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TEMPERATURE MEASUREMENT IN OPERATING REACTORS: In-Reactor Temperature Measurement Associated with Fuel Element Testing

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AUTHOR

R. G. Wheeler

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TEMPERATURE MEASUREMENT IN OPERATING REACTORS: In-Reactor
Temperature Measurement Associated With Fuel Element Testing

- R. G. Wheeler,
General Electric Company, NAFD
Richland, Washington

The Fuel Development Operation at Hanford uses a variety of in-reactor facilities to test experimental and prototypical fuel elements. High pressure-high temperature water loops in constant use are the 6"x9" ETR core facility, the 3"x3" ETR reflector facility and four front-to-rear loops in the 100-K East reactor at Hanford. Low pressure water cooled test facilities in use are located in the MTR and the various Hanford reactors.

Metal sheathed oxide insulated thermocouples are used in most of the irradiation either to monitor the water temperature increase caused by the fuel charge or to measure core temperature. Thermocouples are therefore a large budget item when you consider that about ten irradiated facilities require fuel charges approximately every month on an average.

Stainless steel sheathed thermocouples 1/16-inch diameter insulated with MgO or Al_2O_3 , when properly fabricated and installed, will reliably measure in-reactor temperature up to 1000 C and at least 4000 MWD/T exposure. The following brief description of some of our temperature monitored in-reactor experiments are the basis of the above statement.

J. E. Weber⁽¹⁾, using the MTR to study swelling in uranium contained in stainless steel capsules and surrounded with NaK as a heat transfer medium, measured temperatures to 750 C and exposures up to 2300 MWD/T. The 1/16-inch diameter thermocouples entered the capsules through Swagelok connectors.

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Roake⁽²⁾ measured core temperatures of 1000 C in the UO_2 core of an element exposed in the MTR.

Gamma and fast neutron heat is a significant fraction of the total heat generated in fuel charges in the MTR 3X3 and 6X9 loops. Goffard⁽³⁾ determined the gamma heating in these loops by measuring the temperature gradient in a non-fissionable material, stainless steel cylinders, exposed in place of fuel elements.

High uranium surface and core temperatures were obtained artificially, before the high temperature loops were available, by interposing an Al_2O_3 layer between the jacket and core of fuel elements. In these experiments, Goffard and Minor⁽⁴⁾ have recorded temperatures greater than 600 C at exposures up to 3500 MWD/T. The end cap of one of these insulated and core elements was ruptured mechanically during reactor operation to see what happened when water hit bare uranium operating at a measured temperature of 550 C.⁽⁵⁾ Temperature changes during this event were recorded successfully.

Our Physical Metallurgy Operation under J. C. Tobin is embarking on an extensive in-reactor mechanical testing program. Since in-reactor thermometry is so important to their program, these^{elr} first experiments were to determine the reliability of thermocouples. Lead wires were tested first⁽⁶⁾. These were insulated with either Refrasil or asbestos, baked at 500 C, and placed in an aluminum sheath that was swaged down onto the bundle of insulated wires. This sheathed assembly was bent into a hairpin loop and inserted into a 100-K reactor test hole. Changes in the resistance between wires and the resistance to ground were insignificant during the exposure to about 10^{20} nvt fast neutrons. Having shown the reliability of lead wire insulation, chromel-alumel, iron-

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constantan and copper constantan couples were tested against National Bureau of Standards melting point lead.⁽⁷⁾ At present, the exposure is about 10^{20} nvt fast neutrons and there is no significant change in the calibration of the thermocouples.

Tobin now has a creep test in-reactor in which the variable reluctance type motion transducer, the heaters, the thermocouples and the metal to ceramic seals are based on a relatively new proprietary ceramic insulation "Durock." The test has been in the reactor for twenty-six days and has accumulated an exposure of 10^{17} nvt fast neutrons. The metal to ceramic seals are holding 300 psi helium pressure at 260 C and there has been no loss in resistance to ground in the electrical components. There are different grades of "Durock" - some being more refractory than others. The grade under test has a maximum ex-reactor operating temperature of about 600 C.

The sheathed thermocouples of our fuel element test assemblies are run clear out to the instrument junction box without splices. A completely reliable method for joining sheathed thermocouples to sheathed lead wires with a splice impervious to 350 C 2000 psi water would simplify our assembly problems a great deal.

Our most difficult sealing problem is at the point of entry of a stainless steel sheathed thermocouple into an aluminum jacketed fuel element or capsule. Tube fittings such as Swagelok are used and these are potted in solder to give added protection against leaks. Helium leak detection and autoclave tests are used to determine the effectiveness of these seals prior to reactor testing. In spite of these precautions, the rejection rate is high on aluminum to stainless seals.

