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IN-REACTOR MONITORING OF THE ZIRCALOY-2 PRTR PRESSURE TUBES

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RICHLAND, WASHINGTON

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IN-REACTOR MONITORING OF THE ZIRCALOY-2 PRTR PRESSURE TUBES

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The Plutonium Recycle Test Reactor (PRTR) has been built at Hanford to study the use of plutonium as a possible power reactor fuel. The plutonium bearing fuel elements are periodically removed from the reactor dissolved and fission products removed, refabricated into fuel elements, and operated in the reactor to serve again as the fuel, hence the name "recycle." Besides this primary purpose of testing the plutonium recycle concept, the PRTR also incorporates many features which had previously been untried in reactor designs. These include use of a gas pressure-balance scram and control system for the heavy water moderator level and the first large scale use of Zircaloy-2 as a pressure tube material for either nuclear or conventional purposes. In the PRTR the heavy water coolant at 277 C (530 F) and 1100 psi maximum temperature and pressure is circulated at 120 gpm through each of the 85 Zircaloy-2 pressure tubes. The only previous operating experience with Zircaloy pressure tubes at comparable conditions consisted of about three years operation of a few single tube test loops. Consequently, a surveillance program was initiated on the PRTR pressure tubes to help determine the actual operating performance of this material. This surveillance program consists of in-reactor nondestructive inspection of the pressure tubes and pre and post-irradiation destructive testing.

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* This paper is sponsored by Dr. J. M. Batch, Hanford Laboratories, Hanford Atomic Products Operation, General Electric Company.

A cross section view of a typical pressure tube assembly is shown in Figure 1. Note that the reactor is vertical and that the pressure (or process) tube is tapered at the bottom end and rests inside the aluminum calandria (or moderator tank shroud tube.

To make the required in-reactor nondestructive examinations of the pressure tubes, equipment had to be developed to operate inside the 3 1/4 inch inside diameter, 150 mil wall tubes with access available only from the reactor top face. Furthermore, the equipment had to operate in the anticipated 1×10^7 Roentgen/hr gamma radiation field to a total dosage of 10^9R.

The following measurement and inspection goals were selected at the initiation of the program: (1) measurement of inside diameter to detect creep and/or ovality; (2) measurement of the gas annulus separating the pressure tube and shroud tube to indirectly detect bowing of either tube; (3) visual examination of the tube interior surfaces to detect mechanical damage and unusual or localized corrosion areas; and (4) depth measurement of any marks caused from mechanical damage or localized corrosion. Wall thickness measurement was also initially considered but since the main thickness change was expected to result from creep and not corrosion, thickness measurements were considered redundant.

Two probes were originally developed: one for visual inspection and depth measurements and the other for inside diameter and gas gap (gas annulus) measurements. Both probes incorporated materials and components which had good resistance to gamma irradiation.[1]

