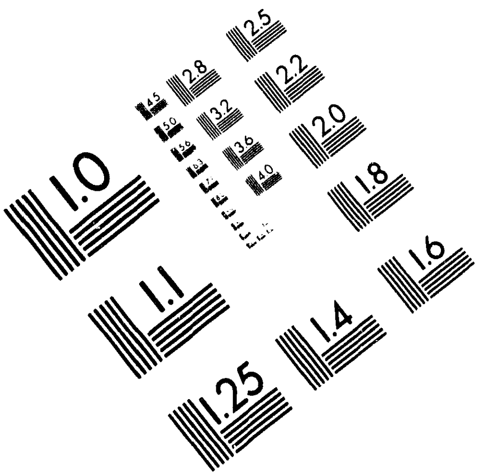

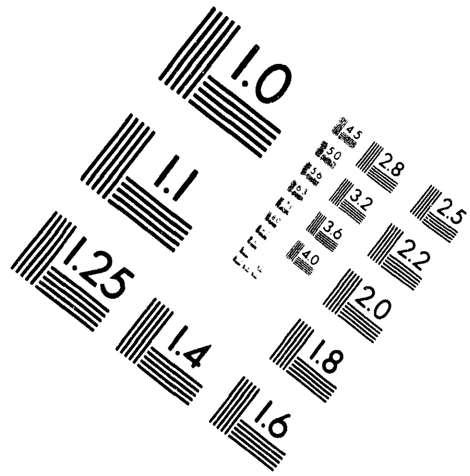

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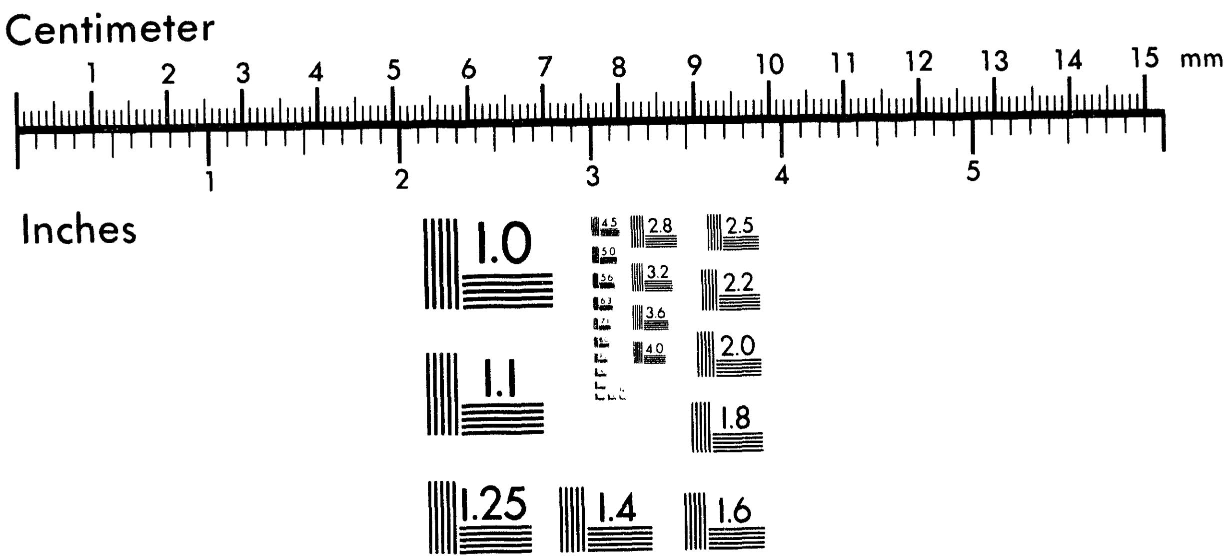

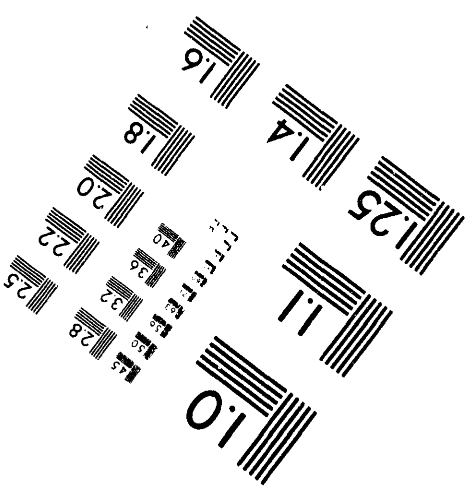

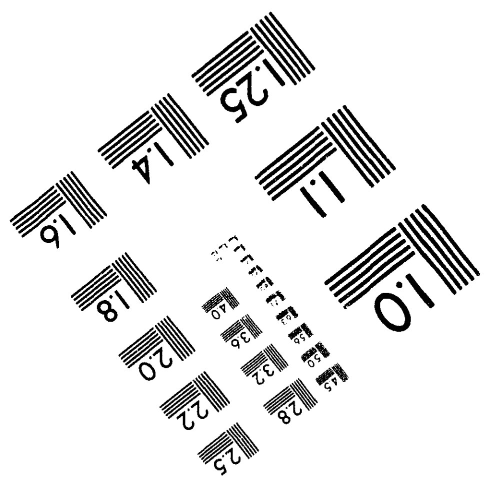

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TFE DESIGN PACKAGE FINAL REPORT TFE VERIFICATION PROGRAM

Prepared under
CONTRACT DE-AC03-86SF16298
FOR THE SAN FRANCISCO OPERATIONS OFFICE
DEPARTMENT OF ENERGY

GENERAL ATOMICS PROJECT 3450
JUNE 1994

GENERAL ATOMICS

TFE DESIGN PACKAGE
FINAL REPORT
TFE VERIFICATION PROGRAM

1. INTRODUCTION

1.1 Objective of TFE Verification Program

The program objective is to demonstrate the technology readiness of a TFE suitable for use as the basic element in a thermionic reactor with electric power output in the 0.5 to 5.0 MW(e) range, and a full-power life of 7 years. A TFE for a megawatt class system is shown on Figure 1-1. Only six cells are shown for simplicity; a megawatt class TFE would have many more cells, the exact number dependent on optimization trade studies.

1.2 Technical Approach

The TFE Verification Program built directly on the technology and data base developed in the 1960s and early 1970s in an AEC/NASA program, and in the SP-100 program conducted in 1983, 1984 and 1985. In the SP-100 program, the attractive features of thermionic power conversion technology were recognized but concern was expressed over the lack of fast reactor irradiation data. The TFE Verification Program addressed that concern.

The technical approach followed to achieve the program objective is shown on Fig. 1-2. Five prior programs form the basis for the TFE Verification Program:

1) AEC/NASA program of the 1960s and early 1970s.
1) SP-100 concept development program (Ref. 1-1).
3) SP-100 thermionic technology program (Ref. 1-2).
4) Thermionic irradiations program in TRIGA in FY-86 (Ref. 1-3).
5) Thermionic Technology Program in 1986 and 1987 (Refs. 1-4, 1-5).

These programs provided both the systems and technology expertise necessary to design and demonstrate a megawatt class TFE.

A TFE was designed that met the reliability and lifetime requirements for a 2 MW(e) conceptual reactor design. Analysis showed that this TFE could be used over the range of 0.5 to 5 megawatts. This was used as the basis for designing components for test and evaluation. The demonstration of a 7-year component lifetime capability was through the combined use of analytical models and accelerated, confirmatory tests in a fast test reactor. Iterative testing was performed where the results of one test series led to evolutionary improvements in the next test specimens.

The TFE components underwent screening and initial development testing in ex-reactor tests. Several design and materials options were considered for each component. As screening tests permitted, down selection occurred.

In parallel with ex-reactor testing, and fast reactor component testing, components were integrated into a TFE and tested in the TRIGA test reactor at GA. Realtime testing of partial

