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DUAL GAGING 2200°C JOHNSON NOISE POWER THERMOMETER

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Abstract

A Johnson Noise Power Thermometer (JNPT) for temperature measurements to 2200°C in reactor fuel rods has been fabricated and is being test evaluated for use in the Loss-of-Fluid-Test (LOFT) reactor safety tests. Temperature is determined by measuring the thermal noise spontaneously generated in a sensor coil. Thermoelement wires are used for connecting leads to the sensor coil and thereby provide for simultaneous temperature measurement as a thermocouple. Evaluation units have been fabricated from 1/16-inch diameter Re/W sheath material and HfO_2 insulators using a 0.010-inch diameter Re sensor coil and Re/W thermoelement wires. The thermocouple probe is sealed with an alumina ceramic-to-metal seal and a stainless steel sheathed compensating lead cable transmits the output signal to the measurement instrumentation.

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I. SUMMARY

A Johnson Noise Power Thermometer (JNPT) determines temperature by measuring thermal noise power spontaneously generated in a resistance sensor coil. The noise power is directly proportional to the absolute temperature of this sensor, and because it is not a direct function of the coil resistance the thermometer output remains unaffected by radiation induced transmutation. Therefore, a JNPT has the potential of providing constant in-situ temperature calibration as well as being capable of operating simultaneously both as a thermocouple and as an absolute temperature calibration source.

The primary obstacle in fabricating a 2200°C JNPT was the construction of a localized high electrical resistance sensor able to be contained and insulated at the tip of a 0.062-inch O.D. sheath probe. A successful sensing coil resistor was achieved by winding 0.003-inch diameter Re wire into a 0.010-inch outside diameter coil and placing the coil inside of a two-hole hard-fired HfO_2 insulator. The coil leads were welded to W/5%Re and W/26%Re connecting thermoelement wires which were also insulated with HfO_2. The four-foot long W/Re probe was hermetically sealed with an alumina ceramic-to-metal seal capable of surviving thermal transients to 350°C/min.

Another obstacle in the operation of a JNPT is the elimination of microphonic noise. Two methods have been developed for minimizing microphonic noise. One method compacts fine HfO_2 powder into all voids around the sensing coil and lead wires thus preventing vibration of the conductor insulator parts. A backup approach draws and swages the Re sheath tubing down to compact the HfO_2 insulators, which are crushable. Rhenium work-hardens with as little as 5% deformation, which makes this procedure more difficult to achieve. However, acceptable procedures for implementing both methods of microphonic noise reduction have been developed and are being evaluated.

Preliminary JNPTs have been fabricated and tested at temperatures to 2200°C. Development units demonstrate excellent stability to 2200°C with emf outputs equivalent to that of 2200°C fuel centerline thermocouples. Checkout of the JNPT sensing electronics is in progress.

II. INTRODUCTION

The program objective is to develop a fuel centerline temperature measuring system that can operate at 2200°C and 2500 psi pressure for a minimum of 400 hours at full Loss-of-Fluid-Test (LOFT) reactor power. Tungsten/Rhenium thermocouples have been developed for fuel assemblies. A JNPT in conj8unction with a W/Re thermocouple is now being developed which will allow for continuous absolute temperature calibration.

The new units are designed to have dual gaging capability. Monitoring the JNPT sensing coil output will allow for "in-situ" continuous calibration unaffected by transmutation affects. In addition, the use of W/5%Re and W/26%Re thermoelement wires to connect to the sensing coil will allow the unit to operate as a thermocouple. Data demonstrates that units constructed in this fashion are capable of operating for over 400 hours at the maximum operating temperature of 2200°C with less than -2% drift in the thermoelement emf output.

Most of the development efforts on the 2200°C JNPT have focused on construction of an insulated high resistance sensor coil small enough to be contained within the 1/16-inch O.D. Re/W sheath probe. Achieving the necessary resistance required use of 0.003-inch diameter wire. Previous development work in 2200°C thermocouples demonstrated that necking down of 0.010-inch diameter thermoelement wires occurs in regions between the HfO_2 insulators, and is caused by corrosion due to trace contaminants left in the interior of the thermocouple. The amount of necking down in previous work caused concern about maintaining the integrity of 0.003-inch diameter wire.

Another obstacle in the construction of a 2200°C JNPT is the difficulty in eliminating microphonic noise caused by vibration of the internal components of the unit. Lower temperature materials allow for swaging and compaction of the insulation material around the connecting leads and sensing coil as a means of eliminating excessive vibration. However, operation at 2200°C requires use of a primarily Re sheath material which work-hardens successively after 5% deformation.

Most of the development efforts to date have focused on these two areas of concern. Electronics capable of monitoring the output signal of the JNPT has already been developed and is considered within the state-of-the-art.

III. JNPT DESCRIPTION

A complete JNPT assembly consists of a measuring probe fabricated from a refractory metal sheath that contains two thermoelement wires insulated with HfO_2 connected to a sensing resistor coil. The probe is sealed by means of an alumina ceramic-to-metal seal and the thermoelement wires are spliced in the seal region to the leads of a compensating lead cable. Stainless steel sheathed MgO insulated twin-axial compensating lead cable connects the JNPT probe to the measurement electronics. The probe sheath is fabricated using a chemical vapor deposition process and is Re augmented with less than 5% W to stabilize grain growth. The inside of the tube is chemically etched to provide the required cleanliness for 2200°C operation. The HfO_2 insulators are fabricated from specially processed high purity powder, which is extruded and then sintered at 1700°C to provide hard-fired 0.044-inch O.D. insulators suitable for JNPT fabrication. The thermoelements used are standard 0.010-inch W/5%Re - W/26%Re wires. The sheath probe is required to be hermetically terminated to withstand thermal transients of up to 6°C/s while continuously pressurized at 7.2 MPa (2500 psi), and pressure transients of 2.4 MPa/s while at 450°C. The seal termination occurs near the top of the fuel rod. An alumina ceramic-to-metal seal with Mo/Ni sleeving was developed to satisfy the service requirements.

