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STABILIZING SRE FUEL ELEMENTS

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STABILIZING SRE FUEL ELEMENTS

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ABSTRACT

The method used to prevent thermal bowing of SRE fuel rods is described. Thermal bowing had resulted in an instability which was subsequently eliminated. Rigidity was achieved by installing a helical wire wrap around the fuel clusters. This reduced the power coefficient, measured at power levels to 5 Mw, from +9/Mw to -2.5¢/Mw.

I. INTRODUCTION

Initial indications of reactor^{*} instability appeared when the reactor power level was increased to 2.0 Mwt with the second core fuel elements (Figure 1). It was found experimentally¹ that bowing of the fuel rods caused a fast, positive power coefficient. This was caused by temperature gradients across individual fuel rods. Bowing the rods outward moved them into a higher neutron flux region and forced sodium into the central or lower flux region, producing a positive reactivity effect. The large (0.162 in.) clearance (Figure 2) between the second-core fuel elements and the walls of the fuel channel allowed radial movement of the rods.

A study was initiated to determine the optimum method of re-establishing the stability associated with the SGR concept as proven by the first core fuel elements. Seventeen alternate methods of restraining the fuel clusters were considered. The criteria specified that the restraint should:

- a) Not fail
- b) Be constant from 1/2 Mw through 20 Mw
- c) Not change characteristics for a time period long compared to fuel life
- d) Be amenable to hot cell handling
- e) Introduce a minimum of poison material into the core
- f) Not materially increase sodium hold-up
- g) Permit fuel handling machine or hot cell visual examination of the fuel rods, and snap gauge dimensional checks in the hot cell.
- h) Not damage the fuel cladding
- i) Permit fuel swelling or warp, without changing the restraint characteristics
- j) Not create hangup points
- k) Not adversely affect heat transfer characteristics of the fuel element.

^{*}See Appendix for brief description of the Sodium Reactor Experiment (SRE).

Figure 1. Thorium-Uranium Fuel Element

a. First Core Fuel

b. Second Core Fuel

Figure 2. Cross Sections of a Five-Rod and a Seven-Rod Fuel Element in a Fuel Channel

The result of this study was the recommendation to use a stainless steel wire to bind each five-rod fuel cluster into a rigid assembly. This report describes the development of techniques and components to install the wire wraps.

II. DESCRIPTION OF WIRE WRAP

The wire wrap design incorporated a helical inner wrap around the central support rod and a helical outer wrap around the fuel cluster (Figure 3). The inner wrap prevents inward bowing of the fuel rods while the outer wrap prevents outward bowing.

Wire material, suitable for reactor components, had been thoroughly investigated prior to first core operation of the SRE. This was required since the first core fuel rods were wire wrapped to promote sodium mixing within the fuel cluster and also to space individual rods with respect to each other. The material chosen, Type 304 stainless steel spring wire, has proven to be compatible with the reactor environment.

Spring wire was selected rather than an annealed wire because it maintained a helical shape when it was installed on a fuel cluster. Annealed wire flattened out in the section that spanned the gap between adjacent fuel rods and formed a pentagon-shaped helix. This would have presented "hangup" points when the fuel element was transferred to or from the reactor with the fuel handling machine, (Figure 4). It would have also compounded the sodium holdup problem where the wire makes a line contact with the fuel rods. Sodium retention on the fuel cluster was thus reduced by maintaining the smooth helical configuration with the spring wire because the sodium flow through this larger area had a more positive flushing action.

Geometry of the wrap is such that wire is loaded as a flexural beam. This permits fuel warp to occur without materially changing load on the wire or vitiating restraining characteristics of the wrap. Spring rate of the restraint is ~ 5.5 lb/mil of bowing at the midplane of the fuel element. This limits total reactivity change to about $1/2\epsilon$ in going from zero to full power.

Projected operation of the reactor at 20 Mwt, with concomitant temperature gradients across the fuel rods, would cause the rods to distort similar to a beam supported at both ends and subjected to varying loads over its entire length. The concave inner surface of the cladding would have tensile stresses induced while the outer surface would be in compression. The helical wire coil, with both ends securely fastened to the center support rod, constrains the fuel element at seven points, thus counteracting the bowing tendency at these locations.

Figure 3. Wire-Wrapped Fuel Cluster in a Fuel Channel

Figure 4. Fuel Handling Machine

Stresses and deformation associated with a thermal bowing deflection of 0.800 in., the result of 20-Mw power level operation, have been calculated for a single point contact band. The maximum stress range is 24,000 psi; hence the amplitude is 12,000 psi. This is below the 20,000-psi endurance limit of Type 304 stainless steel at 1000°F. The maximum cladding deformation is about 0.0075 in. on a fuel rod diameter. The stress in the wire is 175 psi compared to an ultimate strength of 118,000 psi at 1300°F, a safety factor of 675. Based on the yield strength of 30,300 psi, the safety factor is 173.

