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SAFETY ANALYSIS OF THE EBR-II HIGH-TEMPERATURE NUCLEAR INSTRUMENT TEST FACILITY (NITF)

by

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ABSTRACT

The NITF provides a high-temperature (up to 1200°F) facility with high neutron and gamma fluxes for testing and development of neutron sensors and circuits. The facility was designed to satisfy the requirements of the AEC's Liquid Metal Fast Breeder Reactor Program. It has been installed in the J-2 instrument thimble of the EBR-II reactor, tested, and accepted as a high-temperature experimental facility. Safety considerations were evaluated for three areas: (1) modification of the J-2 thimble so it would accept the new facility, (2) operation of the NITF at high temperature, and (3) removal and handling of activated instruments and equipment. The evaluation shows that installation and operation of the NITF will not endanger personnel or equipment and that plant operation will not be affected. No unsafe or hazardous conditions will be imposed over and above those imposed by other instrument thimbles in the EBR-II. A shielded space has been prepared in the reactor-building storage pit for remotely handling the detectors and their carrier.

I. INTRODUCTION

One of the tasks (Task 4-7.1) of the AEC's Liquid Metal Fast Breeder Reactor (LMFBR) Program Plan is the development and prooftesting of neutron sensors and circuits for future LMFBR reactors. Two nuclear instrument test facilities (NITF's) that provide an environment of high temperatures and neutron and gamma fluxes are now available at EBR-II for experimental testing, one in the O-1 instrument thimble, and the other in the J-2 instrument thimble. The expected environmental limits as outlined in the LMFBR Program Plan, Vol. 4, "Inst. and Control," * and the typical operating characteristics of the two thimbles at the

*WASH-1104.

core midplane for an EBR-II reactor power of 62.5 MWt are as follows:

Characteristics	Limits in LMFBR Plan	Environment in 0-1 Thimble	Environment in J-2 Thimble
Neutron flux, n/cm^2-sec	10^1-10^{10}	6.4×10^8	8.0×10^{10}
Gamma flux, R/hr	up to 10^6	5.5×10^4	1.2×10^6
Temperature, °F	up to 1200	125-700	700-1200
Test Volume, in.	4 ID x 48	4.8 ID x 240	6.2 ID x 84

It is apparent that both facilities can fulfill the LMFBR need for testing. This report describes the high-temperature NITF that has been installed in the J-2 instrument thimble and considers all safeguards involved in the installation and operation of this facility.

Because its large diameter and proximity to the EBR-II reactor core provide for high neutron and gamma fluxes, the existing J-2 instrument thimble in EBR-II was modified to accept the NITF that will operate at 700-1200°F. This thimble enters the primary tank at an angle of 11° and penetrates the reactor-vessel neutron shielding. The bottom end rests in a bracket fastened to the outside of the reactor vessel. All internals in the original thimble were replaced.

The facility in the 0-1 thimble, which is now being used for lower-temperature testing, did not require major modification of that thimble.

II. DESCRIPTION OF FACILITY

Major changes incorporated in the final design since the combined CSDD and PSDD[1] was prepared and distributed include:

a. The capability for future installation of a gamma source has been provided. Nine stainless-steel-clad source rods can fit into nine gamma-source tubes that extend from the shield plug to the bottom of the NITF assembly. The portion of the tubes within the oven are embedded in the oven pipe between nine equally spaced strip heaters.

b. The insulation has been changed from laminated stainless steel with a mineral-fiber and/or air gap to Johns-Manville flexible Min-K.

c. The flange and insert-tube assembly has been cut off about 9 ft below the flange.

d. An argon purge line and a sodium-leak detector have been added. The purge line, which runs to the bottom of the oven assembly, establishes an argon blanket in the space between the protective tube of the oven (the oven cover) and the outer shell of the thimble. Cable for the leak detector runs through the purge line.

e. Steel balls, 1/8 in. in diameter, are used instead of heavy concrete as shielding in the 1-1/4-in.-wide annulus at the top and outside of the insert tube.

A. *Modification of the J-2 Thimble*

Figure 1 shows the location of the J-2 thimble, and Fig. 2 shows a sectional view of the new high-temperature NITF. The thimble support flange has two concentric rows of bolts. The inner row fastens the flange to the J-2 thimble, and the outer row fastens the flange to the primary-tank nozzle. The Type 304 stainless steel outer shell of the thimble and the means for attaching the thimble to the primary tank were not changed in the modification. The outer shell has an 18.5-in. OD x 0.5-in. wall to a depth of 4 ft, a 16.5-in. OD x 0.5-in. wall from a depth of 4 to 8 ft, and a 15-in. OD x 0.375-in. wall from a depth of 8 to 28 ft. Everything within this shell was removed. Internal flanges at the top of the thimble and at a depth of 4 ft were machined to receive the new flange and insert-tube assembly of 15 in. OD. The flange and tube together form an assembly.

The new flange and insert-tube assembly has been permanently installed as shown in Fig. 2. The insert tube has a 15-in. OD x 0.25-in. wall to a depth of 4.5 ft, a 15-in. OD x 0.75-in. wall from a depth of 4.5 to 8 ft, and a 14-in. OD by 0.187-in. wall from a depth of 8 ft to 8 ft 3 in. All tube and flange materials are of Type 304 stainless steel. The upper tube of the new assembly was plug-welded to the ring flange of the old thimble. The annular space between the outer shell and the new insert tube was filled with steel shot for shielding. A polyurethane potting compound was poured on top of the shot to form a seal for argon gas.

Removal of the internals of the J-2 thimble went according to plan and on schedule. The J-2 thimble was "mapped" for ID measurements with a go-no go gauge and for straightness measurements with a transit. According to

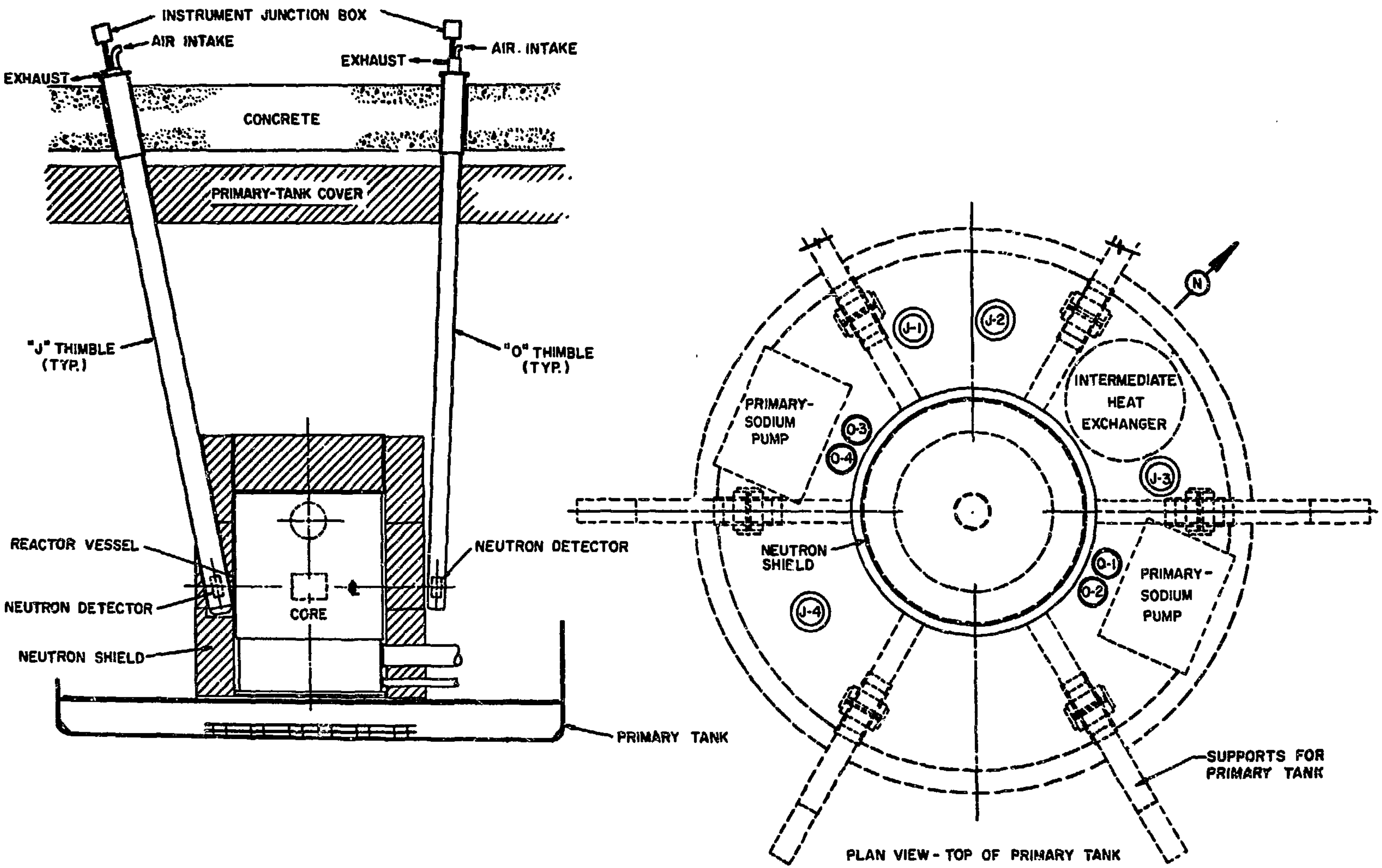
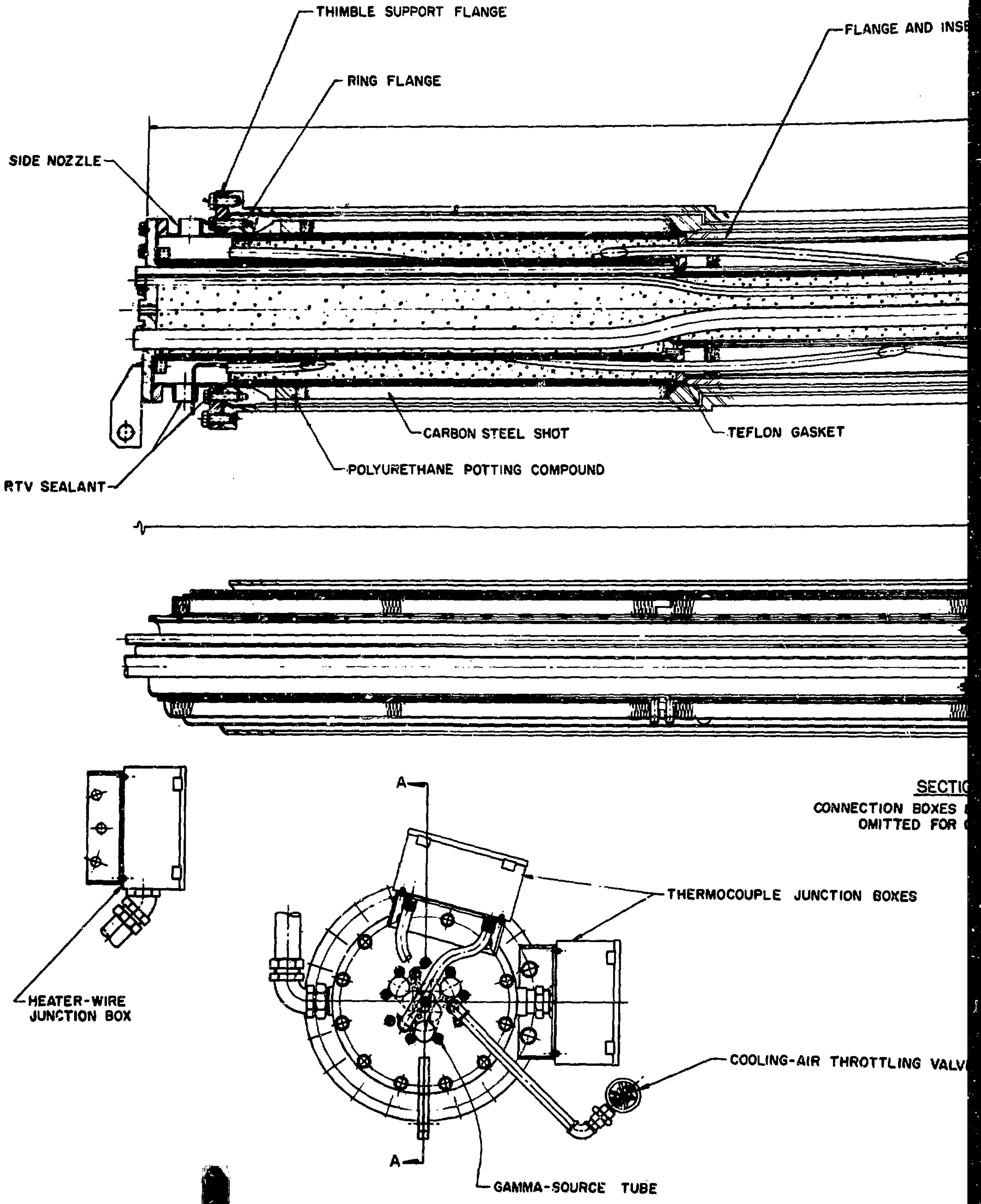


Fig. 1. Location of Nuclear-instrument Thimbles in EBR-II


THIMBLE SUPPORT FLANGE
FLANGE AND INS
RING FLANGE
SIDE NOZZLE
CARBON STEEL SHOT
TEFLON GASKET
POLYURETHANE POTTING COMPOUND
RTV SEALANT
SECTI
CONNECTION BOXES
OMITTED FOR
A
THERMOCOUPLE JUNCTION BOXES
HEATER-WIRE JUNCTION BOX
COOLING-AIR THROTTLING VALV
A
GAMMA-SOURCE TUBE

