THERMOCOUPLES AND CABLES FOR NUCLEAR REACTORS

by

J. M. Stone
Engineering Research Laboratory
Engineering Department
Wilmington, Delaware

October 1953

Photostat Price $ 6.30
Microfilm Price $ 3.00

Available from the
Office of Technical Services
Department of Commerce
Washington 25, D. C.

Declassified with deletions March 1, 1960.

E. I. du Pont de Nemours & Co.
Explosives Department - Atomic Energy Division
Technical Division - Savannah River Laboratory

Contract AT(07-2)-1 with the
United States Atomic Energy Commission

ABSTRACT

The development, design, specification, and manufacture of special-purpose thermocouples sheathed in stainless steel for use in nuclear reactors are described. In connection with this work, a three element cable for transmitting the signal from neutron-flux measuring devices was developed.

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SUMMARY

PROBLEM UNDER INVESTIGATION

The design of nuclear reactors for the Savannah River Works project called for the use of temperature monitoring as a means to control the reactors and to detect fuel-can failure. Rapidly responding thermocouples which would operate in a liquid while exposed to neutron flux were required. This study was undertaken to establish the requirements of these thermocouples, to design them, and to locate and instruct fabricators.

Because of the similarity of the problems involved, this work also included the development of a cable having three concentric conductors to be used to carry a signal from within the reactor to appropriate recording instruments.

IMPORTANT RESULTS

Five types of iron-constantan thermocouples enclosed within metal sheaths have been designed, fabricated, and evaluated. Each thermocouple was prepared for a different severity of exposure. Specifications were written for use in purchase of the thermocouples.

A three-element cable with two tubular conductors concentric about an inner wire was prepared. Resistance between any two elements in this 0.300-inch diameter cable was 10^9 ohms minimum for a 35-foot length. The insulation used was especially prepared silica yarn. Specifications were written for use in purchasing these units.

Fabricators were located and instructed in the preparation of the above thermocouples and cable.

Inspection methods to insure the quality of these thermocouples and the cable were written up and aid in initial supervision was given.

RECOMMENDATION

The specific thermocouples developed in this study and modifications thereof, should find wide application in other reactors and many processes involved in AEC plants. Small design changes would allow such thermocouples to be prepared for any corrosive environment for which a corrosion-resistant metal capable of being drawn as a tube is available.

DISCUSSION

REASON FOR INVESTIGATION

This study was authorized in order to develop several types of thermocouples and a concentric three-element cable which were not commercially available. Need for these items was conceived during the original design of the nuclear reactors of the Savannah River Plant.

ORIGINAL DEVELOPMENT WORK

The original request was for development of a zirconium-aluminum thermocouple which would be attached to, and hence could indicate the temperature of, the fuel cans within an atomic pile. Swelling of fuel cans would cause a decrease in the rate of flow of the cooling medium about the can with a resulting temperature increase. Rapid detection of these failures was essential.

It was proposed that the thermocouple consist of an aluminum wire enclosed within a zirconium tube and insulated from the tube with a material which would withstand neutron bombardment. Lengths of the order of 40 ft. and outside diameter not in excess of 0.030 inch were desired. Simultaneous formation of the thermocouple hot junction and the sealing of the tube-end were to be accomplished in one welding or brazing operation.

A technique was developed to braze aluminum to zirconium, but an investigation revealed: (a) commercial zirconium contains approximately 3% Hf, an element with a high neutron-capture cross section; (b) acquisition of large quantities of zirconium of closely controlled composition, such as would be required for reproducible temperature-voltage characteristics, would be difficult, if not impractical; and (c) commercial experience in handling large quantities of small thin-wall zirconium tubing was nil.

Consequently, the design was changed to a thermocouple consisting of an aluminum tube drawn over an insulated constantan wire. The dimensions were not changed. Such thermocouples were made under Engineering Research Laboratory (E. R. L.) sponsorship by the Precision Tube Co., Philadelphia, Pa. A method for the formation of the hot junction was developed at the E. R. L. as follows. After threading an insulated wire through the tube, the center wire was allowed to extend bare beyond the end of the tube, which was swaged down upon the wire.

The wire was then wrapped back up around the tube end. Sealing of the tube end and brazing of the two elements at the junction was then accomplished by dipping the joint into a bath of molten aluminum-silicon eutectic (13% Si in aluminum) held at 1100°F. Any one of many aluminum fluxing compounds could be used to cover the surface of the bath (examples: Aluminum Company of America fluxes 34 or 53).

These thermocouples consisted of a 0.008-inch diameter constantan wire covered with a varnish-impregnated insulation over which was drawn a 0.030-inch o. d. x 0.006-inch wall 2S aluminum tube. Precision Tube Co. had never drawn such small-size aluminum tubing in lengths greater than 15 ft. They prepared six thermocouples in lengths just exceeding 40 feet. Owing to splits in the tubing during the drawing operation, they lost three assemblies for each one they completed.

Varnish impregnation and boron-containing "Fiberglas", glass fiber insulation such as were used in these thermocouples were not considered satisfactory, but they allowed development of the tube drawing and brazing arts. Organic materials might decompose under neutron bombardment. Materials with high neutron-capture cross sections, such as the boron in the "Fiberglas", were not desirable.

An insulation material which showed promise was a leached "Fiberglas" yarn, approaching pure silica in composition, sold under the name of "Refrasil" by the H. I. Thompson Co., Los Angeles, California. Samples revealed "Refrasil" silica insulation to have poor tensile strength and abrasion resistance. Considerable effort was expended by three wire-insulating companies to develop a technique to braid or wrap "Refrasil" on a small-diameter wire. Braiding was finally accomplished by soaking the "Refrasil" in a mixture of equal parts by volume of carbon tetrachloride and kerosene before application. Although this would have required leaching the insulation with a solvent before enclosure in the tube, it was the only means found which approached practicability.

It was intended that these thermocouples be joined to fuel cans by brazing. However, reports of tests just completed at Hanford revealed that attempts to braze to the cans resulted in an unusually high rate of can failure. This information forced the conception of a new design.

Fuel cans in the Savannah River reactors are so arranged that a rise in temperature of the coolant would reveal the onset of a potentially dangerous condition. This was the basis for the next design.

It was known from experience at Hanford that asbestos is an insulator which will withstand neutron bombardment. Asbestos could not be used on the early thermocouples of this study because it could not be applied in thin enough wall thicknesses to allow a maximum overall diameter of 0.030 inch. The proposed position of the thermocouple junction made it possible to increase this diameter to 1/8 inch.

There were several methods used commercially to apply asbestos to a wire, and all of them involved the use of added organic materials. One did offer hope of modification which would avoid such additions. This technique consisted of felting the asbestos about the wire with equipment similar to textile cards. Usually, commercially applied asbestos contains 5 - 30% cotton and is held in place after application with an organic binder.

Samples of cotton-free asbestos lap were secured from the Raybestos-Manheim Co., Manheim, Pa. This asbestos was successfully applied to a 0.032-inch diameter constantan wire, using distilled water as a binder by the Lewis Engineering Co., Naugatuck, Connecticut and the General Electric Co., York, Pa. The Precision Tube Co. took this covered wire--now 0.080 inch in diameter--and drew over it a 0.125-inch o.d. x 0.020-inch wall 2S aluminum tube. In this larger size, length was no longer a problem. Welded hot-junctions were successfully formed at E. R. L. using the inert gas shielded arc method. To insure a sound thermocouple junction and tube seal, the following practices had to be observed: (a) the area near the weld was kept entirely free of asbestos (b) the tip of the aluminum tube was swaged down on the constantan wire, and (c) welding was accomplished by using 60 c/sec. alternating current of the order of 5 - 10 amps with a continuously superimposed high-frequency current; and (d) a copper chill block was placed around the aluminum tube because of the low melting point (1215°F.) of the aluminum tube relative to constantan (2355°F).

The large difference in the coefficients of thermal expansion of aluminum and constantan (23.9×10^{-6} in./(in.)(°C)and 14.9×10^{-6} in./(in.)(°C), respectively) made it necessary to consider the possibility that the aluminum tube might pull away from the constantan wire during heating. Likelihood of this was increased because of a brittle $CuAl_2$ phase which might form between the copper in the constantan and the aluminum during welding.

A shock testing unit, shown schematically in Figure 1 was designed to investigate this possibility. Forty-eight thermocouples were placed in the tank. They were exposed alternately to 5 min. of cold water followed by 5 min. of steam at 1 atm. pressure. Voltage output of the thermocouples was noted on a Brown recorder to which the output of each thermocouple was successively switched.

All of the thermocouples failed within three days. Upon opening of the tank, it was evident that failed junctions were not the sole cause of the difficulty. Vibration resulting from the flow of water and steam had caused the aluminum tubes to wear against one another until the walls had perforated; then the asbestos insulation had become saturated with water. Sectioning of all of the welded junctions showed that separation had occurred in only three units; all of these had given a faulty temperature indication as soon as the test began. These welds had not been properly made and had not failed because of the test. The susceptibility of the thermocouples to wear was revealed.

A new thermocouple with the aluminum tube replaced with one of Type 304 stainless steel was prepared. Asbestos-insulated constantan wire was again used.

While these thermocouples were on order, the neutron flux concentration at their planned location was reappraised. The new estimate of the neutron flux concentration was such a low value that organics and elements having high neutron-capture cross section did not need to be avoided. An order was placed with the Posen and Kline Tube Co., Norristown, Pa. to draw Type 304 stainless steel sheaths over conventional iron-constantan thermocouple wire pairs insulated with varnish-impregnated "Fiberglas." Out of this work came the Type A thermocouple, which is described in detail below.