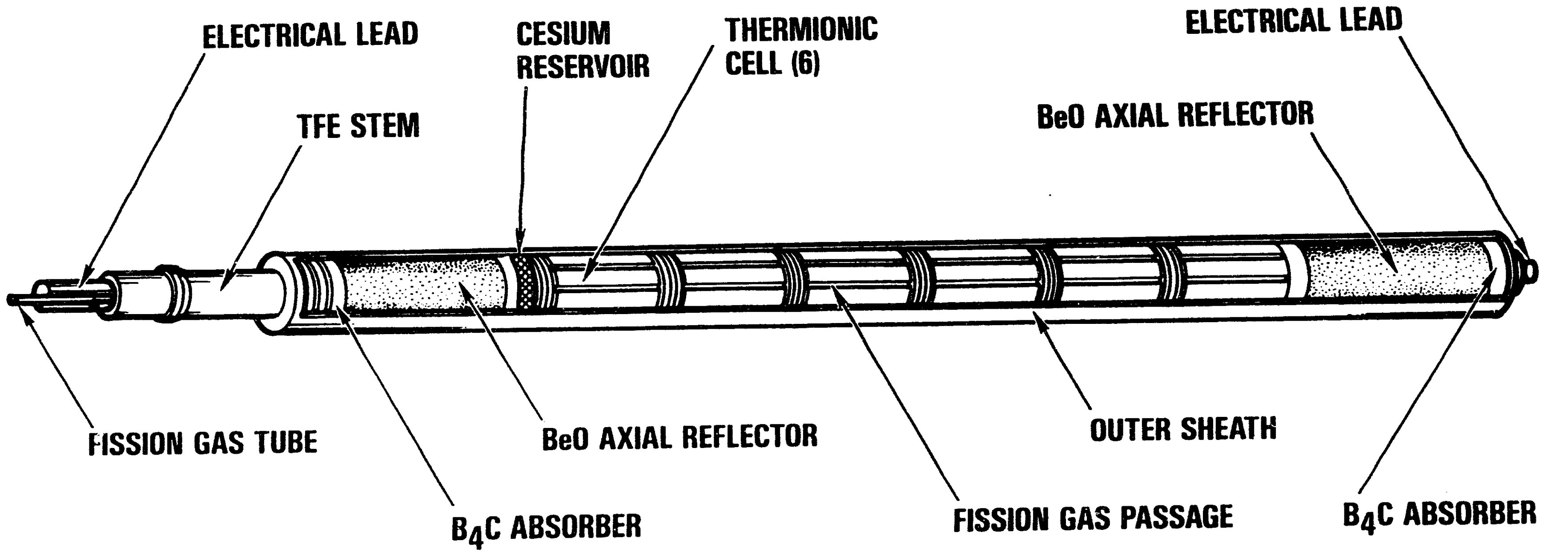


Figure 1-1. TFE for Megawatt Class System

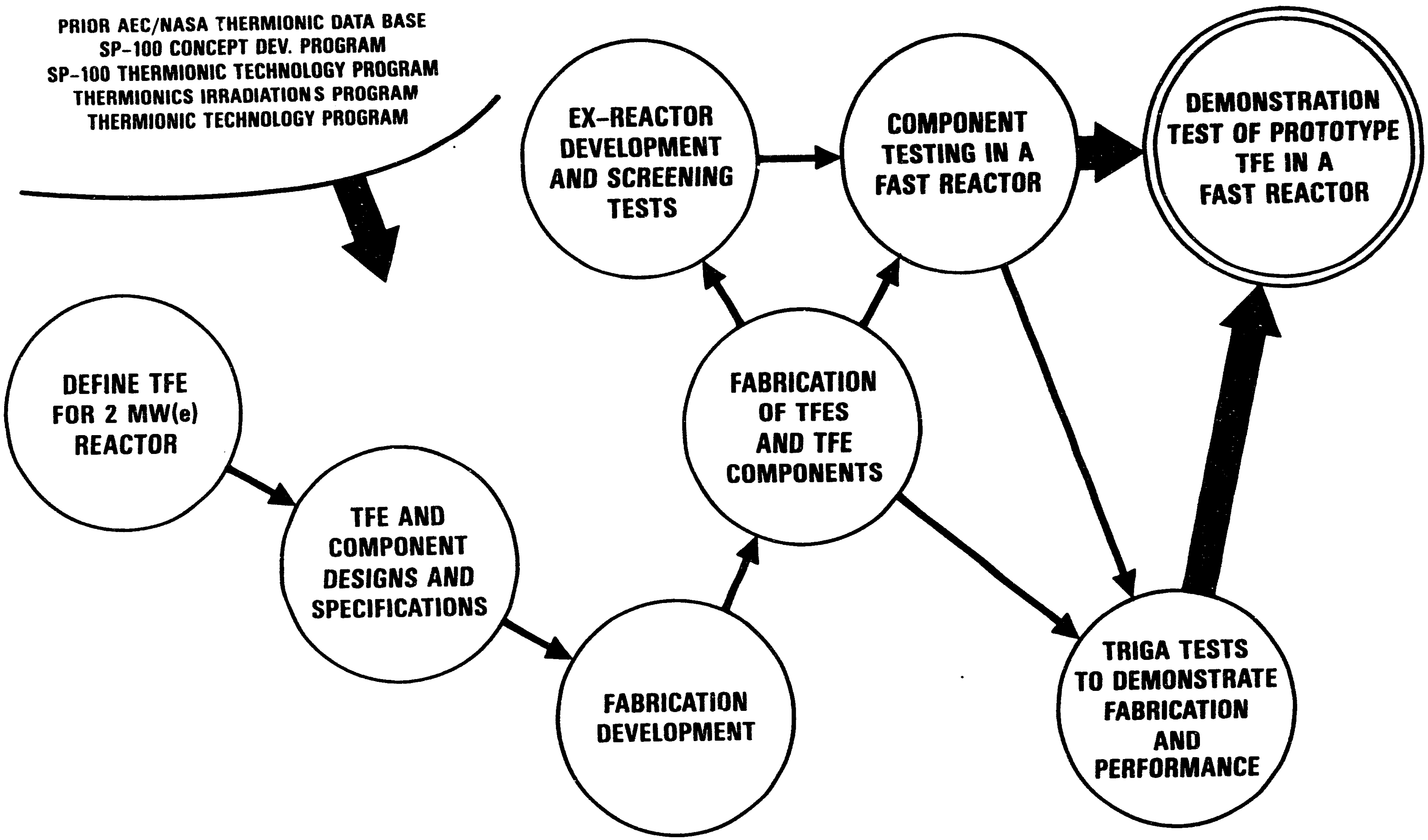


Figure 1-2. Logic to Demonstrate Technology Readiness of Megawatt Class TFE

length TFEs was used to test support, alignment and interconnective TFE components, and to verify TFE performance in-reactor with integral cesium reservoirs. Realtime testing was also used to verify the relation between TFE performance and fueled emitter swelling, to test the durability of intercell insulation, to check temperature distributions, and to verify the adequacy over time of the fission gas venting channels.

Predictions of TFE lifetime rested primarily on the accelerated component testing results, as correlated and extended to realtime by the use of analytical models.

1.3 Organization of the Program

Contracting Agency: Department of Energy, San Francisco Operations Office

Prime Contractor: General Atomics (GA)

Subcontractors:
ThermoTrex Corporation (TTC), a subsidiary of Thermo Electron Corporation
Rasor Associates, Incorporated (RAI)
Space Power Incorporated (SPI)

Fast reactor testing manager:
Westinghouse Hanford Corporation (WHC)

Fast reactor facilities:
Fast Flux Test Reactor (FFTF), with testing managed by WHC.
EBR-II, with testing managed by Argonne National Laboratory-West (ANL-W)

Technical cversight for DOE: Los Alamos National Laboratory (LANL).

1.4 Structure of Test Program

The TFE-VP was broken down into 7 tasks, generally corresponding to the components of a TFE. Figure 1-3 shows a thermionic cell with the various components identified.

Figure 1-4 shows a one cell TFE fabricated for test in the program. A multi-cell TFE has 2 or more cells in series.

When compared to Figure 1-1, it is clear that this test article is not quite prototypical. The test conditions dictate the design to some extent. Also, the test approach is to first test simple TFEs and then gradually test TFEs more prototypic.

For each component, the work involved:

1) Component design and analyses

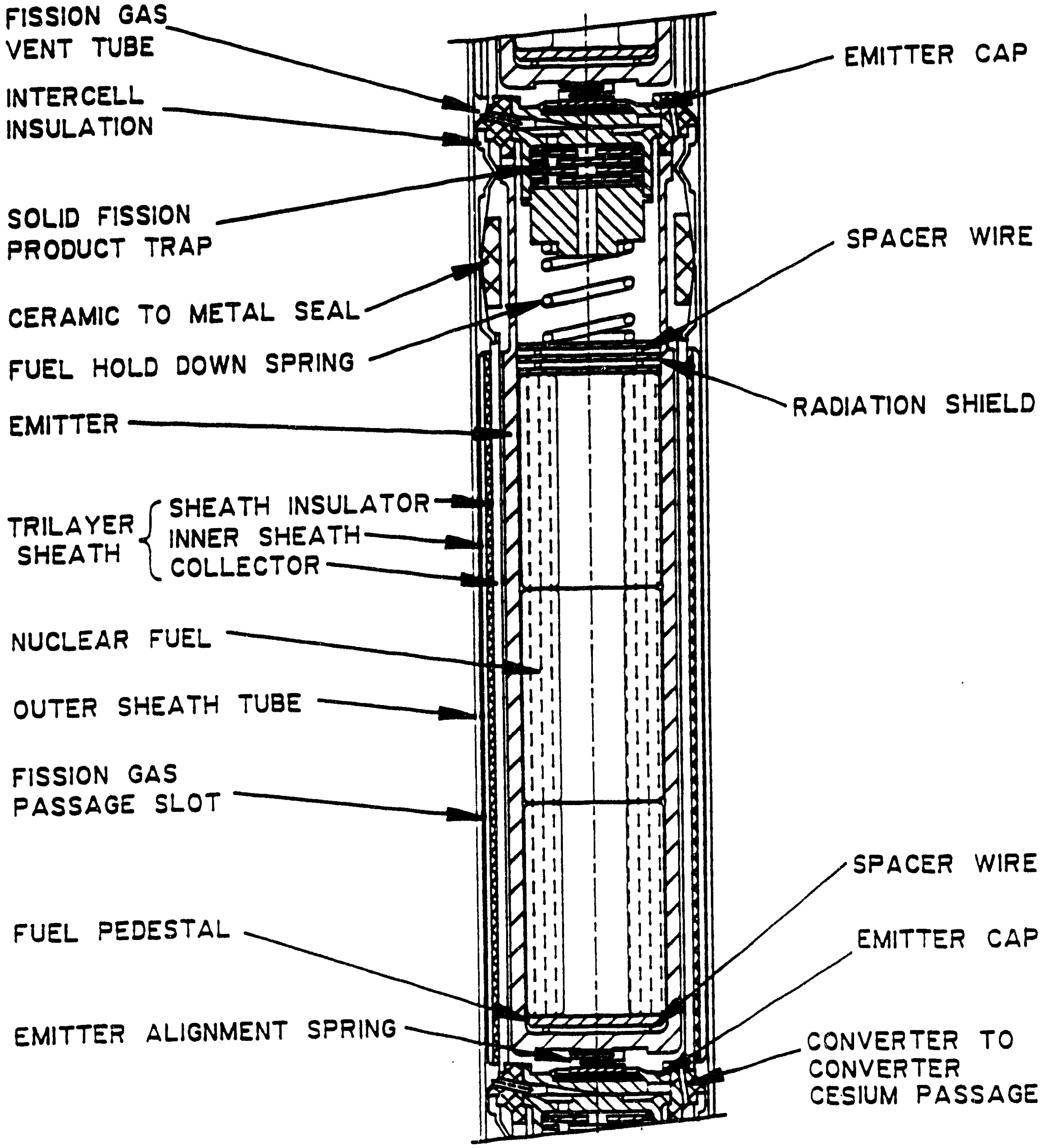


Figure 1-3. Thermionic Cell

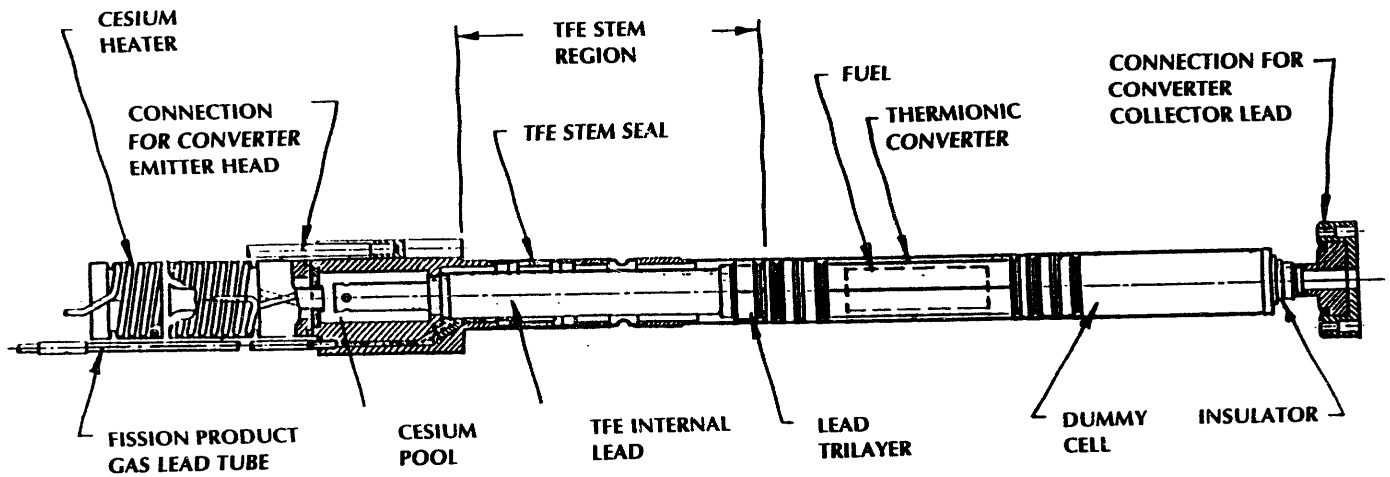


Figure 1-4. One Cell TFE Test in TFE Verification Program

2) Materials evaluation and selection
3) Performance testing
4) Life testing, both accelerated and real time.

In addition, performance models were developed for converter performance, fueled emitters and cesium reservoirs.

A brief description of each task is given below. For each of the component tasks, fabrication process specifications were developed and materials were chosen.

1.4.1 Conceptual Design. A TFE optimized for a 2 MW(e) system was designed. Its scalability over the range of 500 kW to 5 MW was demonstrated.

1.4.2 Converter Performance. The performance of converters of interest for megawatt class systems was measuredd and existing models on converter performance were refined.

1.4.3 Insulator Seals. The insulator seal isolates the space filled with gaseous fission products from the cesium filled interelectrode gap. It also assures that electrons flow from the collector of one cell to the emitter of an axially adjacent cell.

1.4.4 Sheath Insulators. The sheath insulator is a structure composed of 3 layers:

- The inner layer is the collector.
- The middle layer is an insulator electrically isolating the collector from the reactor coolant and structure. It also must conduct reject heat to the reactor coolant.
- The outer metallic layer assures the structural integrity of the sheath.

1.4.5 Fueled Emitters. The fueled emitter is the emitter component inside of which are the following components:

- UO_2 fuel.
- Fuel holddown device to prevent damage to the cell during launch and ascent.
- Fission product trapping components to prevent solid and condensable fission products from exiting the cell.
- Heat shields to protect the upper and lower parts of the emitter from the high temperatures of the UO_2 fuel.

1.4.6 Cesium Reservoir and Interconnective Components

The cesium reservoir provides cesium vapor to the interelectrode gap. A graphite cesium reservoir was demonstrated in the program.

Interconnective components are those metal parts and insulators which are necessary to attach one cell in series with another.

