H. Hodgson
Engineering Section
Fuels Preparation Department

REH/WWH/gb

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APPENDIX

DATA TO BE RECORDED IN PRODUCTION TEST NOTEBOOK

I. Fuel Element Core Lot Number

II. Can Lot Number

III. Assembly Process

- A. Process Used
- B. Brief Explanation of Process
- C. Attendant Conditions

IV. Post Assembly Treatment

- A. Autoclaving
- B. Marking
- C. Inspection
- D. Photography

V. Pre-irradiation Examination

- A. Dimensions
- B. Warp
- C. Weight 1-16 Downstream

VI. Irradiation

- A. Coolant Temperature
  - 1. Inlet
  - 2. Outlet
- B. Panellit and Crossheader Pressures
- C. Number of Shutdowns (Controlled and Scram)
- D. Other

VII. Post Irradiation Examination

- A. Visual
- B. Warp (And Other Profilometer Data)
- C. Photographs
- D. Other

VIII. Log

Running account with dates recording the progress of the PT, unusual incidents (such as a slight change in process during assembly) and other deviations whether or not they seem pertinent at the time of occurence.

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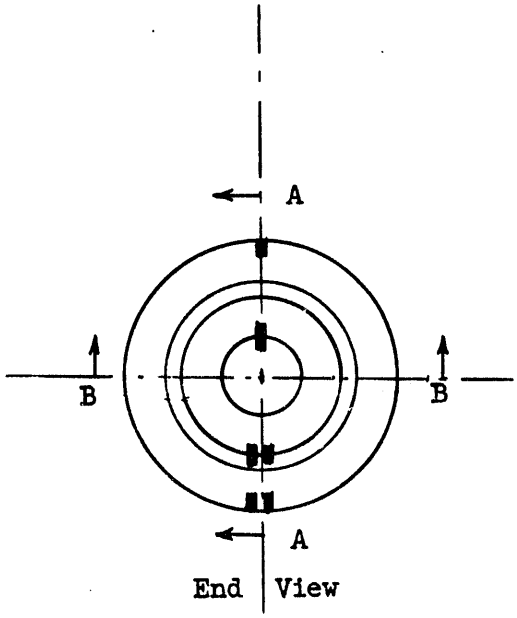


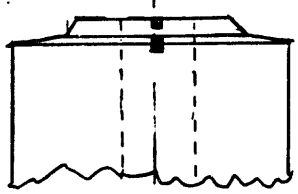
End View

Male End

Section AA

Showing Single

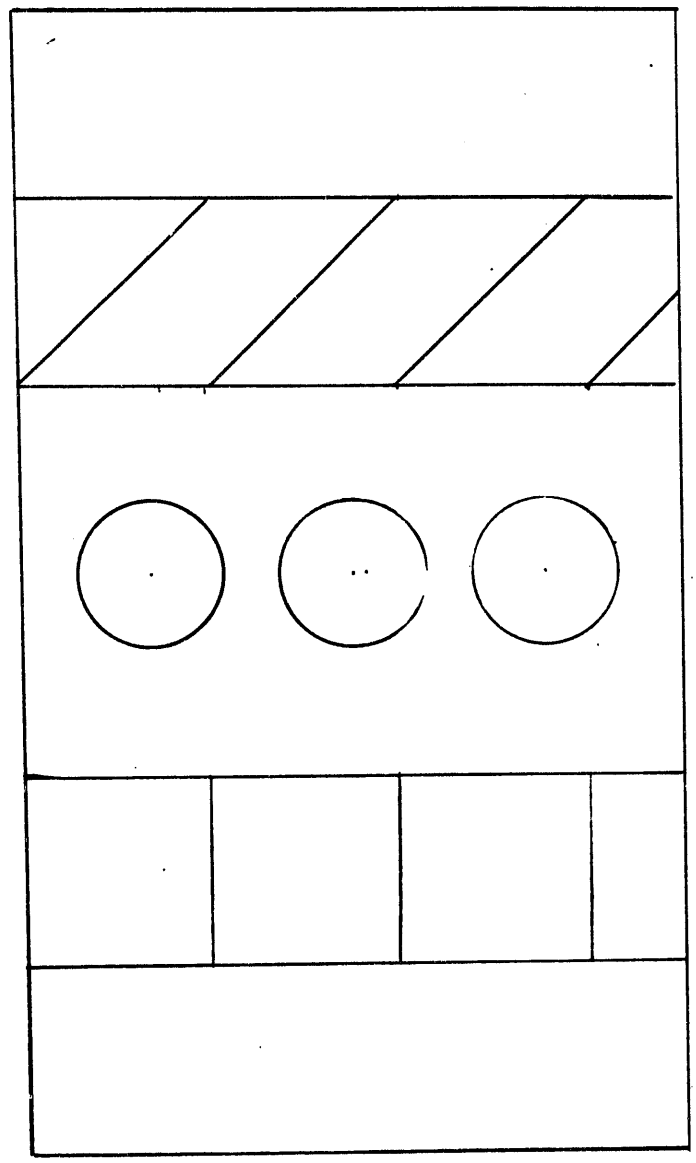
Notch on Left



Side View Showing

Single Notch

MALE END



Extended Fuel Element Surface.
Showing Proposed Scratch Pattern

SKETCH OF PROPOSED MARKINGS ON DOWNSTREAM

FUEL ELEMENTS

DATE
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6/15/94

END