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**THERMAL STRESS TESTING OF
SM-2 FUEL ELEMENTS
FINAL REPORT**

JANUARY 1, 1959 TO JULY 1, 1960

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ALCO PRODUCTS, INC.
NUCLEAR POWER ENGINEERING DEPARTMENT
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**THERMAL STRESS TESTING OF SM-2 FUEL ELEMENTS
FINAL REPORT**

January 1, 1959 to July 1, 1960

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Issued: September 20, 1960

Contract No. AT(30-3)-326
with U. S. Atomic Energy Commission
New York Operations Office

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ABSTRACT

To determine the thermal stability of SM-2 welded, plate-type fuel elements, test specimens were subjected to temperature differences across plate width. Thermal deflections caused by the relatively cool side plates restraining the axial expansion of the fuel region were measured along the axial centerline of the test specimens. Region-averaged temperature differences varied from zero to 116°F, or about 135% of expected reactor operating differentials. Test specimens, machined from standard full-sized fuel elements, consisted of a single fuel plate and its proportionate share of element side plates, and displayed an I-shaped cross-section. A new machining method was used to eliminate the periodic plate rippling which had occurred previously on Phase I test specimens. Thermal deflections of 0.005 in. maximum were measured at the expected reactor operating conditions of 87°F region-averaged temperature differences. With initial (cold) deflections assumed within the SM-2 tolerance of ± 0.008 in., test results indicated that the total operating deflections will be ± 0.013 in. maximum.

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1.0 SUMMARY

Thermal stress testing was performed on portions of reactor fuel elements, as part of the SM-2 fuel element structural test program. Test specimens were subjected to temperature differences across the plate width, and thermal distortions caused by the relatively cool side plates restraining the axial expansion of the fuel region were measured. Test specimens of I-shaped cross-section, machined from standard full-sized fuel elements, consisted of a single fuel plate and its proportionate share of element side plates. In Phase I testing reported in APAE Memo 239*, test plates rippled during the machining operations; in Phase II testing, reported herein, a new machining method was developed to eliminate this rippling. Using test specimens prepared by the new method, a procedure was developed to calibrate the test rig, and deflection readings at temperature differences up to approximately 135% of expected reactor operating conditions were taken on two new I-shaped plates - a solid stainless steel plate, and a fuel plate containing a core of depleted UO_2 .

Initial (cold) deflections of the Phase II test plates were 0.015 in. maximum, at which location 0.005-in. maximum additive deflection due to expected reactor temperature difference of 87°F was measured. Since net thermal deflection is proportional to initial deflection, and initial deflections were assumed within the SM-2 flatness tolerance of ± 0.008 in., the 87°F temperature difference would give additive thermal deflection of less than 0.005 in., or a total operating deflection of less than ± 0.013 in.

Therefore, testing demonstrated the ability of the welded SM-2 fuel elements to withstand representative thermal stresses without severe plate distortion or weld failure.

* Christenson, J. A., "Thermal Stress Testing of SM-2 Fuel Elements," Interim Technical Report, APAE Memo 239, February 9, 1960.

2.0 INTRODUCTION

2.1 GENERAL

As part of the SM-2 fuel element structural test program, thermal stress testing was performed on plate-type, welded reactor fuel elements. When a multiplate fuel assembly is producing power within a reactor, thermal stresses are produced within the element which tend to distort the element and can, in extreme cases, lead to fuel element failure. In the SM-2 element, the major thermal stresses are produced by the temperature difference between the heated portion of the fuel plate and the inert edges of the plate and side plates. The relatively cool inert sections restrain the normal thermal expansion of the fuel portion.

The interim report of Thermal Stress Testing of SM-2 Fuel Elements, issued as APAE Memo No. 239(1), covered Phase I testing. The present report covers all new data taken during Phase II.

2.2 SUMMARY OF PHASE I TESTING

The purpose of the test program was to demonstrate the ability of welded fuel elements to withstand representative thermal stresses without severe fuel plate distortion or failure of the welds which join the fuel plates to the side plates. APAE Memo No. 239 contains a thermal stress analysis, description of the test rig, and the test results listed below. Recent analytical work is reported in APAE No. 69, "SM-2 Core and Vessel Final Design." (2)

Results of testing completed in Phase I were considered inconclusive, due to unrepresentative initial plate distortion. This distortion, in the form of periodic transverse ripples approximately 0.015-in. in amplitude, occurred as the test specimens were cut from the fuel element. Despite this initial distortion, several useful observations were made regarding the welded plate specimens, from tests performed:

1. The effect of thermal stress was to increase the amplitude of original distortions, the original wave length remaining unchanged.
2. With an initial ripple in the test plate of 0.015 in., the distortion approximately doubled at the maximum reactor temperature differential. The additional distortion due to thermal effects was found to be proportional to temperature differential and to ripple length.