1.4.7 TFEs

The TFE is an axial series of one or more cells. It also contains a cesium reservoir. TFEs with one, three and six cells were fabricated and tested.

The TFEs fabricated under the TFE Verification Program are designated the "H" series TFEs, being the next series following the "E", "F" and "G" series which were studied in the 1960s and 1970s. The E series TFEs had an emitter diameter of 0.625 inch; the F series, 1.1 inches; and the H series, 0.5 inches.

A specific TFE has a designation xHy, the "x" being the number of cells in the TFE and the "y" being the specific TFE in question. For example, the TFEs fabricated and tested in the program were:

TFE-1H1, the first of the 1-cell TFEs.
TFE-1H2, the second of the 1-cell TFEs.
TFE-1H3, the third of the 1-cell TFEs.
TFE-3H1, the first of the 3-cell TFEs.
TFE-3H5, the fifth of the 3-cell TFEs. Numbers 2, 3 and 4 were eliminated early in the program.
TFE-6H1, the first of the 6-cell TFEs.

1.5 Semiannual Progress Reports

Semiannual progress reports provide a running account of technical progress which reflects the work done at GA, TTC, RAI and SPI. These reports also summarize the status and results of the irradiation program at WHC, ANL-W and LANL.

Table 1-1 shows a complete list of all semiannual progress reports.

1.6 Final Reports

Final test reports give details on each of the major components outlined in Section 1.4. A list of these final reports is given in Table 1-2. It is assumed in these reports that the reader is familiar with thermionic technology and the structure and operation of thermionic fuel elements and their components.

Table 1-1

SEMIANNUAL PROGRESS REPORTS

Period Ending	Date Issued	Report Number
March 31, 1987	April 1987	GA-A18780
September 30, 1987	March 1988	GA-A19115
April 30, 1988	June 1988	GA-A19269
October 31, 1988	January 1989	GA-A19412
April 30, 1989	September 1989	GA-A19666
September 30, 1989	March 1990	GA-A19876
March 31, 1990	July 1990	GA-A20119
September 30, 1990	January 1991	GA-A20335
March 31, 1991	April 1991	GA-A20493
September 30, 1991	December 1991	GA-A20804
March 31, 1992	April 1992	GA-A20911
September 30, 1992	January 1993	GA-A21210
March 31, 1993	May 1993	GA-A21326
September 30, 1993	January 1994	GA-A21511

Table 1-2

FINAL TEST REPORTS OF TFE VERIFICATION PROGRAM

Report Title	Document No.
Conceptual Design	GA-A21590
Converter Peformance Final Test Report	GA-A21591
Insulator Seal Final Test Report	GA-A21592
Sheath Insulator Final Test Report	GA-A21593
Fueled Emitter Final Test Report	GA-A21594
Cesium Reservoir and Interconnective Components Final Test Report	GA-A21595
TFE Performance Final Test Report	GA-A21596
TFE Design Package	GA-A21597
Fabrication Process Specifications	GA-A21734

1.7 TFE Design Package

The TFE Design Package Final Report contains analyses and drawings which support the design, fabrication, and test of TFEs. The TFE Performance Final Test Report is GA-A21596 (see Table 1-2).

The documentation in the TFE Design Package includes:

- Technical Correspondence: Memoranda that documents calculations, design review and inventions.
- Technical Document Tree.
- Drawing Tree for each test TFE.
- Engineering Drawing Package: All released TFE hardware drawings, latest revision.

The package described above contains several hundred drawings and documents which make general distribution of it impractical. Therefore, this information is being distributed as follows:

- DOE-OAK: One (1) complete package including one (1) print and one (1) reproducible copy of each drawing.
- General Distribution: Same as the DOE-OAK package with the technical correspondence and drawings removed.

1.8 REFERENCES

1-1 General Atomics Report GA-C18062, GES Baseline System Definition and Characterization Study, Final Report for the Period December 1984 through July 1985; Prepared under JPL Contract 956472, August 9, 1985.

1-2 General Atomics Report GA-A18182 (1985), SP-100 Thermionic Technology Program Annual Integrated Technical Progress Report for the Period Ending September 30, 1985, by GA Technologies, Rasor Associates, Inc., Space Power, Inc. and Thermo Electron Corporation, November 1985.

1-3 General Atomics Report GA-A18915 (1987), Thermionic Irradiations Program Final Report, General Atomics, San Diego, CA.

1-4 Cone, V. P. and J. Dunlay (1987), Thermionic Technology Program Fiscal Year 1986 and Final Technical Report, Thermo Electron Report No. TE4400-227-87.

1-5 Hatch, G. L. (1988), Thermionic Technology Program: Thermionic Converter Performance Final Report, NSR-25-25, E-533-003-B053188 (DOE Contract No. DE-AC03-86SF15954).

2. DESIGN ANALYSES

The technical documentation package contains all of the engineering correspondence generated during the TFE Verification Program that related to TFE design. In accordance with the TFE Verification Program Technical Document Tree shown in Figure 2-1, this information is compiled in the TFE Assembly Design Report, GA Document #909061, which is provided in Appendix A.

Appendix B lists the references for the engineering correspondence.

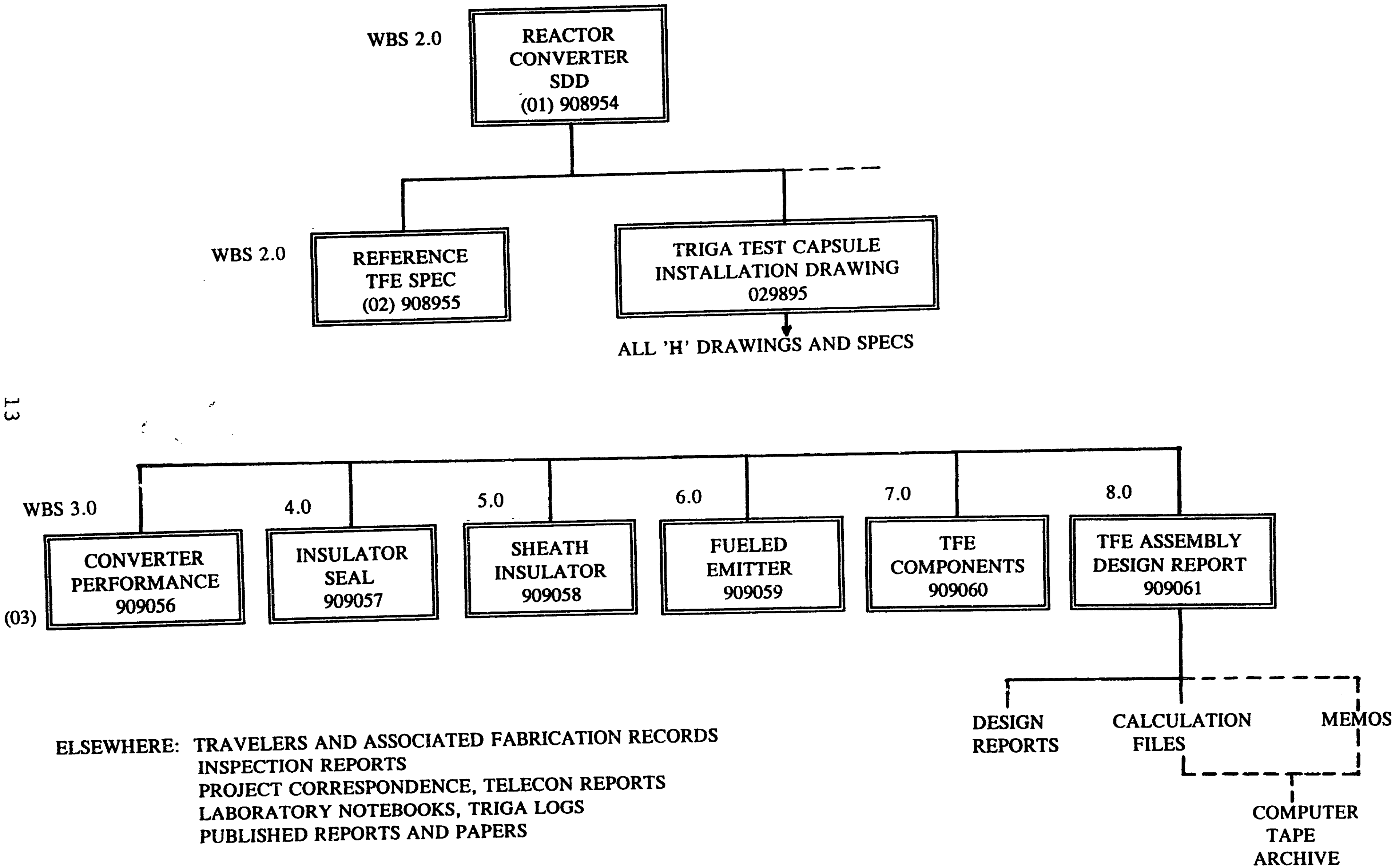


Figure 2-1. TFE Verification Program Technical Document Tree

3. TFE DRAWING PACKAGE

Complete engineering drawing sets for TFEs-1H1, -1H2, -1H3, -3H1, -3H5, and 6H1 are included in the DOE-OAK package. A list of drawing numbers by TFE and the TFE drawing tree numbers are provided herewith in Appendix C.

APPENDIX A

TFE ASSEMBLY DESIGN REPORT

ROLL - 2166 REV-0 & 1

GA 1485 (REV. 10/82)

GA Technologies Inc.

ISSUE SUMMARY

TITLE
TFE ASSEMBLY DESIGN REPORT

☒ R & D
☐ DV & S
☐ DESIGN

APPROVAL LEVEL 2

DISCIPLINE	SYSTEM	DOC. TYPE	PROJECT	DOCUMENT NO.	ISSUE NO./LTR.
M	NA	RGE	3450	909061	1

QUALITY ASSURANCE LEVEL	SAFETY CLASSIFICATION	SEISMIC CATEGORY	ELECTRICAL CLASSIFICATION
NA	NA	NA	NA

INFO 1

ISSUE	DATE	PREPARED BY	APPROVAL: ENGINEERING	APPROVAL: QA	APPROVAL: FUNDING PROJECT	APPROVAL: APPLICABLE PROJECT	ISSUE DESCRIPTION/ CWBS NO.
0	APR 07 1987	D.T.Allen	T.VanHagan H.Horner			R.Dahlberg	3450010182 Initial Release
1	NOV 30 1988	D.T.Allen	T.VanHagan M.H.Horner			R.C.Dahlberg	General update. Add 1H3 and 3H1. 3450081000 Class II Change

CONTINUE ON GA FORM 1485-1

NEXT INDENTURED DOCUMENTS
908955

REV																												
SH																												
REV																												
SH	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56
REV																												
SH	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28

CONTENTS

FIGURES

TABLES

1. SCOPE

Provided is the technical documentation and data base for the overall assemblies of thermionic fuel elements (TFE) designed for incore verification testing. At this issue the scope of this document is limited to TFEs 1H1, 1H2, 1H3 and 3H1.

This report currently occupies the third indenture level of the TFE Verification Program Document Tree, as shown in Figure 1 of GA Document 908954, "Reactor-Converter System Design Description".

2. DESCRIPTION

2.1 Test Article

The partial length and prototypic TFEs for incore testing are made up of a string of thermionic converters with additional portions above and below the string.

The thermionic converter string, which is the portion of the TFE that constitutes the active core of the thermionic reactor, is designed and fabricated to the requirements of the system baseline design, which is defined by GA document 908955, "Reference TFE Specification". The number of converters in the partial length string varies according to test definition.

The portions of the TFE above and below the converter string, which include the cesium reservoir for the TFE, have only been designed thus far for the partial length TFEs. These portions are not prototypic but instead designed for the requirements of the test. However, they are to be fabricated in the same manner as the reactor prototypic TFE, which has an essentially all electron-beam-welded refractory metal envelope, and design changes will progress toward the prototype.

The remainder of the test vehicle is designed to encapsulate the test article as necessary for irradiation in the test reactor, to provide appropriate boundary conditions to assure validity of the test and to accommodate desired instrumentation.