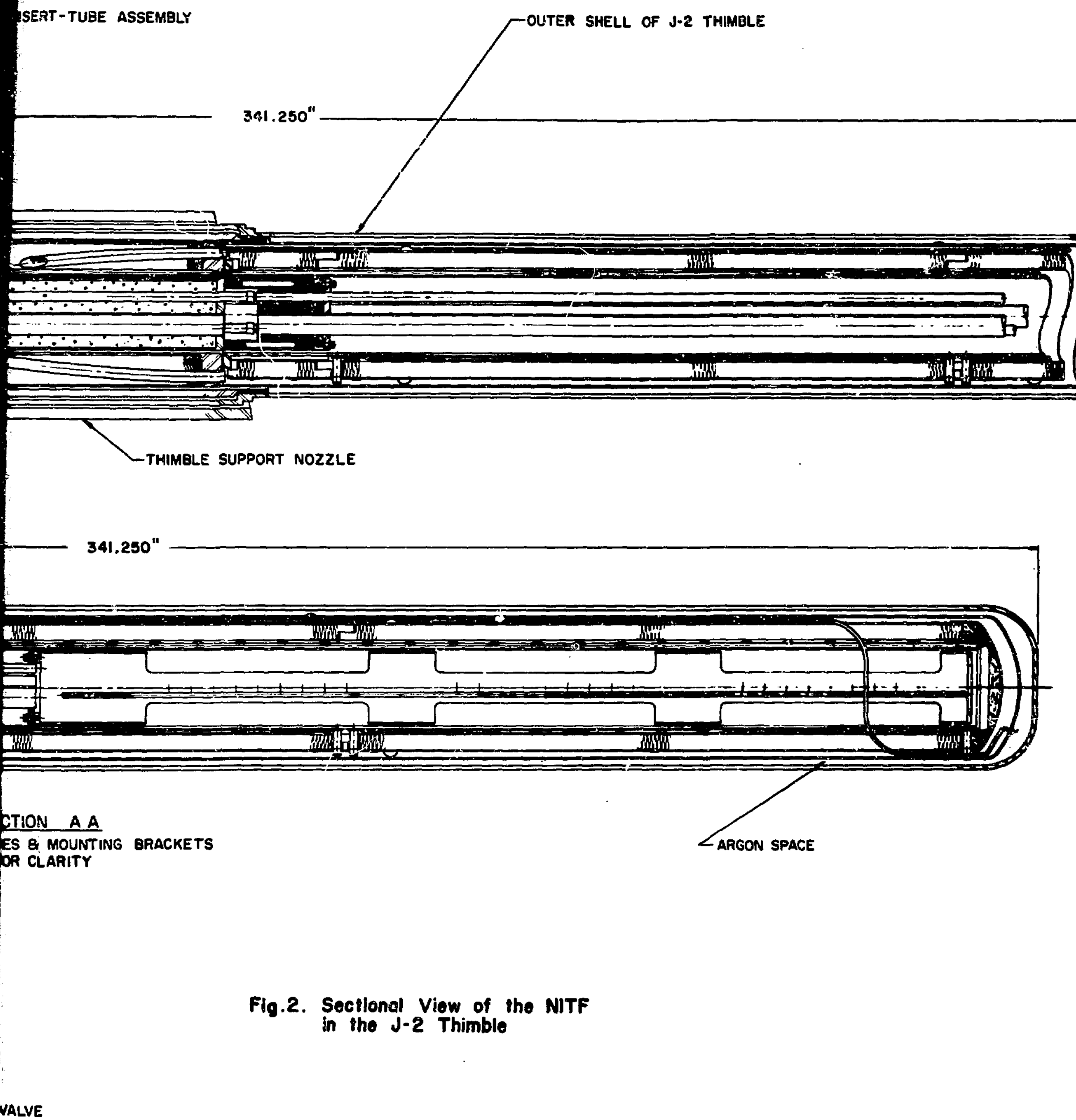


Fig.2. Sectional View of the NITF in the J-2 Thimble

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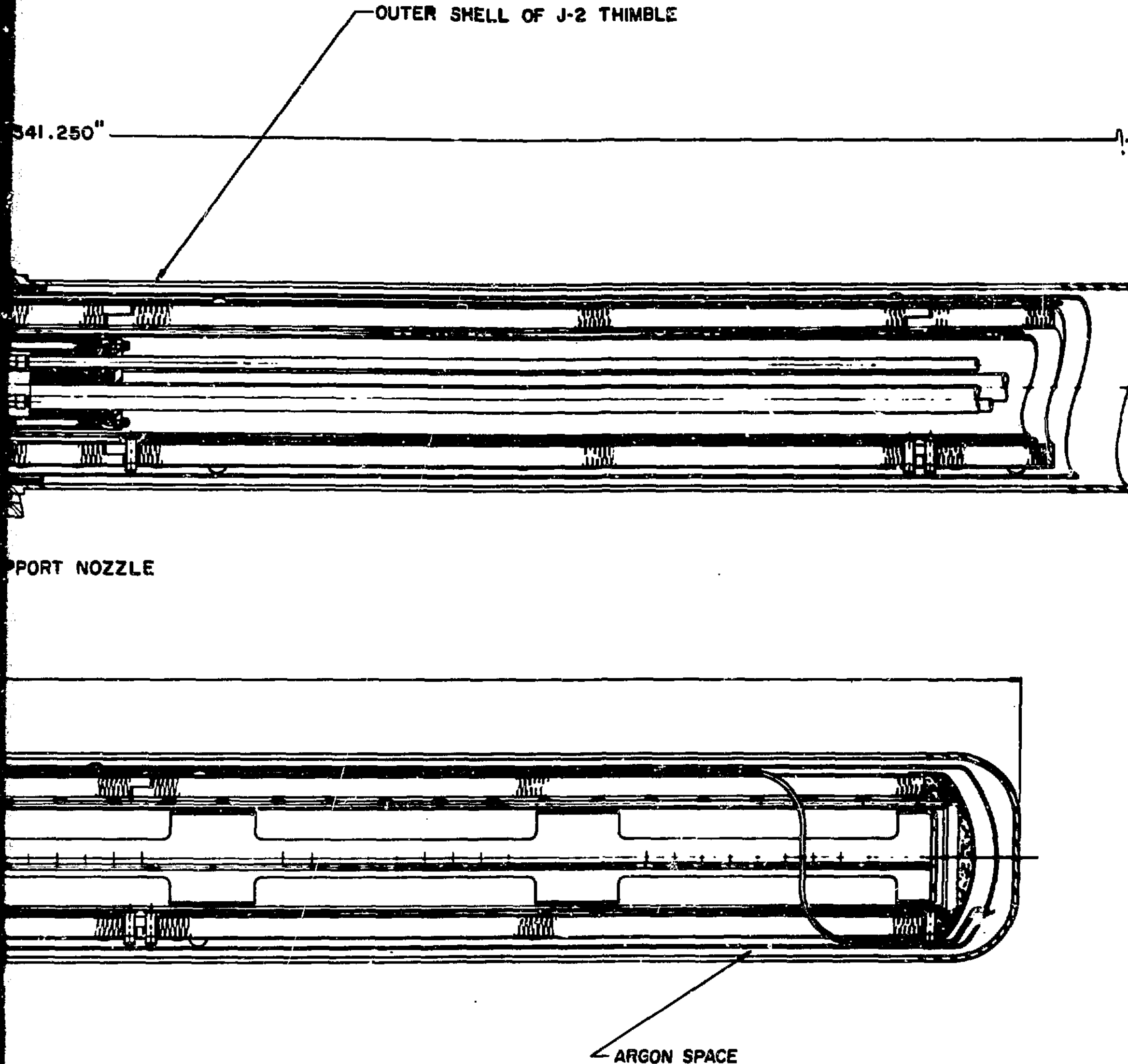

Fig.2. Sectional View of the NITF in the J-2 Thimble

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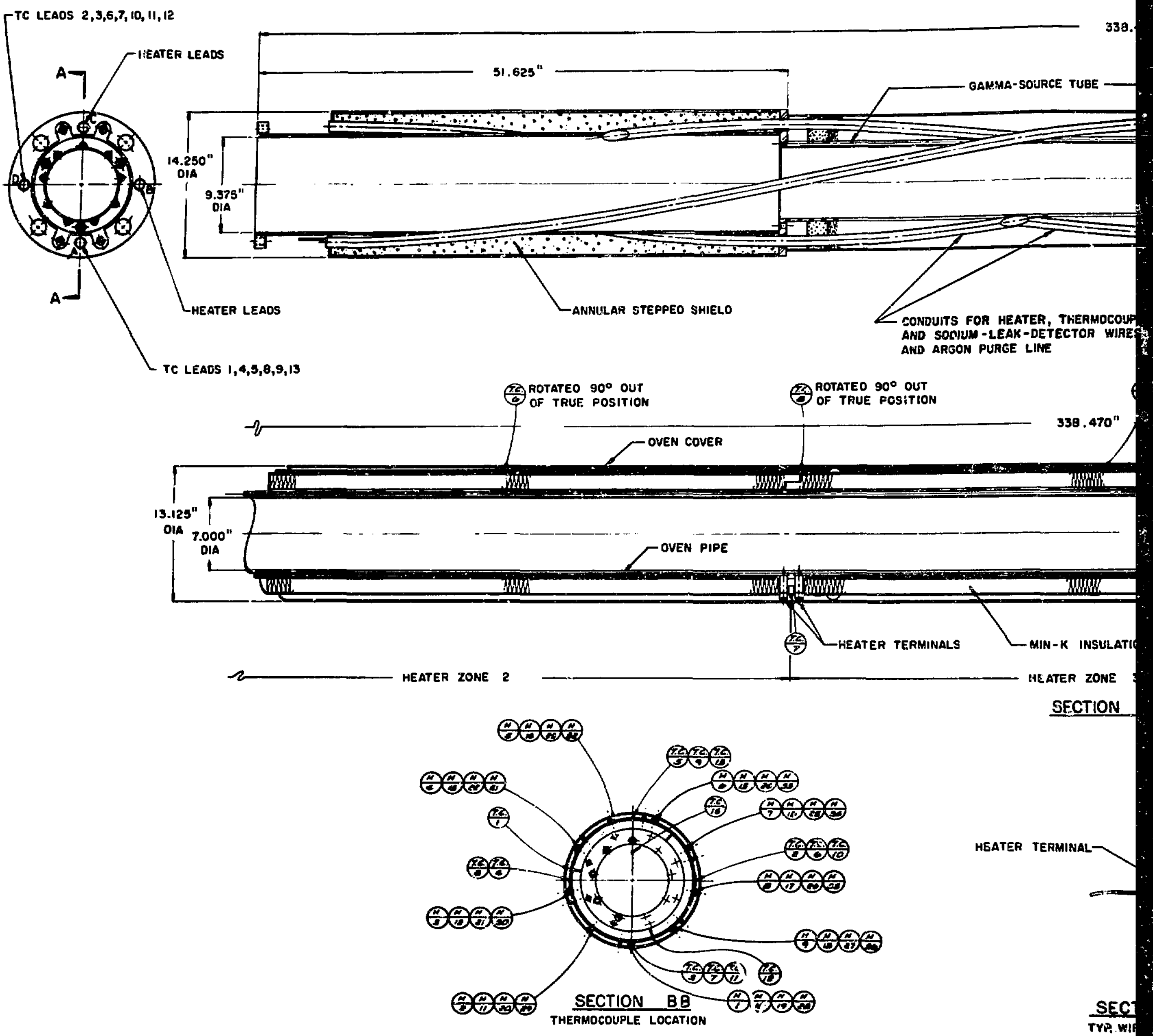
the drawings, the J-2 thimble should have had an ID of 14.250 in. The go-no go gauge, however, indicated that the thimble has a smaller diameter (13.900-13.950 in.) at a circumferential weld joint about 17 ft below the top flange. The straightness measurements showed that the thimble is straight to within ±3/16 in. The total measured length of the thimble is in good agreement with the drawings.

B. Oven Assembly

1. Mechanical

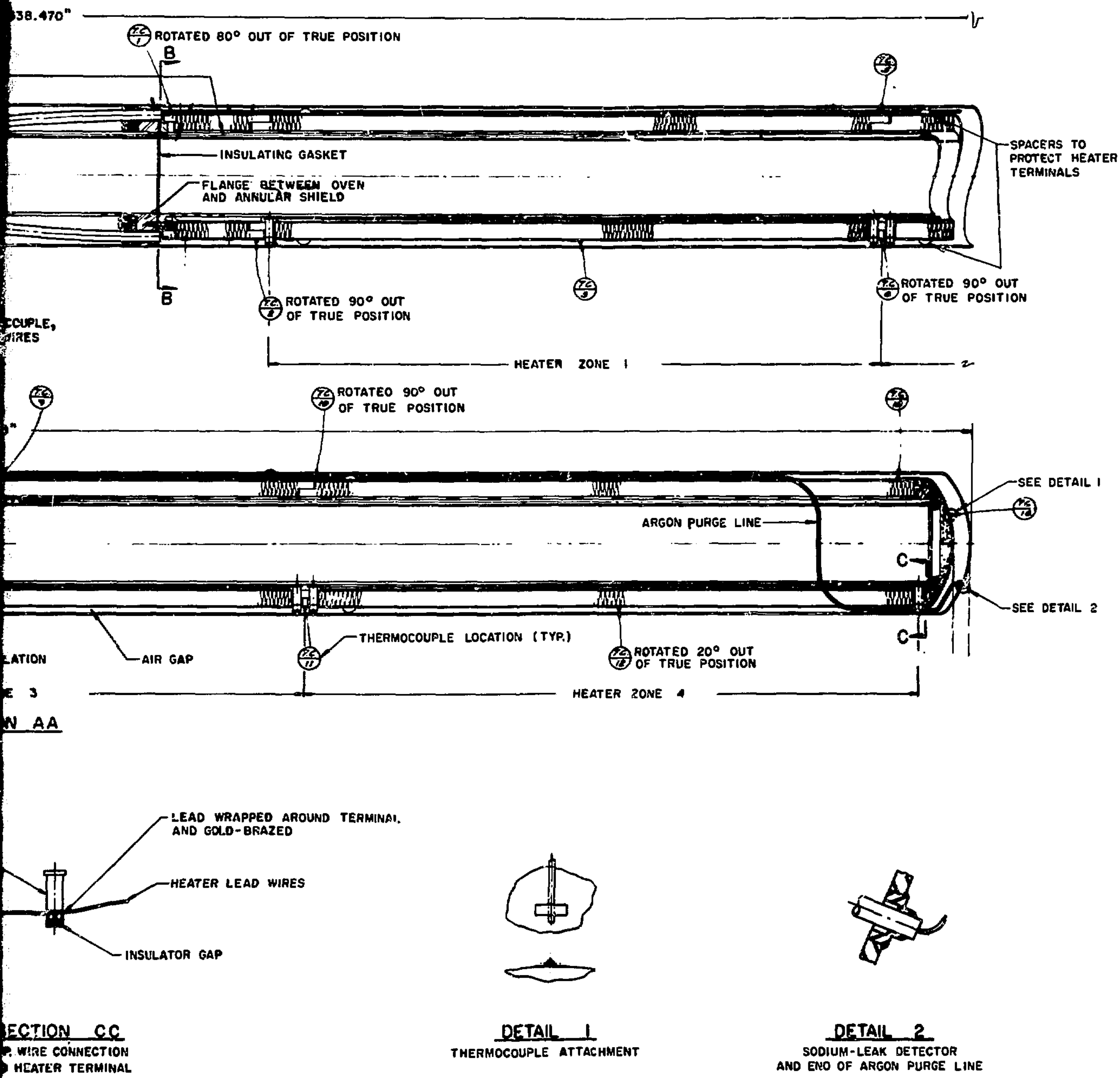
The oven assembly, shown in Fig. 3, contains an annular stepped shield in the upper 8 ft and the oven and insulation in the lower 19.5 ft. This assembly is completely independent of the shield-plug and detector-carrier assembly and will be semi-permanently installed. It may be removed for repairs, if necessary, after removal of the shield-plug and detector-carrier assembly. The entire oven assembly slips into and rests on the step provided 4.5 ft down in the flange and insert-tube assembly. The upper 8 ft of the oven assembly contains an annular radiation shield composed of steel balls and magnetite concrete. Four equally spaced 1-in.-OD conduit tubes are embedded in the annular shield and make a 180° helical spiral over the 8-ft length of the shield. The conduits are used for routing heater, leak-detector, and thermocouple wires and the argon purge line from the oven and insulation section up through the shield section. These wires and the purge line leave the facility through the two side nozzles shown in Fig. 2.