Restraining characteristics of the wire were required to remain essentially constant with regard to time and power level. This was desirable to avoid confusing reactivity change due to a change in fuel restraint with other changes in the reactor and to prevent cyclic power oscillations. These requirements are met by the high creep strength of the wire compared to the service stress; i. e., 18,000 psi for 1% creep in 10,000 hr compared to a service stress of 175 psig. The annealing temperature of the material is in the 1850 to 2050°F range compared to a 1000°F service temperature. The wire wrap is expected to run at the same temperature as the fuel cladding to within $\pm 30^\circ\text{F}$. The variation in diameter of the wrap due to this temperature difference is ~ 0.2 mils.

The coolant channel in an SRE fuel element was considered as two annuli for heat transfer calculations. One, the outer channel, is bounded by the moderator can coolant tube and the outer surfaces of the fuel rods. The other, the inner channel, is bounded by the center rod and the inner surfaces of the fuel rods (Figure 2). Heat flux and flow rates for the two flow channels are different, with the outer surfaces of the rods being preferentially cooled. For uniform cladding temperature, therefore, a certain amount of mixing between the channels is required. The amount of mixing needed for the 5-rod Th-U fuel is about 75% of the amount needed in the first core. The coolant flow in the region close to the fuel rods is directed by the wire wrap and should be adequate for 5-rod fuel elements.

The helical inner wrap (Figure 5) for the 3/8-in. -diameter center support rod was formed with 0.062-in. -diameter wire on a mandrel mounted in a lathe. The completed helix has a 5/8-in. pitch, is 96 in. long and has a 0.404-in. inside diameter.

The 0.089-in. outer wire wrap (Figure 6) was formed on a 46-in. -long mandrel, tapering from a 2-in. diameter on one end to a 1-3/4-in. diameter on the

Figure 5. Pre-formed Inner Wire Wrap

Figure 6. Pre-formed Outer Wire Wrap

other end. A 1/16-in. -deep helical groove was machined in the mandrel for the entire length. The groove helix had a 2-1/2-in. pitch for 33-in. reducing to a 5/8-in. pitch for 13 in. The formed wire coil was then stretch-formed over a cylindrical tube with an 800-lb weight. This tube was 136 in. long and was helically grooved on a 10 in. pitch. Preforming the wire on the mandrel and the tube assured proper lay of the wire on the fuel cluster. The varying helix profile tightened progressively when it was stretched on a fuel cluster, resulting in a snug fit with the desired pitch. Assurance against breakage was provided by using a large factor of safety. During fabrication, the wire was proof loaded to 800 lb compared to a service load of 1 to 2 lb. This test would uncover any faults in the material.

The top and bottom connecting attachments were welded to the wire when the preformed wire coil was fitted on a mockup fuel cluster. This ensured proper orientation of associated components. Assurance of end fastening integrity was provided by mechanically fixing and welding the ends.

III. WIRE WRAPPING THE IRRADIATED FUEL ELEMENT

The development of a technique to wire wrap the irradiated fuel elements was started by constructing a mockup of the SRE hot cell (Figure 7). Manipulators were installed to permit all operations to be performed remotely. The mockup included a 12-in-diameter steel casing imbedded in the floor. This provided the vertical clearance required for correct axial positioning of a mock-up fuel element. The fuel element, suspended on an electric hoist, was thus also positioned with respect to the hot cell wall. Using the mockup hot cell to smooth out details resulted in a well defined wire-wrap procedure, as discussed below.

An irradiated fuel element was first washed to remove residual sodium and radioactive contamination particles. It was then positioned in the hot cell by the fuel handling machine. The clearance between the top guide and support spider, varying from element to element, was measured with a step gauge (Figure 8). The upper hardware yoke was machined to this dimension, minus 0.015 in. to assure a snug fit. Five micarta spacer blocks (Figure 9) were installed between the fuel rods to provide clearance for the center wire wrap. These blocks were positioned no closer than 24 in. from either end to assure that no excessive bending stresses were induced in the fuel rods. The center wire wrap was then introduced into the hot cell through a transfer tube (Figure 10), positioned so that the in-cell delivery end was located between the spread fuel rods and adjacent to the center hanger rod (Figure 11). After a few coils were engaged by screwing the wire onto the center rod, a remotely operated, hydraulic wire cutter was positioned to cut off the first coil of the wire wrap (Figure 12). This was necessary because the first coil had been deformed to a larger pitch and diameter for ease in starting the coil onto the center rod. The wire wrap was screwed onto the hanger rod until the lead end reached the top and the last turn was no farther than 18 in. from the bottom end of the hanger rod. The wire cutter was again positioned and the last engaged coil was cut, allowing the wire wrap to slide down to the bottom of the hanger rod. Each piece of wire that was cut off was inventoried to assure that it did not become lodged between the fuel rods with the possibility of being carried back into the reactor. The micarta blocks were removed, the fuel element was raised, and the bottom guide was removed by withdrawing the cotter key (Figure 13). A preformed outer wire

wrap, with machined-to-fit top hardware, was then transferred to the hot cell through the cell transfer tunnel. The wrap was slipped over the fuel cluster from the bottom with the manipulators (Figure 14), then, the top and bottom hardware were positioned, and the bottom guide replaced (Figures 15 and 16). Wire wrap tension was achieved by tightening the adjusting nut until interference was observed in inserting a 0.005-in. feeler gauge between the fuel rod and the wire wrap (Figure 17). The nut was then tightened one additional turn to take up the 0.005-in. clearance and then locked in position by bending up the tab of the retaining washer against a flat on the nut (Figure 18). The fuel element was then photographed, picked up by the fuel handling machine, and removed from the hot cell.