2.1.1 Converters

The present thermionic converter design is designated as the H-series. There are 12 H-series converters welded together axially and bonded into a common sheath tube in the reference thermionic reactor system design. All of the test articles in the current program plan have from one to six converters per TFE. Figure 1 illustrates a single H-series converter and identifies its parts according to the nomenclature used in the following text. The converters in a TFE string differ from each other only in the fuel enrichment and/or fuel pellet inside diameter.

Emitter. The H-series emitter is 12.7 mm (0.5 in.) in diameter and 51 mm (2.0 in.) long. The emitter cylindrical wall thickness is 1.0 mm (0.040 in.), and the emitter bottom thickness is 1.5 mm (0.060 in.) with a 0.33 (0.013 in.) deep recess to accommodate a 7.6 mm (0.3 in.) diameter converter-to-converter alignment spring (which is discussed further below). At the top end of the emitter is the emitter stem, which serves as both electrical lead to the emitter and as thermal choke for the emitter. The stem is 0.51 mm (0.020 in.) thick and 12.2 mm (0.48 in.) long. The emitter is tungsten, and it is fabricated in two layers. The inner, thicker layer is chemically vapor deposited from WF_6. This is the structural layer of the emitter, and it also makes up the emitter stem. The outer 0.30 mm (0.012 in.) of the emitter is deposited from WCl_6, which provides the oriented emission surface. The emitter is diffusion bonded to a tantalum transition piece at the top end.

Fuel. Inside the emitter is the nuclear fuel. Three annular pellets of UO_2 total 46 mm (1.83 in.) in length. In the reference reactor all fuel pellets are made of fully enriched uranium, and the fuel pellet inside diameter varies depending on axial location of the converter in the TFE and the radial location of the TFE in the core in order to flatten power generation. In the test articles both enrichment and fuel volume are varied according to test goals. A tungsten-26% rhenium pedestal holds the fuel off the emitter bottom for the purpose of maintaining lower and more uniform emitter bottom temperatures than if the fuel were in contact with the bottom. Above the fuel there are four tungsten-26% rhenium discs alternating with formed wire spacers which serve as thermal radiation shields to reduce axial heat loss from the fuel and to inhibit fuel vapor transport. A tungsten-26% rhenium fuel holddown spring locates the fuel and internal parts in place during fabrication and encapsulation. Above the spring is a component to radially and axially locate the spring.

In TFEs 1H1 and 1H2 the spring locator is a stepped disk of tantalum with holes. This component is shown in the cross-section of the converter to TFE lead region in Fig. 6.

In TFEs 1H3 and 3H1 the spring locator is a tantalum housing containing alumina coated disks of molybdenum foil. Fission gas travels a labyrinth-like path through this structure, where both alumina and molybdenum will react with volatile fission products which would otherwise react with or deposit upon the walls of the fission product passages downstream. The solid fission product trap is shown in the cross-section of the 3H1 converter-to-converter region in Fig. 2b.

The fuel space is closed with a cap welded into the transition piece. There are three 0.30 mm (0.012 in.) inside diameter fission product vent tubes located in the transition piece. The tubes are made of polycrystalline high purity alumina and pressed into radial holes 0.66 mm (0.026 in.) in diameter in the transition piece. These vent tubes provide a passage for fission product gases from the fuel cavity inside the emitter to the annular space outside of the ceramic-to-metal seal and the emitter transition piece.

Collector. Opposite the emitter is the collector, and between them is the interelectrode gap, which is filled with cesium vapor during converter operation. The radial interelectrode gap is 0.25 mm (0.010 in.). Cesium is supplied to each converter through six 0.33 mm (0.026 in.) diameter axial holes in the transition piece which provide passages between the converters in the string.

The collector is part of a trilayer structure which is fabricated by gas pressure bonding. It is made up of a 0.76 mm (0.030 in.) thick niobium inner layer, which is the current carrying collector, an intermediate ceramic sheath insulator layer 0.41 mm (0.016 in.) thick, and an outer niobium layer 0.48 mm (0.019 in.) thick, which is called the inner sheath. The trilayer outside diameter is 16.5 mm (0.65 in.). The inner sheath is slotted parallel to its longitudinal axis at places around the outside diameter to a depth of 0.20 mm (0.008 in.), 0.38 mm (0.015 in.) wide, to form axial fission product gas passages from one converter to the next. There would be no slots in the trilayer of the bottom converter in a string, since there is no converter below it to produce gas.

Converter Seal. The converter ceramic-to-metal seal is a subassembly comprised of a 1.4 mm (0.054 in.) thick by 0.64 mm (0.025 in.) wide polycrystalline alumina ceramic insulator ring with niobium skirts brazed to it. The upper niobium skirt is thinned to 0.38 mm (0.015 in.) and formed into a convolution with a depth of 0.76 mm (0.030 in.) and a minimum radius of 0.25 mm (0.010 in.). This convolution compensates for the differential thermal expansion between the ceramic-to-metal seal and the unbonded section of the outer sheath tube. The ceramic-to-metal seal is welded between the fueled emitter subassembly and the trilayer to make up the converter unit, as shown in Fig. 1.

Intercell Region. The individual converters are welded end-to-end connecting the emitter transition of one converter to the collector of the converter above it and completing the electrical series conection. This weld also seals the interelectrode (cesium) space from the fission product space. Figure 2 shows the converter-to-converter region in detail. There are two different intercell alignment arrangements.

In the first three TFEs (the 1H's) the end of the emitter is aligned concentrically within the collector by a conical, tungsten-26% rhenium alignment washer 0.25 mm (0.010 in.) thick, 7.6 mm (0.30 in.) outside diameter, 2.5 mm (0.010 in.) inside diameter and 1.1 mm (0.045 in.) high. This washer is seated in a polycrystalline alumina insulator disk 0.89 mm (0.035 in.) thick and 10.9 mm (0.43 in.) outside diameter. The alignment washer locates on a 2.5 mm (0.10 in.) button on the bottom of the emitter, and the alignment insulator sits in a 10.9 mm (0.43 in.) diameter recess in the emitter cap of the converter below. The emitter cap is tantalum in this arrangement.

For the subsequent TFEs in the top of each converter the emitter is closed with a cap made of a trilayer of niobium, alumina and niobium. An alignment device made of two conical tungsten-26% rhenium washers 0.25 mm (0.010 in) thick welded at the outer edge is placed over a 2.5 mm (0.10 in) diameter projection on the electrically isolated upper portion of the trilayer cap. The alignment device also locates on a 2.5 mm (0.10 in.) diameter button on the bottom of the emitter, providing support for the end of the emitter under mechanical loading and assure alignment of the interelectrode gap.

A 80μ (0.003 in.) thick plasma-sprayed alumina coating is applied over the outside of the ceramic-to-metal seals and transition pieces after the converter string is welded together. The string is then put into a 0.51 mm (0.020 in.) thick niobium-1% zirconium outer sheath tube which has an inner coating of nickel. The radial clearance to the tube is 13 to 18μ (0.0005 to 0.0007 in.). The assembly is subsequently wrapped with tungsten wire and heated to 1500 K, at which temperature the inner sheath and outer sheath tube are forced into contact by the differential expansion of the largely niobium TFE structure and the tungsten wrap. A nickel-niobium braze is accomplished which bonds the converter string into the outer sheath tube. The tungsten wire wrap is removed and the final TFE outside diameter is 17.5 mm (0.69 in.).

2.1.2 Above and Below the Converter String

Dummy Cell. Located below the bottom converter in the single cell (1H) test articles is a "dummy cell". The dummy is welded to the collector of the bottom converter as another converter would be, and it is located within the outer sheath tube. The converter-to-dummy region is shown in Fig. 3. The dummy provides another ceramic-to-metal seal which insulates the collector potential of the converter from the outer sheath tube potential. Figure 3 also illustrates the bottom of the TFE with dummy cell. A brazed niobium-copper lead end piece is welded to the dummy collector lead after TFE sheath tube bonding and final processing. To this is welded a copper bus tube that carries the TFE current back to beyond the top end of the test article.

The three cell (3H) TFE does not have a dummy. A plug terminates the converter string as shown in Fig. 4. In the 3H TFEs the outer sheath tube will be at the collector potential of the bottom converter.

TFE Stem. Above the converter string is the TFE stem region. Above that is a cesium reservoir. Figure 5 shows the complete TFE.

Not only is the cesium supplied to the converter string from above these test articles, but also the converter current and the fission product gases are led away from the string in the same direction. The electric current is drawn from the top of the emitter of the top most converter by a hollow niobium lead. The cesium communicates between the reservoir and the converter through the center of the lead. The region between the converter string and the cesium reservoir is referred to as the TFE stem.

Figure 6 shows the detail of the bottom of this stem region. Between the emitter lead and the top most emitter transition piece is the lead trilayer. This component is a piece of niobium-alumina-niobium cylindrical composite of the same configuration as the collector trilayer in the converters, and it is bonded to the outer sheath tube. It is required in order to mechanically locate the top-most emitter, which otherwise would be supported only on the convolution of its ceramic-to-metal seal.

Outside of the emitter lead the fission product space is enclosed by a stem sheath structure consisting of an expansion joint, to accommodate differential thermal growth, and a ceramic-to-metal insulator. This ceramic-to-metal seal is of the same high temperature brazed design as the converter seals. This stem sheath structure is welded at the bottom to the top of the TFE outer sheath and at the top to the cesium reservoir. The insulator separates the sheath potential from the reservoir structure which is electrically connected to the emitter potential.

Cesium Reservoir. Figure 7 shows the detail of the liquid cesium reservoir and Fig. 8 shows the graphite reservoir. These assemblies are welded niobium, except where fission product tubing has been brazed in place. The heater wires are tantalum sheathed mineral-coated cable and are brazed in position. Leading away from the TFE at the top in each design are the solid niobium emitter current lead and a tube for fission products.

In the TFE, there is complete separation of the interelectrode (cesium) volume from the fission product space. In the event of a leak between the two volumes, the cesium would gradually flow into the fission product space and then out of the TFE and into the external fission gas collection chambers. (The design of the collection system external to the TFE is discussed below under the test vehicle topic.) To assure against such a loss of cesium, which would eventually terminate the test, the TFE design includes a port tube in the fission product system. The port tube passes the noble gas fission products with insignificant pressure drop but reduces cesium vapor leakage out of the TFE, if there should be a leak between the cesium volume and the fission product space. The port tube is located in TFE 1H1 as shown in Fig. 7, and for 1H2 and 3H1 it is illustrated in Fig. 8.

Fission Product Management. Figure 9 is a simplified diagram of the separate cesium and fission product plumbing within the TFE for both liquid and graphite reservoir designs. Shown in the figure are the tubing connecting the TFE to the pumpout and backfill systems at the final processing step. Also shown is the connection to the line leading to the fission gas collection chamber in the TRIGA test capsule configuration.

Electrical Connection. Above the TFE, the solid niobium emitter lead is welded to a solid copper bus, which passes through the primary containment hard seal. Outside of the converter string and TFE stem and reservoir assemblies is a copper bus tube connected to the bottom converter collector potential, as shown in Figs. 3 and 4. This bus tube continues upward to the hard seal where there is a transition to a copper bus, which passes through the seal.

2.2 Test Vehicle

The test vehicle described here is the irradiation capsule for testing TFEs 1H1, 1H2, 1H3, 3H1 in the Mark F TRIGA reactor. No significant engineering has yet begun on capsules for the other tests in the overall program.

A schematic diagram of the capsule is shown in Fig. 10.

In the TRIGA reactor, the test vehicle will be inserted in place of a TRIGA fuel element, which is 38 mm (1.5 in.) in diameter. The test vehicle must be dimensionally compatible with the reactor core. The test vehicle is required to meet the safety criteria and technical specification limits of the reactor license.

The test vehicle design must permit operation of the test article over the range of TFE thermal and electrical parameters desired to meet the test objectives. Instrumentation must also be provided in accordance with the test plan.

