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Attached is one (1) copy of WANL-TMI-1893, "Inhouse Fabrication of the XE-2 High Temperature Thermocouples" dated April 3, 1968. This document is transmitted for your information and use.

MASTER

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Enclosure - 1

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WANL-TMI-1893

TITLE: INHOUSE FABRICATION OF THE XE-2 HIGH
TEMPERATURE THERMOCOUPLES

DATE: April 3, 1968

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ABSTRACT

This report describes fabrication of high temperature thermocouples for use in a nuclear environment, specifically the Nerva XE-2 Reactor. The thermocouples, WANL 978D270H02D, consisted of molybdenum tubing enclosing beryllium-oxide insulation around the tungsten-tungsten 26% rhenium thermoelements.

The processes described in this report indicate the control placed on preventing impurity contamination during thermocouple assembly. Also discussed are the special fixtures which aided assembly, which was made on a limited-production basis.

1. INTRODUCTION

Thermocouples of the WANL 978D270H02 design previously built for Nerva Reactor core temperature measurements had shown a marked reduction in output voltage at elevated temperatures. This undesirable characteristic was believed to be due to impurities residing in the thermocouple material or picked up during assembly or, most probably, a combination of both. It was planned to improve the thermocouple performance for the Nerva XE-2 Reactor by using higher purity materials and requiring stringent cleanliness controls during assembly.

Thermocouple material was purchased for assembly to upgraded specifications which limited the impurity content. The most significant change was in ordering molybdenum tubing produced by vapor-deposition rather than by drawing. This change was a result of the success which the WANL Sensor Development group was experiencing with vapor-deposited molybdenum sheathed thermocouples.

This report describes the fabrication of 978D270H02D thermocouples for the Nerva XE-2 Reactor. Emphasis is placed on the contaminant preventative techniques employed throughout assembly. Also described are the special fixtures devised for brazing, welding, cleaning and testing operations which aided building the thermocouples on a limited production basis. The final section of the report discusses the results of the qualification testing of the completed thermocouples to reactor requirements.

2. SUMMARY

In an attempt to improve the high temperature performance of 978D270H02 thermocouples for the Nerva XE-2 Reactor, special operations were employed during fabrication to minimize impurity contamination. Metal parts for the thermocouples were initially cleaned by controlled mechanical and/or chemical processes. Contaminants were driven from the ceramic parts before use by torch heating the pieces to a specified temperature for a fixed time. Thermocouple assembly took place in an area where the cleanliness of the surroundings was maintained. Contamination of parts during assembly handling was minimized through use of clean lint free gloves. Brazing and welding operations were performed in an inert atmosphere, low in impurities.

The problems encountered during assembly were generally due to the fact that this was a first-time production effort for the fabrication of reactor grade thermocouples containing fragile vapor deposited molybdenum sheathing. Molybdenum breakage has held at a minimum by incorporating specially devised fixtures for assembly, handling and shipping operations. Typically, as the technicians gained experience in assembly, the discrepancies and work time were greatly reduced.

Two representative thermocouples were qualification tested upon completion of fabrication. These thermocouples were found to have a relatively better accuracy at elevated temperatures than any previously tested thermocouples of this type.

3. PREPARATION OF THERMOCOUPLE PARTS

The following preparation operations were performed to ensure that clean parts meeting design requirements were available for assembly. The nomenclature used for the various parts with respect to their position in an assembled thermocouple is as shown in Figure 1.

3.1 Preparing the SST Thermocouple Cable

Each cable was first dimensionally checked to ensure lengths were adequate for assembly. The end of the cable which was to be brazed to the transition sleeve was then tapered by hand filing and finished with emery cloth. This operation was found to be quite delicate and sometimes resulted in nicking the thermocouple wires. As the operators gained experience, this problem was nearly eliminated. Cleaning of the thermocouple wires followed. Each wire was lightly rubbed with emery cloth, flushed with 0.1N HCL acid solution, rinsed with distilled water and finally wiped dry with a clean lint free cloth. Cables were then baked out in a vacuum oven heated to 400°F in order to remove any moisture that entered during preparation. The cables remained stored in the oven at 400°F until required for the next assembly. In each case, the bakeout period exceeded 24 hours.