The inclusion of two wires that are commonly used for thermocouples was of a distinct advantage because it eliminated the necessity of securing large quantities of stainless steel tubing of reproducible temperature-voltage characteristics. It also eliminated possible formation of natural thermocouples between the reactor shield and the thermocouple sheath, which could considerably alter the true signal from the thermocouple.

Forty-eight stainless-sheathed thermocouples (16 single-wire and 32 double-wire) were exposed in the shock testing unit for over 7,000 cycles. Three with bad welds operated inaccurately immediately and the remainder survived the entire test.

TYPE A THERMOCOUPLE

This thermocouple with the iron-constantan wires insulated with asbestos in a stainless steel sheath was labeled "Type A."

An order for the total Savannah River Plant requirements was placed with the Posen and Kline Tube Co. It is illustrated in Figure 2.

Insulated Wire The thermocouple wires were of iron and constantan. Each bare wire was 0.032 inch in diameter. Individual wires were wrapped in varnish-impregnated "Fiberglas." The iron and constantan wires were paired so that the temperature indicated by the e.m.f. of any one pair did not vary from that of any other pair by more than 0.44°C when the hot junction was held at 50°C and the cold junction at 30°C. When properly matched, the paired wires were covered with a varnish-impregnated "Fiberglas" braid. The varnish impregnation was not allowed to penetrate the insulation to the wire as this would have necessitated an especially careful cleaning of the wire to assure a sound hot junction weld. Wire meeting these specifications was ordered from the Brown Instrument Co. for the first order.

Fabrication Procedure

a. The insulation is stripped for 3 - 4 inches from the end of an appropriate length of iron-constantan paired wires.

b. This length of paired wires is threaded through an oversize (approximately 3/16-inch o.d.) 0.020-inch wall Type 304 stainless steel cover. A length of piano wire can be used to draw the wire in the tube. Welded tubing is used here in preference to seamless because of its lower price (20% lower).

c. With the paired wires drawn through the tube, the stripped ends of the wires are cut back so that only 3/8 inch is uninsulated.

d. The wires are drawn back into the tube until the stripped ends are 3 - 4 inches from the end of the tube.

e. A swaging machine is used for "pointing" this end of the tube so that it will easily slip into a 0.125-inch diameter tube-drawing die.

f. The tube is drawn down to a 0.125 ± 0.002 inch o.d. on a standard small-tube bull block.

g. After removing from the bull block, a small wire probe is inserted into the swaged end to determine precisely the position of the ends of the wires..

h. Having established these positions, the swaged end of the tube is trimmed off with a small cut-off wheel so that the ends of the wires and the end of the tube are flush.

i. As shown in Figure 2, the end of the tube is swaged again to bring the tube down on the uninsulated wire. This causes the end of the tube to approach the welding characteristic of the end of a rod. Moreover, should the weld "ball up" slightly, its diameter will still be less than the 0.125-inch diameter of the tube and it will pass through any opening that the tube will clear.

j. This second swaging operation causes the tube to grow slightly so that its end is not now flush with the wire ends. Because of this, the tube is again trimmed with the cut-off wheel until it is flush with the wire.

k. The thermocouple junction is formed by welding, using the inert-gas shielded arc method with a current of about 15 amps., straight polarity (electrode negative) and an argon gas shield. A section of a typical weld is shown in Figure 2. The thermocouple is now ready for inspection. Care must be taken during fabrication to see that the interior of the tube is clear and free from lubricants. This is especially true for that portion of the tube near the weld, because such contamination can be the cause of a leaking weld.

Thermocouples as long as 78 ft. were prepared according to this design. This was longer than was contemplated for plant use, where the maximum length was approximately 35 feet.

Inspection Experience Four hundred and ten Type A thermocouples ordered for testing and experimental use were inspected at the E. R. L. Each thermocouple was subjected to six tests as follows:

a. Speed of response. The length of time required for the thermocouple to indicate 60% of the total temperature differential when it was rapidly changed from 0°C to 100°C was established with the aid of a Brush recorder.

In this test, the time varied from 0.27 to 1.70 sec. Six thermocouples with responses of from 1.37 to 1.70

seconds were sectioned and found to meet fully the specification that the length of uninsulated wire at the hot-junction end could be no longer than 7/16 inch. The mean response was 0.71 sec.; the standard deviation was 0.22 sec.; and the three-sigma limit (which includes approximately 99.7% of the cases) was 0.65 sec., a rather large spread.

b. Indicated temperature accuracy was determined. Voltage output with the cold junction at 0°C and the hot junction at 100°C was measured with a semiprecision potentiometer. This output voltage was compared with a Brown Instrument Co. standard iron-constantan curve to arrive at a corresponding temperature value. Deviation of this temperature from the differential between calibrated thermometers in the hot and cold bath was recorded.

On the temperature calibration test, only two thermocouples were rejected: one reading 15°C low and the other 60°C low. According to the specification on which the wire for the thermocouples was purchased, the range of accuracy could vary 2.2°C over a 100°C range. The range for the accepted thermocouples tested was 1.4°C. The mean value of these thermocouples was 0.40°C under the Brown Instrument Co. standard curve; the standard deviation was 0.23°C; and the three-sigma limit was 0.68°C.

c. The diameter of each stainless steel sheath was measured.

Every thermocouple sheath was found to meet the specifications of 0.125 ± 0.002 inch in diameter.

d. Each thermocouple weld bead was passed through a 0.125-inch diameter gage to show that it was not oversize.

Every weld bead passed through 0.125-inch gage as required.

e. Resistance between the iron wire and the constantan wire leads of each thermocouple was measured with a Simpson test meter.

Resistance of the thermocouples varied from 10 to 23 ohms. No open circuits were detected. Variation was due to the limited accuracy of the measuring instrument used and to the different thermocouple lengths. The measurement taken was that of the iron and constantan wires in series.

f. A leak test of the sheaths was run. Each tube was filled with helium to a pressure of 500 lb./sq.in. and the welded tip and 6 ft. of tubing at the weld tip end were checked with a helium leak detector.

Leak testing revealed 82 faulty thermocouples. Of these, 52 had leaky welds and 30 had split tubes. Seventy-eight were returned to the fabricator for replacement and the remainder were held for sectioning. According to the fabricator, 5% split tubes is normal. Hence, the 7.1% was not greatly out of line. Twelve and three-tenths per cent of the tubes which exhibited leaky welds were not representative of typical production. The order was delivered in two parts of 265 thermocouples and 145 thermocouples, the latter part arriving about six weeks after the first delivery. Of the 145, only two (1.3%) had leaky welds and eight (5.1%) had split tubes. Lack of experience on the part of the welder was no doubt responsible for the large number of leaky welds in the first part of the order. Many of the splits occurred beyond the first 6 ft. of the thermocouple, but, since they made it impossible to build up helium pressure in the weld region, these thermocouples were also rejected.

Inspection Procedure The following procedure was recommended for inspection of all Type A thermocouples.

a. Each thermocouple is checked for the accuracy of its temperature-voltage relationship. The hot bath may be made according to Figure 3. This bath contains boiling distilled water at a constant level. No more heat should be applied than is necessary to maintain boiling. Boiling chips should be used. A thermometer certified to be correct within 0.1°C is used to measure the water temperature. The two wires extending from the opposite end of the thermocouple sheath are connected to a pair of the terminals of the multiple thermocouple calibration switches, shown in Figure 4.

This switcher apparatus provides a means of calibrating these thermocouples on a production-line basis. Ten thermocouples can be inserted in boiling water and connected to one side of the switcher. While one operator is rotating Switch No. 1, recording the temperature from the indicator, and comparing this temperature to that indicated on the thermometer, another operator can be inserting a second set of thermocouples in a second bath and connecting them to the other side of the switcher.

Wire for the Type A thermocouples was purchased according to a specification stating that the e.m.f.'s of the wire pairs purchased cannot differ from each other by more than 0.44°C when the hot junctions are at 50°C and the cold junctions are at 30°C. Since the calibration test takes place at 100°C and 0°C, maximum variation of 5 x 0.44°C, or 2.20°C is allowed. Experience with the NYX thermocouples showed that 99.7% of these had a maximum variation from one another of only 1.35°C.

b. A measurement of the diameter of each thermocouple should be made at some random point along the length in two positions 90° apart to insure roundness. The diameter must be 0.125 ± 0.002 in.

c. Weld-bead diameters should be checked to detect any which might be oversize. Each bead should pass through a 0.127-inch diameter hole. A standard tube or wire-drawing die is recommended as a test gage.

d. The resistance between the iron wire and the constantan wire should be measured. Resistance should not exceed 25 ohms. This is for thermocouples having maximum length of 35 ft., which includes all Type A thermocouples ordered.

e. Each thermocouple should be filled with helium to 500 lb./sq.in. and searched with the probe of a helium leak tester (Consolidated Engineering Corp.). Tubes leaking at the weld or within 6 ft. of the weld should be rejected. If rewelding corrects the the leak, the thermocouple can then be accepted.

Corrosion Resistance Type A thermocouples were to be exposed to extremely high purity water. Stainless steel sheathing was chosen because of its good corrosion resistance. However, the weld bead is not stainless steel but a mixture of stainless steel (18% Cr - 8% Ni - balance Fe), iron, and constantan (55% Ni, 45% Cu). Ten thermocouples with the standard weld bead

(Figure 2) and ten whose weld beads had been enriched with "Nichrome" (80% Ni, 20% Cr) wire were exposed to high-purity water at 60°C. for 10 weeks. Careful microscopic examination revealed no attack on either the standard or the enriched bead.