The procedure used to fabricate the JNPT assembly is summarized as follows. The sheath material is thoroughly cleaned using a combination of acids and solvents. The sheath tubing is then vacuum baked and the insulators are air baked immediately prior to assembly. The insulators, conductor components, and ceramic seals are then assembled together in ambient air and the assembled unit is vacuum baked and backfilled with high purity argon gas. The sensor coil is attached to the thermoelement wires by means of laser welding prior to assembly into the sheath. After backfilling with the argon gas, the units are seal welded closed, and a transition region and the required amount of compensating lead cable are added to complete the assembly. Note that operation at 2200°C was achieved without prebaking the components at similar temperatures and without assembly in a glovebox. Figure 1 is a photograph showing the appearance of a completed JNPT assembly. Figure 2 shows a cross-sectional illustration of the junction region of a JNPT unit.

IV. THERMOCOUPLE DEVELOPMENT, RESULTS, AND DISCUSSION

JNPTs fabricated to the design shown in Figure 2 have been fabricated and demonstrate excellent stability in furnace tests to 2200°C. In addition, the emf outputs are equivalent to that of previously developed 2200°C thermocouples. As previously discussed, the sensing resistor consists of a 0.003-inch diameter Re wire closely wound in a coil with an O.D. 0.010-inches. Figure 3 is a photograph showing an enlargement of the small diameter (0.010-inch) sensor coil. The coil is placed inside of a "standard" two-hole hard-fired HfO_2 insulator and the coil leads are laser welded to the W/Re thermoelements of the assembly. Evaluation studies have demonstrated that residual contaminants known to remain in the sheath interior preferentially attack W and do not appear to effect Re. Stability tests at 2200°C show negligible change in resistance of the 0.003-inch O.D. Re sensor coil wire. An increasing resistance with time at temperature would be evidence of corrosion.

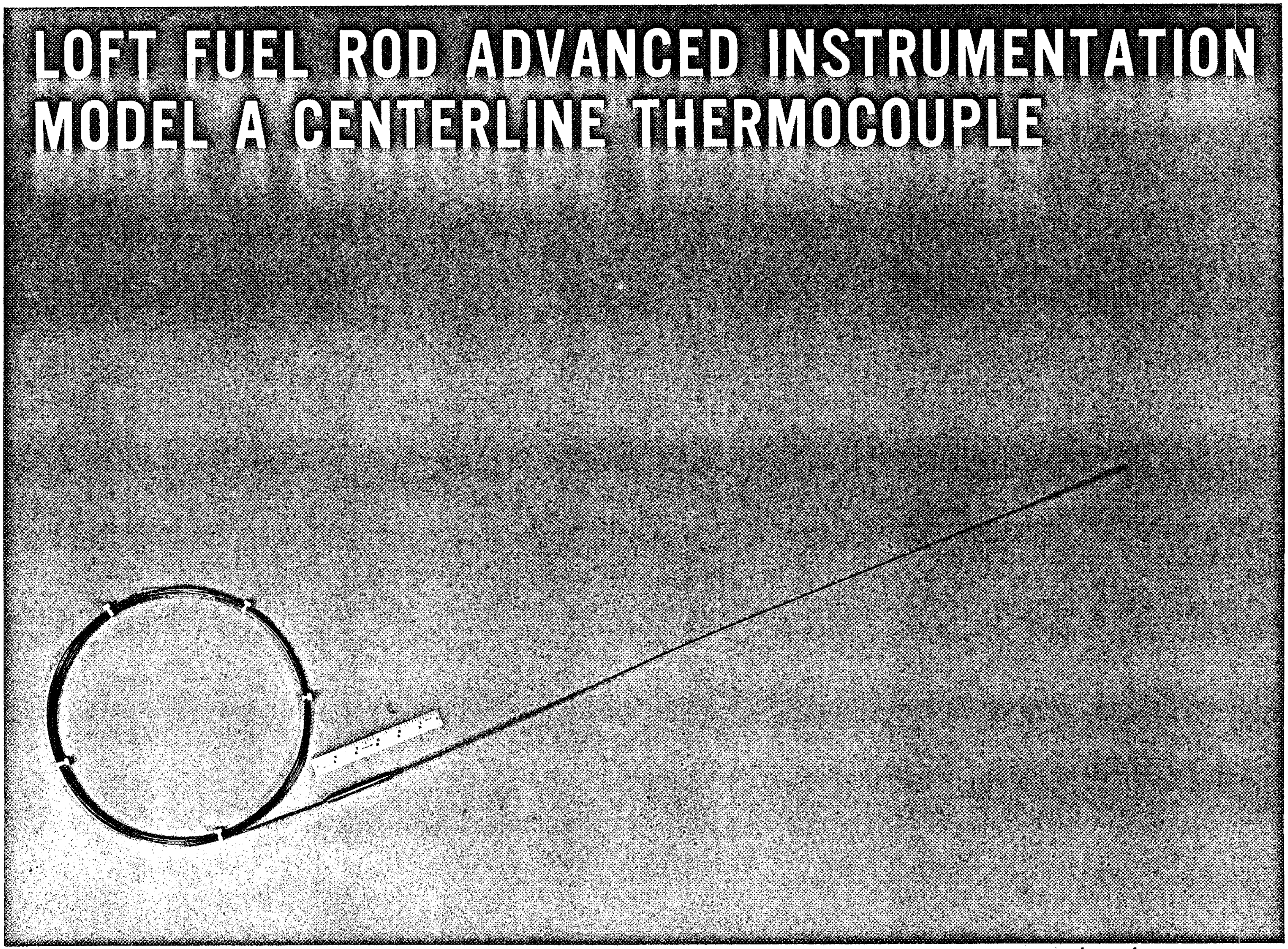

FIGURE 1. Photograph Showing The Appearance of a Completed Johnson Noise Power Thermometer (JNPT).