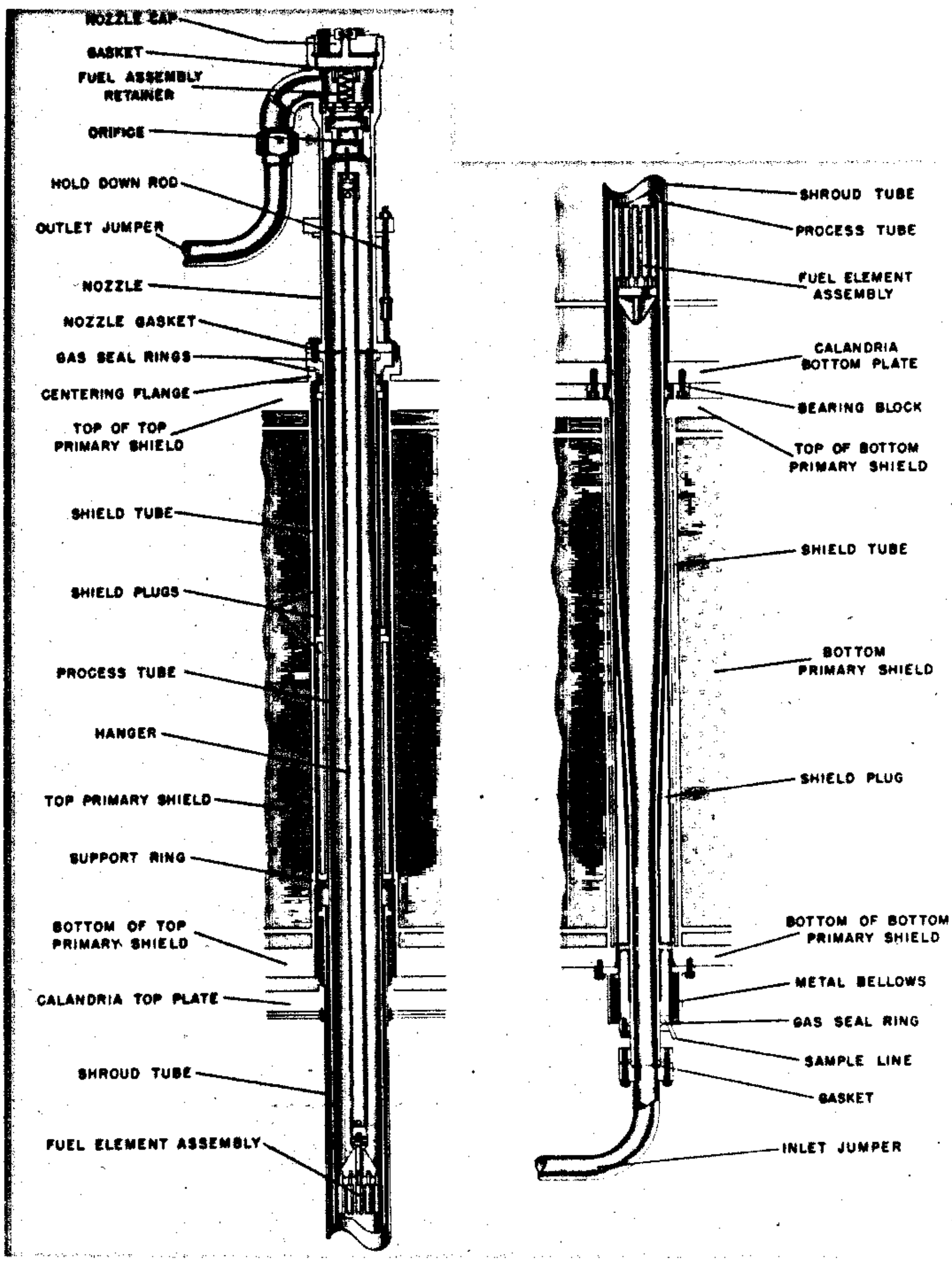


FIGURE 1
PRTR pressure tube assembly

The only two methods of visual examination that appeared feasible were a borescope or a closed circuit television camera small enough to fit inside the pressure tube. The closed circuit TV camera appeared the better method because of the problems involved in making the 18 foot vertical traverse with a borescope viewed by a human observer shielded from the radiation beaming from the tube. A small commercially available nonradiation-resistant TV camera was used for reactor examinations at low irradiation levels. Using the TV camera to view directly through the borescope eyepiece did not appear practical because the borescope light losses were too great to give an acceptable TV picture with the illumination that could be provided inside the tube. Consequently, development work was started on a radiation-resistant TV camera for use at the anticipated high levels of gamma irradiation. Before this development work was completed, however, a TV camera vidicon tube usable at low light levels became available which made TV viewing through the borescope possible. This TV-borescope combination has been developed and used for inspections during the past two years. This system has also provided a means for remote and simultaneous viewing by several persons and has permitted movie film records to be made with a kinescope recorder. A piston-actuated dial indicator operating in conjunction with the borescope has provided an acceptable method for measuring depths of marks found in the pressure tubes. The borescope light mount and dial indicator assembly are shown on the left side of Figure 2.