Effect of Bending on Thermocouple Accuracy The sharpest bend to be made in a Type A thermocouple was a 3-inch radius 180° bend. Four such thermocouples were given three turns around a 1-1/2-inch radius pipe. Their calibrations in boiling water before and after bending were compared. No change was found.

Effect of Absorbed Hydrogen on Calibration It was proposed that the water environment of the thermocouples might be very slightly ionized as a result of pile reactions. A test was run deliberately exaggerating the hydrogen influence to determine the effect of possible hydrogen absorption. A 0.1 N solution of nitric acid was held in a constant temperature bath at approximately 50°C. The ends of a Type 304 stainless steel rod and a 10-inch long Type A thermocouple were held in the solution and connected to a 6-V battery for 99 hr. with the thermocouple as the cathode. Gas evolution from the thermocouple surface was vigorous. Immediately adjacent to the thermocouple, but not touching it was a second thermocouple and a laboratory thermometer. The potential developed by the two thermocouples was measured before and after exposure to the hydrogen evolved by electrolysis. The thermocouple which served as the cathode read 0.13 mv. higher than the standard Brown Instrument Co. curve before the test and 0.006 mv. higher than the curve after the test. The second thermocouple (not in the electrical circuit) read 0.010 mv. lower than the curve before the test and 0.009 mv. lower than the curve after the test.

The amount of hydrogen developed at or near the surface of each thermocouple was far in excess of that which is estimated for the service conditions and yet the variation of the two thermocouples was within the accuracy of the measurement.

Shock Tests The shock testing unit described previously (Figure 1) was used to test the Type A thermocouple. Fifteen of these and 17 differing only in that the stainless steel sheath wall thickness was 0.010 inch instead of the standard 0.020 inch were run for over 7,000 steam-cold-water cycles (over 14,000 temperature reversals). Two of the thin-wall thermocouples failed, both within the first hour. Each had given a high resistance measurement (approximately 400 ohms) between the iron wire and the constantan wire prior to installation, indicating incomplete welding. The remaining thermocouples were still performing satisfactorily at the end of the test.

Exposure to Neutron Flux Tests in which the Type A thermocouples were exposed to flux concentrations equivalent to or exceeding service conditions were run. Six such thermocouples were inserted in the CP-3 heavy-water moderated reactor at the Argonne National Laboratory and held there for 20 days.

These thermocouples were fabricated with no welded junction so that the iron wire and the constantan wire were electrically separate. Thus, a simple resistance measurement between the two wires would have shown insulation failure if it had occurred. No such change was detected.

The tube, however, was closed by welding at the hot-junction end. The open end was connected with a manometer system in order to measure any gas generated within the tube owing to decomposition of the varnish on the insulation. No change in the manometer reading was detected after 20 days. The system was accurate to 0.1 cc.

TYPE B THERMOCOUPLE

According to the reactor design, the reference junction for the Type A thermocouples would be placed in a position where its temperature would follow the temperature of the coolant as it enters the reactor after leaving the heat exchangers. Thus, if the incoming water varies in temperature, the e.m.f. reading of the Type A thermocouple would not be influenced. Type A thermocouples would then read only the change in coolant temperature that takes place in the reactor. The reference thermocouple has been labeled Type B.

Actually, it was very similar to Type A, differing only in the formation of the thermocouple junction. As can be seen from Figure 2, the Type A thermocouple had the two wires welded to the stainless sheath. This provided a very rapid temperature response. Rapid temperature changes were not to occur at the location of the reference junction and rapid response was not a requirement. The essential features of the Type B thermocouple can be seen in Figure 5. A "Fiberglas" sleeve was used to insulate the junction from the stainless sheath. This was necessary to avoid an electrical path from the Type A junction through its stainless sheath, the reactor shell and the Type B sheath to its junction.

<u>Fabrication Procedure</u> The steps in the fabrication of the Type B thermocouple are as follows:

a. The insulated thermocouple wire is threaded through a 3/16-inch o.d. x 0.020-inch wall, Type 304 stainless steel tube with piano wire. Welded tubing is used. The wire must meet the same specifications as that of the Type A thermocouple.

b. With the wire through the tubing, the insulation is stripped from one end for 2 - 3 in. The two exposed wires are twisted together and then cut off until only 3/8 in. or less is uninsulated. The wires are welded together with an oxyacetylene torch using no flux. Each weld is inspected visually to see that thorough fusion has taken place.

c. A 1-in. long "Fiberglas" sleeve is slipped over the exposed thermocouple junction. The sleeve serves to insulate the junction from the stainless sheath. The particular sleeving used successfully was "Ben Har A.S.T.M. Grade A special-treated "Fiberglas" tubing, size No. 18" as supplied by the Bentley-Harris Co., Conshohocken, Pa.

d. The wire is drawn back into the tube so that the welded junction is within the stainless tube and 3 - 4 in. from the end of the tube. This end of the tube is then swaged down until it will pass through a 1/8-in. die.

e. A small standard tube bull block is used to draw the tube down to 0.125 ± 0.02-in. o. d.

f. Remove the drawn tube from the bull block and insert a wire probe into the swaged end to determine precisely the position of the end of the wire.

g. The swaged end of the tube is trimmed off with a small cut-off wheel so that the end of the tube extends 1/4 in. beyond the welded junction.

h. This end of the tube is swaged again if necessary to decrease the diameter and make it easier to weld.

i. The end of the tube is sealed by welding by the inert-gas shielded arc method using a thoriated tungsten electrode, straight polarity and direct current of about 15 amp. The thermocouple is now ready for inspection.

Inspection Experience Twelve Type B thermocouples were inspected for NYX at the same time as the 410 Type A thermocouples were tested. The temperature response was, as could be expected, slower than that of the Type A thermocouples, requiring 1.53 - 1.90 seconds to follow 60% of a temperature change of 0° - 100°C. No thermocouple varied from the Brown Instrument Co. standard iron-constantan curve by more than 0.1°C. Only one was rejected because of a short circuit from the wires to the stainless sheath.

Inspection Procedure All Type B thermocouples are inspected by the same procedure used for the Type A thermocouples. In addition, one measurement of resistance is made to show that the thermocouple junction is insulated from the stainless steel sheath.

TYPE C THERMOCOUPLE

The third type of thermocouple, referred to as Type C, was designed for use at points within the reactor where the neutron flux concentration was expected to be great enough to decompose the varnish-impregnated "Fiberglas" insulation used in the Type A thermocouple, but where the thermocouple would lie along a neutron-absorbing seal so that its neutron-capture cross section was not a significant factor.

A diagram illustrating the essential features of the Type C thermocouple is shown in Figure 6. The basic differences between this and the Type A thermocouple were the wire size and the insulation. B. & S. gage No. 24 (0.020-in. diam.) iron wire and constantan wires were used as more space was required within the 0.085-in. i.d. Type 304 stainless steel sheath to accommodate the asbestos insulation.

Experience at the Hanford Plant had shown that asbestos would withstand exposure to high neutron flux and that organic materials generally would not. Commerically available asbestos for use as a wire insulator contains from 5 - 30% cotton and usually is impregnated with an organic binder to hold it in place on the wire. Both cotton and the binder were thought to be objectionable for this application, hence, it was necessary to find a means of eliminating them.

Two methods of applying asbestos to wire are used commercially. One is to mat the asbestos fibers (containing 5% or more cotton) about a cotton, rayon, nylon, or "Fiberglass" thread and to wrap this matted thread around the wire. The other is to gather cotton-containing asbestos fibers around the wire by feeding from a modified textile card. The fibers are spun tightly against the wire and impregnated with an organic binder to hold them in place. The latter method was chosen as the one which could be most easily changed to meet our requirements.

With the cooperation of the Raybestos-Manheim Co., Manheim, Pa., a lot of select long-fiber Canadian asbestos with no cotton addition was secured. The General Electric wire and cable plant at York, Pa., succeeded in adjusting their carding machinery to handle this cotton-free asbestos lap. Organic binder was replaced with distilled water. The resulting insulation had much the appearance of a felt.

Fabrication and Inspection Procedure No. 24 gage (0.020-in. diam.) iron and constantan wires are each covered with a thickness of 0.007 inch of asbestos, and the pair is then covered with the same thickness. Asbestos as applied to individual wires and to the pair is wet throughout with distilled water. Because this water will corrode the iron wire and lower the electrical resistance of the asbestos, it is necessary to remove all except the water of hydration immediately and all water eventually.

One-thousand-foot lengths of both single wires and wire pairs are heated with infrared lamps as they are spooled from the felting machine. The spools are held in an electrically heated oven at at least 110°C for at least two days before the next layer of insulation is applied or until they are packaged in "VPI" (vapor-phase inhibitor) impregnated paper bags.

The thermocouples are fabricated in essentially the same manner as the Type A thermocouple. After fabrication and before inspection, each thermocouple is heat-treated for 3 hr. at 1050°F to remove the water of hydration from the asbestos. After air-cooling, the open end of the thermocouple is sealed with "Glyptal" enamel.

Thermocouple inspection procedure is the same as for the Type A thermocouples except that the maximum resistance allowed when measuring along the two conductors may be no more than 50 ohms.