The lower section of the oven assembly is attached to the upper annular shield section by a bolted flanged joint. High-temperature gasket-type insulation was placed in the joint to minimize heat transfer from the hot oven area to the shield area. The oven pipe and oven cover of the oven assembly are Type 304 stainless steel tubes. The pipe has a 7.50-in. OD and a 1/4-in. wall; the cover, a 13.125-in. OD and a 1/8-in. wall. The pipe has nine equally spaced flats machined down its length to hold and position the electric strip heaters. Between flats, a groove is machined to contain the 1/2-in.-OD source tubes. The strip heaters are retained by Type 316 stainless steel bands. Electrical-insulator caps insulate the terminals attached to each end of the individual strip heaters.



HEATER GROUP	HEATER NO.	HEATER ZONE
GR 1	1, 4, 7	1
GR 2	[illegible]	1
GR 3	[illegible]	1
GR 4	10,13,16	[illegible]
GR 5	11,14,17	[illegible]
GR 6	12,15,18	[illegible]
GR 7	19,22,25	[illegible]
GR 8	[illegible]	[illegible]
GR 9	[illegible]	[illegible]
GR 10	[illegible]	[illegible]
GR 11	[illegible]	[illegible]
GR 12	[illegible]	[illegible]

Fig.3. Oven Assem



ssembly of the NITF

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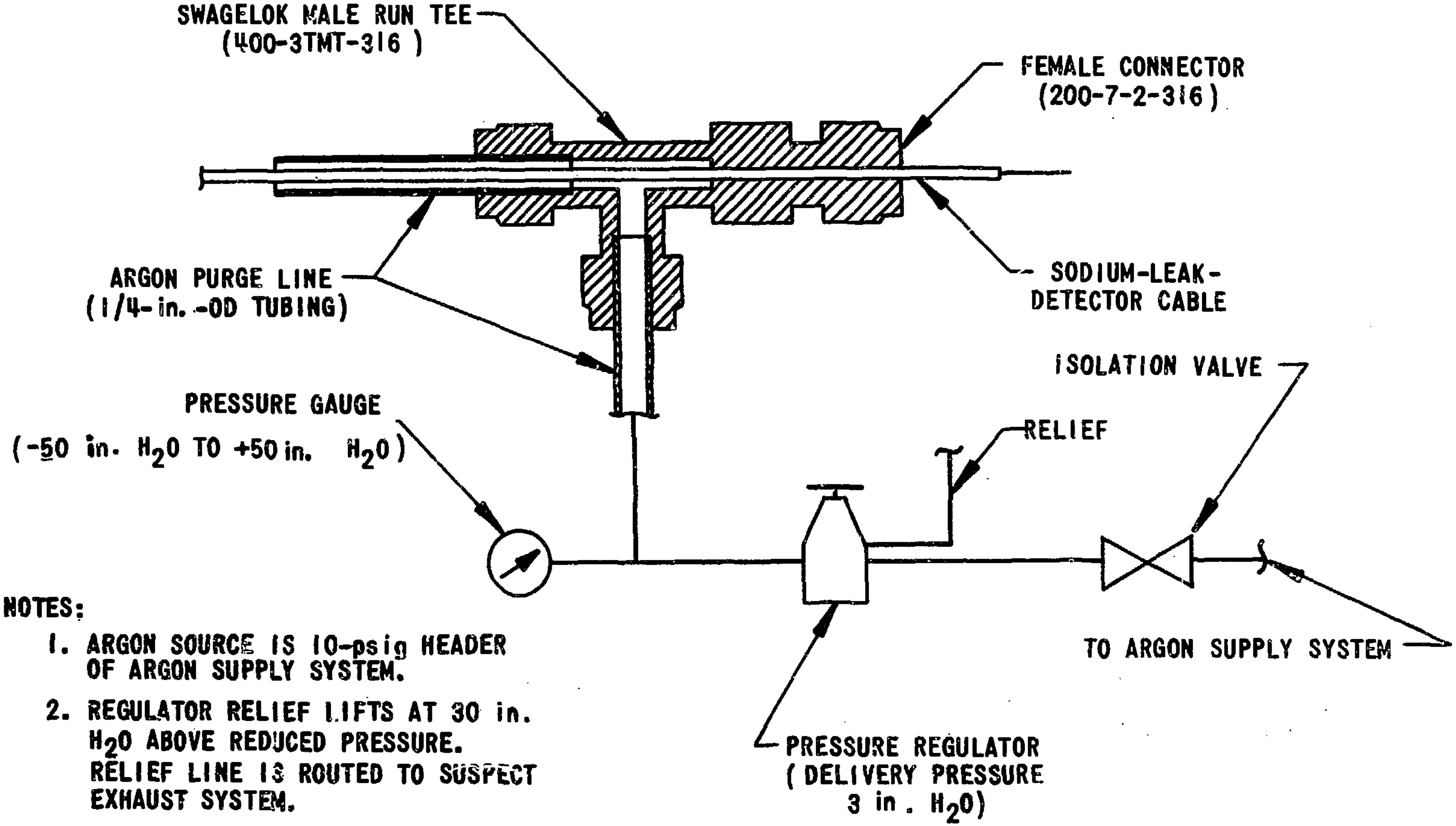
The oven pipe and the strip heaters are surrounded by a 1-1/2-in. thickness of commercially available Johns-Manville Min-K insulation contained in vented Type 304 stainless steel cans. Clearance holes are provided where the insulation sections fit around the heater terminals. Sufficient clearance is also provided to allow for differential expansion between the heater elements and the insulation. An annular air gap of approximately 0.5 in. exists between the OD of the insulation cans and the ID of the outer cover of the oven assembly. This space is used for the heater, leak-detector, and thermocouple wires and the argon purge line that are routed upward through the four 1-in. conduits in the top annular shield, as shown in Fig. 3. An additional wrap of quartz-fabric electrical insulation is provided over the heater wiring. After assembly of the oven strip heaters, insulation, wiring, and instrumentation was complete, the oven cover was slipped over the entire assembly and attached to the flange between the oven and the annular shield. This oven cover is welded to the upper annular shield to make the oven assembly leak-tight to the top of the thimble.

The space between the oven assembly and the outer shell of the thimble is sealed leak-tight, and an argon atmosphere is maintained in the space as a safety feature in case of sodium leakage. The leak-tight space is established by the polyurethane potting compound on top of the steel balls and a Teflon gasket on the insert-tube step that supports the oven assembly. Figure 4 is a schematic of the argon supply and regulating system. The 2-in. side nozzles at the top of the thimble are potted with a RTV compound to provide a secondary seal. Any leakage from the argon annulus will be contained by the secondary seal and vented to the EBR-II suspect exhaust system. Spacers extending beyond the heater terminals are welded to the cans of Min-K insulation to protect the insulation cap on the end of the heater terminal. The cans are rigid, because they are made of 1/16-in.-thick Type 304 stainless steel banded tightly with Type 316 stainless steel bands. Four spacers are placed at each terminal elevation; the terminals are approximately 56 in. apart. With the NITF assembly at an angle of 11° in the J-2 thimble, the spacers on the lower side will be partially supporting the inner oven and detector-carrier assemblies. The spacer loading at the elevation of each group of heater terminals is approximately 50 lb. The insulation cans will support loads considerably higher than this without significant deflection.



NOTES:

1. ARGON SOURCE IS 10-psig HEADER OF ARGON SUPPLY SYSTEM.
2. REGULATOR RELIEF LIFTS AT 30 in. H_2O ABOVE REDUCED PRESSURE. RELIEF LINE IS ROUTED TO SUSPECT EXHAUST SYSTEM.
3. FEMALE CONNECTOR DRILLED THROUGH TO RECEIVE 0.125-in.-dia LEAK-DETECTOR CABLE.

Fig. 4. Argon Purge System for the NITF

2. Temperatures and Stresses

Calculations indicate that heat losses from the 19.5-ft-long NITF oven will be about 3.5 kW at 1200°F. Temperatures in the air annulus outside the insulation should be less than 800°F. The calculations were based on an assumed heater temperature of 1250°F with 700°F sodium in contact with the outside wall of the thimble.

An estimated integrated power of about 40 kWh will be required to heat the entire NITF oven and contents from the 700°F ambient temperature of the EBR-II primary tank up to 1200°F. The use of one or two heater circuits in each heater zone (see Sec. II.F for heater arrangement) will accomplish this temperature elevation in 5 or 10 hr, respectively. The use of highly efficient insulation to reduce heat losses from the NITF will limit cooldown of the facility to about 30°F/hr. Radial and axial clearances are sufficient to allow free expansion of components during heatup, except for the lightweight inner insulation can, which is 0.007 in. thick. This sheet will probably buckle or ripple between heater bands with the design radial temperature gradient of about 400°F through the insulation. There is space between the heater bands for expansion of the cans, however, so this expansion should cause no problem.

Thermal stresses developed because of thermal gradients within components are not a problem. The component of most concern is the 6-5/8-in.-OD flange of the shield plug and detector-carrier assembly at the top of the cooling-air plenum. The center of the flange is cooled by air flowing into the plenum. The outside of the flange is connected to tubing that runs to the 1200°F oven 9 in. below. Calculated thermal stresses in the flange are less than 5000 psi for an air-plenum temperature of 500°F.

C. Shield-plug and Detector-carrier Assembly

This removable assembly (shown in Fig. 5) is installed after the flange and insert-tube assembly and the oven assembly have been installed in the J-2 thimble. It is the innermost assembly in the NITF (see Fig. 2). The upper 8 ft of the assembly is the shield plug, which is filled with high-density concrete. The concrete space is vented at the top and bottom of the concrete's steel container to prevent pressure buildup in the space. Three 2-in.-OD detector-cable conduits, two 1-in.-OD instrumentation conduits, one 1-in.-OD air-outlet tube, and nine 7/8-in.-OD source tubes penetrate the shield plug. The nine source tubes contain stainless steel plugs. The other six tubes are offset one diameter or more to reduce radiation streaming. The detector cables and connectors are connected into external control-and-instrumentation equipment. The air-outlet tube is piped into the existing EBR-II instrument-thimble-cooling system. The two instrumentation conduits terminate at an electrical connection box. The flange of the shield plug supports the entire assembly and is bolted to the flange of the insert tube.

Immediately below the shield plug and at the top of the NITF oven is the insulated air plenum. The flow of cooling air through this plenum reduces the temperature of the nuclear-detector cables at the outlet of the 1200°F oven. This reduction is intended to minimize perturbations of the detector signals caused by temperature gradients along the cables. The plenum is maintained at a negative pressure by the instrument-thimble-cooling system. This negative pressure in turn causes air to flow from the reactor building, through filters, and into the cable conduits, where it flows down past the cables and into the air plenum. The cooling air flows from the air plenum through the 1-in. air-outlet tube, which is connected to the thimble-cooling system.