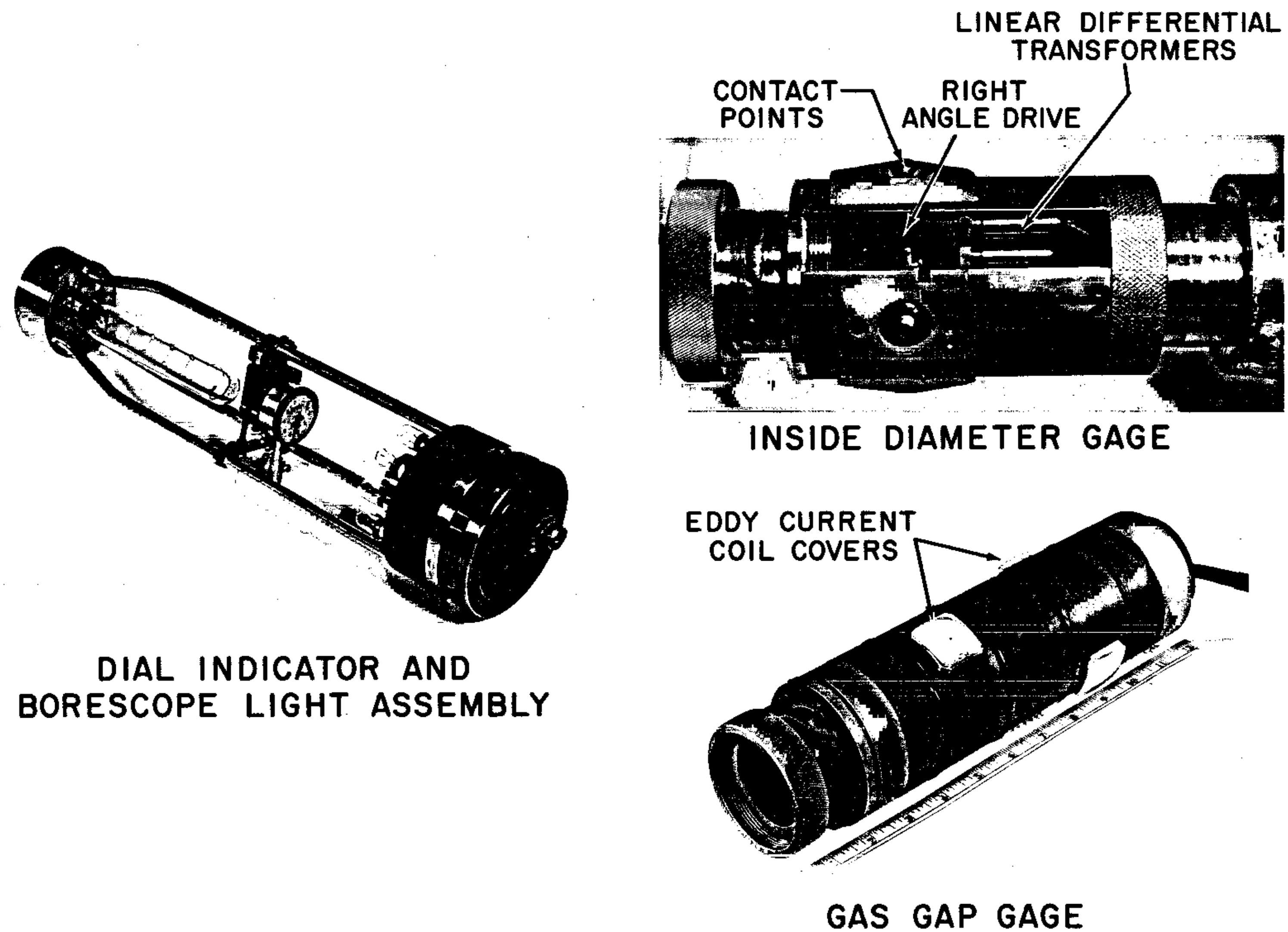


FIGURE 2

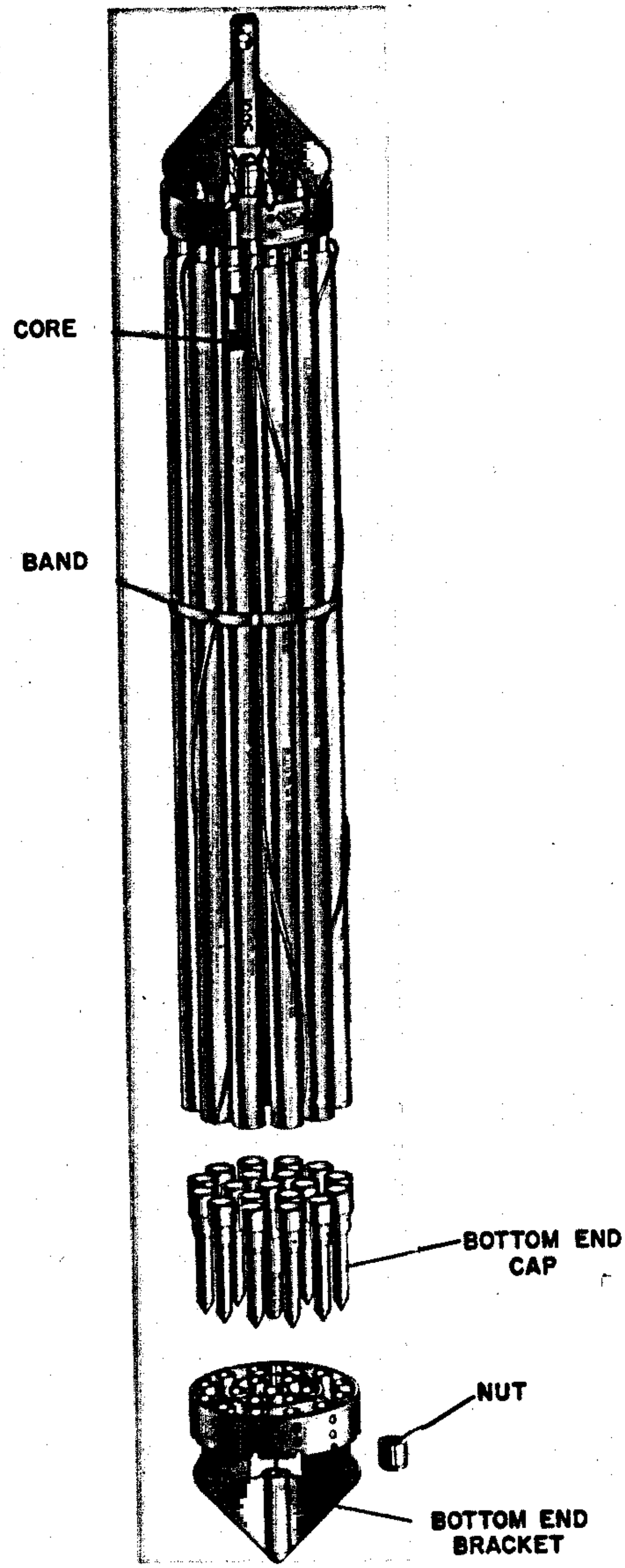
Monitoring Equipment Components

The inside diameter gage uses four linear variable differential transformers (LVDT) spaced 90° apart actuated by mechanical right angle drives. The unique gas gap gage uses four eddy current coils spaced 90° apart to sense the spacing between the Zircaloy-2 pressure tube and aluminum shroud tube.(2) Analog recordings of the inside diameters and gas gaps are measured on two perpendicular axes by circuiting diametrically opposed units to provide single measurements. Both gages are shown on the right side of Figure 2.

This Hanford developed equipment has been used successfully during the past two and one-half years to evaluate pressure tube performance in four categories of interest. First, there has been no detectable creep of the pressure tubes as evidenced by no general change in inside diameter measurements. Second, the relative position of the pressure tubes in the shroud tubes has essentially stabilized after some minor shifting during the first year of operation It was found necessary to reposition two tubes to provide satisfactory annular spacings. Repositioning was done by rotating the pressure tube until the small inherent bows of the pressure and shroud tube aligned to give a satisfactory spacing. Third, visual examination has provided assurance that visible phenomena on the tube inner surface such as localized corrosion spots, mechanical damage, material imperfections, or crud deposition can be detected and at least partially evaluated with the tubes remaining in place.