Fabrication Experience The necessity of the high-temperature heat-treatment was pointed out quite markedly during fabrication. Thermocouples assembled and heat-treated within 2 months after the asbestos was applied to the wires were found to be satisfactory. Thermocouples assembled and heat-treated 4 months after insulation of the wire had a very high rejection rate. This was due to pitting of the iron wire, presumably by moisture trapped in and made alkaline by the asbestos. The importance of fabricating and heat-treating the thermocouples as soon as possible after wire insulation cannot be overstressed. Because of this problem, many Type C thermocouples were later replaced with Type E thermocouples, as described later.

TYPE D THERMOCOUPLE

The fourth type of thermocouple was for use within the heart of the reactors. The absorption of neutrons by the thermocouple was of as much concern as was the influence of these neutrons on the thermocouple materials. These Type D thermocouples were to be used within the instrument tubes to provide a temperature profile of the reactor. Type D thermocouples differ from Type C thermocouples mainly in use of 2S aluminum instead of stainless steel sheath and in the use of smaller wire size.

<u>Fabrication Procedure</u> The wire used is iron-constantan of B. & S. gage No. 30 (0.010-in. diam.), the smallest size of any of the thermocouples so that a minimum of neutron-absorbing materials is present. The insulation is the same high-purity cotton-free asbestos felt used on the Type C thermocouple. Each wire is covered with 0.010 in. of insulation and the two insulated wires are covered with another 0.010 in. of asbestos.

The sheathing material is 2S aluminum tubing, replacing the stainless tubing (0.125 ± 0.002-inc. o.d. x 0.020-in. wall) used on Types A, B, C and E. All tube drawing for this assembly was done by the Precision Tube Co., Philadelphia, Pa. The fabrication procedure, similar to those given previously, is as follows:

a. The asbestos-insulated wire pair is drawn through a 3/16-in. o.d. x 0.020-in. wall 2S aluminum tube with a length of piano wire.

b. After the wire is threaded through the tube, the insulation is stripped from one end for a length of 1/4 - 3/8 in.

c. The two wires are spot-welded together, and the weld is examined visually for soundness of the junction.

d. The exposed junction is covered by a small amount of the same kind of asbestos as is used for the insulation. The junction should be so covered that when the thermocouple is completed the wires will be electrically insulated from the aluminum sheath. False readings will result if this is not done.

e. The wires are drawn back into the sheath so that the welded junction is 3 - 4 in. from the end of and within the sheath.

f. This end of the sheath is then swaged down for 2 - 3 in. until it will pass through a 1/8-in. die.

g. The drawing operation is performed by reducing the aluminum tube to 0.125 ± 0.002-in. o.d. x 0.020-in. wall on a standard bull block.

h. A small wire probe is inserted into the swaged end to determine the position of the thermocouple junction.

i. The swaged end is cut off so that the junction is 3/8 in. inside the tube.

j. The end is reswaged to bring the diameter down to 0.090 in. or less and is swaged back no farther than 3/8 in.

k. The end of the tube is welded using the inert-gas shielded arc method. A tungsten electrode is used with approximately 10 amp. of 60 c/sec. alternating current plus a continuously superimposed high-frequency (1 - 2 Mc/sec.) current.

l. The thermocouple is heat-treated at 1025°F for 3 hr. All comments pertaining to the necessity of heat-treating the Type C thermocouple as soon as possible after insulating the wire apply here.

m. The thermocouple is ready for inspection.

Inspection Inspection of the Type D thermocouple is identical with that of the Type A thermocouple with three exceptions: (a) a continuity check must be made to show that the wire is electrically insulated from the sheath, (b) the resistance between the two wires should not exceed 200 ohms for a length of 50 ft. or less, and (c) the thermocouple sheath should be submerged in a tank of water for three-quarters of its length from the seal end for one week. The resistance between either wire and the sheath must not decrease in this time. This is a leak test which is performed in addition to the helium test, which will not always be effective with asbestos-insulated thermocouples. The asbestos can, in some cases, act as a gasket to prevent the passage of helium through the tube.

Bend Test The planned installation of the Type D thermocouple called for a slight (approximately 15°) bend near the weld end. The test illustrated in Figure 7 was performed to show that even sharp 90° and 180° bends do not break the wires, rupture the sheath, or short-circuit the wires to one another or to the sheath. A continuity check showed no short-circuits or wire breaks, and microscopic examination did not reveal tube rupture.

TYPE E THERMOCOUPLE

Information available on the behavior of organic materials in atomic-reactor environments was quite limited. Therefore, when a high-flux density reactor for materials testing became available, several thermocouples made with commercially available wire were exposed. These thermocouples were identical with other stainless-sheathed assemblies previously described, except for the insulation and that the two wires were not joined in a thermocouple junction. It was possible to follow any changes in the resistance of the insulation simply by reading the resistance between the two wires or between either wire and the sheath at the open end of the thermocouple extending from the pile. This technique was previously described for the Type A thermocouple (Page 16).

Six such thermocouples made with Leeds & Northup Catalog No. 50-4 insulated iron-constantan wire were exposed for 50 days in the Materials Testing Reactor at Arco, Idaho. During this time, the resistance between the wires varied erratically from 55 - 1,000 megohms when inserted into the pile.

Because of the iron wire corrosion encountered in the fabrication of the Type C thermocouples, wire identical with that used in this test was ordered and has since been used for thermocouples in positions previously set aside for Type C.

Fabrication and Inspection The fabrication and inspection of Type E thermocouples is identical with that of the Type C thermocouples except that, with the new insulation, the heat-treatment is no longer required.

"TRIAXIAL" CABLE

Knowledge of the neutron flux at various points within the reactor is desirable to the operator. Such measurements could be made with a specially prepared device designed at the E. R. L. and described in DP-26. However, no cables were available to carry the signal through the high-flux field to a junction box outside of the reactor.

Requests for design of these cables stated that they should consist of an insulated wire covered by a tube which in turn was insulated and covered by a second tube. Tube and wire were to be 2S aluminum. The inner tube was to act as an electrical guard or shield between the wire and the outer tube. The insulation was required to have a resistance of not less than 4×10^8 ohms for a maximum length of 35 ft. The cable was to operate in a liquid medium. The insulation could not break down on exposure to high neutron flux.

The names "triax" and "triaxial" cable most commonly used when referring to this assembly are misnomers; there was actually only one axis, not three, as can be seen from Figure 9.

During the development, all tube drawing was done by the Precision Tube Co., Philadelphia, Pa. The inner tube was drawn on a standard tube-drawing bull block. The outer tube, being less flexible, was drawn on a standard tube-drawing bench.

The usefulness of the "triax" depended upon the overall diameter of the cable. If the cable could be held to a maximum diameter of 0.300 in., it would be possible to insert three cables within each instrument tube.

Insulation The minimum resistance of 4×10^8 ohms was a difficult requirement. Ordinarily, cables having such resistance depend upon any of several organic materials for their high electrical insulation resistance. Such materials as extruded polythene or resin-impregnated fibrous materials are typical. These materials, however, were arbitrarily excluded from use here.

The investigation resolved itself into a study of five types of insulation all of which were eventually made usable.

"Refrasil" and the "Refrasil" Cable Insulation selected as a final choice was "Refrasil" silica yarn, a product of the H. I. Thompson Co., Los Angeles, Calif. "Refrasil" is a borosilicate "Fiberglas" yarn which has been leached with hydrochloric acid. This produces a nearly pure silica yarn. An analysis is given in Table I.

Efforts to wrap or braid "Refrasil" on a wire as an insulator for the Type C and Type D thermocouples indicated such a method to be impractical. It was decided to have Thompson braid the "Fiberglas" yarn into a sleeve so that the inner wire could be threaded within this sleeve. It was thus possible to prepare "Refrasil" sleeves by leaching and firing the "Fiberglas" already in the form of a sleeve. An aluminum tube could be drawn over the sleeving and it, in turn, could be threaded in a second sleeve. A final aluminum tube could be drawn over the assembly to form the completed cable. Ability to thread the wire and the first tube in the "Refrasil" sleeve resulted from the fact that the sleeve was braided to behave like the well-known Chinese finger trap. As the ends of the sleeve were forced toward one another, the diameter of the sleeve would grow. The wire was then passed through the sleeve. The sleeve was then stretched out and the diameter decreased so that the insulation fitted snugly about the wire. A similar procedure was used to thread the assembly into the outer aluminum tube. Figure 8 shows a diagram of this cable and a picture of a 16-in. length.

The as-received "Refrasil" sleeve had an electrical resistance of the order of 10^6 to 10^7 ohms/35 ft. of cable. It was established that heat-treating the "Refrasil" at 1800°F for 8 hr. would provide an insulated cable with a resistance between any two elements of 10^{11} ohms. Heat-treatment at lower temperatures did not show this improvement. However, the treated material was so embrittled that handling would have been impossible. A compromise heat-treatment of 2 hr. at 1800°F. was found to give cable resistances of 10^9-10^{10} ohms without excessive embrittlement if handled in the braided-sleeve form.

Arrangements were made with the Thompson Co. to supply the appropriate sizes of "Refrasil" sleeving as established by trial. They were to take special pains to assure maximum silica and minimum boron contents by careful and thorough leaching and washing. They would certify a maximum boron content of 200 p.p.m., which was acceptable to the du Pont operating department.

By agreement, the code numbers S-100-1-DS and S-100-2-ADS were chosen to refer to the sleeving which would be used specifically for the inner and outer insulation, respectively, of these cables.