The test vehicle design incorporates a double austenitic stainless-steel encapsulation of the test article with the primary (inner) containment leak tight to less than 2×10^{-8} scc/sec. All instrumentation penetrations of the primary containment must be leak tight to 1200 K. Heat rejection to the TRIGA reactor coolant must not exceed the threshold for nucleate boiling.

The basic electrical arrangement and performance diagnostics for a 1H TFE are shown in the schematic diagram in Fig. 11. Figure 12 is the schematic for the 3H.

Surrounding the test article, the test vehicle for the 1H and 3H series of TFEs consists of concentric thin walled stainless steel containment envelopes. Above the TRIGA core there is a transition to a larger diameter, and there the primary containment is closed with a hard seal. The primary containment is permanently filled with one atmosphere of helium. The outer containment extends to above the top of the reactor pool, a distance of approximately 7.5 m. It is closed 2.5 m above the core with a cast epoxy seal, but by means of a tube extending to the top of the pool the gas in the secondary containment volume can be changed during the test.

Between the TFE and the containment tubes there is a filler block which incorporates a pair of heater coils. The collector temperature of the TFE can thus be controlled by both adding heat to the redundant coils on the filler block and changing the gas mixture in the secondary containment. Two similar heaters are brazed to the cesium reservoir heater block for control of the reservoir temperature, and hence control of the cesium vapor pressure in the TFE and the thermionic performance. In TFE 1H1 two stainless steel-clad heater cables will be wrapped around the cesium reservoir stem to trim the temperature of the top of the TFE. For 1H2 and 3H1 there will be heaters wrapped around the pinchoff tubes at the end of the TFE.

The dimensions of the various heat transfer gaps and other relevant thicknesses are shown in Figs. 13 and 14. Also shown are the general locations of the heaters.

Emitter temperature is dependent upon current density, cesium pressure (proportional to reservoir temperature), collector temperature and fuel heat generation. Nuclear heating in the fuel can be reduced by lifting the entire test vehicle assembly above and away from the core centerplane. As a result, the principal parameters of emitter temperature, cesium pressure and collector temperature can be adjusted by changing elevation, collector (filler block) heater power, cesium reservoir heater power and secondary containment gas composition.

The 1H1, 1H2 and 1H3 capsules for in-core TRIGA testing are instrumented with twelve thermocouples to monitor the TFE. These are ceramic-insulated, Inconel-clad, floating junction, chromel-alumel thermocouples of 1.0 mm (0.040 in.) diameter. Tables 1 and 2 describe the location and summarize the purpose of each thermocouple for the 1H TFEs. Figures 15 and 16 show the approximate thermocouple locations. The 3H capsules will have sixteen thermocouples. Table 3 shows the 3H instrumentation. Figure 17 shows the thermocouple locations.

Current leads will link the TFE to the load, located outside the reactor. These bus bars are designed for 150 amps of continuous electric current. In the 1H TFEs a third lead will be attached to the outer sheath potential to allow drawing current across the sheath insulators. Current in this lead will be only a few milliamperes. Three voltage probes will tap the cell emitter potential and the collector potential, and in addition for the 1H TFEs the outer sheath potential. This arrangement is shown in the schematic diagrams of Figs. 11 and 12.

The TFE fission product system consists of the passages within the converter region of the TFE which connect the fuel space to the volume between the converters and the sheath tube. This space communicates with the annular space in the cesium reservoir stem region outside the emitter lead and inside the enveloping sheath assembly. Through passages in the cesium reservoir block, tubes lead out of the TFE and into an external fission gas collection chamber. The collection chamber is a stainless vessel one liter in volume and initially a vacuum. Xenon and krypton are the major noncondensable fission product constituents, and based on their projected generation rate in a one-cell TFE, the chamber pressure would rise to 4.5 mbar at the end of 20,000 hours.

3. REQUIREMENTS

3.1 Design Requirements, Generic

The test objectives and TFE design definition for each incore test vehicle (capsule) is governed by the project control document PC-000241, "Task 8 - Thermionic Fuel Element Test Plan". Table 4 is a summary of the TFE design features which differentiate the test assemblies documented herein.

Design of converters for all TFEs must conform to the component functional descriptions in Table 1 of GA document 908955, "Reference TFE Specification", and to the configuration definitions in Table 2 of the same specification.

Initial test capsules will be irradiated in the GA TRIGA Mark F reactor and later tests in the U.S. Department of Energy FFTF at Hanford, Washington. At this issue the scope of this document is limited to the TRIGA test capsules.

3.2 Design Requirements, 1H1

The incore test cpasule shall be designed to operate as a single converter TFE and otherwise meet the performance defined in Table 2 of GA document 908955, "Reference TFE Specification". As such the converter thermal power is to be 625 W when located at the axial flux center of TRIGA reactor location E2.

The liquid pool-type cesium reservoir is to operate in the temperature range of 500 to 580 K while the converter is at the reference performance point.

The 1H1 TFE assembly shall be guided by the document tree shown in Fig. 18.

3.3 Design Requirements, 1H2

The incore test capsule shall be designed to operate as a single converter TFE and otherwise meet the performance defined in Table 2 of GA document 908955, "Reference TFE Specification". As such the converter thermal power is to be 625 W when located at the axial flux center of TRIGA reactor location E10.

TFE 1H2 will be different from TFE 1H1 in using a graphite cesium reservoir instead of a liquid pool reservoir. This difference requires a different design above the TFE string.

The graphite cesium reservoir is to operate in the temperature range of 1000 to 1200 K while the converter is at the reference performance point.

The TFE will be otherwise the same as 1H1 except as follows:

1. The converter trilayer will be Al_2O_3 instead of Y_2O_3.

2. The one-piece fuel pedestal designed for the UFAC test will replace the disc and wire spacer used in 1H1.

The test vehicle will differ from 1H1 as follows:

1. A thicker lead trilayer inner conductor section will be provided to reduce resistive electrical loss between the converter and diagnostic voltage probes. For the same reason the collector potential voltage probe will be located as close to the collector as possible.

2. Filler block heating wires will have longer lead sections in order to permit lengthening of the primary containment for easier assembly.

The 1H1 TFE assembly shall be guided by the document tree shown in Fig. 19.

3.4 Design Requirements, 1H3

The test article and test vehicle shall duplicate TFE 1H1 with the following exceptions:

1. The fission product gas space will communicate with the cesium (interelectrode) space in order to duplicate the worst case of a leak between the two volumes internal to the converter.

2. The fuel enrichment shall not exceed 20% by weight, and the capsule will accordingly be located in the TRIGA core as required to meet performance objectives.

3. A solid fission product trap, similar to the design in TFE 6F5, will be included inside the converter above the fuel.

4. The converter trilayer will be Al_2O_3 instead of Y_2O_3.

5. The one-piece fuel pedestal designed for the UFAC test will replace the disk and wire spacer used in 1H1.

6. The dummy cell will be shortened to reduce resistive electrical loss.

7. Filler block heating wires will have longer lead sections in order to permit lengthening of the primary containment for easier assembly.

8. Other evolutionary changes to design detail to improve TFE and capsule assembly.

The 1H3 TFE assembly shall be guided by the document tree shown in Fig. 20.

3.5 Design Requirements, 3H1

The incore test capsule shall be designed to operate as a three-converter TFE and otherwise meet the performance defined in Table 2 of GA document 908955, "Reference TFE Specification". As such the thermal power in each converter is to be 625 W when the middle converter is located at the axial flux center of TRIGA reactor location C4.

The converters will be of the same design as 1H3 but without mixed cesium and fission products, which is the same as 1H1 with the solid fission product trap feature, except for the emitter alignment arrangement. The alignment arrangement will consist of a niobium-alumina-niobium trilayer emitter closure cap and an alignment device made of two coned washers between the cap and the emitter bottom of the converter above.

The TFE shall have a graphite cesium reservoir and region above the converter string the same as TFE 1H2.

The 3H1 TFE assembly shall be guided by the document tree shown in Fig. 21.

4. DESIGN PACKAGE, 1H1

4.1 Nuclear Analysis

Nuclear analysis of 1H1 is documented in Ref. 1.

4.2 Converter Thermal Analysis

Thermal analysis of the 1H1 converter and capsule is documented in Refs. 2 and 3.

4.3 Cesium Reservoir Loading and Thermal Analysis

Cesium loading is documented in Ref. 4. Thermal analysis is documented in (later).

4.4 Mechanical Analysis

(Later)

4.5 Fission Product Transport Analysis

Design of the fission product venting system for 1H1 is documented in Ref. 4.

5. DESIGN PACKAGE, 1H2

5.1 Nuclear Analysis

Nuclear analysis of 1H2 is documented in Ref. 1.

5.2 Converter Thermal Analysis

5.3 Cesium Reservoir Loading and Thermal Analysis

Cesium loading is documented in Ref. 4. Thermal analysis is documented in (later).

5.4 Mechanical Analysis

(Later)

5.5 Fission Product Transport Analysis

Design of the fission product venting system for 1H2 is documented in Ref. 4.

6. DESIGN PACKAGE, 1H3

(Later, by TECO)

7. DESIGN PACKAGE, 3H1

7.1 Nuclear Analysis

Nuclear analysis of 3H1 is documented in Ref. 1.

7.2 TFE Thermal Analysis

(Later)

7.3 Cesium Reservoir Loading and Thermal Analysis

The cesium reservoir design loading and thermal environment of 3H1 are identical to 1H2.

7.4 Mechanical Analysis

TFE 3H1 is mechanically identical to 1H2.

7.5 Fission Product Transport Analysis

The fission product system for 3H1 is identical to that of 1H2.

8. REFERENCES

1. GA Memorandum, A. R. Veca to Distribution, "1H1 Fuel Pellet Design", 17 November 1986, 660:ARV:066:86.

2. GA Memorandum, D. T. Allen to Distribution, "Meeting to Resolve 1H1 Fuel Power and Collector to Coolant Heat Transfer Gaps", 11 November 1986, 3450:143:DTA:86.

3. GA Memorandum, D. T. Allen to Distribution, "Representative 1H TFE Temperatures", 5 October 1988, 3450:329:DTA:87.

4. GA Memorandum, D. T. Allen to M. H. Horner, "Fission Product Port Sizing and Cesium Loading for TFEs 1H1, 1H2, 1H3", 14 June 1988, 3450:405:DTA:88.