3.2 Preparing the Molybdenum Tubing

The molybdenum tubing was first cleaned internally using the following chemical solutions and mechanical means:

- 1) Hydrochloric Acid (2 normal solution) flush for 15 minutes
- 2) Tap water rinse for 5 minutes
- 3) Helium dry for 1 minute
- 4) Abrasive blast for 5 minutes at each end (using White Model C Air Brasive Unit and No. 1 grit)
- 5) Ammonium Hydroxide (normal solution) neutralize for 5 minutes

- 6) Tap water rinse for 5 minutes
- 7) Distilled water rinse for 1 minute
- 8) Helium dry for 1 minute

The cleaning of more than one tube at a time with the solutions indicated above was accomplished by devising a manifold arrangement as shown in Figure 3.

Upon completion of cleaning, the tubes were helium leak-checked by internally pressurizing them at 1000 psi. A production type system was devised for this operation. Tubes were inserted into the fixture shown in Figure 4 and helium was supplied to the lot. A helium leak detector sniffer was placed in proximity with the tubes and if no leaks were detected, the entire lot was acceptable. When leaks were detected, the faulty tube(s) could be singled out by pressurizing and checking individual tubes. Although this system was beneficial in reducing the time required for leak checking, some breakage of the fragile tubes was experienced.

Acceptable tubes were sent to the WANL Machine Shop to be tapered at one end for future fit to the SST transition sleeve. The dimensional requirements for this taper are shown in Figure 5. Particles were removed after the machining by blowing helium through the inside of each tube.

The prepared tubes were individually placed in clean cardboard containers and stored for future use.

3.3 Preparing the BeO and MgO Insulators

The BeO insulators were placed in a BeO crucible and torch-fired in a ventilated fume hood at approximately 2500°F for a minimum of two hours. This operation was performed to further eliminate possible contaminants. After firing, the insulators were placed in a clean desiccator jar. Handling of the insulators was accomplished through use of surgical gloves, previously cleaned with distilled water. The desiccator jar containing the prepared insulators was then stored in an oven (preheated to 250°F) until required for assembly. The MgO insulators were prepared in the same manner as the BeO insulators except that a MgO crucible was used and the firing temperature was reduced to 1800°F.

3.4 Preparing the SST Transition Sleeves

The transition sleeves were fabricated from Type 348 SST tubing to the dimensional requirements shown in Figure 2. Each sleeve was then cleaned internally by flushing with the same chemical solutions and rinses as indicated for the molybdenum tubing in Section 3.2. The cleaning system shown in Figure 3 was used for this operation. The transition sleeves were stored in a clean plastic bag until required for assembly.

3.5 Preparing the Molybdenum Tubing Subassembly

This operation required induction brazing of the SST transition sleeve to the moly tubing. A special housing fixture shown in Figure 6 was devised for this operation to ensure that the proper atmosphere would be maintained during brazing. Incorporated in this housing was a clamping fixture which was designed to ensure that the parts being brazed would be concentric with each other. Also included in the housing was a specially devised induction coil, shown in Figure 7. Prior to production brazing, a detailed procedure was established which specified the necessary steps in brazing with the forementioned fixtures. This procedure, Instrument Applications number 67022, was approved for use after qualified samples were produced. The brazing operation involved clamping the parts in the concentric fixture such that the area to be brazed was located at a specific location within the induction coil. The housing was evacuated and backfilled with Argon. The braze was made by energizing an RF Generator connected to the induction coil.

4. THERMOCOUPLE ASSEMBLY

The following operations were performed to complete thermocouple fabrication.

4.1 Stringing the Thermocouple Insulators

Prior to starting this operation, a clean work table was prepared and covered with plastic. The thermocouple cable was removed from the storage oven and electrically checked to ensure requirements were satisfactory and that chemically-produced emf's were not present. Each wire of the cable was cleaned with crocus cloth and wiped with a clean lint free cloth wetted with acetone. The insulators were removed from the storage desiccator jar and inserted over the thermocouple wires. Clean lint free gloves were worn while handling the insulators.