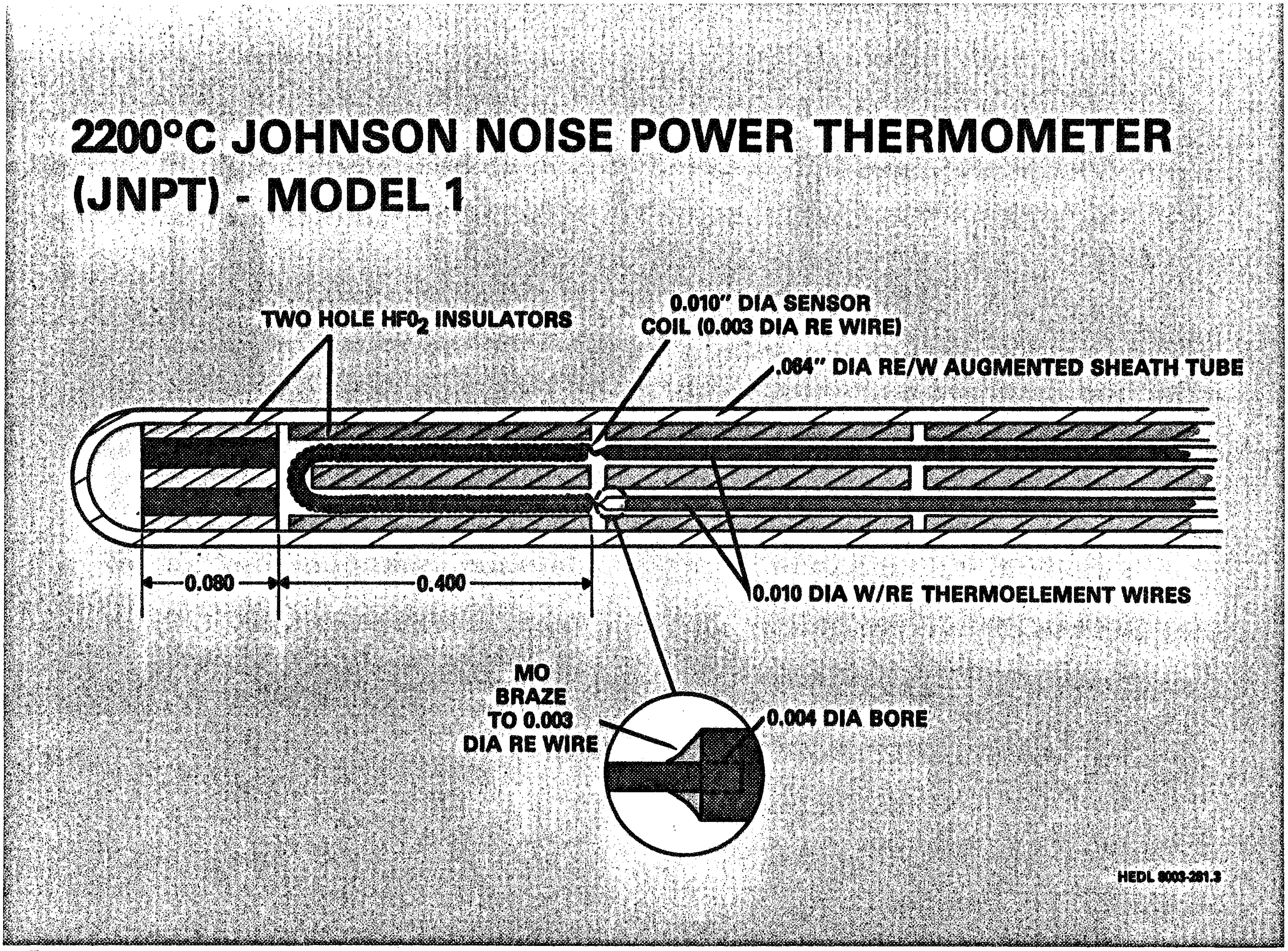

FIGURE 2. Cross Sectional Illustration of the Sensor Region of the Primary Design JNPT.