3. Tensile stresses in the side plate sections were measured as approximately 10,000 psi at maximum reactor temperature difference. This stress seems reasonable since the buckled plate would not develop full theoretical stress (26,000 psi).
4. Individual weld loadings in shear were measured as 38 lb per weld. Strength tests performed on individual welds revealed that the minimum tensile load resulting in weld failure was 1270 lb. Weld strength of the SM-2 TIG welded elements appears to be fully adequate.

2.3 OBJECTIVES OF PHASE II TESTING

Phase II test objectives were: (1) to obtain test specimens of representative initial flatness and (2) to calibrate the test rig to insure accurate and reproducible dimensional readings during testing. This problem was complicated by the need for a flexible support system to permit overall thermal expansion of the test specimen during testing.

2.4 DESCRIPTION OF FUEL ELEMENTS

The fuel element proposed for use in the SM-2 core is a multiplate assembly featuring the use of a tungsten electrode inert gas shielded (TIG) welding process. Figure 1 shows the welded element. The welds, 16 to each fuel plate, are each 1/2-in. in length and spaced 3 in. apart. The weld pattern is staggered, a weld on one edge of a fuel plate occurring at the midpoint between welds on the opposite edge. The same staggered pattern is used between adjacent fuel plates.

3.0 TEST PROCEDURES

3.1 . GENERAL

The test procedure consisted of measuring test plate deflections at 16 positions along the axial centerline of the plate. After room temperature measurements were taken on various plates to calibrate the test rig, two test plates - a solid stainless steel plate and a fuel plate containing depleted UO_2 - were subjected to region-averaged temperature differences (fuel plate centerline to side plates) ranging from zero to values near 135% of expected reactor operating temperature differences.

3.2 RIG MODIFICATION

The thermal stress rig was modified at the start of Phase II testing by installing thicker seal springs at a finer angle to the specimens, to eliminate any tendency of the spring to bite into the fuel plates when the rig was assembled. Figure 2 shows the thermal stress test complete assembly. Figure 3 is an assembly drawing of the test rig. A complete description of the test rig is given in APAE Memo No. 239.

3.3 TEMPERATURE PROFILE

As in Phase I testing, temperature differences between the portion of the fuel plate that produces heat in reactor operation and the inert edges of the plate and side plate were produced by applying radiant heat to the central portion and cooling the edges with a water spray. Thermocouples were spaced across the plate width at the midpoint between top and bottom of the plate. Figure 4 shows welded test plate dimension with thermocouple and deflection measurement locations. The average ΔT from central portion to edge was calculated by subtracting the average of the two outer couples from the average of the five inner couples.

Two additional thermocouples were located at the opposite ends of the test plate (top and bottom) to monitor centerline temperatures.

4.0 TEST RESULTS

4.1 FLATNESS MEASUREMENTS OF 1/8-IN. THICK GROUND PLATE IN TEST RIG

The straightness of the test rig with respect to a flat test sample is shown by the curve in Fig. 5. However, this curve was not used because the 1/8-in. plate thickness was so much thicker than the regular 0.040-in. test plates that the rig could not accommodate it properly, and the calibration readings were therefore not representative.

4.2 FLATNESS MEASUREMENTS OF AN UNWELDED, SIMPLE 0.040-IN. THICK FUEL PLATE IN TEST RIG

Calibration of the test rig was attempted by taking deflection measurements of an unwelded, simple (flat plate rather than I-section) plate of high initial flatness. A large bow can be seen at the bottom end of the curve (Fig. 6), indicating that the plate was too flimsy to stand up vertically without sagging under its own weight. This test showed the importance of obtaining a valid I-shaped test plate.