In the fourth area of interest in pressure tube performance, close surveillance has been maintained on fretting/wear corrosion marks formed at areas of contact between the fuel elements and the tube wall. Before reactor operation it was anticipated that only a few isolated occurrences of fretting/wear corrosion would ever be found, but actual operation has disclosed this to be one of the major factors influencing pressure tube life. The PRTR fuel elements initially were of the two general 19 rod-cluster designs shown in Figure 3. Both were approximately eight feet long and were centered in the pressure tube by three short 1/16 inch wide spacers 120° apart. Spacing between fuel rods was maintained on both designs by spiralled wires wrapped around certain rods. The uranium oxide (UO_2) fuel elements used an additional wire spiralled around the cluster to bind it together and to help center the element in the pressure tube. The plutonium-aluminum (Pu-Al) fuel elements used five 1/4 inch wide bands to bind the cluster together.

Fretting/wear corrosion marks were found in all pressure tubes at the first inspection after the reactor had operated about two weeks with nuclear heat generation. Since high concentrations of chlorine and fluorine were subsequently found in water samples taken during this initial reactor start-up period, separation could not be made between chemical attack and actual fretting/wear corrosion. The marks found were of two general types: those formed from contact with wire wraps around the fuel cluster or individual rods and those formed from contact with the upper and lower fuel element end bracket spacers. Typical marks of both types are shown in Figure 4. These pictures are taken through a borescope equipped with a mirror to give a right angle image in addition to the usual 360° borescope view.[3] No depth measurements could be made since equipment was not available.



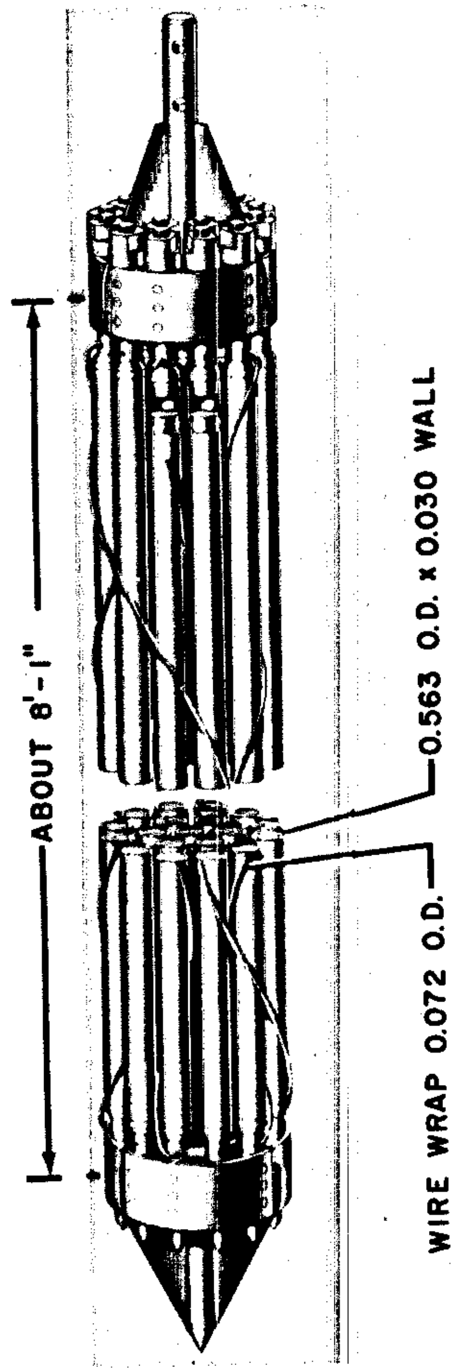


FIGURE 3
19-rod PRTR fuel elements
PuAl type (left)
UO_2 type (above)

After about one calendar year of reactor operations depth measurement recordings on a few selected tubes revealed a general increase in the number and depths of marks. Therefore, another visual inspection of all pressure tubes was made. In this full reactor inspection 11% of the pressure tubes had fretting/wear corrosion marks ranging from 10 to 26 mils in depth, 14% had marks 6 to 9 mils deep, and 75% had marks 5 mils or less. A total of over 1600 marks of all types were found, with 95% of the total being 5 mils or less in depth and only 2% 10 mils or greater in depth. The maximum number of marks found in a single tube was 78. The maximum penetration of 26 mils into the 150 mil wall tube was found to have occurred in about two months of reactor operation. Typical marks of all kinds, including marks from contact of two fuel rods, are shown in Figures 5, 6 and 7.