PHOTO OF 0.010 IN DIA JNPT SENSOR COIL - MODEL 1

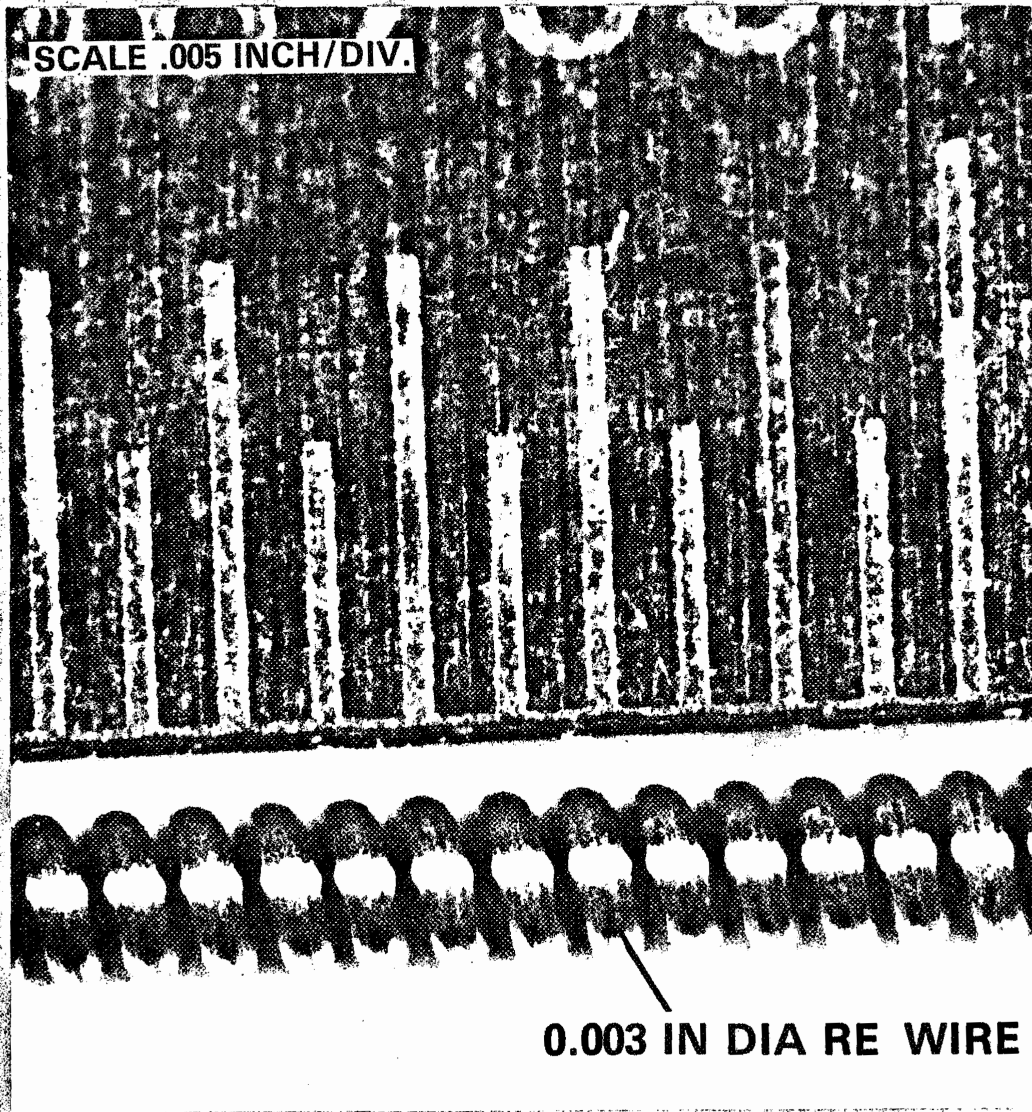

FIGURE 3. Photograph of Small Diameter (0.010-Inch O.D.) Re Sensor Coil.

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Figure 4 is an illustration of a cross-section for a JNPT design used as a backup position. The design uses a 0.003-inch diameter Re wire sensing coil wound to a coil diameter having a diameter of 0.041-inches. The coil is insulated by depositing HfO_2 on it using a chemical vapor deposition process, and the design calls for the coil to be inserted into a single-hole hard-fired HfO_2 insulator as shown in the illustration. Figure 5 shows photographs of this size sensor coil, along with the coil that has been coated with HfO_2. Figure 6 is a photograph comparing the relative sizes of the two types of sensor coil. The design illustrated in Figure 2 is considered the preferred construction because all insulation is in the form of previously developed hard-fired HfO_2 insulators. However, construction of backup models is proceeding for test and evaluation.

Figure 7 shows two designs for reducing microphonic noise in the JNPT. One method compacts fine HfO_2 powder in all voids around the sensing coil and lead wires, thus preventing vibration of conductors and insulator parts. The procedure to do this has been developed and evaluation units have been fabricated and are now being test evaluated. Another method, considered a backup approach, draws and swages the Re sheath tubing down and compacts the HfO_2 insulators, which are crushable. Although Re work-hardens with as little as 5% deformation, an acceptable process for reducing the Re sheath tubing to the required diameters has been developed.

Evaluation units have been constructed and are now being furnace tested. Results to date demonstrate good stability at 2200°C regarding all physical parameters measured; insulation resistance is comparable to standard 2200°C thermocouples as is illustrated in Figure 8. EMF drift is projected to be the equivalent of 2200°C thermocouples and is illustrated in Figure 9.

The electronic measurement apparatus for measuring RMS voltage and current outputs of JNPT units has been procured, assembled, and is now being checked out. Algorithms have been prepared to process the output data from the measurement electronics. Evaluation tests to 2200°C inside of a controlled atmopshere furnace are now being conducted with the JNPT measurement apparatus.

2200°C JOHNSON NOISE POWER THERMOMETER (JNPT) (MODEL 2)