4.2 Installing and Brazing the Moly Tubing Subassembly

The moly tubing subassembly was slid over the insulated wires and mated to the thermocouple cable. This operation took place on the same plastic-covered table as the stringing operation. The transition sleeve was then brazed to the thermocouple cable in the same manner as described in Section 3.5. Electrical checks were performed after brazing to ensure characteristics were not impaired.

4.3 Installing the Molybdenum Plug

Each plug was "tailor-filed" to the configuration shown in Figure 8 to fit the tube in which it would be installed. Electrical checks were made after installing the plug to serve as a reference for the checks to be made after welding.

4.4 Welding the Thermocouple Junction

Prior to production welding, a detailed welding procedure, Instrument Applications 67023, was established and qualified for use. The TIG welding of the junction in accordance with this procedure was performed in a welding chamber backfilled slightly above atmospheric pressure with helium. More than one thermocouple was handled during the welding

operation through use of the fixture shown in Figure 9. This fixture also protected the thermocouple during transfer to and from the welding area. Electrical checks were performed after junctioning and compared to preweld readings to ensure false junctions and discontinuities were not present.

4.5 Leak Testing the Thermocouple

Leak testing of the thermocouple was accomplished through use of the pressure chamber fixture shown in Figure 10. The chamber was pressurized with helium to 1000 psi for a minimum of 10 minutes after inserting the thermocouples. Upon completion of pressurization, the thermocouples were transferred to an identical unpressurized chamber. This chamber was evacuated and then checked for the presence of helium with a mass spectrometer leak detector. No leaks in excess of the specification limit (5×10^{-8} cc/sec) were ever detected during this operation.

4.6 Radiographing the Thermocouple

Each thermocouple was radiographed at both the welded junction and brazed transition sleeve area to ensure that drawing and specification requirements were met. The most frequent discrepancy found during the junction radiographic inspection was the failure to meet the specified mechanical contact length between the plug, sheath and wires. Radiographic inspection of the transition sleeve in a few cases revealed inadequate braze flow. When this occurred, the area was rebrazed and again X-rayed to ensure acceptability.

4.7 Tungsten Coating the Thermocouple Sheath

Since no qualified methods were available at WANL to vapor deposit the tungsten coating on the thermocouple sheath, this operation was performed by the Carman Sapphire Company of California. Protection of the fragile thermocouples during shipment was accomplished by first covering the moly sheath with a rigid tube as shown in Figure 11. The SST thermocouple cable was then covered with a polyethylene bag and the entire thermocouple mounted to a plywood board. Two thermocouples were mounted to each board. A large container was constructed to permit shipment of five mounting boards for a total of ten thermocouples.

Upon return from coating, each thermocouple was checked to verify tungsten thickness and ensure straightness requirements of the coated area had been maintained. Electrical checks were also performed and compared to previous readings to ensure discontinuities or false junction were not present.

5. QUALIFICATION TESTS

Two thermocouples were randomly chosen from those fabricated in the manner previously described and qualification tested for reactor installation. A description and specific results of the test are reported in memo EI-7950 (CRD) dated February 5, 1968, and will not be detailed in this report. In general, the tested thermocouples were found to have a superior performance at elevated temperatures to any previously tested thermocouples.

6. CONCLUSIONS

As evident from the results of qualification tests, high performance 978D270H02D thermocouples were produced on a limited production basis for the Nerva XE-2 Reactor. The success of the buildup can be ascribed to the use of high purity materials coupled with the special cleaning operations and the contaminant preventative techniques employed during assembly.

ACKNOWLEDGMENTS

Substantial contributions from the Sensor Development, Materials and Quality Engineering Departments at WANL were key factors in the success of the thermocouple assembly and were greatly appreciated.

FIGURE 1. 978D270 Thermocouple Illustration

978D270 THERMOCOUPLE ILLUSTRATION

G Chambers
3-28-68

SAE-SK-346

348 SST SLEEVE FOR 978D270 THERMOCOUPLES

WALL AT END SHALL TAPER FROM .004 TO .011 IN A
SMOOTH TAPER

.097 O.D.

.066 I.D.

