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Refractory Oxide Insulated Thermocouple Designed and Analyzed for High Temperature Applications

A study to determine the feasibility of constructing high temperature thermocouples to measure nuclear fuel pin temperature has been conducted by Glenn F. Popper and Logan Z. Zerlin of Argonne National Laboratory, Argonne, Illinois. Included in the study is a hot zone error analysis, a prototype design for a thermocouple using a tantalum sheath, thoria insulation, and W-3% Re/W-25% Re wires, and design for hot junction and connector pin connections.

Certain phases of Argonne's Fast Reactor List program require sensors which can measure fuel pin temperature up to 2760°C, the melting point of UO₂. Resistance thermometers, gas expansion devices, a thermionic diode and thermocouples were considered for this application, but thermocouples seemed to be the best suited sensors and thus were analyzed.

The thermocouples were selected because they are small in size and can be installed in small diameter fuel pins. The small size and mass also contribute to a better time response, important for transfer-function type experiments. Finally, with thermocouples, only electrical leads need penetrate the reactor vessel.

High temperature thermocouples, however, can only be used in surroundings which will not affect their thermoelectric output. Usually, a sheathed construction is required. This sheath metal must be compatible with the fuel material, atmosphere, and insulator over the thermocouple wire, or solid-phase reactions occur rapidly, destroying the sensor. The thermocouple wires must likewise be compatible with their electrical insulator. The refractory oxide, used as an electrical insulator, must have a high electrical resistivity at the operating temperature or it will act as a

shunt, possibly causing erroneous readings called "hot zone" errors.

Thus in the prototype design of the fuel pin thermocouples, first a literature search was made to determine the compatibility of the materials considered potentially useful for thermocouples—the sheath metal, the electrical insulation, and the thermocouple wire. Thoria (ThO₂) was chosen as the electrical insulator, for it is stable with tantalum up to 2795°C and has low electrical conductivity values.

Many metal alloys were studied for use as the thermocouple materials at high temperatures. Tungsten-rhenium alloys were compatible with thoria up to 2760°C. W-3%Re/W-25% Re was selected as the prototype design combination because of its superior mechanical properties and high output at extreme temperatures.

These thermocouples terminate at an in-vessel connector which has base metal pins. The splice between the thermocouple wire and the pins and/or extension lead wire at the in-vessel connector will operate at temperatures between 250° and 650°C. Extension lead wire for this temperature range is not commercially available; therefore, various base metals are studied for this application. Stainless steel (308)/Alumel alloy proved to be the best base metal extension lead wire at high temperatures with W-3%Re/W-25% Re thermocouples.

The "hot zone" errors were determined by treating a thermocouple as a dc transmission line having a generator with some internal resistance as a source, distributed series and shunting components of resistance along its length, distributed voltage sources

(continued overleaf)

along its length, and an infinite impedance load across the receiving end at null balance.

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