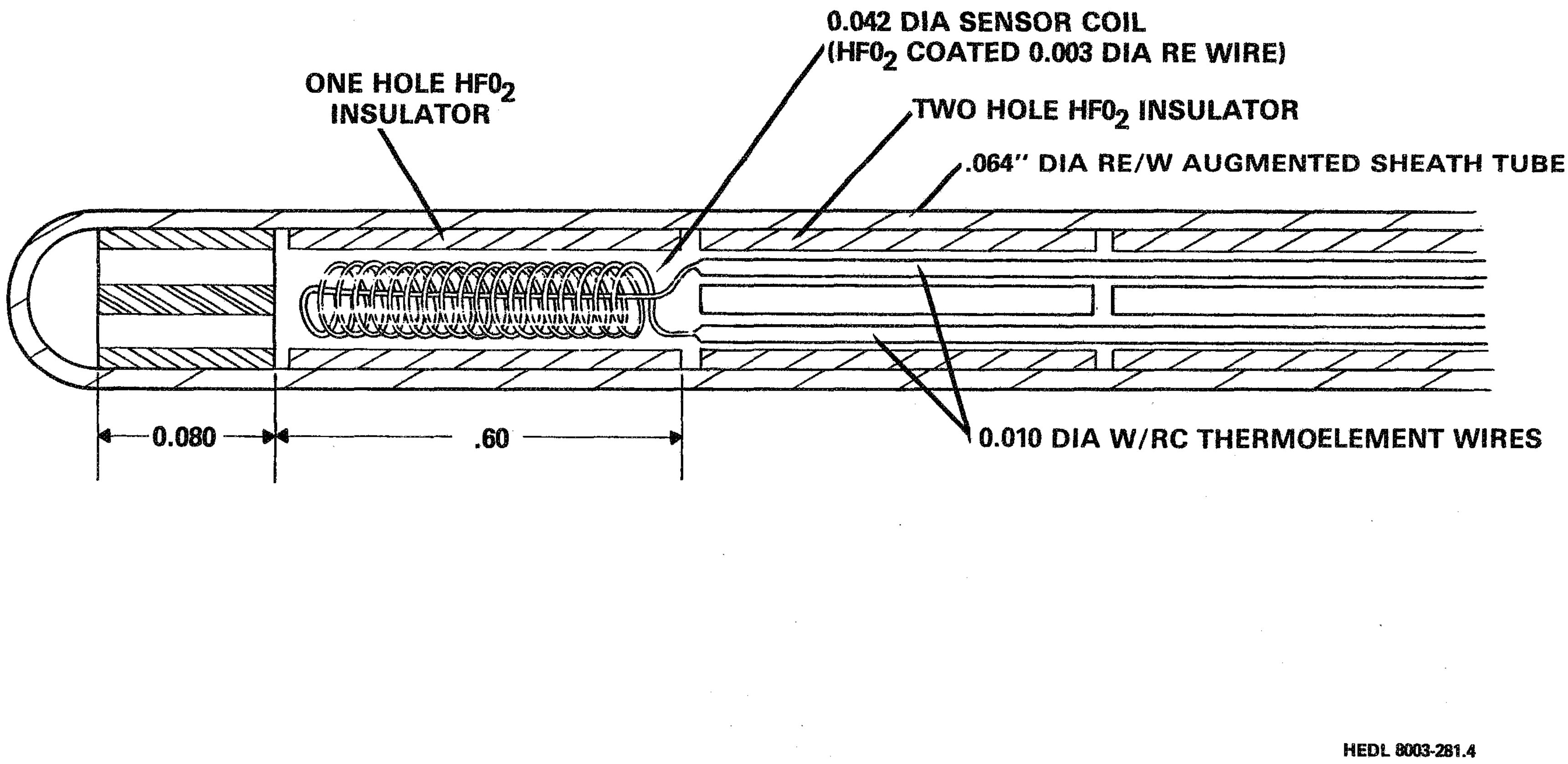
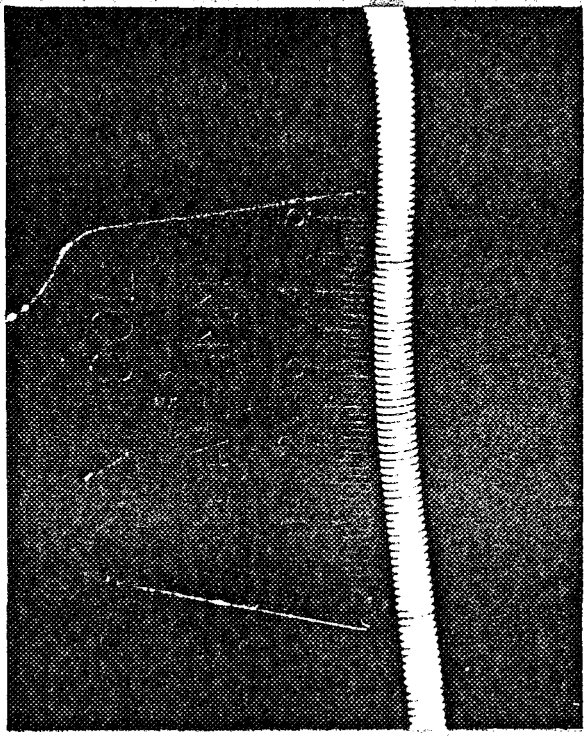
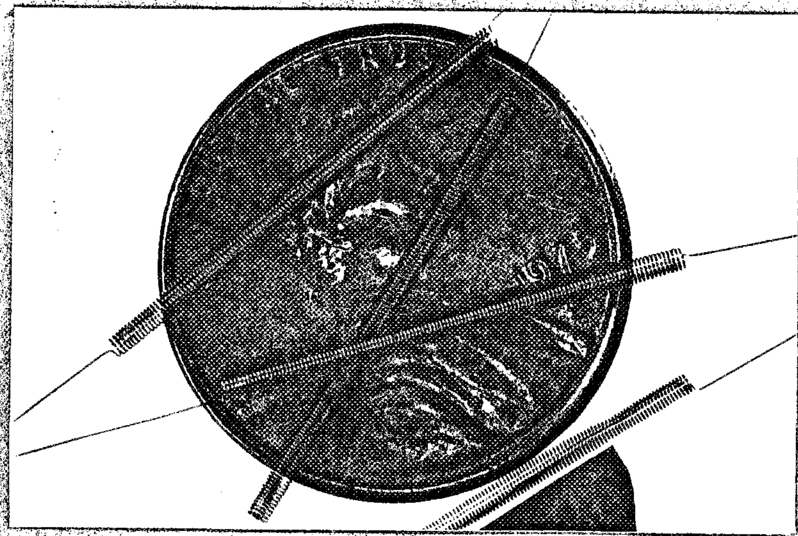


FIGURE 4. Cross Sectional Illustration of the Sensor Region of the Backup Design JNPT.