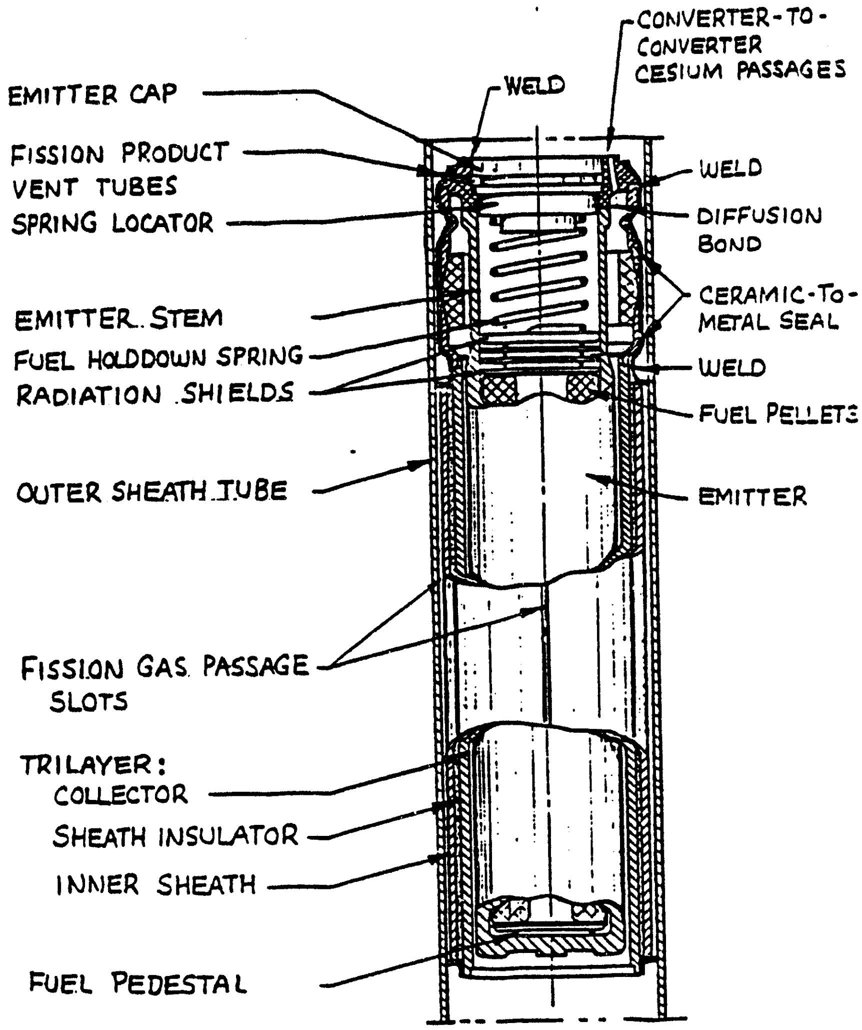
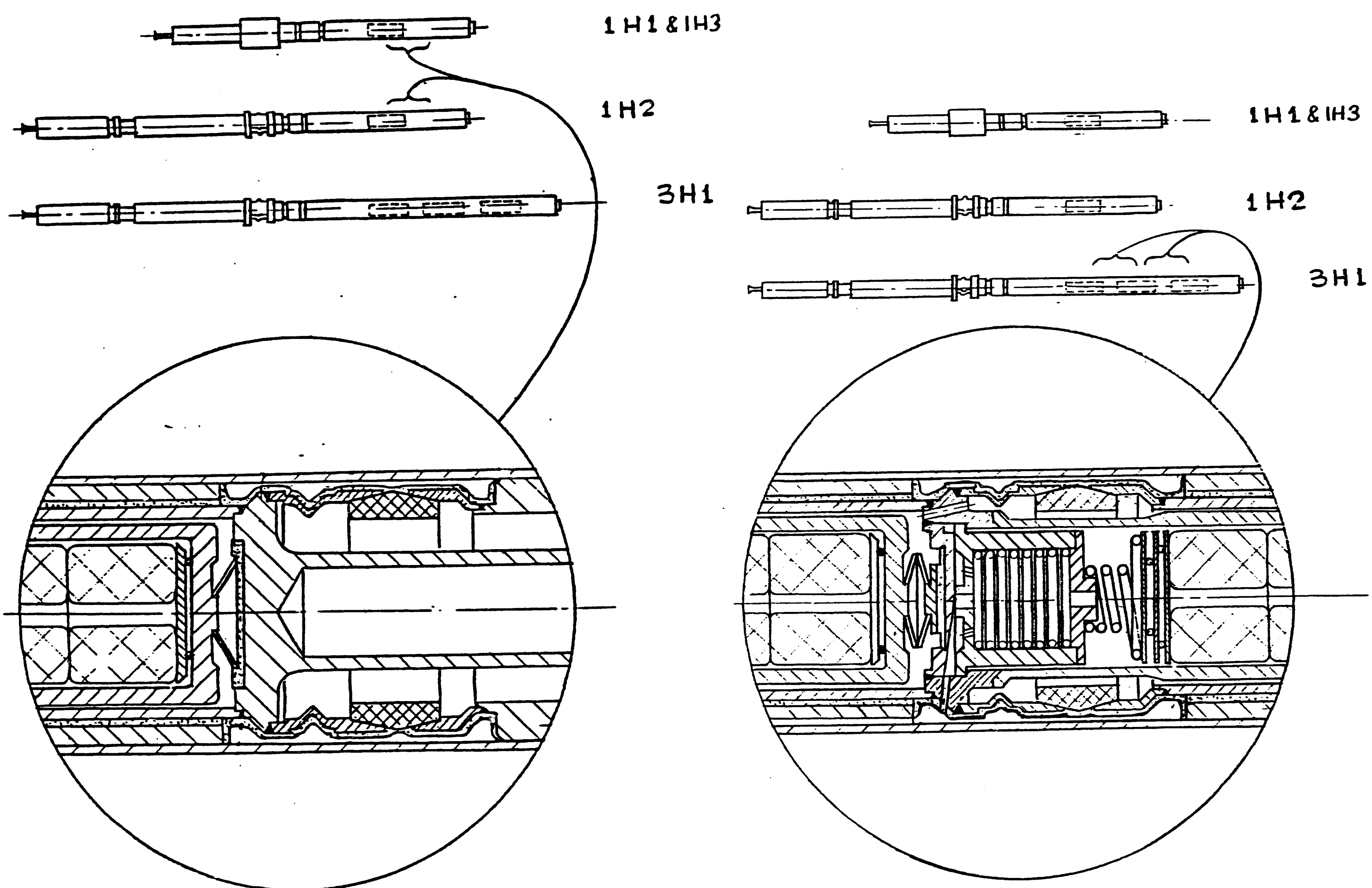


Fig. 1 - H-Series Thermionic Converter



a) Two-piece alignment arrangement.

b) One-piece alignment arrangement; also shows solid fission product trap.

Fig. 2 - Converter-to-converter region

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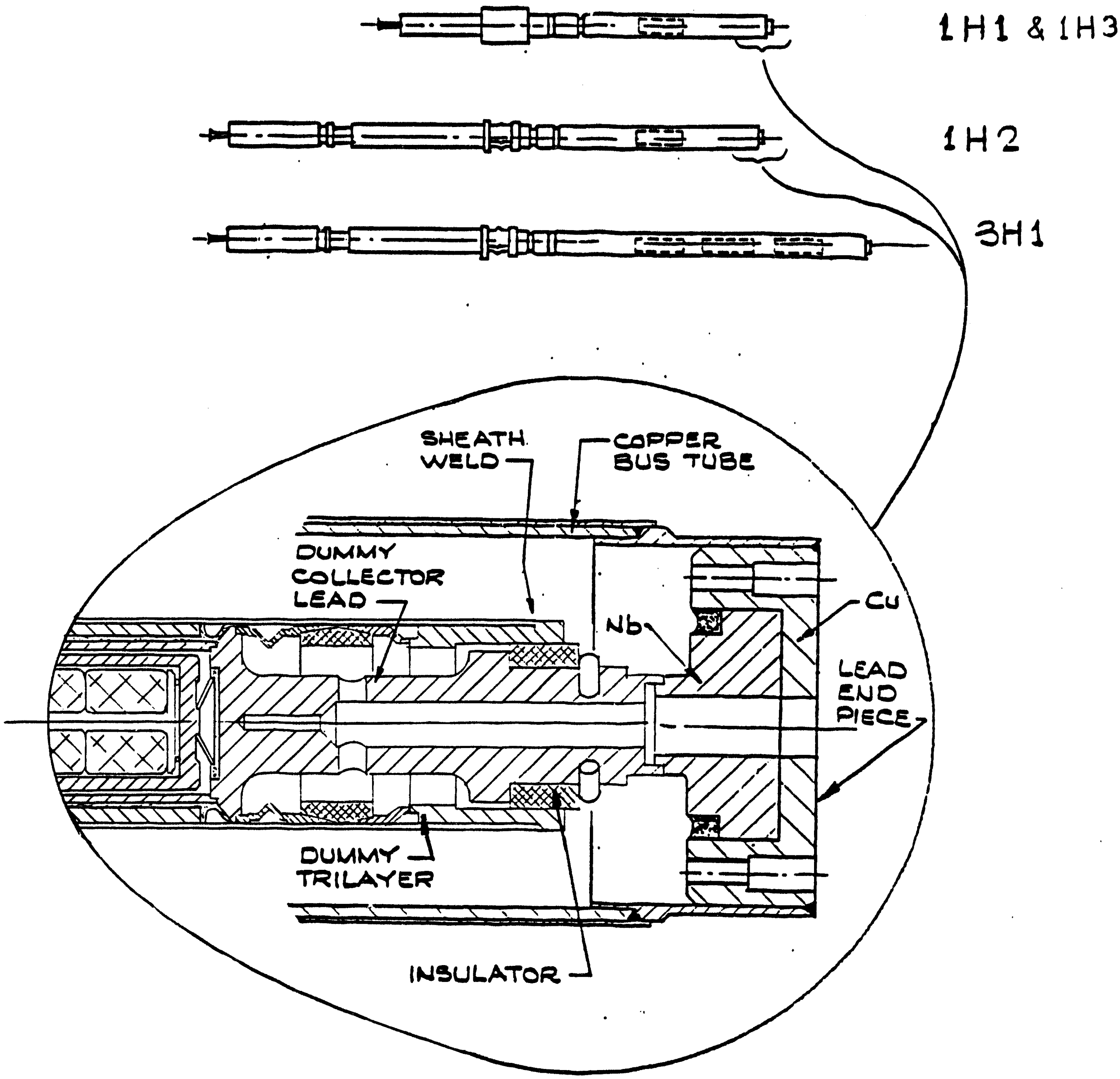