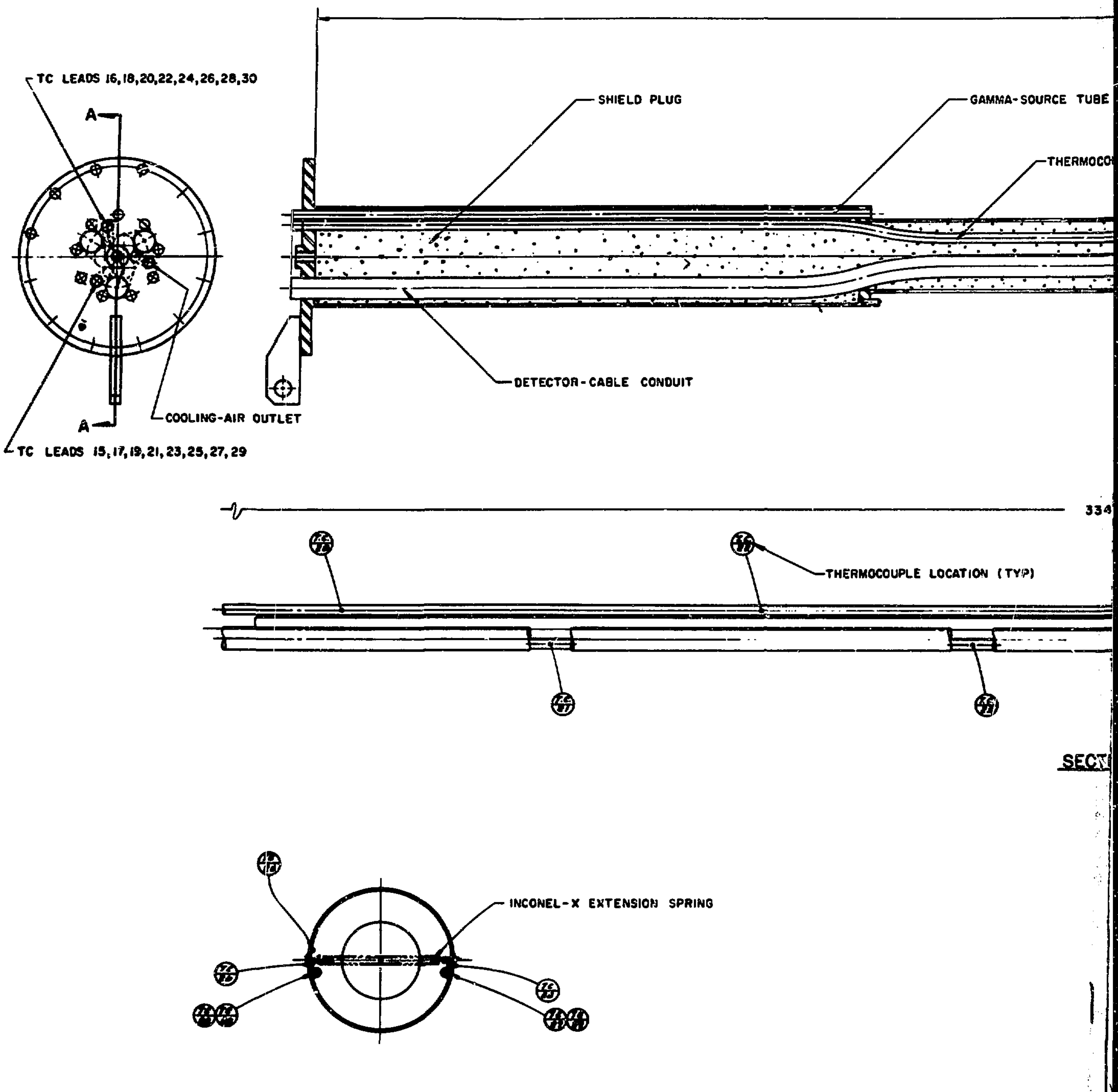
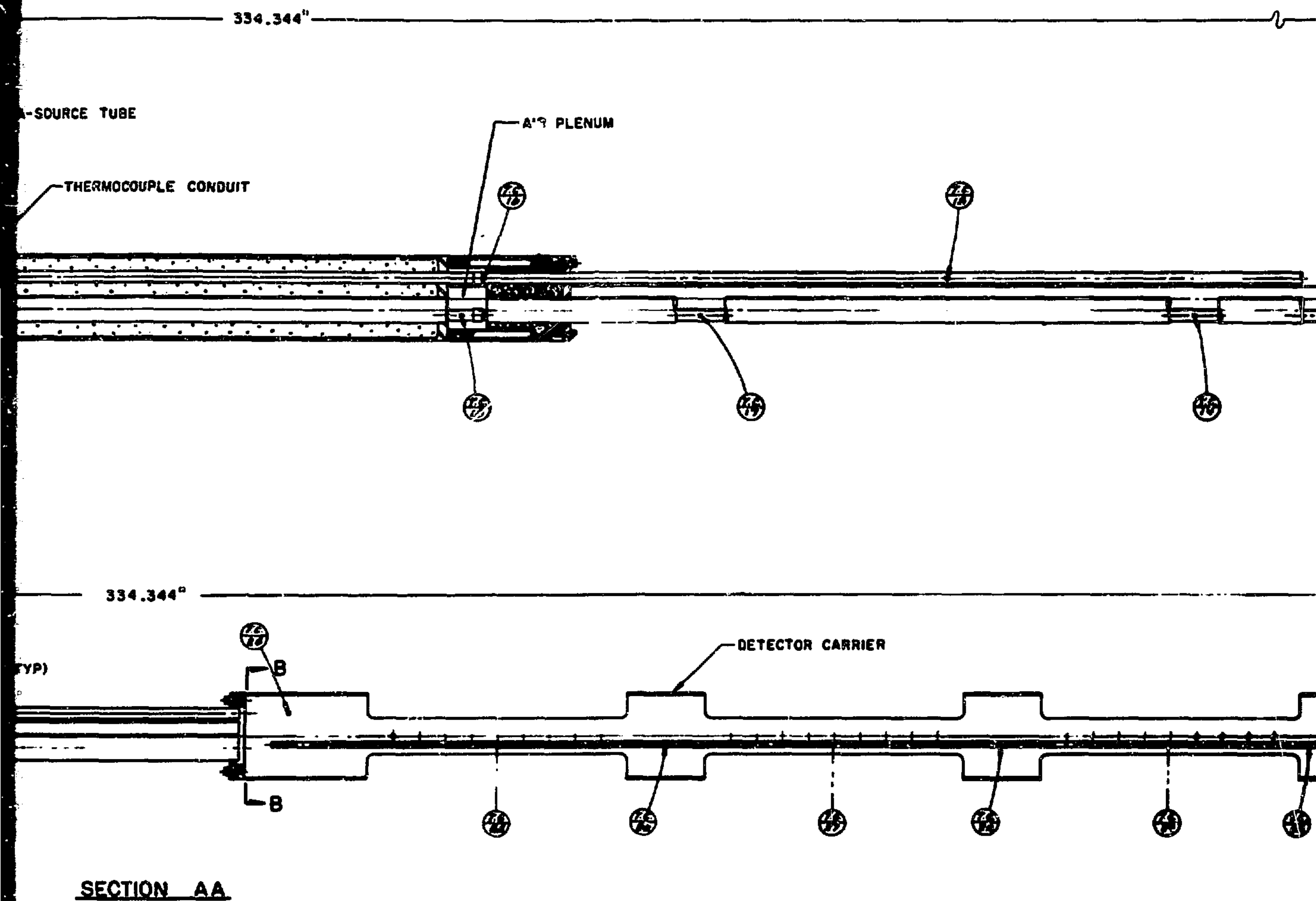


Fig. 5. Shield– plug and Dete



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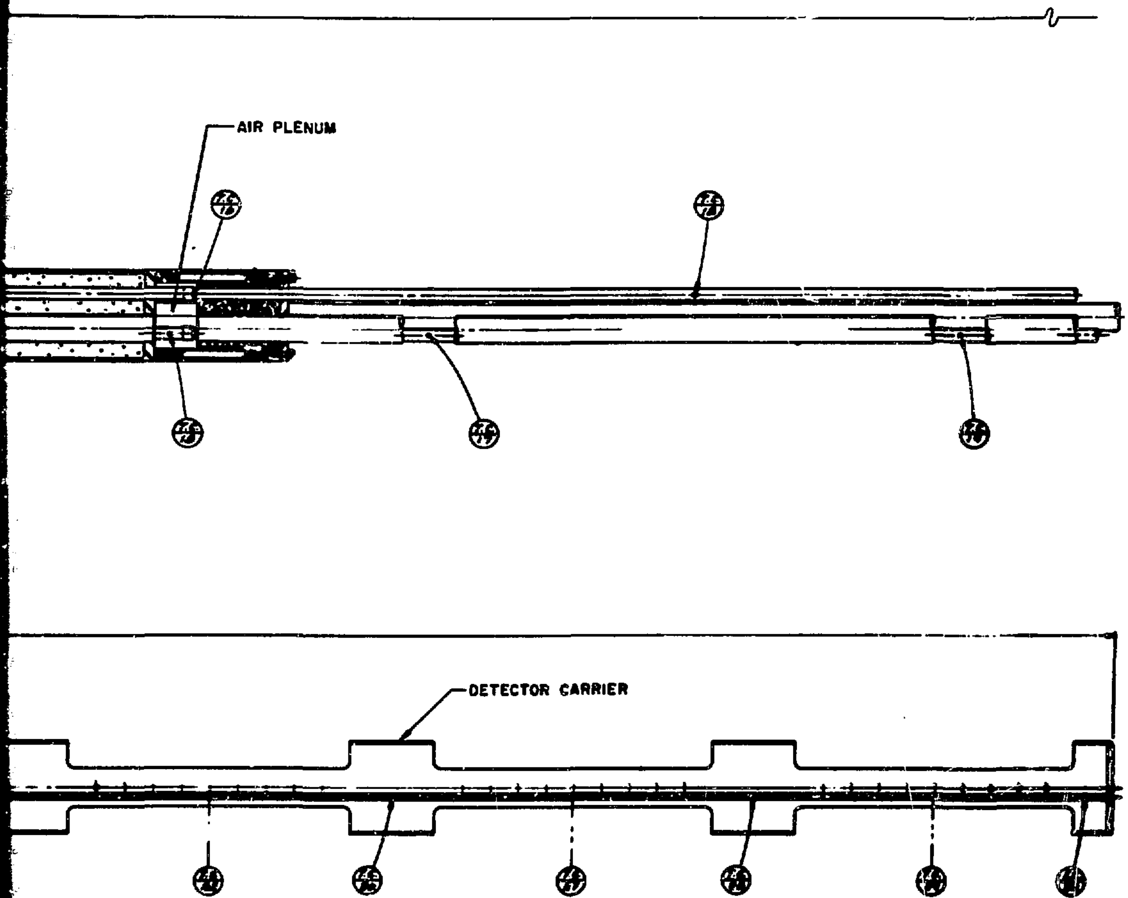

nbly of the NITF

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The three 2-in. conduits and the two 1-in. conduits pass through the air plenum and down into the NITF oven, and serve to join the shield plug to the detector carrier positioned in the bottom of the oven. The top of the grouped tubing is flanged and bolted to the air plenum. The bottom is flanged and bolted to the carrier section.

The detector carrier, 7 ft long, is capable of firmly holding three experimental detectors at a time. Each detector can be electrostatically shielded by mounting it in a stainless steel can expected to be about 3.5 in. in diameter by 2 ft long. The carrier is constructed of 6.625-in.-OD, thin-wall stainless steel tubing. Sections 20 in. long by 5.75 in. wide are cut from both sides of the carrier at three different elevations, as shown in Fig. 5. These openings, plus a 5-in.-dia opening in the bottom of the carrier, will be used for installing the experimental detectors and cables inside the carrier. Any one detector-and-cable assembly may be removed from the carrier with minimum disturbance of the others. The detector-cable bundle is fed into one of the carrier openings and up into one of the three cable-outlet conduits. The cables of each detector can be electrostatically shielded as a bundle with a flexible stainless steel hose. A long wire cable with a gripper device may be dropped down through the cable conduits and fastened to the detector cables to aid in threading them out of the facility. High-temperature Inconel-X extension springs hold the experimental detectors firmly against the inside wall of the carrier. The springs are shown in Section BB of Fig. 5. Although the detector-holding springs may be positioned at 2-in. intervals throughout the length of the carrier, it is expected that three to five springs, each providing a force of 5-10 lb, will adequately hold each detector to the inside wall of the carrier. Detector loading and unloading procedures have been proved by testing in a full-scale mockup.

D. <u>Gamma Heating</u>

Gamma-heat generation in the J-2 thimble will make a substantial contribution to heating of the NITF. On page 53 of the Addendum to the EBR-II Hazard Summary Report,[2] the statement is made that the maximum internal gamma-heat generation in the stainless steel EBR-II reactor-vessel wall is between 0.01 and 0.02 W/cm^3. More recent information[3] gives a maximum value of 0.035 W/cm^3 outside row 14 of the outer blanket at the core midplane. Since the thimble is outside the reactor-vessel wall, the gamma-heating rate in stainless steel in the thimble is assumed as 0.02 W/cm^3. The gamma-heating should be less than in the reactor vessel wall, because the thimble is farther from the core. However, the higher value specified for the wall is used in an attempt to be conservative. The amount of stainless steel within the NITF thermal insulation where gamma heating is a factor, is about 2500 cm^3/ft. Therefore, the gamma-heating rate within the thimble is 50 W per foot of length. The rate of gamma-heat generation for a future nine-rod gamma source is estimated to be between 1.1 and 1.5 W/cm^3 per rod. Each cobalt rod would contain 5.44 cm^3/ft, so the maximum heat-generation rate per foot of total source length (for nine rods) would be about 9 x 1.5 W/cm^3 x 5.44 cm^3/ft = 73.4 W/ft. This results in a total possible rate of gamma-heat generation (thimble plus source rods) of 123.4 W/ft.

Total calculated heat loss from the NITF is about 3.5 kW, or about 175 W/ft. If a 2- to 3-ft-long source is installed at the bottom of the thimble, the combined gamma and source heating in that portion of the oven should still be 30% less than the heat loss, so some additional electrical heating will always be necessary. The flexible, four-zoned oven-heating arrangement will allow heat to be produced in the NITF in amounts and locations as necessary to maintain approximately uniform temperatures throughout the facility.

E. Cooling of Nuclear-detector Cables above Oven

Heat-transfer studies with the General Electric THTB computer code[4] have been made to determine the temperature gradients in the nuclear-detector cable and a large-diameter electrostatic shield above the oven. (None of the figures in this report show this shield, which will be a part of each experiment. The insulated cable will be within the shield, which is expected to be a 1-5/8-in.-dia flexible stainless steel tube. The cooling air will flow down around the outside of the shield.) Axial and radial heat transfer both were considered. An initial rapid cooling just above the 1200°F oven is induced by the cooling air flowing through the air plenum. Conductor temperatures decrease very rapidly from oven temperatures in the first 6 in. of axial distance above the oven. The rate of temperature decrease above this point is small. (See Fig. 6.)