To determine the effect of the fretting/wear corrosion on tube strength, two tubes were removed from the reactor for destructive testing. Compared with unirradiated tubes, the room temperature burst strength was not adversely affected on tube sections with marks up to 17 and 26 mils deep.

Analysis of inspection results showed that the greatest number and deepest marks resulted from contact with the cluster wire wrap on the UO_2 elements with upper and lower end bracket spacers on both UO_2 and Pu-Al elements. Consequently, both designs and a new fuel element design using mixed uranium and plutonium oxides for fuel were modified by incorporating 1/4 inch wide spacers instead of the previous 1/16 inch spacers and by using metal bands instead of wire wraps to bind the cluster together. Examinations

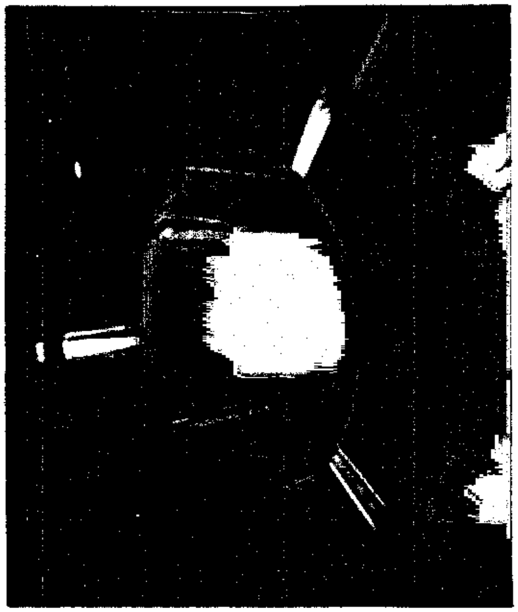


FIGURE 4a
Wear Corrosion Produced by Fuel Bundle End Bracket (360° view)

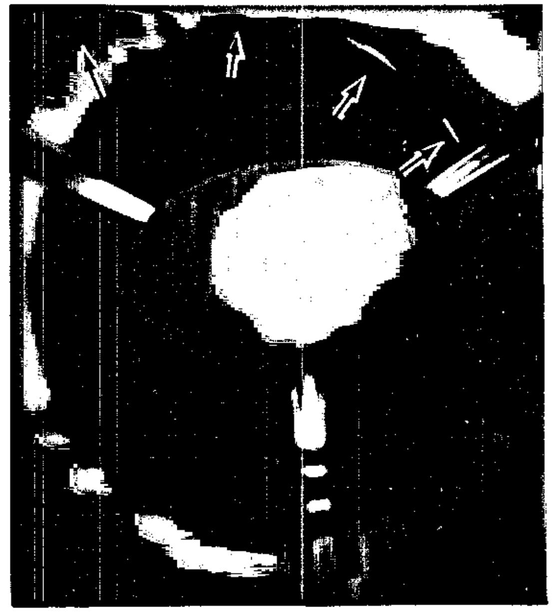


FIGURE 4b
Spiral Wear Corrosion Occurring from Fuel Rods Pressing the Fuel Bundle Wire Wrap (At 11, 12, 1 and 2 o'clock)