1. <u>Fabrication Procedure</u> The fabrication steps are as follows:

a. An appropriate length of 0.032-in. diam. 2S aluminum wire is threaded through the same length of S-100-1-DS "Refrasil" sleeve. The sleeving is then stretched out lengthwise so that it fits snugly about the wire.

b. This insulated wire is drawn through a 2S aluminum tube with a 0.010-in. wall and an approximate diameter of 0.180-in.

c. The tube is drawn down to a 0.120-in. o. d. on a standard tube-drawing bull block. The i. d. of the tube now meets the o. d. of the sleeving.

d. This assembly is straightened and cleaned of drawing lubricants.

e. It is threaded through a length of S-100-2 ADS "Refrasil" sleeving. This sleeving is then drawn out until it fits snugly about the aluminum tube.

f. This is threaded through an aluminum tube with a 0.049-in. wall and an o. d. of 0.400 in.

g. The outer tube is drawn down to an o. d. of 0.298 in. The i. d. of the tube now just meets the o. d. of the larger "Refrasil" sleeve. Welding of the measuring device to the outer tube wall is possible because of the 0.049-in. wall thickness.

h. All metal members must be carefully cleaned before assembly so that no organic drawing lubricants are included.

Asbestos and the Asbestos Cable The cable insulated with asbestos had the same dimensions as the cable insulated with "Refrasil" silica fiber, and the inner tube of the latter cable was replaced by braided 2S aluminum wire.

As-received asbestos is a poor insulator just as is as-received " Refrasil". Commercial asbestos insulation is always impregnated with a varnish or similar organic binder if high electrical resistance is required.

Attempts to heat-treat this fiber in order to improve the resistance at first indicated that, although the resistance could be brought to a satisfactory level, the physical properties deteriorated markedly and carding it on wire and tubing would be impossible. The ideal heat-treating conditions were 1 hr. at over 1,000°F.

Several cables were prepared with the tubing identical in size with that on the "Refrasil" cable shown in Figure 8. The cables were then heat-treated after fabrication. The 1025°F. temperature used was near the 1180°F. melting point of the 2S aluminum. During heat-treatment, the evolved water of crystallization ruptured the soft aluminum tube walls.

Two solutions to this difficulty were found. First, it was learned that, if asbestos was heat-treated in small batches for not more than 1 hr. at 1,000°F., the minimum acceptable resistance was achieved. Although the physical properties were poor owing to embrittlement, it was still possible--though difficult--to card the fibers on to a wire. Second, a cable was designed in which the inner tube was replaced with a braided 2S aluminum wire sleeve. A second cover of asbestos was applied over the aluminum braid and the entire assembly heat-treated after insulation but before covering with the outer tube. The open aluminum braid could pass the water vapor evolved during heat-treatment.

The resistance of such cables varied somewhat but averaged 5 - 8 x 10^8 ohms for a 35-ft. length. From a fabrication point of view, the second type of asbestos cable listed above was preferred over the first, but neither was as simple to make nor as high and uniform in electrical resistance as the cable insulated with "Refrasil".

Ceramics and the Ceramic Cables The use of ceramic tubes as insulators was considered, but it was quickly learned that the goal of a 0.300-in. o. d. maximum could not be reached. However, cables with an o. d. of 0.500 in. were designed and the components ordered. These cables would have been used had the efforts to provide a high-resistance "Refrasil" or asbestos-insulated cable failed. The large o. d. of these cables would have limited the number of devices to one per instrument tube. The limiting factor was the inability of the suppliers to provide small-diameter thin-wall ceramic tubes.

Figure 9 shows the proposed design of the ceramic-insulated "Triax". Fabrication would have been done by hand. The wide spacing between the insulators and the aluminum elements was required to provide for (a) maximum warpage of 0.006 in./in. along the length of the insulators,

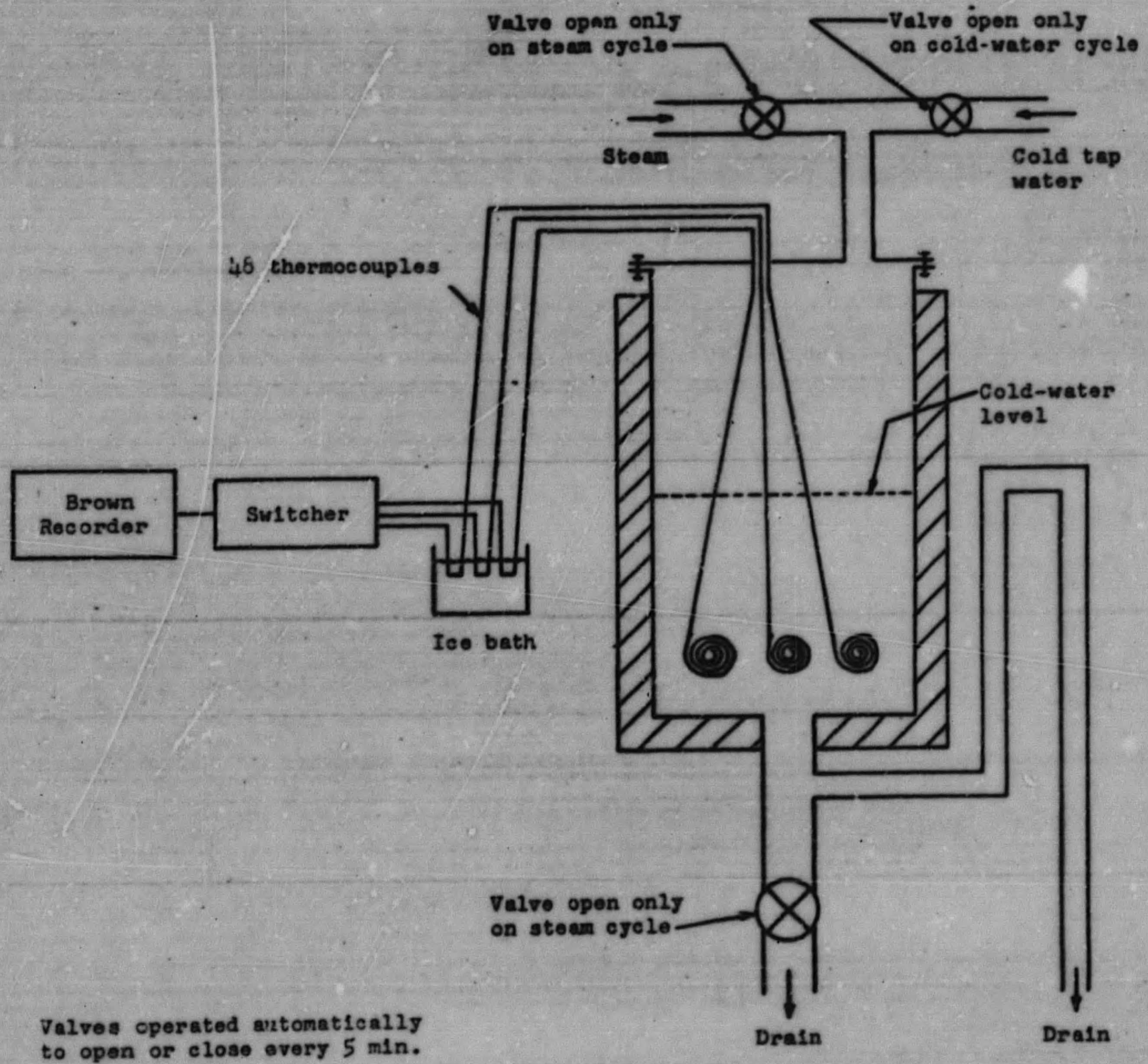
(b) the - 0.010-in. o. d. and i. d. tolerances required by insulator suppliers, and (c) free slippage of the insulators along the wire and tubes during assembly.

Three types of insulators were chosen. "AlSiMag" Ceramic is an Al_2O_3- MgO-SiO_2 body made by the American Lava Co.; "Alundum" fused alumina is a product of the Norton Co.; and "Amersil" fused silica is made by the American Silica Co. Any of these would have provided a cable with a resistance of the order of 10^{14} ohms.

Development was discontinued when small-diameter cables having sufficiently high resistance were fabricated using either "Refrasil" or asbestos.

J M Stone
J. M. Stone
Engineering Department
Wilmington, Delaware

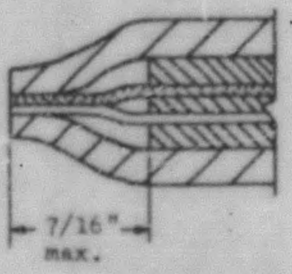
Figure 1



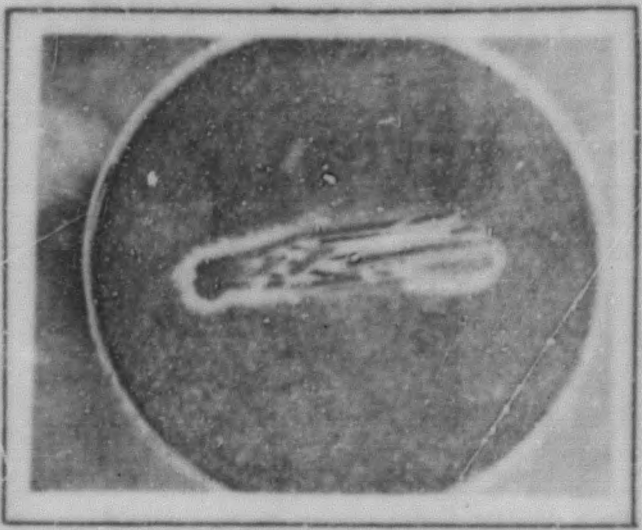
Valves operated automatically to open or close every 5 min.