It has been demonstrated that a fuel cluster can be wire-wrapped in the hot cell in 80 min.

Figure 7. Hot Cell Mockup

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Figure 8. Clearance Gauging

Figure 9. Installing the Spacer Blocks

Figure 10. Hot Cell Mockup Showing Transfer Tube

Figure 11. Installing the Center Rod Wire Wrap

Figure 12. Cutting the Center Wire Wrap

Figure 13. Removing the Bottom Guide

Figure 14. Installing the Outer Wire Wrap

Figure 15. Wire Wrap Upper Hardware in the Holding Fixture

Figure 16. Replacing the Bottom Guide

Figure 17. Adjusting the Tension of the Wire Wrap

Figure 18. Completed Installation
of the Upper Hardware

IV. RESULTS

Thirty-five irradiated fuel elements were wire-wrapped in the hot cell and twelve unirradiated fuel elements were also wire wrapped (Figure 19). Low power physics measurements were performed at power levels to 3 Mw with 40 wire-wrapped fuel elements in the reactor. Results indicate that the power coefficient has been reduced to -2.5¢/Mw from $+9\text{¢/Mw}$ before wire wrapping. Stability of the reactor has been restored. Loss in reactivity due to wire wrapping is $\sim 95\text{¢}$ of which 22¢ is the poisoning effect of the stainless wire. The geometry change effected by restricting fuel rod bowing contributed 73¢ . This was additional proof that outward bowing caused the positive power coefficient.

Figure 19. Wire
Wrapped Fuel Cluster

V. CONCLUSIONS

As a result of this effort, the following conclusions have been drawn:

- 1) Bowing of the fuel rods during operation of the SRE caused reactor instability.
- 2) Constraining the fuel rods prevented bowing which restored reactor stability.
- 3) The wire-wrap method has met all requirements specified to assure reactor integrity. The restraint has:
 - a) Not failed or damaged the fuel cladding
 - b) Proved amenable to hot cell and fuel handling machine manipulation and visual inspection without creating hangup points
 - c) Not increased sodium holdup
 - d) Been constant and has not changed characteristics during reactor operation to 5 Mw; subsequent operation of the reactor to 20 Mw will verify that this requirement has been satisfied.
 - e) Introduced a minimum of poison material into the core.
- 4) The wire wrap has adversely affected the heat transfer characteristics of the fuel elements. Experimental measurements with two fuel elements, before and after wire wrapping, show that the inner annulus temperature has increased. This has not restricted reactor operations since temperatures are well within specified SRE parameters.
- 5) Wire wrapping irradiated fuel clusters has proven to be a fast, easy, and safe method of fuel rod constraint, demonstrating the ease of maintaining and modifying SRE core components.

APPENDIX

The SRE² is a sodium-cooled, graphite-moderated, thermal, heterogenous type reactor (Figure 20). Heat is removed by a main sodium system consisting of a primary, radioactive loop which transfers its heat to a secondary, non-radioactive loop through an intermediate, sodium-to-sodium, heat exchanger. The moderator elements, 10 ft long and 11 in. across the flats, consist of hexagonal graphite logs clad with zirconium. Forty-three 2.805-in. -diameter axial channels through the center of the moderator cans form the lattice in which the fuel elements are suspended. Control rods, safety rods, and experimental elements are installed in corner channels formed where the moderator cans meet.

The present fuel element consists of a cluster of five fuel rods suspended from a center stainless steel hanger rod on a 1.510-in. -diameter circle. A fuel rod contains twelve 0.750-in. -diameter by 6-in. - long Th-7.6 w/o U alloy slugs in a Type 304 stainless steel tube. This tube is 96 in. long, has a 0.790-in. -outside diameter, and has a 0.010-in. wall thickness. The tube is filled with a sodium-potassium alloy (NaK) to a level 9 in. above the fuel slugs. The remaining volume is filled with a helium-argon gas mixture. The tube is sealed at both ends with stainless steel plugs circumferentially welded to assure fuel rod integrity.

Each fuel rod is spirally wrapped with a 0.091-in. -diameter stainless steel wire on a 10.5-in. pitch. This wire promotes sodium mixing within the fuel cluster, increases heat transfer characteristics by inducing turbulent flow, spaces individual rods with respect to each other, and also prevents the fuel rod cladding from touching the walls of the fuel channel. The complete fuel element assembly, consisting of the fuel cluster, hanger rod and shield plug is 285.5 in. long.

The fuel elements are installed in the reactor with the vertical centerline of the fuel coinciding with the vertical centerline of the moderator element. This fuel moderator configuration results in a 2-ft graphite reflector area above and below the horizontal end planes of the fuel.

Figure 20. Cross Section of the SRE

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