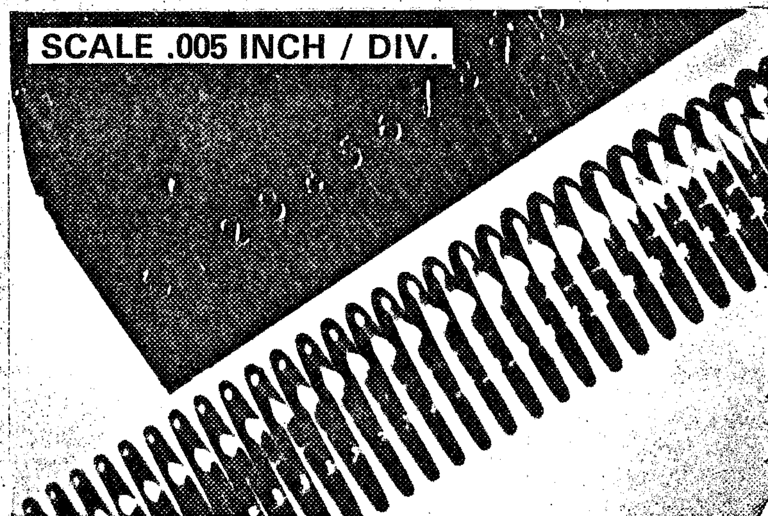
JNPT 0.042 DIA SENSOR COIL DEVELOPMENT



0.042 DIA SENSOR COIL — HFO_2 COATED 0.003 DIA RE WIRE



0.042 DIA SENSOR COILS ON U.S. PENNY



0.042 DIA SENSOR COIL — 0.003 DIA RE WIRE

FIGURE 5. Photograph of 0.042-Inch Re Coils.

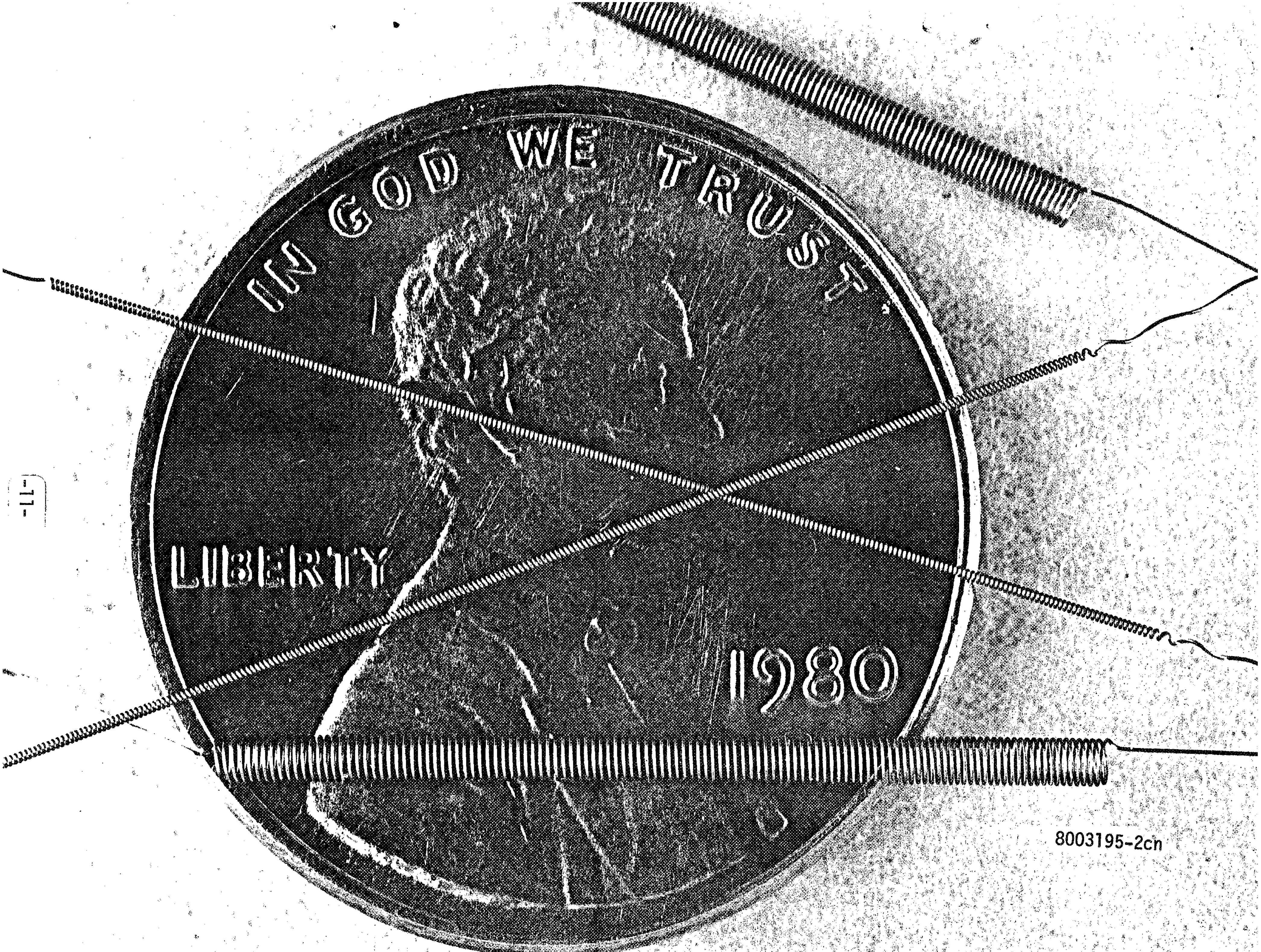


FIGURE 6. Photograph Comparing the Two Sizes of Sensor Coils.