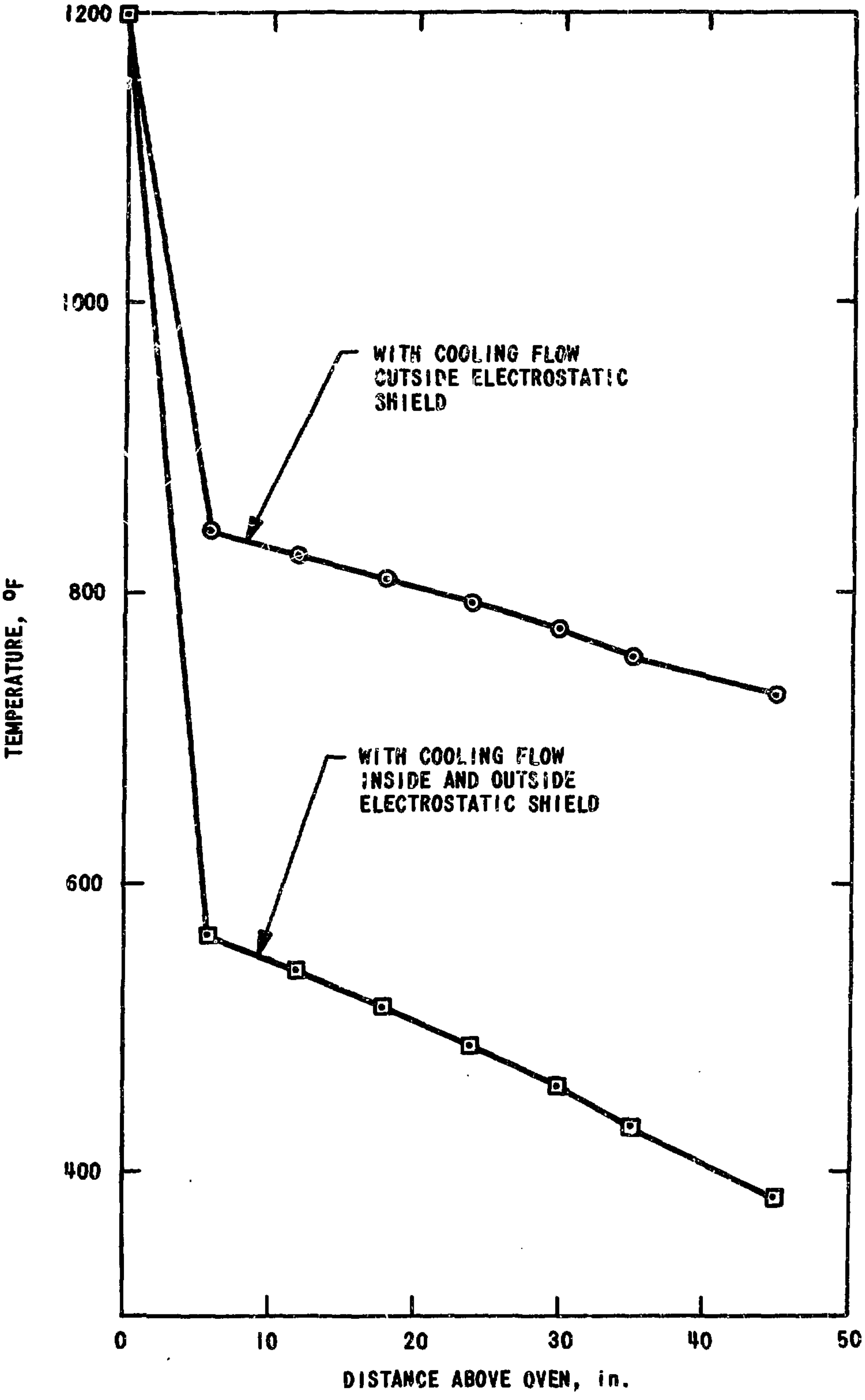


Fig. 6. Temperatures of Nuclear-detector Cables above the NITF Oven

The electrical insulation around the cable and electrostatic shield and the dead air space within the electrostatic shield resist the transfer of heat in a radial direction from the conductor to the cooling air.

The study shows that hot spots should not develop in the cable spaces above the oven. Cables can be cooled to a lower temperature and at a faster rate by routing cooling air to the inside of the electrostatic shield. The existing NITF design is capable of providing such a flow. If a lower cable temperature is desired, the experimenter must make provision to allow cooling air to flow between the electrostatic shield and the cable.

F. Instrumentation and Control

Figures 2, 3, and 5 show the arrangement for mounting the heaters, thermocouples, and experimental nuclear detectors in the NITF assembly, and Fig. 7 shows a block diagram of the NITF instrument-and-control system. This system includes all necessary equipment and interconnections required to monitor and control the oven temperature for high-temperature testing of the experimental detectors and detector cables, but does not include the detectors and cables or any detector instrumentation and associated interconnections.

The 19.5-ft-high x 7-in.-ID NITF oven is divided vertically into four zones for control purposes, and the temperature of each zone is individually and automatically controlled to within ±20°F of any selected temperature between 700 and 1200°F. Space is provided in the detector carrier, inside the oven, for mounting up to three experimental detector-and-cable assemblies for simultaneous testing at the selected temperature. Thirty-six strip heaters are selectively energized and controlled to provide the required heat to the oven. Thirty thermocouples monitor temperatures for control and evaluation purposes.

The heater and thermocouple leads and the experimental-detector cables pass upward through the NITF assembly to an area outside but near the top of the J-2 thimble, just below the removable floor plates of the operating floor in the reactor building. Connection boxes for the heater and thermocouple leads are mounted in this area, on top of the NITF assembly, and some space is available for mounting such small equipment as preamplifiers or other cable terminations for the experimental detectors. The instrument-and-control

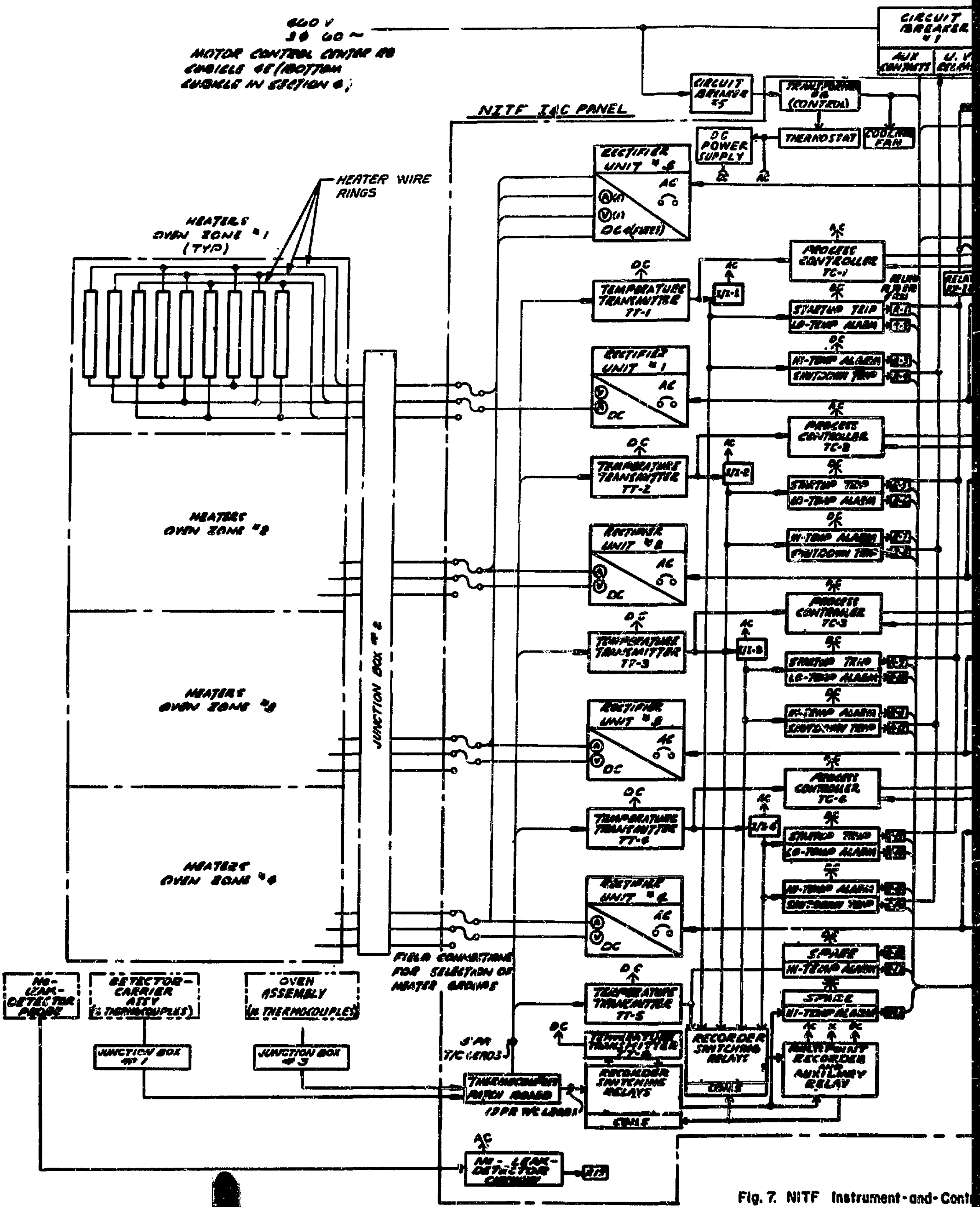
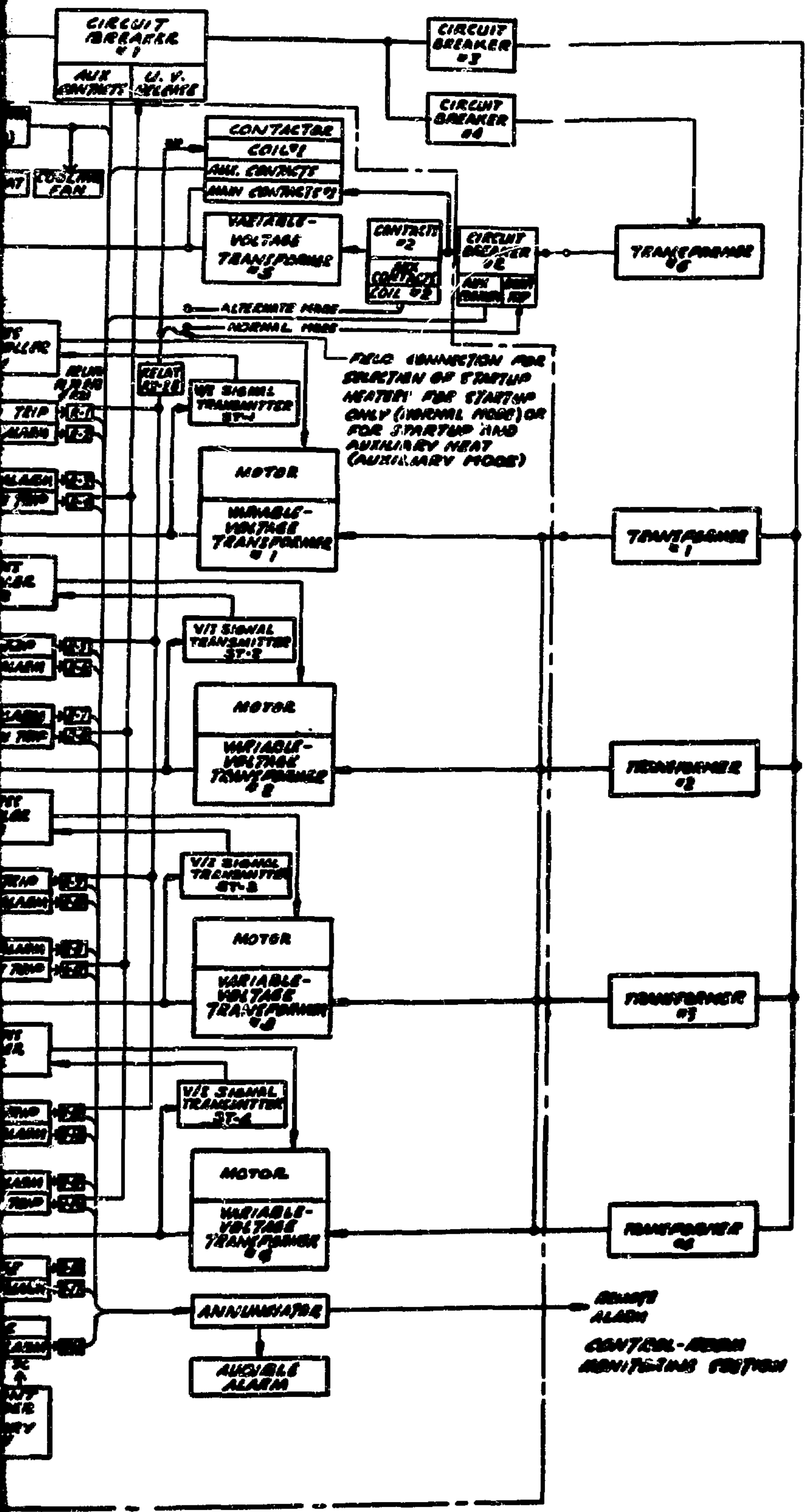


Fig. 7. NITF Instrument-and-Cont



...trument-and-Control System

panel (I & C panel) is installed in the test instrument room (TIR) on the mezzanine platform of the reactor building, and limited space is also available in the TIR for other instrumentation equipment required by the experimenter. The transformers for heater power are installed in the basement, almost directly beneath the TIR.

All instruments and controls required for routine operation and monitoring of the facility are in readily accessible positions on the front of the I & C panel, and appropriate alarm signals are transmitted to the EBR-II control room. Provision is included for recording temperature signals from any 24 of the 30 thermocouples installed in the facility. All other equipment required for calibration, alignment, and startup is within and accessible from the front of the panel. All heaters and thermocouples, the transformers in the basement, and the power source are connected to this panel. Terminal-board connections provide for selection of heaters for the different operating and spare functions, and a patchboard permits selection of the thermocouples for the control, monitoring, and spare functions.

1. <u>Oven Heating</u>

Nine strip heaters are in each of the four oven zones. They are installed vertically around the outer circumference of the oven. Each of the 36 heaters is 1 in. wide x 56 in. long and has a 55-in.-long heated length. Each is conservatively rated for this application at 10 W/in., or 550 W total, with 250-V dc applied. The nine heaters in each zone are equally spaced at 40° intervals around the oven and are electrically divided into three identical groups, with every third heater connected in parallel to form a group. The three heaters of any one group are thus spaced at 120° intervals, thereby providing even heat distribution by any group to the corresponding oven zone. One three-heater group per zone is designated as normal heaters and maintains the desired oven temperature for normal operating conditions. The second group per zone is designated startup heaters and can be energized along with the normal heaters for a more rapid heatup or for additional heat if required during normal operations. The third group of heaters per zone is an installed spare not connected to a power supply. Each group of normal heaters is controlled as a single unit rated at 1650 W with 250-V dc applied. All startup heaters are controlled as a single unit rated at 6.6 kW with 250-V dc applied.