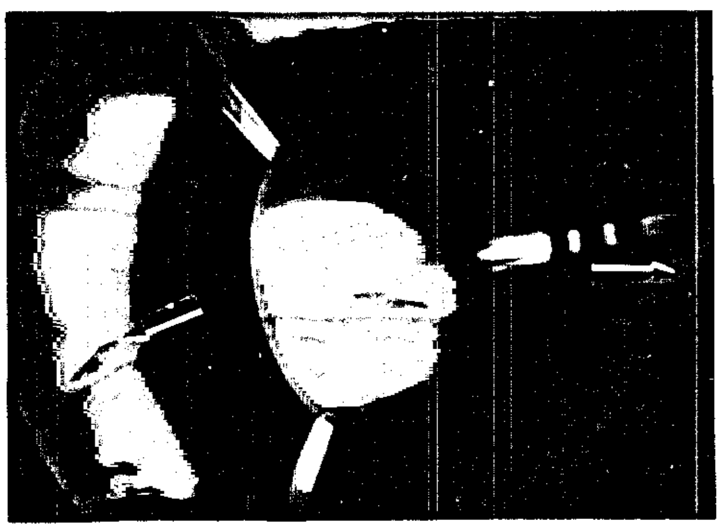


FIGURE 4c

Spiral Wear Corrosinn (at 3 and 9 o'clock) Produced by Fuel Rod Wire Wrap

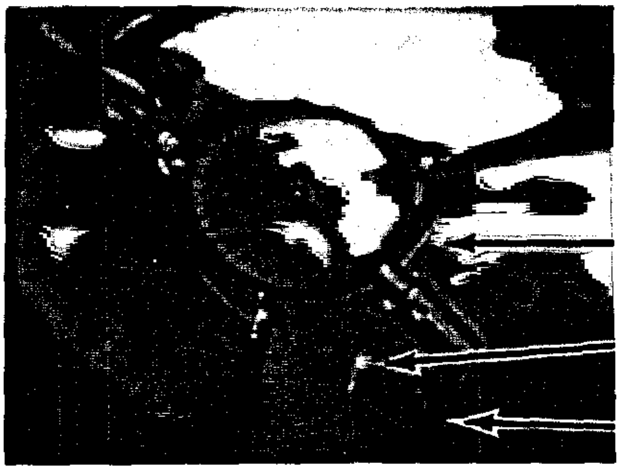


FIGURE 5

General View of Upper Fuel Element End Bracket Area in Pressure Tube with 78 Fretting Marks

Fuel Bundle Spiral Wire Wrap Marks

Single Fuel Rod Spiral Wire Wrap Marks

Upper Fuel Element End Bracket Marks

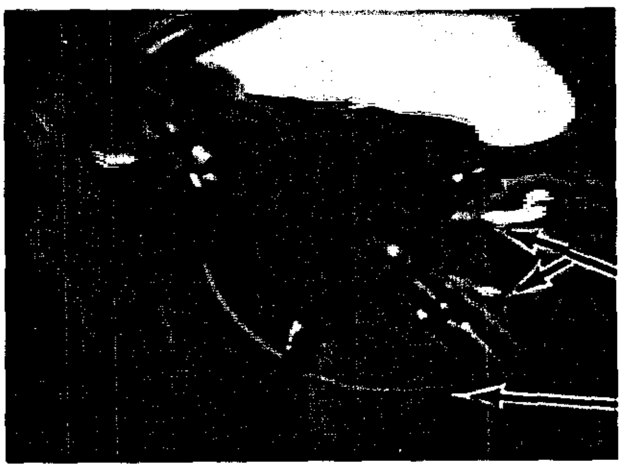


FIGURE 6

View 3 Inches Below Upper Fuel Element End Bracket in Pressure Tube with 78 Fretting Marks

Fuel Rod Contact Areas

Fuel Bundle Spiral Wire Wrap Marks

FIGURE 7

View 10 Inches Below Upper Fuel Element End Bracket in Pressure Tube with 78 Fretting Marks