4.3 ATTEMPT TO IMPROVE INITIAL FLATNESS OF TEST PLATE

The feasibility of obtaining a high degree of initial flatness by edge restraint was investigated on the precision bed of a milling machine. Long, square bars were clamped down on each side of the plate to the point where a 0.001-in. feeler gage could no longer be inserted anywhere under the side plates. Some improvement in initial flatness was shown, but the improvement gained did not warrant the effort which would have been required to incorporate a method of restraint into the rig.

4.4 DEVELOPMENT OF MACHINING METHOD

The new method developed for machining fuel elements into individual test plates utilized a 0.040-in. thick, 3-in. diam milling saw to slice and final machine the side plates all in one operation. The periodic rippling obtained by the old method was eliminated, although some plates had an overall bow along their lengths. Depleted plates distorted more than solid plates by as much as 1/8-in. overall bow.

4.5 FINAL CALIBRATION OF TEST RIG

The calibration curve shown in Fig. 7 is the result of the method developed to calibrate the rig itself. Deflection readings taken with the same test plate in four different positions: (1) normal test position; (2) same as (1) but turned over; (3) same as (1) but turned upside down; and (4) turned over and upside down, were averaged to obtain the calibration curve.

4.6 FLATNESS MEASUREMENTS OF SOLID TEST PLATE USING DIFFERENT CLEANING PROCEDURES

These readings were taken on the same test plate installed in the rig with the support clamp screws tightened different numbers of turns. After subtracting the calibration curve, the readings were plotted (Fig. 8). These curves show the sensitivity of initial test plate flatness to the assembly procedure, and point out the problems inherent in supporting a flexible plate by a flexible support system.

4.7 COMPARISON OF TEST PLATE FLATNESS WITH OUTER PLATE FLATNESS OF A FUEL ELEMENT ASSEMBLY

Both the solid and the depleted Phase II test plates show more initial distortion than the outer plate of a welded element, (Fig. 9), but are within the SM-2 flatness tolerance of $+0.008$ in. with the exception of position 6 on the solid plate (0.009 -in. distortion), and positions 2 through 5 on the depleted plate (up to 0.015 -in. distortion).

Thus, large portions of each Phase II test plate are dimensionally representative of a welded fuel element assembly. Comparison with Phase I test plates (Fig. 6-1, APAE Memo 239) shows the improvement that was made in initial flatness.

4.8 TEST TEMPERATURE DISTRIBUTION ACROSS WIDTH OF TEST PLATE

Temperature distributions on the Phase II plates were more peaked than those on Phase I plates, (Fig. 10 and 11). The fact that the edges of the Phase II plates were painted glossy black rather than flat black may account for some of this peaking; variations in air valve and Variac settings could also account for some peaking. Centerline temperatures at the top and bottom of the plate were close to centerline temperatures at mid-height, showing that the temperature distribution across the plate width was approximately the same along its entire length.

4.9 FUEL PLATE DISTORTION RESULTING FROM THERMAL STRESS

Temperature testing was accomplished on both the solid test plate and the depleted test plate for various region-averaged temperature differences from no differential to values approximately 135% greater than expected at reactor operating conditions. For the solid plate, data plotted after subtracting the calibration curve is shown in Fig. 12. When the calibration curve was subtracted from depleted plate data, it became evident from the resultant curves that additional bowing or shifting of the plates had occurred during the test. To correct for this shifting, a straight line was drawn through the nodal points of the curves; the curves were then re-plotted with the straight line as the X-axis (Fig. 13). Since the initial deflections had been measured before the shifting took place, this data was disregarded and the cold deflections after test substituted as the initial cold reading.

4.10 TEST PLATE DISTORTION AS A FUNCTION OF TEMPERATURE DIFFERENCE

Comparison of these curves (Fig. 14 and 15) with the corresponding curves of Phase I plates (APAE Memo 239, Page 53) shows that Phase II curves are flatter, or less sensitive to ΔT .

4.11 TEST PLATE DISTORTION AS A FUNCTION OF RIPPLE LENGTH

Points on this graph (Fig. 16) were more scattered than those on the Phase I graph (Fig. 6-13 of APAE Memo 239), but the same general trend was shown, i. e., increase in net distortion with increasing ripple lengths.

4.12 TOTAL TEST PLATE DISTORTION AS A FUNCTION OF INITIAL PLATE DISTORTION

The Phase II curve is not as steep as Phase I, but the same general trend can be seen by comparing Fig. 17 with Fig. 6-15 of APAE Memo 239.