The upper terminals of a group of three heaters are at the same elevation and are connected electrically together by wires in the annular gap just outside the canned thermal insulation. The upper terminals of the remaining two groups in a zone are similarly connected, making a total of up to three wire ring segments (see Fig. 7) at the same elevation. The lower terminals of the three groups are connected in a like manner. Individual lead wires are also connected to each terminal of one heater per group, and these 24 wires (six per zone) extend upward just inside the oven cover. The wires then pass through two of the four 1-in. spiral conduits located at 90° intervals in the shield plug, out of the J-2 thimble, and to one of the two fixed connection boxes mounted on the NITF assembly.

A high-temperature, radiation-resistant insulated wire is used for the strip-heater wiring circuits. The wire is constructed of nickel-clad copper strands, reinforced mica insulation, and a coated glass braid. The wire is rated for 600-V ac, a maximum conductor temperature of 1200°F, and a total radiation dosage of 10^{12} R with negligible change in electrical properties. The wire is No. 12 AWG, has a 0.121-in. finished OD, and is rated at approximately 14 A continuous after being derated according to the manufacturer's recommendations for an ambient temperature of 800°F, and again being derated to about half the rating for a single conductor in free air to allow for 12 current-carrying conductors in a conduit. The wire is brazed directly to the heater terminals with a high-temperature gold-nickel braze. An additional 0.050-in.-thick wrap of quartz-fabric insulation is provided over the wiring.

The use of normal heaters only for steady-state operation is the normal mode of operation. The use of both normal and startup heaters for steady-state operation is an alternate mode of operation. In the alternate mode of operation, the startup heaters remain energized at full or at a reduced power level, as required, to provide auxiliary heat.

The heater groups within a zone can be interchanged as to function (normal, startup, or spare) at the I&C panel to permit startup and normal operation with any one group out of service in each zone or, for the normal mode only and at the expense of longer startup time, with any two groups out of service in each zone. Only the normal mode of operation is expected to be used; the alternate mode is provided as a contingency for the unlikely possibility that the heat requirements should prove to be grossly higher than the calculations indicate and that more than 6.6 kW are required to sustain heat losses from the oven. The total flexibility provided would also permit startup and continued operation, possibly with somewhat unbalanced heat distribution, with some individual heaters out of service in every group.

2. Temperature Monitoring

Of the total of 30 thermocouples installed, 14 are around the outside of the oven, and 16 are in the shield-plug and detector-carrier assembly. Each thermocouple is assembled with 0.02-in.-OD Chromel-Alumel wires in a compacted magnesium-oxide insulation, has an insulated (ungrounded) junction, and is protected by a 1/8-in.-OD stainless steel sheath over its entire length. Each was manufactured and tested to specifications based on RDT Standard C 7-6T as modified for this application and was factory-calibrated at 212, 450, 787, 1000, and 1350°F.

One thermocouple is below the insulation at the bottom of the oven. Another 13 thermocouples, also in the oven assembly and located at various elevations in each quadrant around the outside of the oven insulation, measure representative temperatures for evaluation of insulation effectiveness. The leads of these 14 thermocouples extend upward in the annular air gap just outside the insulation, through two of the four 1-in. spiral conduits in the shield plug, out of the J-2 thimble, and to one of the two fixed connection boxes mounted on the NITF assembly. The thermocouple leads are routed out of the assembly in the same manner as the heater leads, but through different conduits and terminating in different connection boxes.

Small conduits are provided for protecting the 16 thermocouples in the detector-carrier assembly. Seven of these thermocouples are located to measure temperatures near the top, center, and bottom of each experimental detector. Another seven are located at various elevations to measure representative temperatures of the detector cables, and the remaining two are in the cooling-air plenum. The leads of these 16 thermocouples extend upward through two offset conduits in the shield plug, out of the J-2 thimble, and to a connection box mounted on the shield-plug and detector-carrier assembly.

A patchboard in the I & C panel permits selection of the thermocouples for monitoring and control, and signals from the selected thermocouples are connected through appropriate signal conditioning to the control, alarm, and recording circuits. Four thermocouples in the shield-plug and detector-carrier assembly, one representative of the temperature for each zone, are selected for temperature control and for operation of abnormal-temperature alarms. One thermocouple in the air plenum is selected for operation of a high-temperature alarm to indicate loss of cooling air. Provision is included for recording the temperature signals from these five thermocouples and any other 19 of the 30 installed thermocouples. The records can be used for evaluating temperature distribution throughout the oven, effectiveness of the oven insulation, and temperature reduction in the cooling-air plenum.

No thermocouples are specifically designated as installed spares, but a more-than-adequate supply is distributed throughout the NITF assembly. Some thermocouple failures are expected, but temperature distribution should remain essentially constant, and fewer thermocouples will be required after the initial data recording and evaluation. The design of the NITF lends itself to replacement of thermocouples if necessary.

3. Temperature Control

Electrical power for the facility is obtained from a 480-V, three-phase source, through a 30-A circuit breaker in position 4E of motor control center R3. One 3-kVa transformer for each of the four groups of normal heaters and one 9-kVa transformer for all four groups of startup heaters convert the 480 V to 208 V. Taps on each transformer provide adjustment for voltage drop in the system. These transformers also provide appropriate electrical isolation for operation of the system with either grounded or ungrounded heater circuits.

One motor-operated, three-phase, variable-voltage autotransformer (VVT) for each group of normal heaters automatically modulates the ac voltage from its associated 3-kVa isolating transformer, as commanded by the temperature controller for that zone, and supplies this controlled voltage to a dc power supply. The VVT also sends a feedback signal indicative of its tap position to the controller. Each of these four VVT's is rated for 240-V service and for 13 A with a constant-impedance load and has an adjustable upper-limit switch in the motor circuit to limit the output voltage.

A similar VVT, but manually operated and rated for 28 A, and a three-pole double-throw contactor rated for 50 A control the voltage from the 9-kVa isolating transformer to a dc power supply for the startup heaters. During startup, the contactor allows the VVT to be bypassed so the full 208 V is applied to the power supply. During steady-state operation, the contactor disconnects the voltage from the power supply or, for the alternate mode, reduces this voltage to a level determined by a front-panel adjustment calibrated in percent. The position of a jumper wire at the terminal boards in the panel determines the mode of operation.

For each group of normal heaters, one three-phase, full-wave, 208-V ac to 250-V dc power supply, rated for 10 A dc, converts the controlled ac voltage from the associated VVT to a dc voltage for application to the heaters. A similar power supply, but with four individual outputs each rated for 10 A, converts the voltage to dc for application to the startup heaters. Each power supply includes three-phase, full-wave bridge rectifiers for low waveform distortion, and filtering is provided to hold ac ripple within 625 mV (for a balanced input) for a low-noise output. The rectifier bridges are assembled with silicon diodes rated for 900 PIV (peak inverse voltage) or higher for dependability. Fuses and circuit breakers are included for isolating and protecting individual circuits. Front-panel voltmeters and ammeters are included for the output circuit to each heater group.

The described method of power conversion and control was chosen to provide heater power with a minimum of electrical noise in the area of the experimental neutron detectors and cables. These items, as sources of high-impedance signals, are very susceptible to electrical noise. Investigations into solid-state and other methods of power control, which would require less maintenance, indicated that such methods would not satisfy the requirement for low noise.

Each of the four motor-operated VVT's is individually controlled by a three-mode (proportional, reset, and rate) temperature controller that also includes a sensitivity adjustment. The proportional band, reset action, rate action, and sensitivity are each adjustable to permit matching the controller with the dynamic characteristics of the system. Complete closed-loop control is provided: a selected thermocouple in each oven zone provides the temperature signal, and the

VVT provides a signal corresponding to tap position. Each controller has an adjustable setpoint calibrated from 500 to 1500°F and provides indication of deviation of temperature from setpoint and of VVT tap position in percent of full travel.

The proportional action of the controllers will provide narrow-band control and will result in longer heater life than would on-off control. Reset action will provide near-zero offset of actual temperature from setpoint and should also easily compensate for any variations in supply voltage. (Automatic regulation of line voltage is not included in this system.)

The sensitivity adjustment will permit optimization of the frequency of VVT operation in relation to temperature deviation from setpoint; the optimum relationship will be established during actual operation. For this application, which is almost constant load, the oven temperature is expected to be held within ±20°F of setpoint, and only moderate wear and required maintenance of the VVT's is anticipated.

The same thermocouple signals supplied to the controllers are also applied to monitor switches for control of the startup heaters, zone abnormal-temperature alarms, and shutdown circuits. A signal from one of the thermocouples in the air plenum is applied to another monitor switch for control of a high-temperature alarm. The setpoint for tripping of each monitor switch is adjustable over the range of 500 to 1500°F. Operation of the appropriate contactor and automatic opening of a shunt-trip circuit breaker deenergizes all startup heaters for the normal mode or keeps them energized at a reduced power level for the alternate mode whenever any one zone reaches the startup trip temperature. Automatic opening of an undervoltage release circuit breaker completely deenergizes all heaters of all zones if any one zone reaches the shutdown trip temperature, which is above the high-temperature alarm setpoint but not above a safe temperature.

Each control and alarm circuit for each zone tends to act as a backup for the corresponding circuits of the other three zones, because the zones are not thermally insulated from each other and only a limited temperature differential can exist between them. Additionally, an upper-limit switch on each VVT limits the maximum power available for otherwise uncontrolled operation. The degree of inter-zone backup protection provided and the maximum temperature attainable versus maximum power available depend on the temperature-distribution and heat-loss characteristics of the oven. These characteristics were determined by out-of-reactor preoperational testing, and all setpoints and limits have been established so as to limit all temperatures to a safe value.

4. <u>Temperature Recording</u>

Signals from the five thermocouples selected for control and alarm of the oven-zone and air-plenum temperatures and from any other 19 thermocouples are routed to a multipoint stripchart recorder in the I & C panel. The recorder continuously scans the 24 points at a rate of two points per second, pauses for 15 sec per point to record any selected points, and automatically switches to recording all 24 points whenever any input exceeds a preselected limit. The recorder chart can be switched to be either stopped or running at 2 in./hr during normal operation; in either case, it will automatically switch to a speed of 20 in./hr whenever any input exceeds the preset limit. This higher speed is adequate for printing all points on the chart without overlap of point identification.

Recorder zero and span adjustments are included to permit recording of temperatures over any selected range. The recorder is at present equipped with a linear chart calibrated over 0-100% of span. Because of thermocouple nonlinearity, the record made on this chart may be in error as much as about 0.3% of span. Nonlinear charts to compensate for this error are available. They are calibrated in °F, and can be obtained for particular temperature ranges required by the experimenter. The electrical signal recorded for the air-plenum temperature is increased by the equivalent of 500°F to permit recording this lower temperature on the same chart as the other temperatures, and this 500°F difference must be taken into account when reading the chart. The air-plenum temperature can be recorded only when it is within 500°F of the low end of the selected recording range for the other temperatures.

5. <u>Alarms and Protective Devices</u>

Table I lists the alarms and protective devices of the I & C system. Individual alarms are annunciated at the I & C panel, and a common alarm is annunciated in the EBR-II control room. Power-on conditions are also individually indicated at the I & C panel for control power, heater power, startup heat, and auxiliary heat.

TABLE I. Alarms and Protective Devices

Protective Feature	Setpoint
Startup trip temperature[a]	SST[b] - 50°F
Low-temperature alarm[a]	SST - 30°F
High-temperature alarm[a]	SST + 30°F
Shutdown trip temperature[a]	SST + 50°F
VVT upper-limit switch[a]	Limits power to normal heaters to keep temperature below 1450°F
Air-plenum high-temperature alarm	Normal plenum temperature + 50°F
Sodium-leak-detector alarm	---------

[a]One for each of the four heater zones.
[b]SST = Steady-state temperature.

The temperature of the oven is automatically controlled such that the rate of temperature increase is reduced as the setpoint temperature is approached, alarms alert operating personnel to the existence of any abnormal temperatures, and the system is automatically shut down before dangerously high temperatures can be reached. Each control and alarm circuit is designed to operate in as fail-safe a manner as practical for the most probable circuit failures, including loss of power and open thermocouple circuits. Circuit protection is provided by circuit breakers and fuses where required. Some redundancy of the control for each zone temperature is provided, supplemented by the effect of all other zone temperatures upon the controls for any one zone. Maximum temperatures attainable are further limited by the maximum power available to the heaters. The limit switches on the VVT's are set to limit maximum temperatures to safe values.

In addition to the protective circuitry built into the instrument and control system, the NITF is operated in accordance with well-defined operating procedures to ensure operation in a safe and reliable manner without risk to the facility, the experimental nuclear detectors, or the EBR-II reactor plant and personnel.

III. SAFETY REVIEW

The following NITF Review is divided into three parts: (1) modification of the J-2 thimble, (2) operation of the facility at high temperature, and (3) removal and handling of activated instruments and equipment. In addition to the requirement for personnel safety, it is imperative that the reactor plant not be endangered or its operation affected. Since the J-2 thimble is outside the reactor vessel, no credible nuclear hazard has been postulated from any failure in the NITF. Safeguards concerned with the installation and handling of gamma sources have not been considered in this report, since sources will not be initially used in the facility. An appropriate analysis will be made before they are used.

The installation is considered safe because (1) the three outer stainless steel boundaries remain intact for the most credible accident of uncontrolled heating, (2) an argon blanket exists between the two outer boundaries in case of sodium leakage through the outer boundary, (3) a sodium-leak detector in the argon space at the bottom of the facility will detect any leakage of sodium through the outer boundary (no sodium leakage has occurred in any of the J or O thimbles to date), and (4) multiple alarms and protective devices will prevent an uncontrolled heating condition. Alarms alert operations personnel locally and in the control room of abnormal conditions, and protective devices either limit heater power or deenergize heaters. There is no known reason to question the integrity of the existing 15-in.-OD x 3/8-in.-thick wall of the J-2 thimble or any other instrument thimble. The NITF will be as safe, from a containment standpoint, as the existing thimble installations.