Fig. 3 - TFE end arrangement-dummy cell

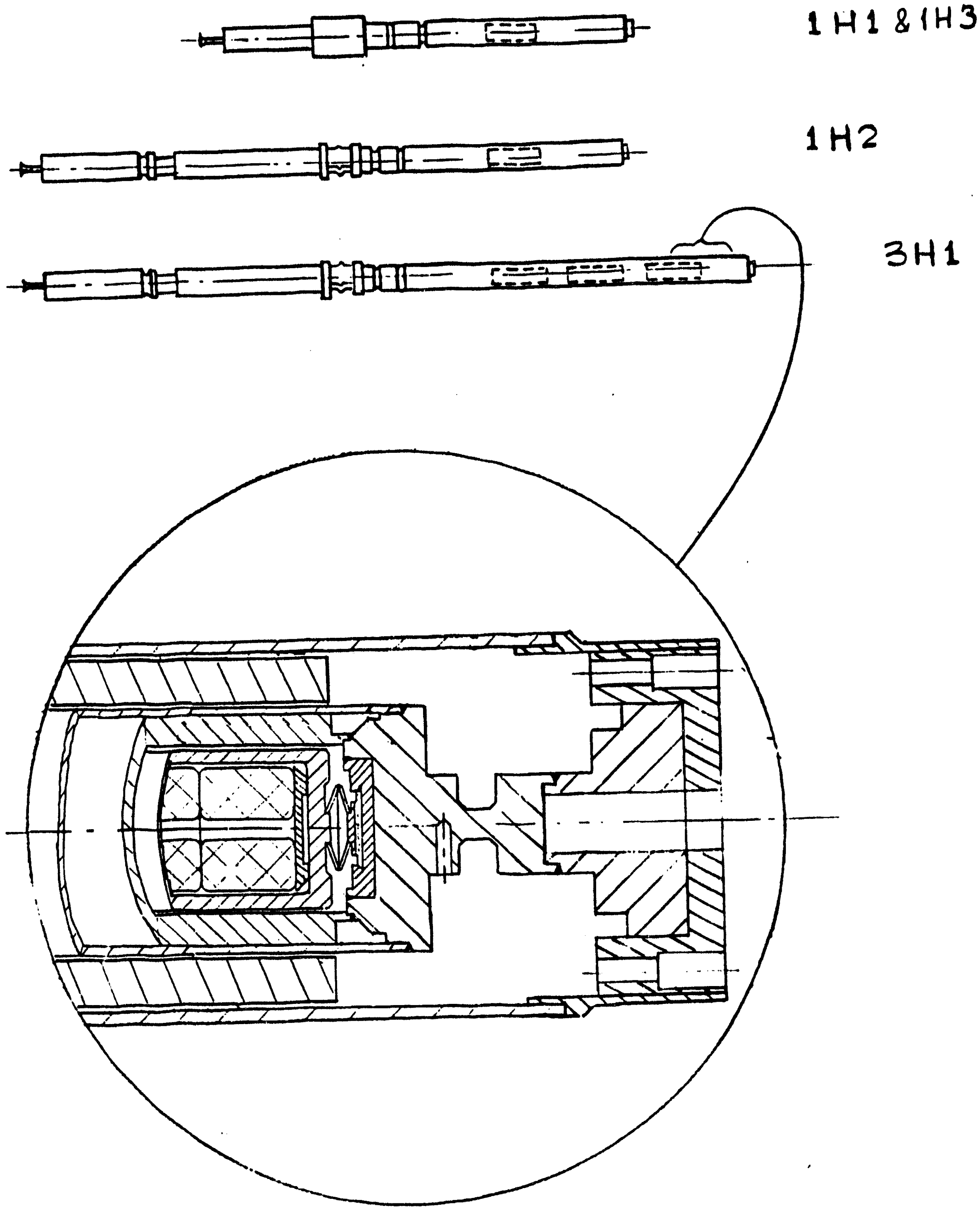

Fig. 4 - TFE end arrangement - no dummy

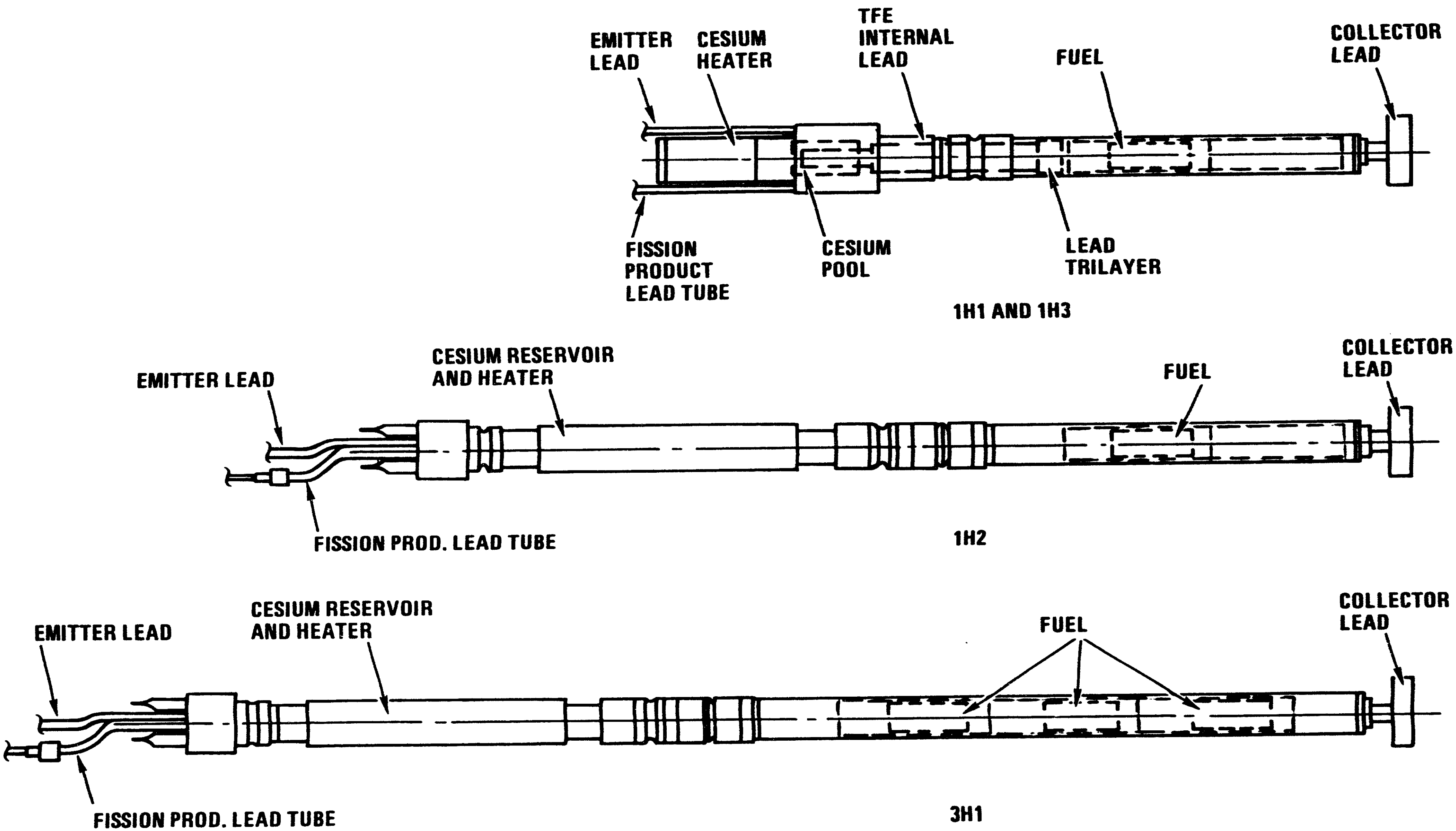

Fig. 5 - TFE for TRIGA test

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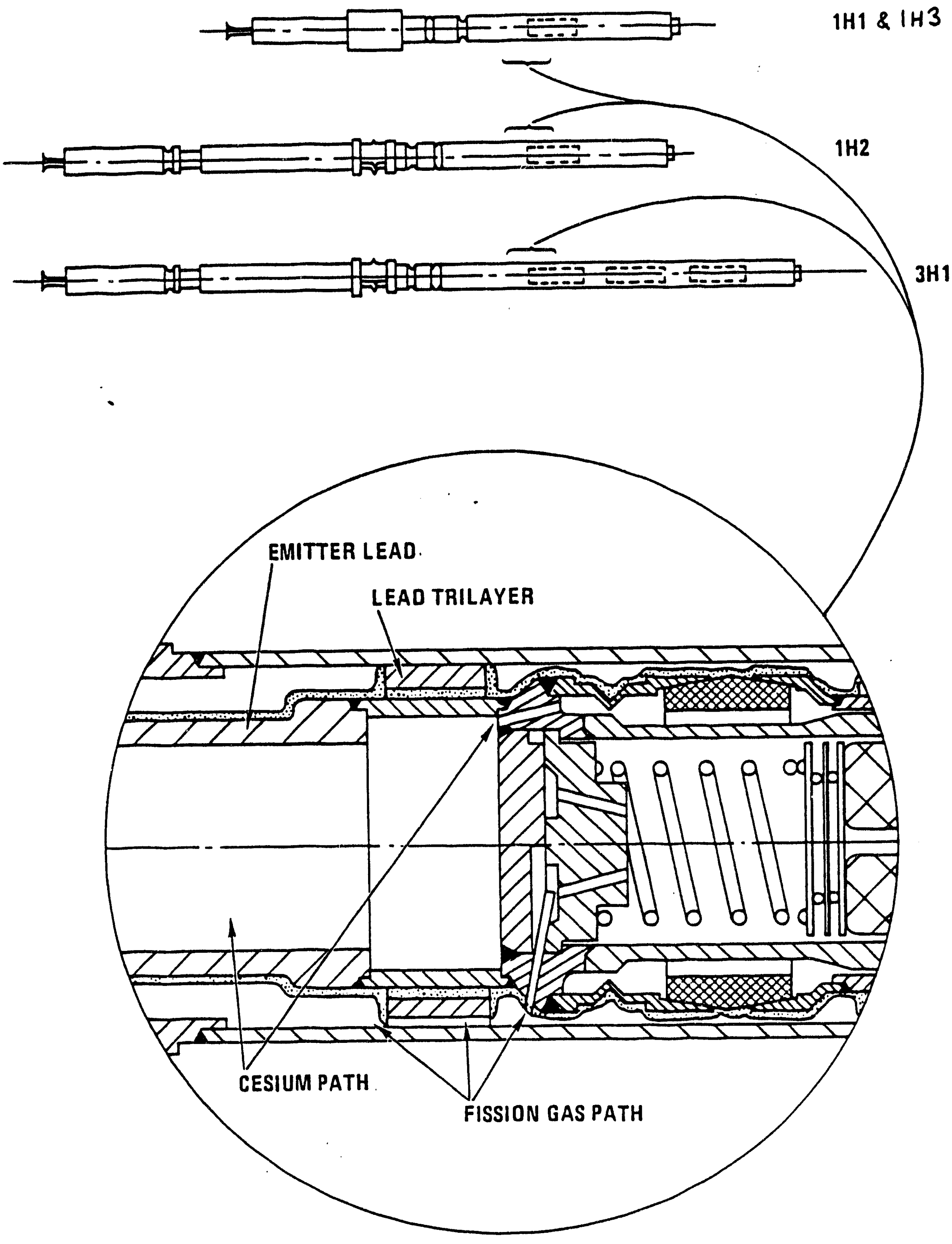