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Electron beam welded joints between 1/16" diameter stainless steel sheaths and stainless steel jackets have worked well at temperatures and exposures up to 530 C and 3250 MWD/T respectively. The type of seal used is illustrated in Figure 1.

An effective seal between the jacket of Zircaloy-2 clad fuel element and a 1/16-inch diameter stainless steel thermocouple sheath was made as illustrated in Figure 2. Boring between the male Zircaloy-2 taper and the female stainless steel taper is accomplished by clamping the extreme end of the stainless steel in the vertical chuck of an electron beam welder. The male taper on the end cap is forced into the female taper in the stainless steel and the stainless steel is then heated with an electron beam as it is rotated by the chuck. Heating is discontinued when formation of a stainless-zirconium eutectic bond is indicated by the appearance of a fillet where the Zircaloy-2 enters the stainless steel taper.

We have some of the same type of problems with swaged thermocouples as were mentioned in the papers of Johansson and others, but a few of these problems may deserve elaboration. When specifications are written tight enough to eliminate unreliable vendors or inferior products, delivery times are often excessively long. Then, too, the art of making reliable reactor quality thermocouples is so new that most of us are unable to write realistic specifications. Poor sheath ductility, low resistance to ground before beading, poor bead quality and leaks in the sheath are our major causes of failure. Poor quality in the thermocouple is generally detected before reactor exposure, but one factor contributing to failure over which the user has little control is rough handling at the reactor.

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In summary, our major problem areas are thermocouple specifications, thermocouple splices, thermocouple end connections and seals between stainless steel thermocouple sheaths and aluminum.

Questions:

Mr. Dieter I. Rall (Advanced Tech. Lab., Mountain View, California): "Who supplies 'Durock'?"

Mr. Wheeler: "Durock is supplied by: Technical Industries Corporation
389 North Fair Oaks
Pasadena, California
Murray 1-5644."

Mr. Theodore W. Hunt (Westinghouse Atomic Power, Pittsburgh, Pennsylvania):

"Was the joint connecting zirconium to stainless steel an ordinary weld?"

Mr. Wheeler: "The iron, nickel, and chromium of stainless steel each tend to form a low melting eutectic when alloyed with zirconium. When the stainless steel is heated in contact with Zircaloy-2, solid state diffusion causes a low melting point eutectic to form where the two metals are in contact. In our case the heating is stopped when eutectic completely fills the joint between the Zircaloy and stainless steel as revealed by the appearance of a fillet where the zirconium taper enters the stainless steel.

Mr. George Johanneson (Westinghouse Atomic Power): "Do you apply slight pressure during the stainless steel to zirconium joining process?"

Mr. Wheeler: "The stainless steel does expand away from the zirconium during the heating process and, as you imply, some force is necessary to keep the two metals in contact. A weight of a few ounces is placed on the Zircaloy-2 end cap is sufficient to cause the male Zircaloy-2 taper to slip down into the female stainless steel taper as the latter expands thus maintaining sufficient contact to the eutectics to form.

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Mr. Funt: "Is this induction heating and is it in vacuum?"

Mr. Wheeler: "I feel sure induction heating in vacuum would lend itself to this joining process. In this case, however, electron beam heating in a dynamic vacuum was used. The work is made anodic to a hot tungsten filament by a few thousand volts. A focussed beam of electrons boiling off of the filament strikes the work releasing their kinetic energy to cause local heating just as the target of an X-ray tube would be heated to its melting point if it were not water cooled."

Mr. J. A. McCann (KAPL, Schenectady, New York): "I suggest that this is the same bond we were talking about which is just a diffusion produced bond made up of Ni-Zr, Ni-Zr-Cr and other inter-metallic compounds. The next point I want to make is that these types of bonds, although non-ductile, will perform quite satisfactorily if stresses are compressive. Since these joints do not like tensile stresses, they must be designed to always be in compression."

Mr. Wheeler: "I can only agree with Mr. McCann."

Mr. Johansson: "What is your technique for using helium leak testing for the tightness of seals?"

Mr. Wheeler: "I should have mentioned in the talk that helium leak detection is generally used on the thermocouple seals at one end of a capsule in those cases where the other, open end, may be connected to the leak detector. I know of no good technique for helium leak checking fuel elements with bonded jackets or completely sealed capsules unless they contain helium (are-vented in a helium atmosphere)."

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FPD - means Fuels Development operation.

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FIGURE I

Sketch Showing Method of Sealing Stainless Steel Sheathed Thermocouple Into a Zircaloy-2 Clad Fuel Element

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FIGURE II

Sketch Showing Method of Sealing Stainless Steel Sheathed Thermocouple Into a Stainless Steel Clad Fuel Element

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