FIGURE 2. SST Sleeve for 978D270 Thermocouples

SST TRANSITION SLEEVE
978D270 THERMOCOUPLES

J. Montgomery
2-16-67

SAE-SK-259-A

FIGURE 3. CLEANING SYSTEM FOR MOLYBDENUM TUBING

CLEANING SYSTEM FOR
MOLYBDENUM TUBING
-ILLUSTRATION-

R. Kiser
J. Montgomery
3-28-68

SAE-SK-348

FIGURE 4. Helium Leak Check System for Molybdenum Tubing

HELIUM LEAK CHECK SYSTEM
FOR MOLYBDENUM TUBING
ILLUSTRATION

R Kiser
J. Montgomery
3 28-68

SAE-SK-347

FIGURE 5. Molybdenum Tubing Taper Requirements

TAPER REQUIREMENTS FOR MOLY
TUBING - 978D270 THERMOCOUPLES

J. Montgomery
3-18-68

SAE - SK-314A

FIGURE 5

-16-

FIGURE 6. Brazing Fixture for 978D270 Thermocouples

BRAZING FIXTURE
978D270 THERMOCOUPLES

J. Montgomery
10-3-67

SAE-SK-323
sheet 1 of 2

FIGURE 6. (Continued)

BRAZING FIXTURE
978D270 THERMOCOUPLES

J. Montgomery
10-3-67

SAE-SK-323
Sheet 2 of 2

Technical drawing of a mechanical assembly, likely a valve or actuator, showing dimensions and labels.

Labels:

- $\frac{3}{8}$ DIA (pointing to a circular feature)
- $\frac{1}{8}$ TUBE FITTING NUT (pointing to a nut on the right)
- BRAZE TO Cu PLATE (pointing to a vertical plate)

Dimensions:

- Vertical dimensions on the left: $\frac{5}{8}$, $\frac{1}{4}$, $\frac{5}{8}$, $\frac{1}{4}$.
- Horizontal dimensions on the left: $\frac{5}{8}$, $\frac{1}{4}$.
- Vertical dimensions in the center: $3\frac{1}{2}$, $\frac{1}{8}$, $\frac{1}{8}$.
- Horizontal dimensions in the center: $\frac{3}{8}$, $\frac{7}{8}$, $1\frac{1}{2}$, $\frac{7}{8}$.
- Horizontal dimensions on the right: 1 .

Notes:

- Q. OF T/C

MAT'L: COPPER END PLATE $\frac{1}{8}$ " THICK
 $\frac{1}{8}$ " COPPER TUBING

FIGURE 7. Induction Heater Coil

INDUCTION HEATER COIL FOR
978D270 THERMOCOUPLE BRAZING

R Kisen
10-10-67

SAE-SK-306

MOLYBDENUM PLUG FOR 978D270. HIGH TEMP. THERMOCOUPLES.
FILE TO FIT AT ASSEMBLY.

FIGURE 8. Molybdenum Plug for 978D270 Thermocouples

MOLYBDENUM PLUG FOR
978D270 THERMOCOUPLES

J Montgomery
2-23-67

SAE-SK-265

FIGURE 9. Thermocouple Welding Fixture

WELDING FIXTURE
978D270 THERMOCOUPLES

J. Montgomery
R. Kiser
11-16-67

SAE-SK-326
Sheet 2 of 2

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FIGURE 10. Leak Test Pressure Chamber

OPERATING PRESSURE
1000 PSI - HELIUM

FIGURE 10

-22-

<p>PRESSURE CHAMBER FOR LEAK TESTING 978 D270 THERMOCOUPLES</p>	<p>J Montgomery 6-28-67</p>	<p>SAE-SK-305</p>
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ITEM	MATERIAL	SIZE
1	$\frac{5}{16}$ SHRINK SLEEVING (WHITE)	$2\frac{1}{2}$ IN. LONG
2	RIDGID ACRYLIC TUBING	$\frac{1}{4}$ O.D. $\times$ $\frac{1}{8}$ I.D. 60 IN LONG

FIGURE 11. Thermocouple Shipping Tube

SHIPPING TUBE
978D270 THERMOCOUPLES

J. Montgomery
7-14-67

SAE-SK-310