A. Modification of the J-2 Thimble

In the NITF, there are two containment boundaries between the sodium and the heater region: the 3/8-in. wall of the J-2 thimble, which is immersed in sodium, and the 1/8-in. wall of the oven cover. The space between these boundaries is filled with argon as a safety feature in case of sodium leakage through the wall of the thimble. There are three boundaries between the sodium and the nuclear-detector test space:

the two mentioned above and the 7-1/2-in.-OD by 1/4-in.-wall oven pipe. The oven pipe, although machined with flats and grooves to fit the strip heaters and source tubes, is a leak-tight boundary up to the bottom of the shield annulus, where there is a bolted and gasketed flanged joint and where the four conduits for the thermocouple leads and heater wires vent the heater space.

Leakage of any magnitude through the outer boundary (the wall of the thimble) will be reason to terminate use of the NITF and will require sealing it off at the top. The leak detector in the bottom of the thimble will cause an alarm.

The upper section of the flange and insert-tube assembly was welded in position, and the ~1-1/4-in. annulus outside the 15-in.-OD insert tube was filled to a depth of about 4 ft with 1/8-in.-dia steel balls. Concrete was removed from this space during the removal of the internals of the J-2 thimble. Although steel is only a fair absorber of neutrons, it is a moderately good scatterer. Consequently, neutrons will scatter into the concrete regions surrounding the steel balls, and the neutron beam will be effectively absorbed.

B. Operation at High Temperature

1. Uncontrolled Heating

Heat-transfer studies have been made to determine maximum temperature within the oven assembly: (a) in the highly unlikely event that the startup-heater on-off controls or the normal heater proportional controls, or both, fail in an unsafe condition; and (b) in an even more unlikely triple failure, when the failures given in (a) occur followed by failure of the automatic high-temperature protective trips to de-energize the heaters and failure of either the alarm circuits or of the plant operators to take corrective action in response to the alarm signals. Each control and alarm circuit is designed with the reliability of solid-state circuitry to operate in a fail-safe manner. Circuit protection is provided by fuses and circuit breakers. An open thermocouple will result in a high-temperature condition that will alarm and shut down the system. A grounded thermocouple will result in a noisy circuit and less accurate indication, but the system will remain operable. A shorted thermocouple may result in a low-temperature alarm if the short is outside the oven. The temperature indication will tend to be an average between the temperature at the short and at the thermocouple. An open heater will remain deenergized, and more power will be supplied to the two other heaters in a normal bank. If any of the heaters are shorted, circuit breakers will open to remove the power supply. All control relays are set up so that, on loss of power, an abnormal temperature condition is indicated, which will sound an alarm or shut down the system. System design, protective circuitry, and well-defined operating procedures will ensure facility operation in a safe and reliable manner.

Only the first condition listed in Table II, Case A, which could be caused by a single failure, is considered a credible (though highly unlikely) accident. All other cases identified would require either a minimum of three component failures or a minimum of two component failures and a failure of the plant operator to heed alarms; therefore, these cases are considered incredible.

Case A is considered highly unlikely, because application of uncontrolled heat caused by a single fault could occur only if the fault affected the control signal to the controller and each of the four trip units of a single zone control. Further, for the fault condition to continue and not actuate an alarm, the fault would have to maintain the control signal at an incorrect (low-temperature) value between the rather close limits of a correct signal and low-temperature alarm setpoint signal. The upper-limit switch of the variable transformer was set to limit the power so as to stabilize the temperature at a safe value at or below the maximum calculated temperature of 1450°F. The maximum normal operating temperature for the facility is 1200 + 20°F. The maximum test temperature used to check shutdown trips was 1250°F. The switch setpoint for 1450°F was made by extrapolation from operating data obtained below 1250°F.

TABLE II. Calculated Maximum Steady-state Temperatures for Six Postulated Conditions of Heating Failure in the NITF

Case	Failure Condition	Minimum Required Failures	Max Oven Temp, °F	Max Temp Outside Insulation, °F
A	Normal heater controls for one of four zones fail	1	1450	800
B	Normal heater controls for all zones fail	3	1730	875
C	Startup heater controls for all zones fail	3	1730	875
D	Normal and startup heater controls for one of four zones fail	4	1790	900
E	Startup heater controls for all zones and normal heater controls for one of four zones fail	4	2070	900
F	Normal and startup heater controls for all zones fail	4	2400	1010

The methods used in calculating Cases B, C, and F are described in Appendix A. Heat transfer, by both conduction and radiation, was considered in a radial direction only through 1.5 in. of insulation and one air and one argon annulus separated by stainless steel tubes. Heat transfer by convection was negligible. Experience in making these calculations was used in estimating maximum temperatures outside the insulation for the remaining cases. In Cases A, D, and E, heat transfer was considered in both radial and axial directions. Conduction was considered in a radial direction only through the 1.5 in. of insulation to the air annulus at the assumed temperature. Both conduction and radiation were considered in an axial direction. It was determined that higher temperatures would result in the lowest zone, because heat transfer through the bottom end was less than that through the upper end or to an adjacent zone. Temperatures of adjacent zones were assumed to be 1200°F for Cases A and D and 1730°F for Case E. Gamma-heating, which was not considered in this study, contributes significantly to the lower zone only. The maximum oven temperatures in Table II are upper limits.

The temperature of the outer wall of the J-2 thimble, in contact with primary sodium, will remain at approximatley 700°F for all cases. The first inner liner, the leak-tight oven cover, will not exceed a temperature of 900°F for all cases. The study shows that these two containers will remain intact and undamaged for all cases. The oven cover will contain any components that might be damaged. The second inner liner, the oven pipe, forms a third leak-tight boundary.

The Johns-Manville Min-K insulation used in the facility is rated for 1800°F. The Watlow Firebar strip heaters should be capable of continuous operation for one year or more at a temperature of 1200°F, and should be capable of operation at the conditions of Case A for a considerable length of time. No component of the NITF will be damaged for this case.

Cases B and F cannot occur from any single failure, because the normal heaters have completely separate controls for each zone. Case C can begin but cannot continue, because the high-temperature trip for any one zone will completely deenergize all heaters (startup and normal) for all zones. Case D could occur,and Case E could occur during startup, as a result of failure of a temperature transmitter. However, both of these cases would become Case A before the setpoint temperature is reached, because the startup-heater circuit would open to deenergize all startup heaters when the temperature of any other zone reached the setpoint of the startup trip unit. Setpoints of the startup trip units for each zone will be adjusted independently, and each will be set well below normal operating temperature. Therefore, a trip in any one zone will remove startup-heater power from all zones before an excessive temperature is reached in any zone.

2. Thermal Insulation

The Johns-Manville Min-K insulation used in the NITF is considered to be the best material available for this application. The insulation has a low neutron-absorption coefficient, and Johns-Manville is currently advertising it for application to nuclear-reactor vessels. The insulation cans are vented to ensure that no internal pressure will build up from outgassing of the insulation. The oven cover, which would collect any of the gas,is vented,through the conduits for the thermocouple and electrical leads,to the suspect exhaust system.

The detailed composition of the Johns-Manville Min-K insulation is proprietary; however, the following approximate composition is specified:

SiO_2	84%
TiO_2	16%

Small amount of asbestos fiber

Impurities

Moisture	1-1/2 to 2 wt %
Sulfur	0.01 wt %
Chloride	0.01 wt % (about half comes from the asbestos fiber)
Teflon	Trace

Before the NITF was installed in the J-2 thimble, the Min-K insulation was outgassed during out-of-reactor heating and testing of the oven and insulation assembly. The heat drove out small quantities of moisture and vaporized a Teflon film applied to the quartz thread for quilting the fabric and insulation core together. During the test, the entire NITF assembly was covered with a standard pipe insulation, and normal operating temperatures existed within the oven and insulating assembly.

Min-K insulations have been tested under both gamma and neutron irradiation by General Electric Co., Knowles Atomic Power Laboratory. The irradiation did not harm the insulation and had a negligible effect on thermal conductivity and mass. Radiation fields for these tests were 3×10^6 R/hr gamma and 3.6×10^{12} nv neutrons. The tests were conducted in the Brookhaven reactor for a period of 60 days, and the total dose and fluence were 10^{10} R and 1.5×10^{19} nvt. Results were reported in Refs. 5, 6, and 7.

3. Shielding

The size of the three outlet conduits for the detector cables being tested is 2 in. OD x 1.938 in. ID. This is the maximum size conduit that can be accommodated in the shield plug and still allow an adequate offset in the conduits to minimize radiation streaming. A mockup shield plug was installed in the J-2 thimble before it was modified. The mockup plug had three conduits penetrating the shielding. Two conduits were offset one diameter, and one was straight. The straight conduit was filled with a solid steel plug. During operation at 50 MWt, the conduit offset was shown to be satisfactory in reducing radiation streaming to 30 mR/hr or less at contact. Removal of the plug in the straight conduit resulted in a radiation field of 3 R/hr. Operation of the reactor at 62.5 MWt will result in still higher radiation fields; an estimated 38 mR/hr at the offset conduit and an estimated 3.8 R/hr for the straight conduit. However, the top of the thimble is 2 ft below the operating floor, and the cable outlet conduits will be partially filled with detector-cable materials. Any conduits not in use will be plugged. The area will be closely monitored during initial and high-power operation at 62.5 MWt. If necessary, auxiliary shielding will be installed over the thimble to bring the radiation level down to an acceptable level at the operating-floor level.

C. Removal and Handling of Activated Detectors and Equipment

The shield-plug and detector-carrier assembly is installed into and removed from the J-2 thimble and transported between the thimble and the reactor-building storage pit with the reactor-building crane. The storage pit was modified for unloading and reloading detectors in the carrier by the installation of a shield window, grappler-tool assembly, and two manipulators.

1. Need of Shielding for Detector-carrier Assembly

The need for shielding the detector-carrier assembly when it is transported with the shield plug, by crane, from the J-2 thimble to the reactor-building storage pit has been investigated. Shielding calculations show that activation of the 6-5/8-in.-dia, 7-ft-long assembly to a saturation level will result in a gamma field of 15 R/hr measured at a distance of 1 ft, 3-1/2 ft from one end. Therefore, shielding of the assembly for personnel protection will not be required. Personnel will be able to use distance to prevent over-exposure. It is always normal practice to have full-time coverage of qualified Health Physics personnel during this type of operation. This coverage will ensure adequate protection.

Handling procedures will be similar to EBR-II Standard Maintenance Procedure STM 10-68, Rev. 1, for disassembly and removal of EBR-II control-rod drives. Radiation fields from the control-rod drives are more than an order of magnitude higher than those expected for the detector-carrier assembly. The drives are removed and stored without the use of any special shielding.

2. Adequacy of Shield-window Installation

The shield-window installation in the reactor-building storage pit consists of a 9-in.-thick lead-glass window mounted flush with the outside of the 3-ft-thick concrete wall. A lead plug at the right side of the window is removed to allow loading of new test instruments into an activated detector carrier.

A shielding test was conducted with a cobalt source to check the adequacy of the shield-window installation. Test results and subsequent calculations show that the gamma field in the working area at the window will be 15 mR/hr or less when the activated detector-carrier assembly is in the pit. Caution must be exercised when the shield plug is removed from the window assembly for the loading of new detectors into the carrier. A maximum radiation field of about 1 R/hr can be expected at the plug opening. Mockup testing, however, has shown that the detectors and their cables can be loaded without direct exposure of personnel.

The shield-window assembly will provide adequate protection for working on the detector-carrier assembly. However, Health Physics coverage will be required to establish allowable working conditions during the loading and unloading of the detectors.

3. Procedure for Replacing Nuclear Detectors

A special operating procedure for replacing the nuclear detectors in the detector-carrier assembly has been prepared. This procedure is shown as Appendix B of this report.

IV. SUMMARY

The installation and operation of the NITF do not endanger personnel or equipment or affect plant operation. Operation of the NITF in the J-2 thimble will not impose any unsafe or hazardous conditions over and above those of other instrument thimbles in the EBR-II.

Studies have been made to investigate the consequences of uncontrolled heating by a part or all of the oven heaters. The conclusions showed that the three oven containers would remain intact and that system components would not be damaged following the worst credible, though highly unlikely, accident. The worst credible accident is considered to be a condition of uncontrolled heating where normal heater controls for one of four heater zones fails to shut off when it should.

A special facility for handling the radioactive detectors and equipment was installed in the reactor-building storage pit. A shield window, two manipulators, and a grappler tool are now operational. Mockup testing has demonstrated that nuclear detectors can be removed from and loaded into the detector carrier from outside the storage-pit shield window.

APPENDIX A

Heat-transfer Calculations for Normal Operation of the NITF

A first approximation of the temperature gradient across the assembly was made by setting up conduction equations and assuming that the heat transfer by radiation is a certain ratio of that transferred by conduction. Several trial approximate calculations gave an indication of that ratio, which depends primarily on the thickness of the annulus and the temperatures of the walls. This method was used because several equations containing the radiation transfer term $(T_1^4 - T_2^4)$ are not easily solved.

The maximum values of the Grashof Number, $Gr = \rho^2 g\beta(T-T_\infty)L^3/\mu^2$, are less than 500 for both the air annulus and the argon annulus. Hence, no heat flows by free convection. Kreith[8] indicates that, for Grashof numbers less than 8000, there is no heat transfer by convection in vertical enclosed air spaces. The physical properties of argon are similar enough to air to also conclude that there will be no heat transfer by convection in the argon space. The temperature gradient across the metal boundaries is only a fraction of a degree. Therefore, a constant temperature was assumed through each of the metal walls. It was also assumed that the boundary walls are flat plates and that the outer thimble wall is isothermal at 700°F. The strip-heater region and the inner insulation boundary were assumed isothermal at 1250°F to provide a 1200°F oven temperature.

The conduction equations for the approximate calculations were:

Min-K Insulation

$$q = (KA/t)\,(T_1 - T_2)$$

$$= 0.544\,(1250 - T_2) \text{ when}$$

$K = 0.0258$ Btu/hr-ft-°F,

$A = 2.63\ ft^2$,

$t = 0.125$ ft, and

$T_1 = 1250$°F.