THERMOCOUPLE SHOCK TESTER

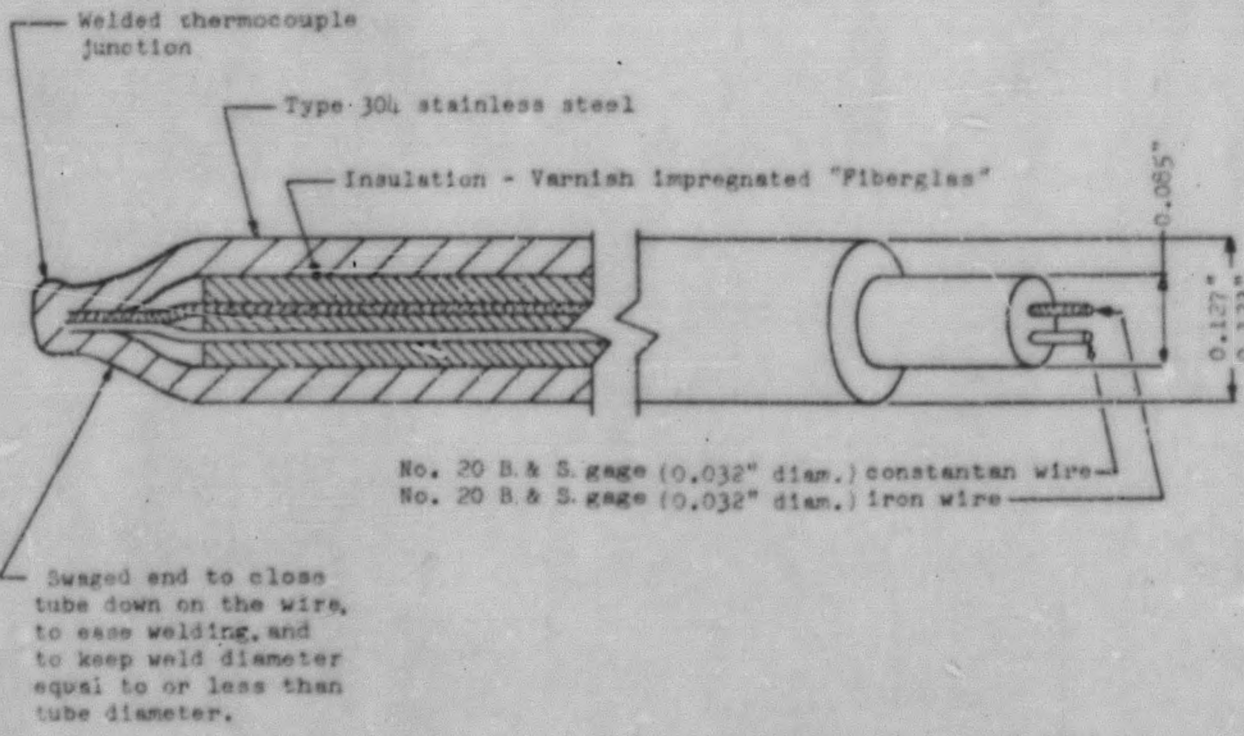
Figure 2



Thermocouple Junction Prior To Welding

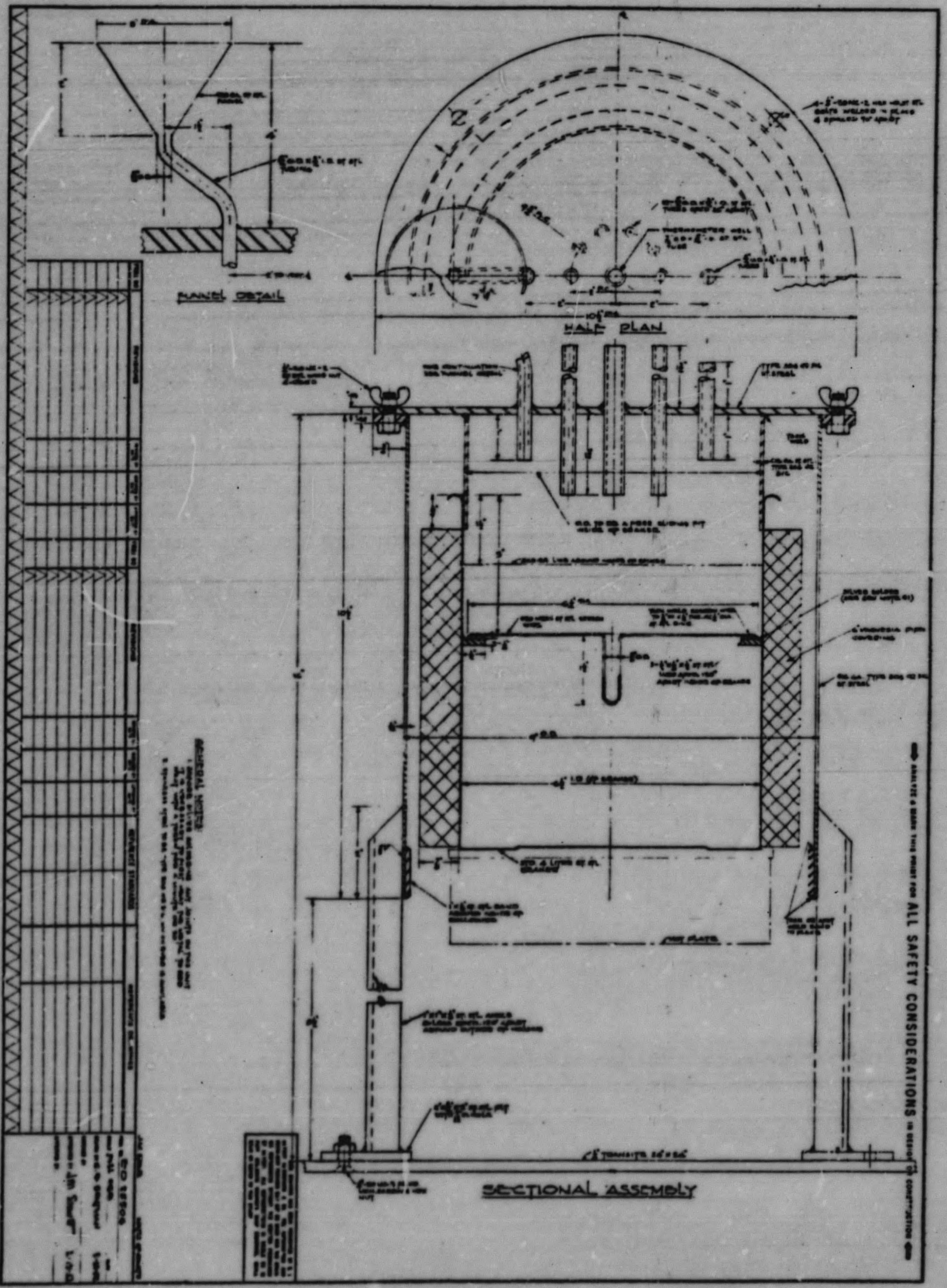


Typical Weld Section



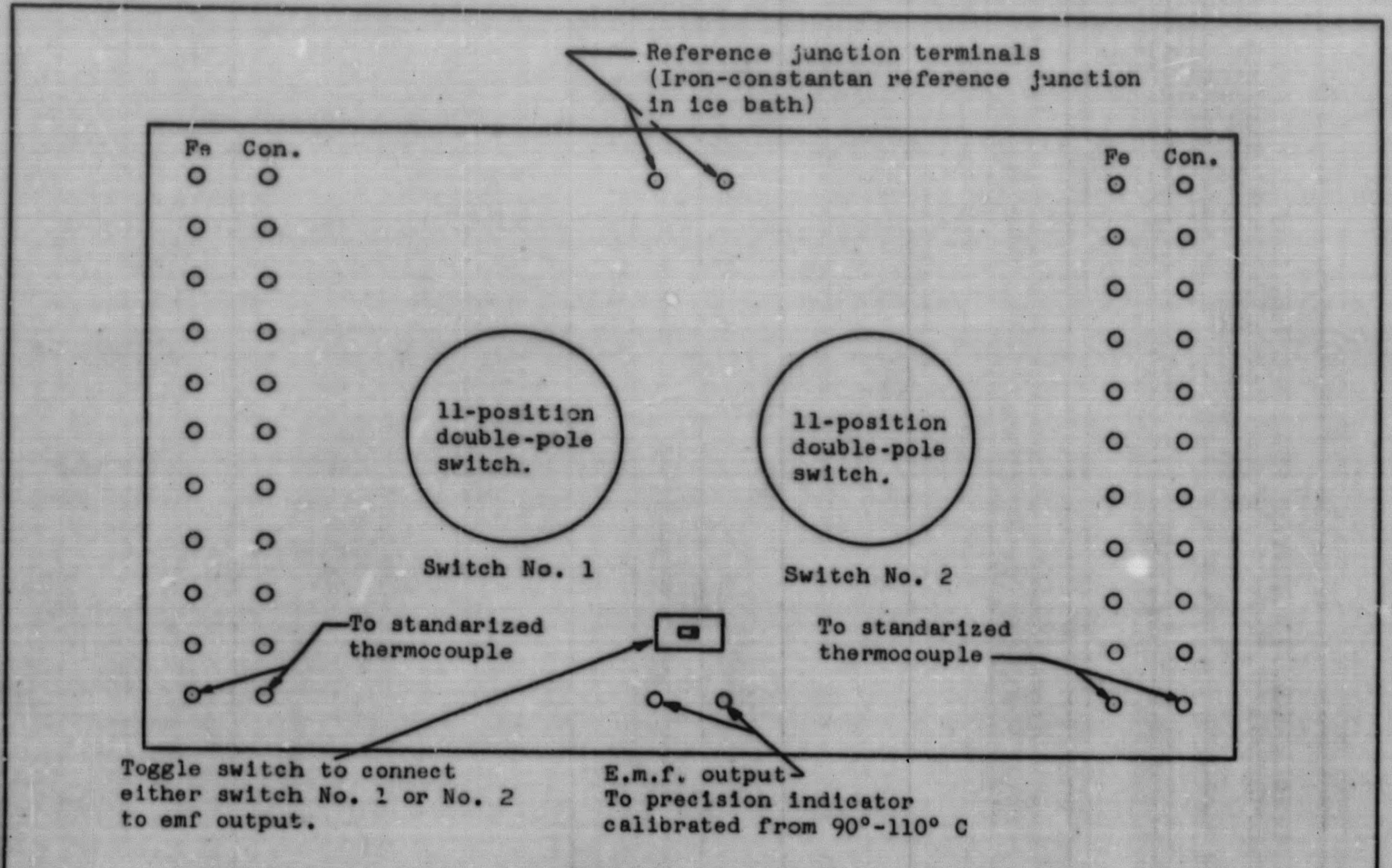