Single Fuel Rod Spiral Wire Wrap Marks

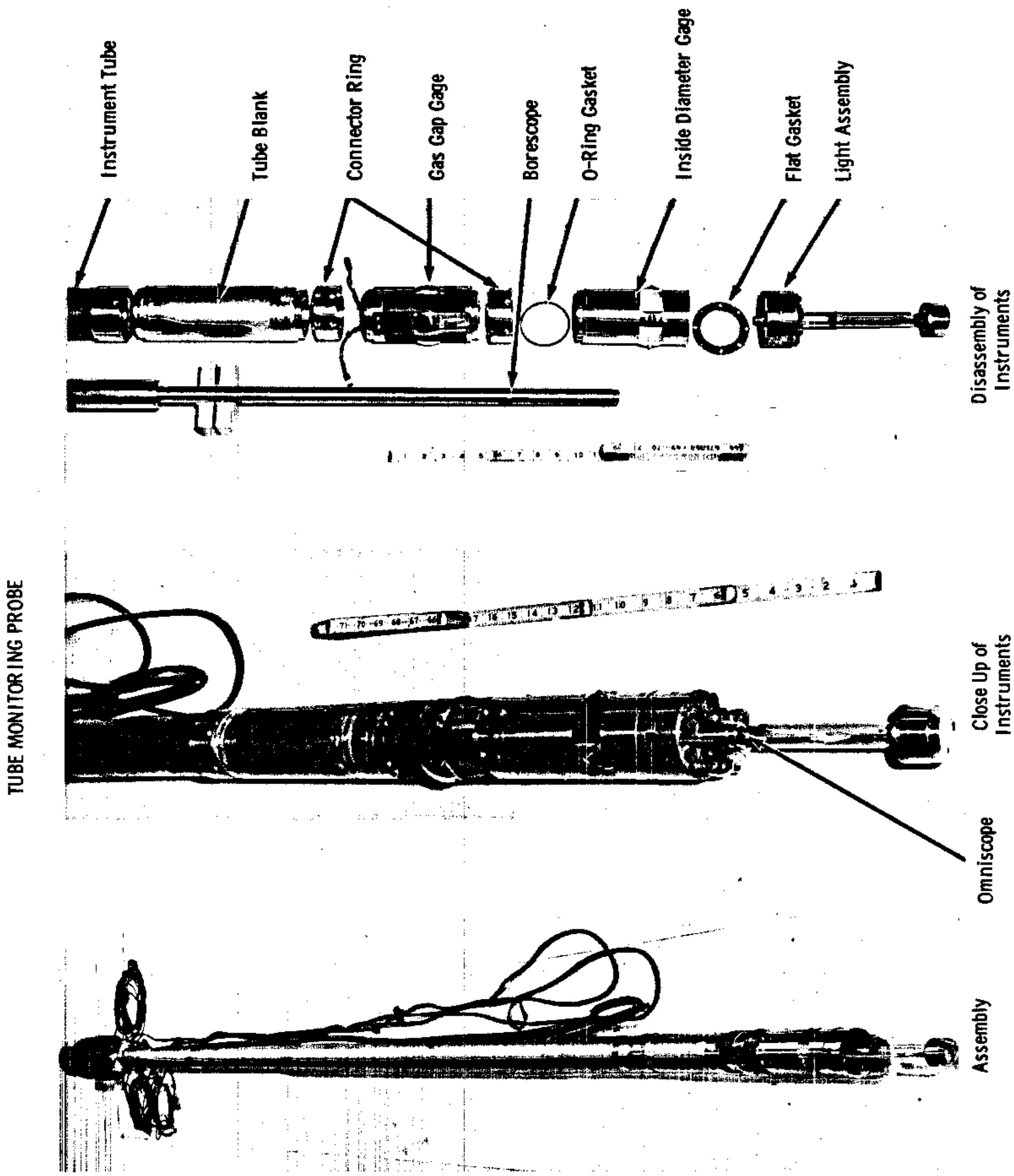


FIGURE 8 REDESIGNED TUBE MONITORING PROBE

during the 1 1/2 years since these changes have been made show that the severity of penetration from fretting/wear corrosion has decreased although prevalence is unreduced.

New equipment for continuing the in-reactor monitoring program is shown in Figure 8. This equipment combines the two original probes into a single probe; provides for easier, more accurate probe manipulation and data read-out; and provides better radiation shielding and contamination containment.

In summary, two important results have been obtained from the PRTR in-reactor monitoring program: (1) acceptable performance of the Zircaloy-2 pressure tubes has been confirmed, and (2) the in-reactor monitoring equipment has successfully provided both visual and statistical information on the tube conditions. This includes discovery of the fretting/wear corrosion evaluation of methods taken to minimize the condition, and a continuing assurance of knowledge of interior tube conditions. Experience gained in the design and operation of this equipment is being incorporated into similar equipment now being designed for monitoring the pressure tubes of the New Production Reactor (NPR) now nearing completion at Hanford.

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