Air Annulus

$$q_T = (KA/t)\ (T_2 - T_3)$$

$$= 12.670\ (T_2 - T_3) \quad \text{when}$$

qr (the heat transferred by radiation) = $6q_K$ (the heat transferred by conduction),

$q_T = q + 324$ Btu/hr-ft,

K = 0.0282 Btu/hr-ft-°F,

A = 3.21 ft^2, and

t = 0.050 ft.

Argon Annulus

$$q_T = (KA/t)(T_3 - T_4)$$

$$= 8.433\ (T_3 - 700) \quad \text{when}$$

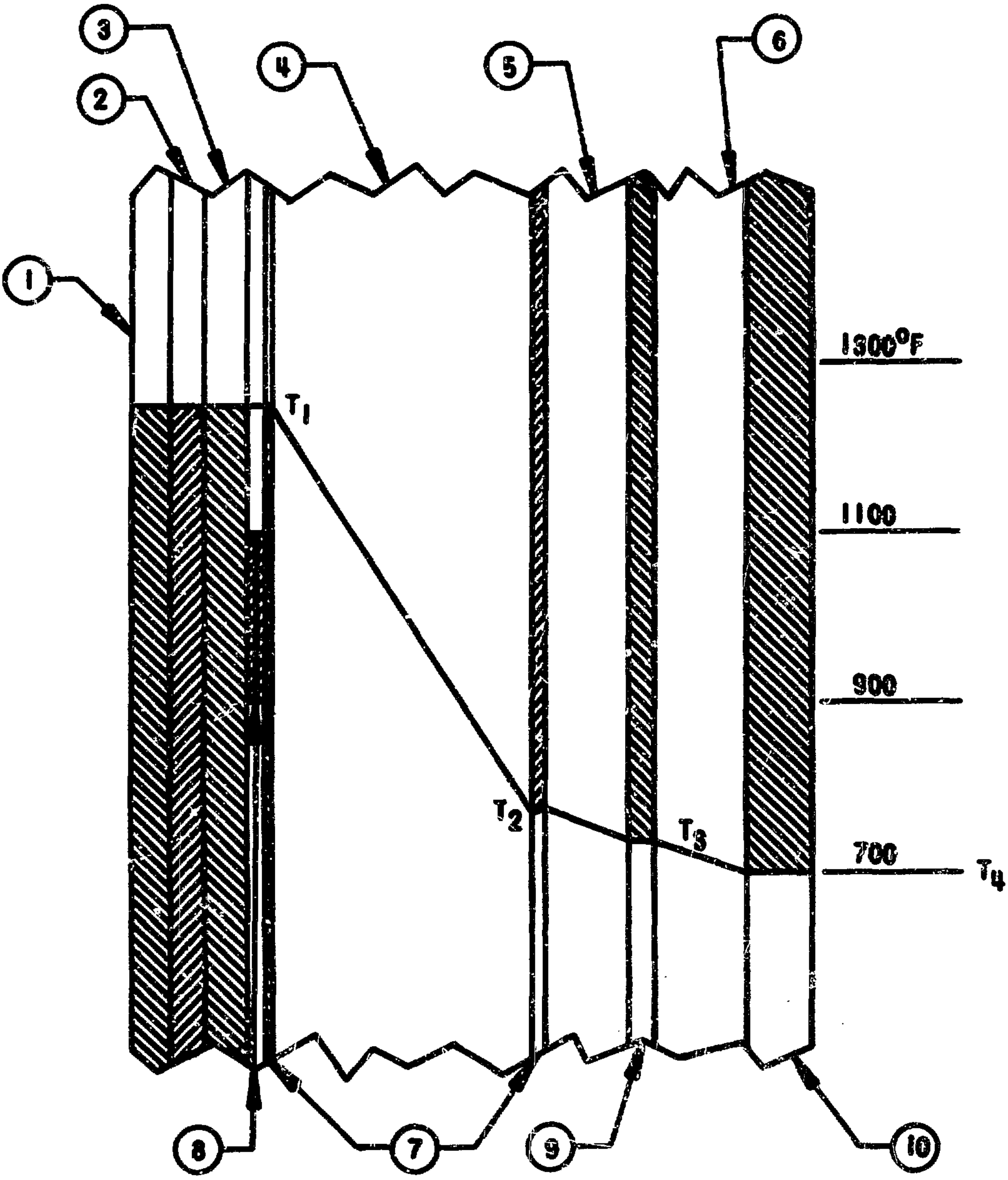
$q_r = 5q_K$,

K = 0.0190 Btu/hr-ft-°F,

A = 3.60 ft^2, and

t = 0.047 ft.

The temperatures $T_1 - T_4$ are defined in Fig. 8. The quantity q is the heat transferred, per foot of oven length, through the Min-K insulation. The quantity 324 Btu/hr-ft is the heat transferred through the insulation can, heater terminals, insulation gaps, etc. This heat loss is assumed to be distributed uniformly along the length of the oven.



1. OVEN TUBE
2. STRIP HEATER
3. SPACER
4. INSULATION
5. AIR ANNULUS
6. ARGON ANNULUS
7. INSULATION CANNING
8. HEATER CLAMPING BAND
9. OVEN COVER
10. J-2 THIMBLE

SCALE: APPROXIMATE

Fig. 8. Radial Temperature Gradient across the NITF

Solution of the above three equations gave approximate results. A more rigorous (exact) analysis was then made of the gas annuli, using the previously calculated approximate results. If no heat is transferred by convection, the total heat transferred in the argon annulus is

$$q_T = q_K + q_r = (KA/t)\ (T_3 - T_4) + \sigma FA\ (T_3^{\ 4} - T_4^{\ 4})$$

where σ = Boltzmann constant = 0.173×10^{-8} Btu/hr-ft^2-°R;

F = Geometrical factor = $1/\ (\frac{1}{\varepsilon_1} + \frac{1}{\varepsilon_2} - 1)$, and

ε = emissivity.

Solving for $T_3 - T_4$,

$$T_3 - T_4 = (t/KA)\ [q_T - \sigma FA\ (T_3^{\ 4} - T_4^{\ 4})].$$

This equation requires a trial-and-error solution. Data for first and second trial solutions are presented in Table III. The second trial solutions indicate convergence and no further need for iteration.

The effect of using a higher value of emissivity for the stainless steel surfaces was considered. A value of 0.5 was used for the initial calculations. This value is representative of the steel as fabricated and is approximately half way between the values for stainless steel that has been buffed and polished (0.2 at 1000°F) and stainless steel that is fully oxidized (0.85 at 1000°F). Use of an emissivity value of 0.75 increases heat transferred approximately 3% and thus slightly lowers the temperatures outside the insulation assembly. Therefore, long-term oxidation of stainless steel surfaces should have little effect on the total heat loss and the power requirements of the oven.

TABLE III. Heat Losses from NITF Oven

	First Trial Solution		Second Trial Solution		Second Trial Exact Solution with Higher ε
	Approx.	Exact	Approx.	Exact	
q, Btu/hr-ft	252	252	257	257	274
q_T, Btu/hr-ft	576	576	581	581	598
Input, kW	3.38	3.38	3.40	3.40	3.51
T_2, °F	787	776	778	779	747
T_3, °F	741	738	739	739	723
ε	-	0.5	-	0.5	0.75

Figure 8, based on the results of the above analysis, shows the temperature gradient from the oven to the primary-tank bulk sodium.

APPENDIX B

Special Operating Procedure for Replacing Nuclear Detectors in the NITF

1. PURPOSE

The purpose of this procedure is to provide the detailed procedures and instructions required for the initial installation and removal of experimental nuclear detectors to be tested in the NITF. This preliminary procedure and the first operating experience will be used in formulating an operating procedure for the system.

2. SUPPLEMENTARY PROCEDURES

2.1 Tagging procedure

2.2 Safe Work Permit

2.3 ANL Supervisor's Safety Manual

2.4 Electrical Safety Procedure SA-3-69

3. DESCRIPTION

When irradiation testing has been completed on one or more nuclear detectors, they will be removed and new detector experiments will be installed in the detector carrier in the reactor-building storage pit. The reactor-building storage pit has been modified for this reloading by the installation of a shield window and grappler-tool assembly and two Central Research Laboratory Model D manipulators. Operators will accomplish the detector change remotely by using the two manipulators and the grappler tool in the shield-window assembly. New experiments will be loaded into the detector carrier through an opening from which a plug has been removed in the shield window and by using the remote-handling equipment.

4. SAFETY REQUIREMENTS

4.1 Health Physics

4.1.1 Health Physics shall provide exclusion areas as required at the J-2 thimble and reactor-building storage pit on the operating floor and advise workmen entering the areas as to the requirements for limiting exposure and the spread of contamination. Floor covering and protective shoe covers may be required to prevent possible spread of contamination. Only workmen equipped with proper safety equipment (this may include "supplied air" or respirator equipment) will be permitted in the work area.

4.1.2 Caution shall be exercised when the shield plug is removed for access through the shield-window assembly. Health Physics shall provide an exclusion area as required at the shield window and advise workmen as to the requirements for limiting exposure.

4.1.3 Cumulative radiation doses for individuals shall not exceed the calendar-quarter dose guidelines established by the Federal Radiation Council, by AEC Manual Chapter 0524 and Appendix 0524 (Standards for Radiation Protection), and by the applicable radiation dose control guidelines established by the Idaho Facilities Health Physics Section.

4.2 Industrial Safety

4.2.1 Safe Work Permits will be required.

4.2.2 All rigging shall be inspected and approved by the Safety Engineer.

4.2.3 Normal safety practices, as required by supplementary procedures of Section 2, shall be followed.

4.2.4 Use of standard industrial type clothing including hard hats, gloves, safety shoes, safety glasses, "supplied air" or respirators, etc. will be required.

5. PREREQUISITES

5.1 The NITF instrumentation and control system shall be de-energized, and CB1 and CB5 red-tagged open.

5.2 The thermocouple extension cables (Nos. 15 through 30) from the detector carrier shall be disconnected at the connection box on top of the J-2 thimble. This connection box will be removed with the shield plug and the carrier.

5.3 Nuclear-instrument cables and cooling-air tubing shall be disconnected at the top of the J-2 thimble. The NITF top flange will be unbolted.

5.4 The shield-plug and detector-carrier assembly shall be lifted from the J-2 thimble and lowered into the reactor-building storage pit. In the pit, the assembly is to be supported by the reactor-building crane, the portable gantry crane with the chain hoist, or the support structure at the top of the storage pit.

5.5 All storage-pit lighting and manipulators must be operative.

5.5 The carrier shall be locked in the lateral support bracket located at the top of the shield window by using the grappler tool or with the manipulators.

5.7 An operator shall be stationed at the top of the assem' on the operating floor, and two or more operators shall be stationed at the shield window.

5.8 Phone communications shall be established between the shield window and the top of the shield-plug and detector-carrier assembly at the operating-floor level.

5.9 New detector experiments to be tested shall be ready for loading at the storage-pit shield-window work area in the EBR-II reactor building.

6. RELOADING PROCEDURE

6.1 Unloading

6.1.1 Attach the cable-protector assembly with extension cable (drawing ID-1D-14549) to the top of the electrostatic shield of the nuclear detector that is to be removed. If more than one detector is to be removed, start at the top and work down.

6.1.2 Rotate the carrier assembly so the nuclear detector to be removed is toward the shield window. Position the carrier assembly vertically so the detector is in view and near the top of the shield window.

6.1.3 Using one or two manipulators and/or the grappler tool, manually pull on the electrostatic shield at the top of the assembly to raise the detector one or two inches as necessary to allow the bottom of the detector to swing free from the carrier. This action may only be necessary for detectors in the two top positions, since a detector in the bottom position may be removed through the side or lowered straight through the bottom of the carrier.

6.1.4 Grasp the detector with one or more of the remote-handling tools and pull it out away from the carrier and down. An operator at the top of the assembly will release the extension cable as required and may assist by pushing cables from above.

6.1.5 Set the detector on the shield-window ledge and continue to pull the flexible electrostatic-shield hose downward. The electrostatic shield shall be coiled on the window ledge. Alternate methods for handling highly radioactive detectors are as follows:

1. Allow the detector to be lowered into the storage pit as it is pulled from the shield-plug and detector-carrier assembly.

2. Firmly grip the detector with manipulators at the shield-window station and carefully lift the shield-plug and detector-carrier assembly away from the detector.

6.1.6 Lower cable into the reactor pit for removing the nuclear detector. Reach through the opening in the shield window with a pair of tongs and retrieve both cables from the remote-handling tools. Hook the cables together and then raise the nuclear detector to the operating floor. Load the detector into its shield coffin and/or handle it as required by the experimental procedure covering its testing and in accordance with instructions from Health Physics personnel.

6.2 Loading

6.2.1 Visually and with the manipulators, check the springs in the carrier. Replace damaged springs with the remote-handling equipment as necessary.

6.2.2 Lower the cable-protector assembly through the proper two-inch conduit in the shield plug. Retrieve the lower end with the remote-handling equipment and bring it out through the opening in the shield-window assembly.

6.2.3 Attach the cable-protector assembly to the electrostatic shield of the detector to be loaded. (This may be accomplished with tape or by tack-welding.)

6.2.4 Pull on the cable at the top of the shield-plug and detector-carrier assembly while feeding the detector cabling through the opening in the shield window. Continue this until the detector is one to two inches above its normal vertical position in the carrier.

6.2.5 Use the storage-pit manipulators to push the bottom end of the detector into the carrier against the spring action, and lower the detector to lock it in place.

6.3 One, two, or all three detectors can be replaced per Sections 6.1 and 6.2, above. All removal operations shall be completed before any reloading starts. When loading more than one detector, load into the lowest position in the carrier first.

7. COMPLETION OF INSTALLATION

7.1 After completing the reloading of experimental detectors, the shield-plug and detector-carrier assembly shall be reinstalled in the J-2 thimble with the reactor-building crane.

7.2 Thermocouple extension cables, cooling-air tubing, and the nuclear-instrument cables are to be connected at the top of the thimble. Further testing and checkout will be accomplished by PM No. 270C (Instrumentation and Control Section of the NITF).

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