TYPE A THERMOCOUPLE

Figure 3



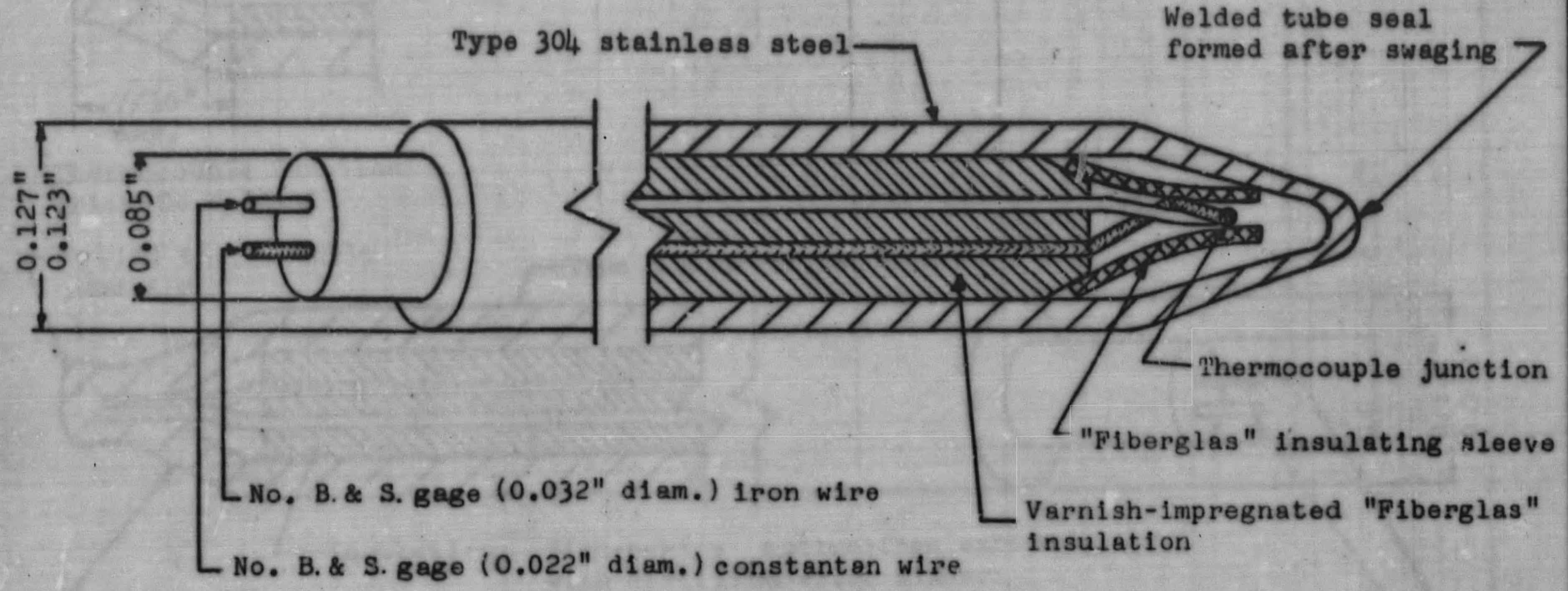
CONSTANT TEMPERATURE BATH

Figure 4



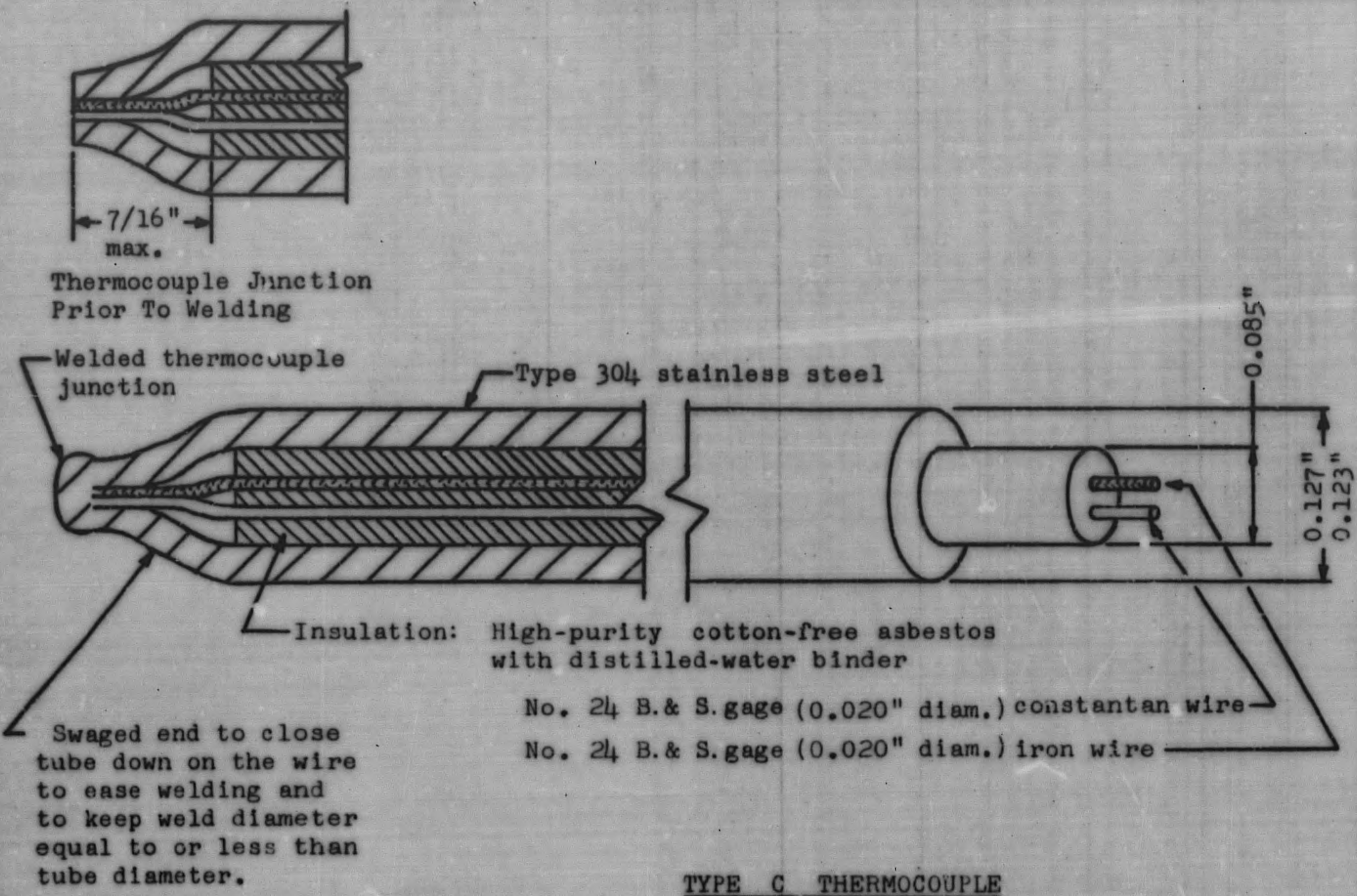
<u>MULTIPLE THERMOCOUPLE CALIBRATION SWITCHER</u>