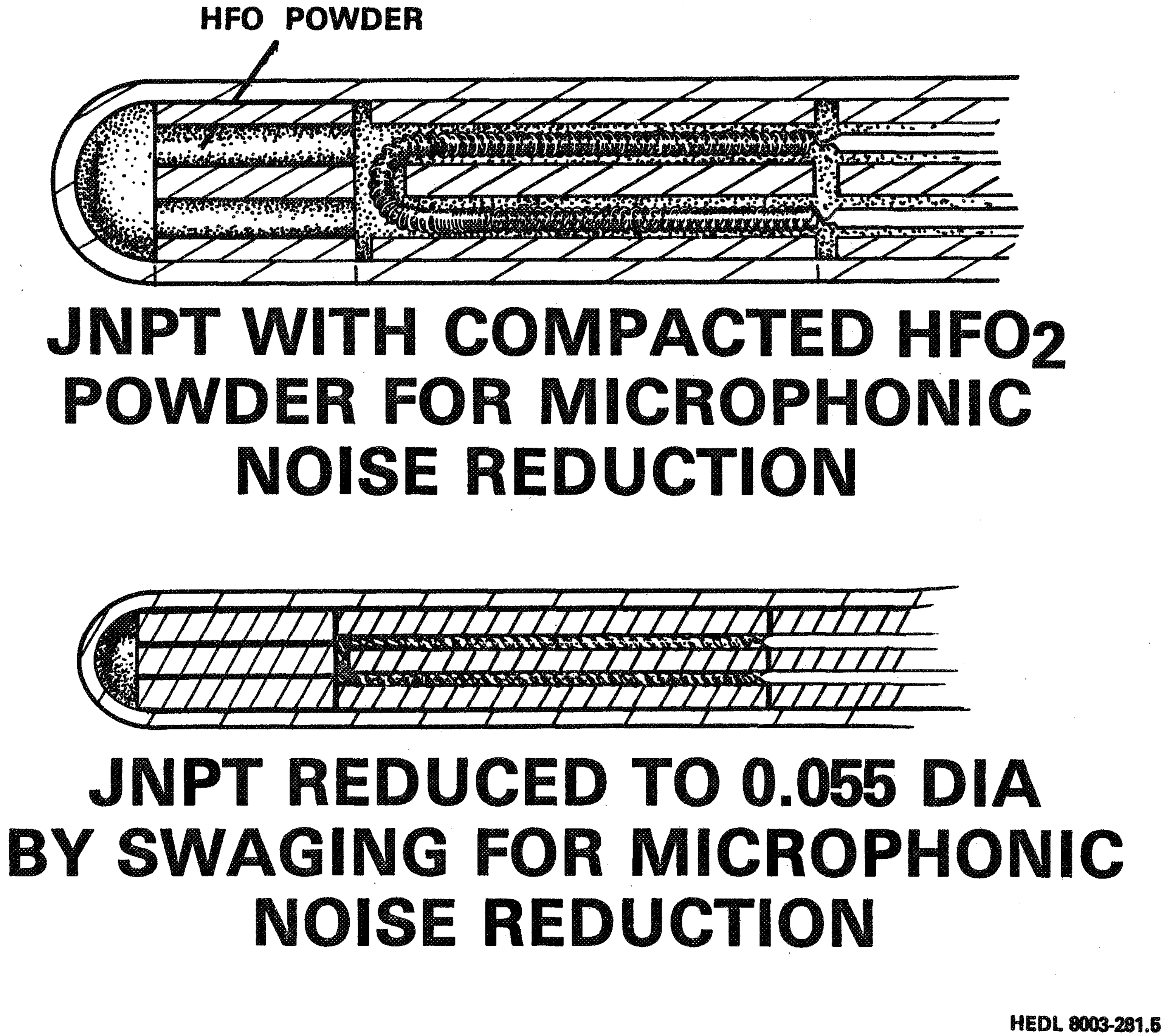


FIGURE 7. Illustrations of Two Designs for Reducing Microphonic Noise.