5.0 CONCLUSIONS

Phase II thermal stress testing performed on portions of plate-type reactor fuel elements demonstrated the ability of welded fuel elements to withstand representative thermal stresses without severe plate distortion or failure of the welds which join the fuel plates to the side plates.

Initial (cold) deflections of the test plates were 0.015-in. maximum, at which location the maximum thermal deflection was 0.005 in. Since net thermal deflection is proportional to initial deflection, SM-2 fuel plate flatness tolerance of ± 0.008 in. would give additive thermal deflections of less than 0.005 in., or a total deflection of less than ± 0.013 in. for expected core operating conditions of $\Delta T = 87^{\circ}\text{F}$.

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1. Christenson, J.A., "Thermal Stress Testing of SM-2 Fuel Elements," Interim Technical Report, APAE Memo No. 239, February 1960.
2. APAE No. 69 Draft, "SM-2 Core and Vessel Design Analysis," H. L. Hoover, Project Engineer, July 15, 1960.
3. Allred, W.B., Ascoli, G., Savage, H.C., "Thermal Stability of Multiplate Assemblies," ORNL-113, July 1948.

FIG. 1 - TIG WELDED FUEL ELEMENT-END FIXTURES REMOVED FOR CLARITY

FIG. 2 - SM-2 TASK 6.2 THERMAL STRESS TEST
COMPLETE ASSEMBLY

469 016

- DEFLECTION MEASUREMENT LOCATIONS (NOT TO SCALE)
- THERMOCOUPLE LOCATIONS

**WELDED TEST PLATE DIMENSIONS SHOWING
THERMOCOUPLE AND DEFLECTION MEASUREMENT LOCATIONS**

FIG. 4

FLATNESS MEASUREMENTS $\frac{1}{8}$ IN. THICK GROUND PLATE
INSTALLED IN TEST RIG.

FIG.5

FLATNESS MEASUREMENTS OF AN UNWELDED 0.040 IN. FUEL
PLATE INSTALLED IN TEST RIG.

FIG.6

DEPLETED TEST PLATE

CALIBRATION CURVE
FOR AVERAGE OF FOUR DIFFERENT PLATE POSITIONS
FIG. 7

SOLID PLATE

VARIATION OF TEST PLATE FLATNESS CAUSED BY
CLAMPING PROCEDURE VARIATIONS

FIG. 8

COMPARISON OF TEST PLATE FLATNESS
WITH FUEL ELEMENT PLATE FLATNESS

FIG. 9

REFERENCES:
APAE MEMO #239
PG. 39

SOLID PLATE

TEST TEMPERATURE DISTRIBUTION ACROSS
WIDTH OF TEST PLATE

REFERENCE:
APAE MEMO
239 PG. 48,50

FIG. 10

DEPLETED PLATE- NO. 3DI2

TEST TEMPERATURE DISTRIBUTION ACROSS
WIDTH OF TEST PLATE

FIG. II

REFERENCE :
APAE MEMO #239
PG.48-50

SOLID TEST PLATE

FUEL PLATE DISTORTION RESULTING FROM THERMAL STRESS

FIG. 12

REFERENCE:
APAE MEMO #239
PG. 52

DEPLETED TEST PLATE

FUEL PLATE DISTORTION RESULTING FROM THERMAL STRESS

FIG. 13

REFERENCE:
APAE MEMO #239
PG. 52

**TEST PLATE DISTORTION
 AS A FUNCTION OF TEMPERATURE DIFFERENCE**

REFERENCE: APAE MEMO
 #239 PG.53

FIG. 14

**TEST PLATE DISTORTION
 AS A FUNCTION OF TEMPERATURE DIFFERENCE**

REFERENCE: APAE MEMO
 #239 PG.53

FIG. 15

TEMPERATURE DIFFERENCE 87°
DEPLETED TEST PLATE

TEST PLATE DISTORTION
AS A FUNCTION OF RIPPLE LENGTH

REFERENCE:
APAE MEMO #239
PG. 54

FIG. 16

TEMPERATURE DIFFERENCE 87°
DEPLETED PLATE

TOTAL TEST PLATE DISTORTION
AS A FUNCTION OF INITIAL DISTORTION

REFERENCE:
APAE MEMO #239
PG. 56

FIG.17