Figure 5



TYPE B THERMOCOUPLE

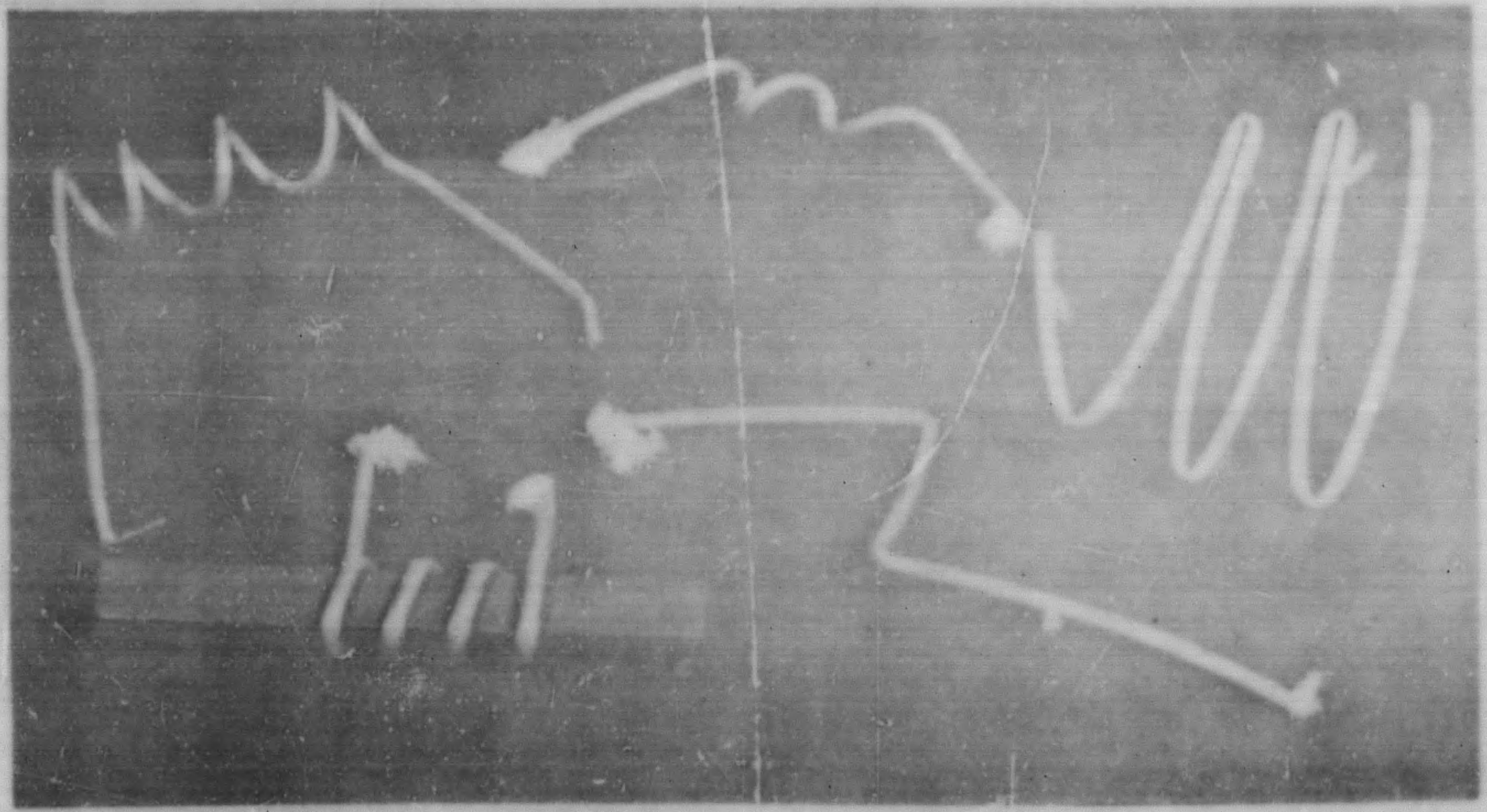
Figure 6.



TYPE C THERMOCOUPLE

~~CONFIDENTIAL~~

Figure 2

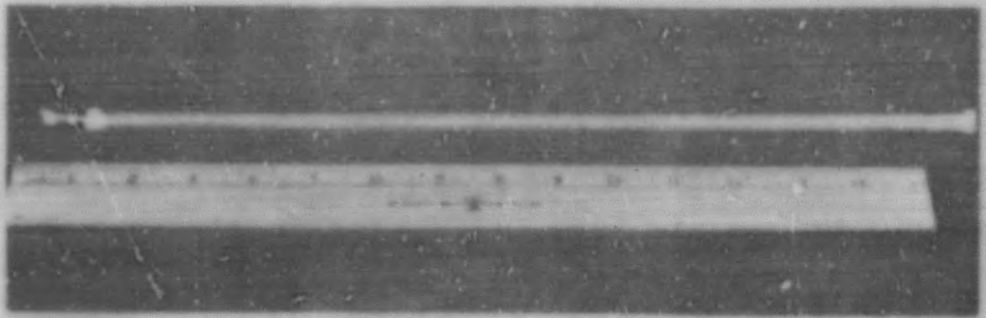


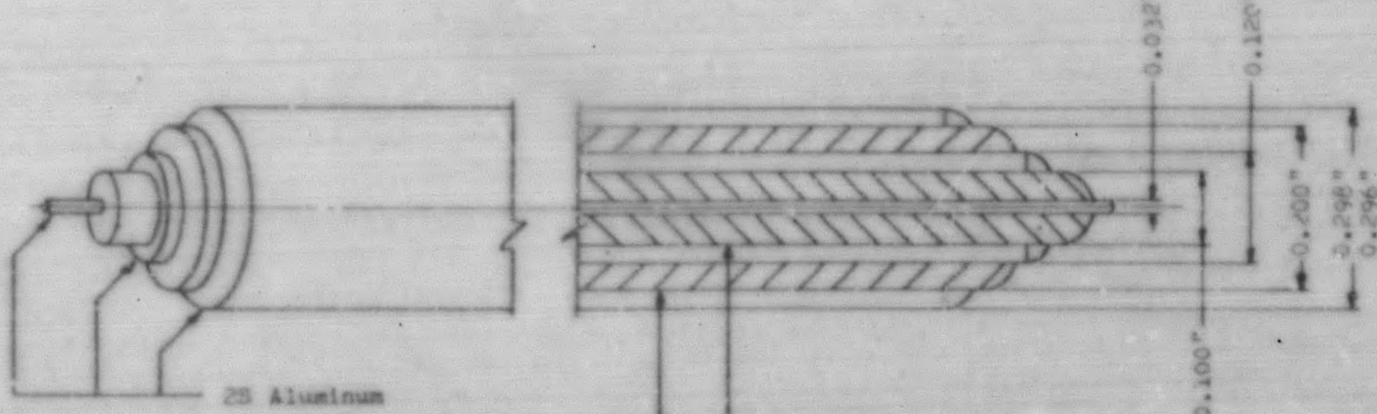
TYPE D THERMOCOUPLE: BEND TEST

~~CONFIDENTIAL~~

CONFIDENTIAL

Figure 8





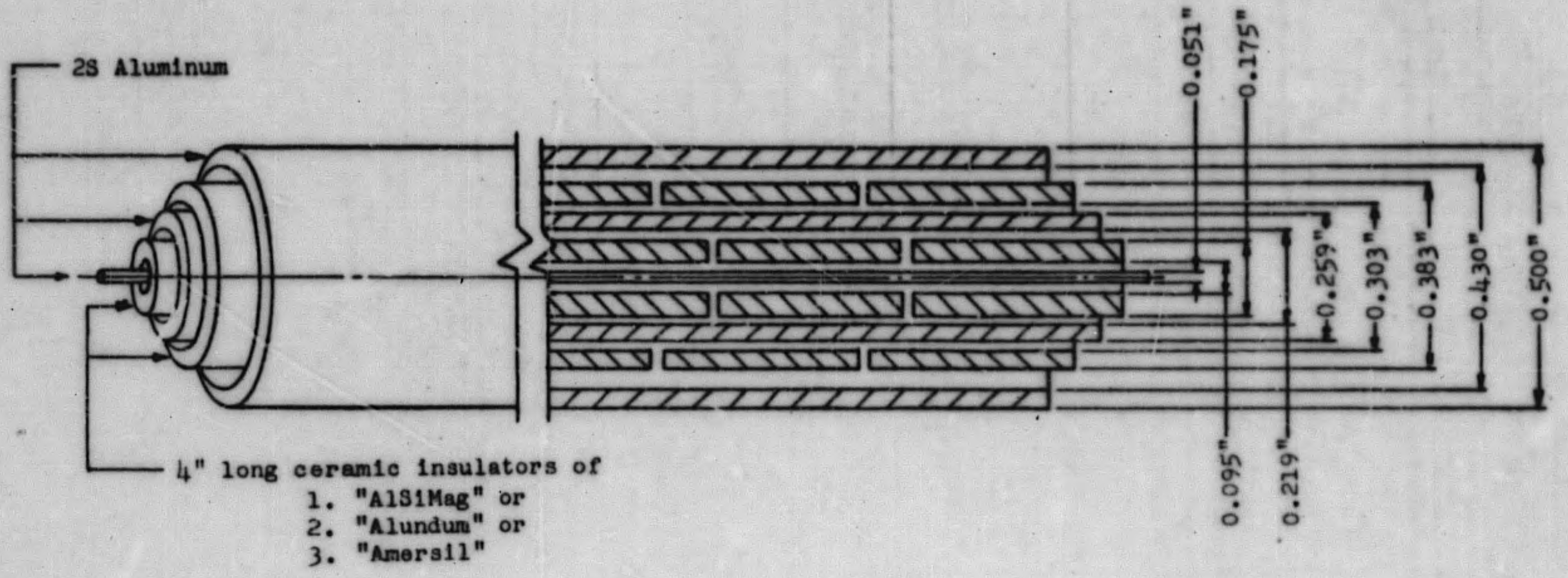
Lengths up to 36' 5"

* Product of the H. I. Thompson Co.
1733 Cordova Street
Los Angeles, California

"TRIAXIAL" CABLE

CONFIDENTIAL

Figure 9



Lengths up to 20 ft.

Note: Wide clearances required to allow for:
1. Warpage of insulators
2. Poor tolerances held
3. Freedom of movement during assembly.

CERAMIC - INSULATED "TRIAXIAL" CABLE

TABLE I

ANALYSIS OF "REFRASIL" SILICA INSULATION

10 - 100 p.p.m.	100 - 1,000 p.p.m.	0.1 - 2%	2 - 99%
Na	Zr	None	Si
Al	Ti		
Mg	Ca		
Cu	B		

Based on spectrographic analysis

Note: O, N, and H are not reported.

END