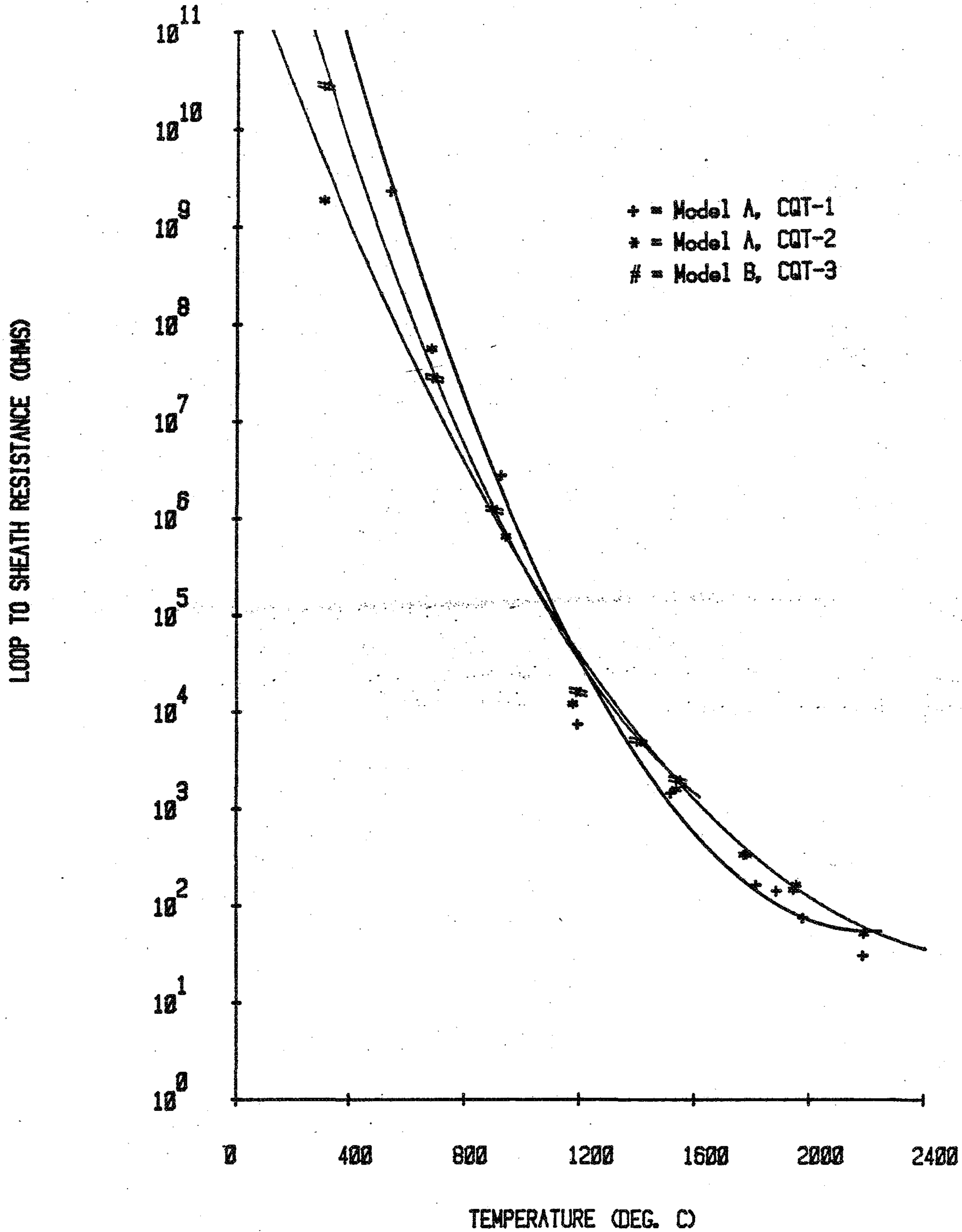


FIGURE 8. Plot of Insulation Resistance vs. Temperature for Typical 2200°C Thermocouple and JNPT Units.

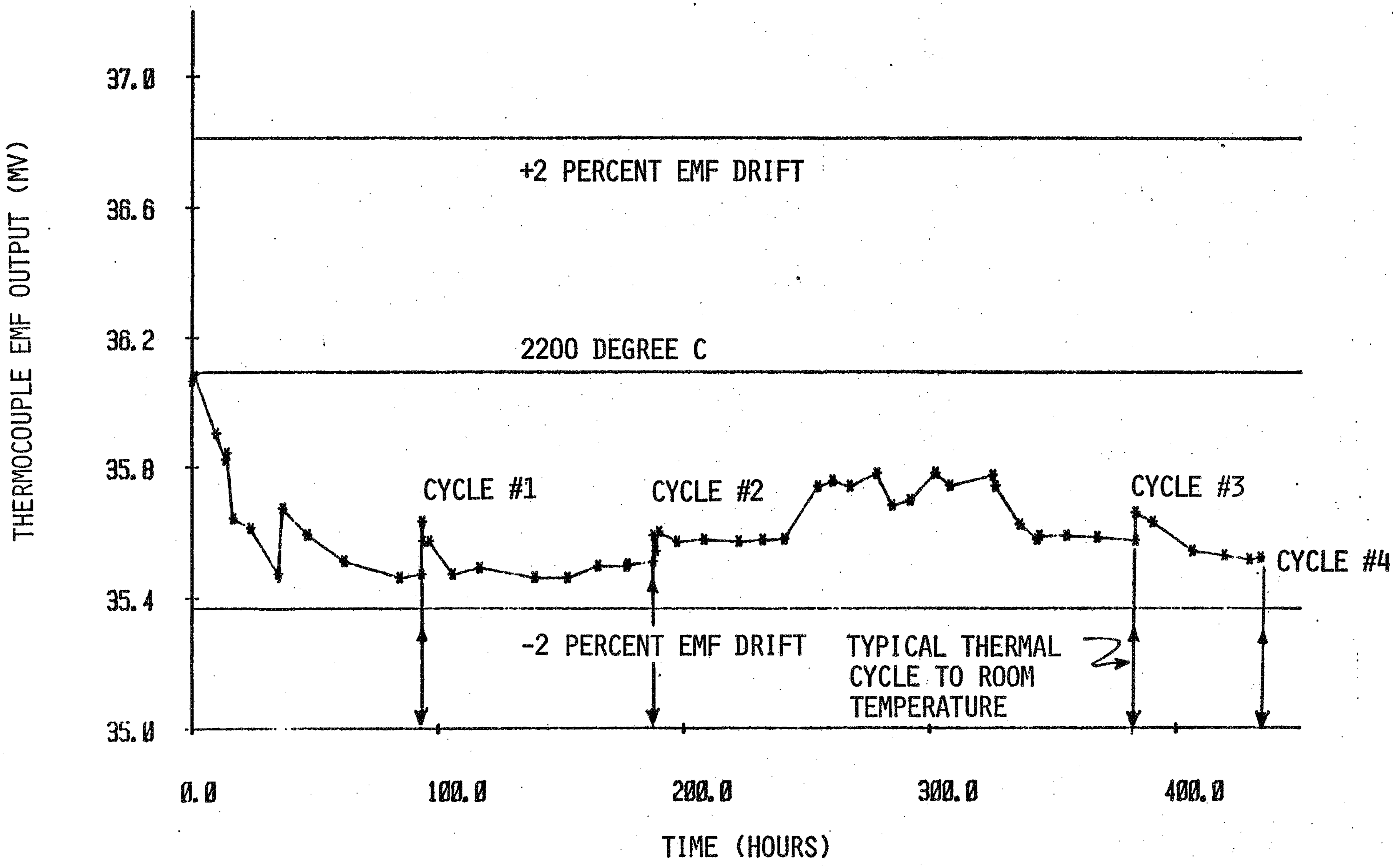


FIGURE 9. Plot of EMF vs. Time for 2200°C Thermocouple Operation.

V. CONCLUSIONS

Evaluation JNPT units designed to satisfy the LOFT in-fuel temperature measurement requirements have been fabricated using commercial suppliers. Tests have been completed that have demonstrated good stability at temperatures to 2200°C. Evaluation tests using the JNPT measurement electronics at furnace temperatures to 2200°C are now in progress. Completion of these tests will conclude development of a commercial supplier of JNPT assemblies.