Figure 6 - Converter-to-TFE Lead Region

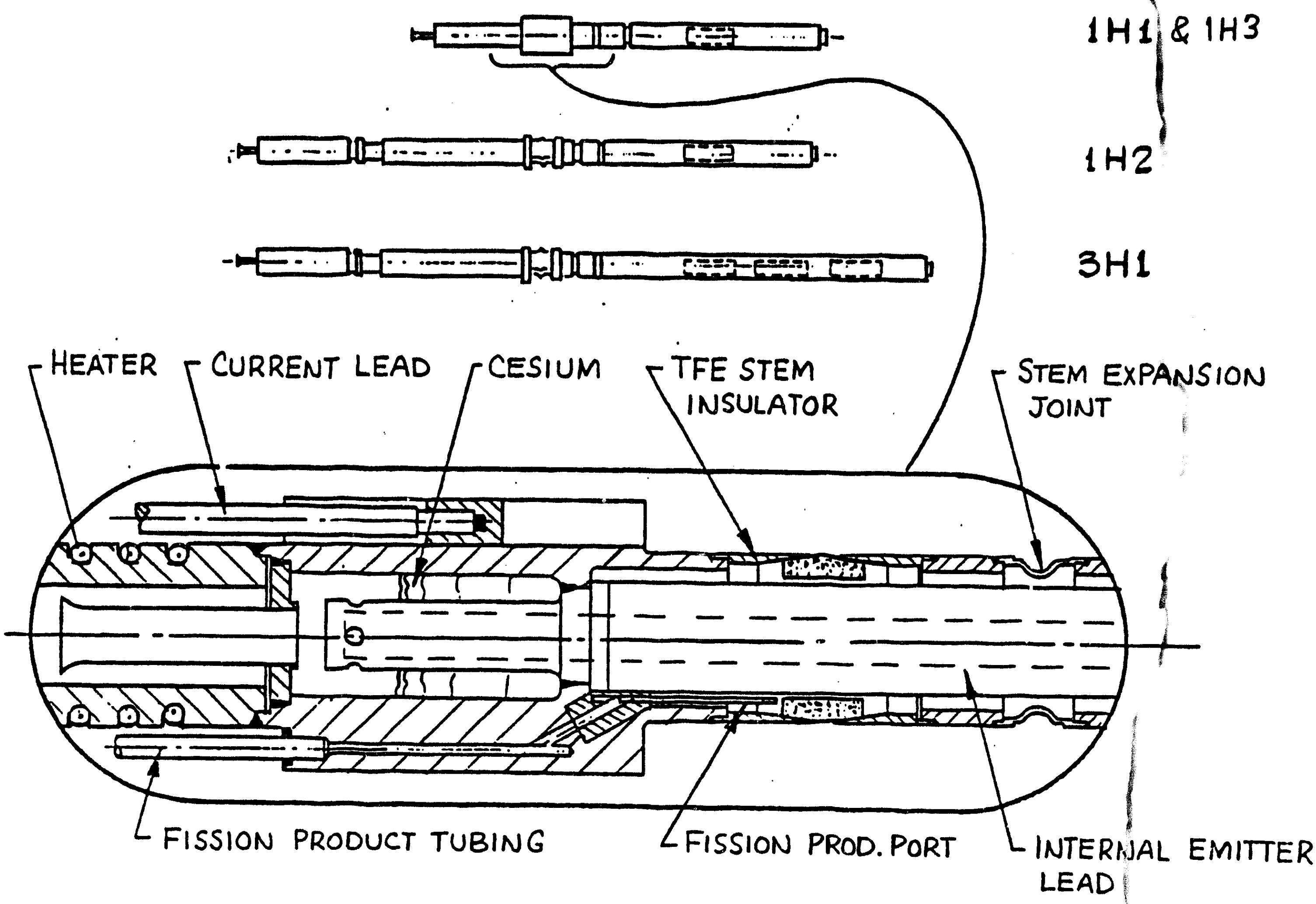

Figure 7. Liquid Cesium Reservoir

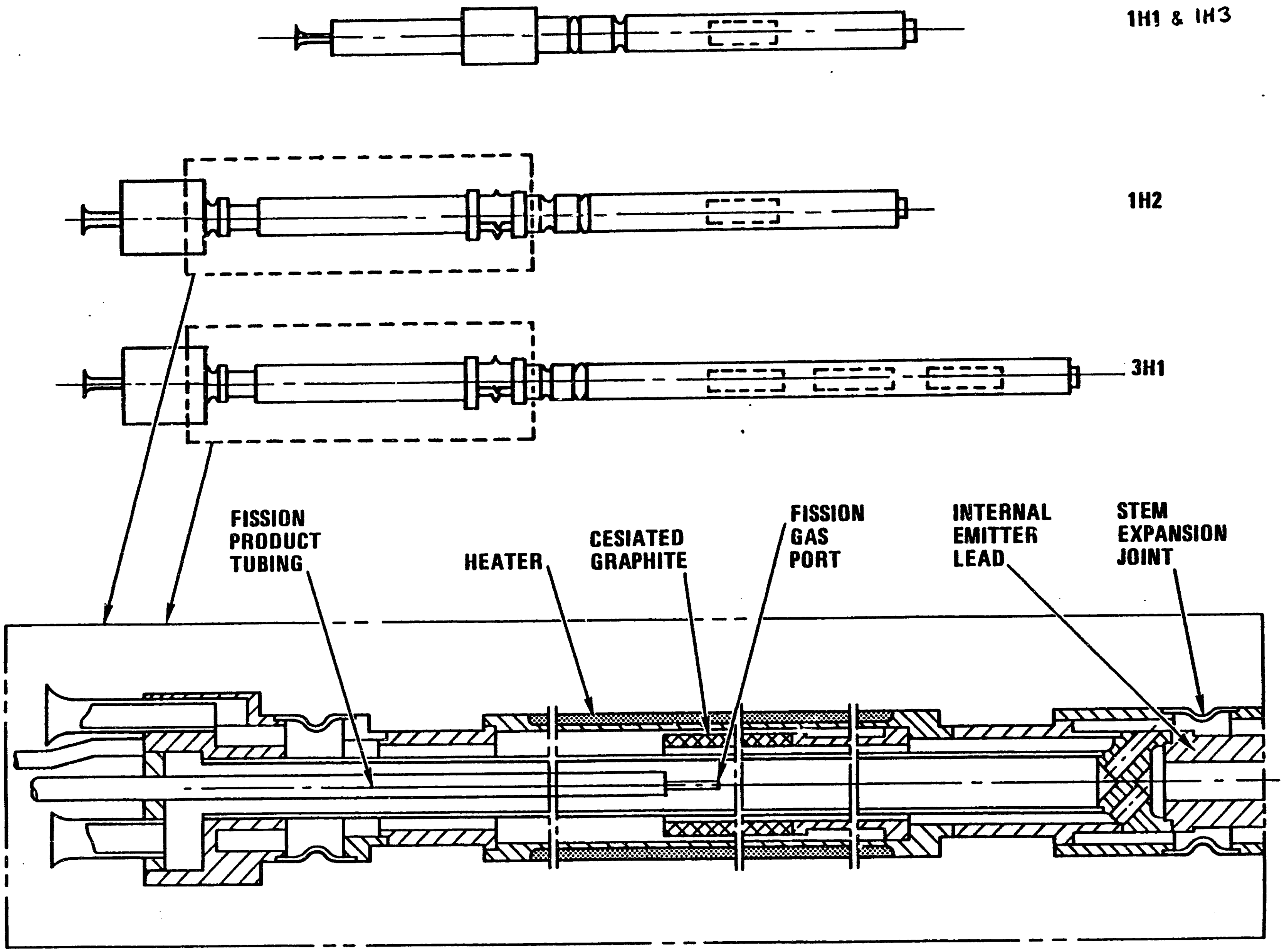

Fig. 8 - Graphite cesium reservoir

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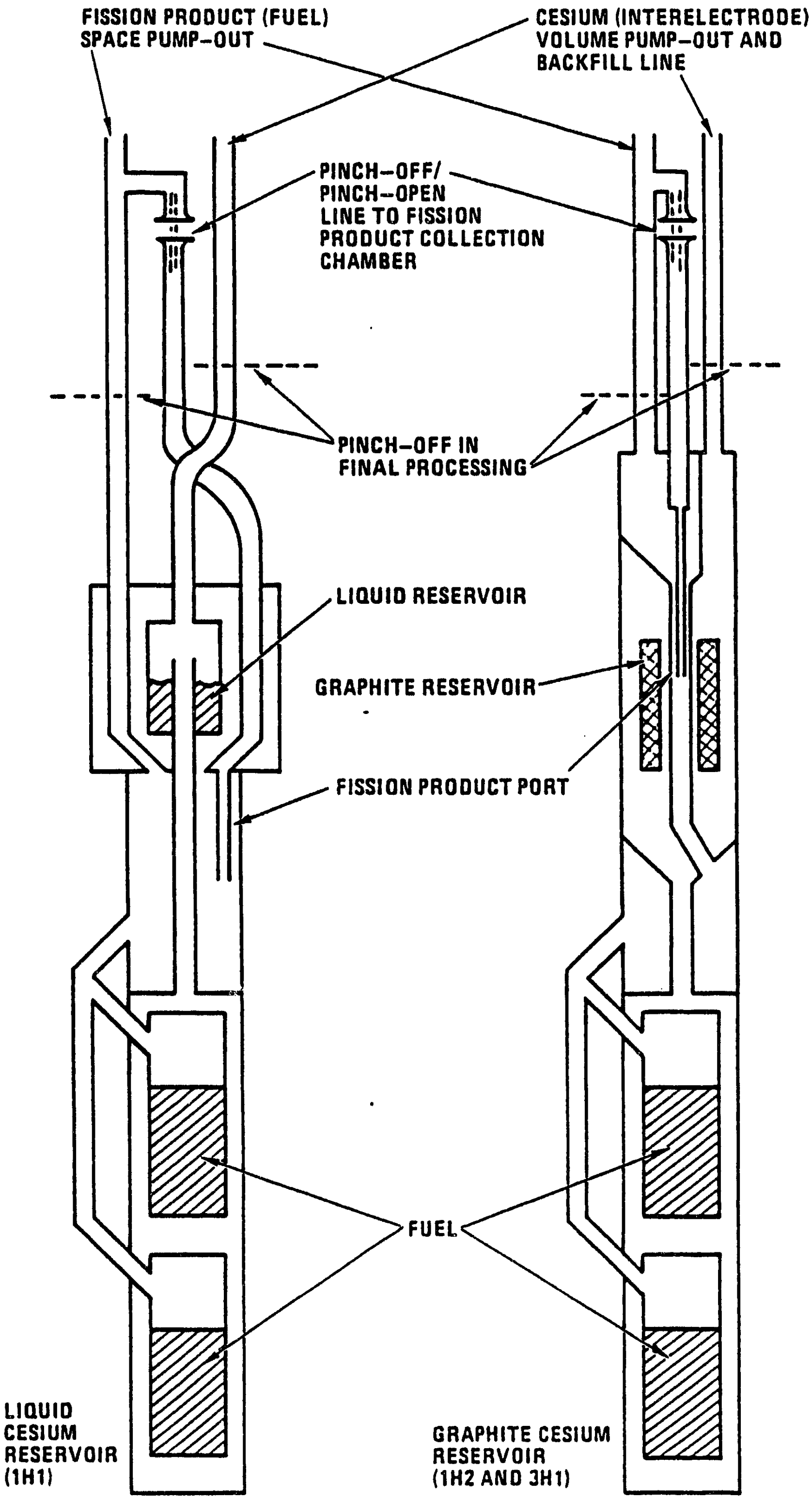

Figure 9 - Cesium and fission product plumbing

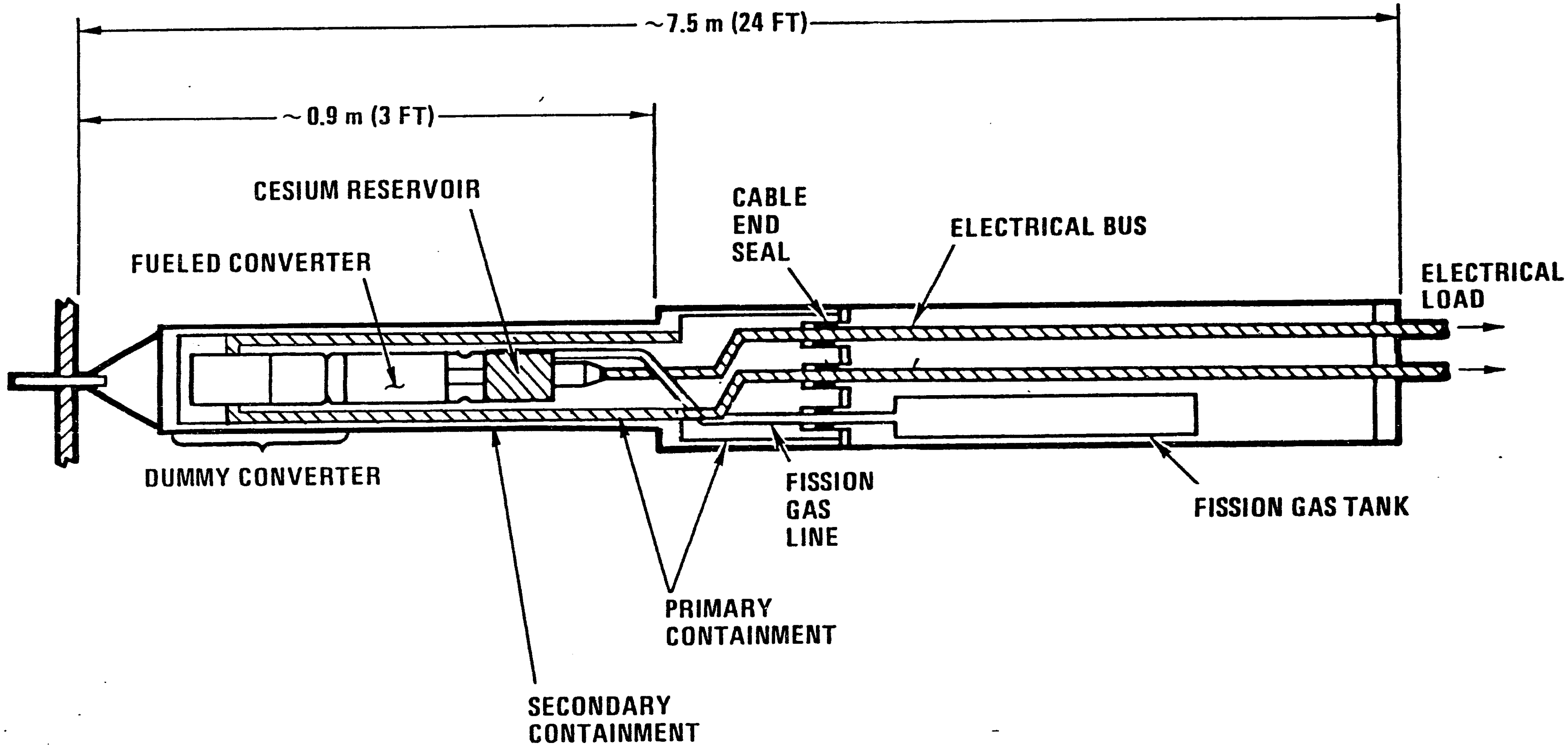

Fig. 10 - Capsule schematic (TFE 1H1)

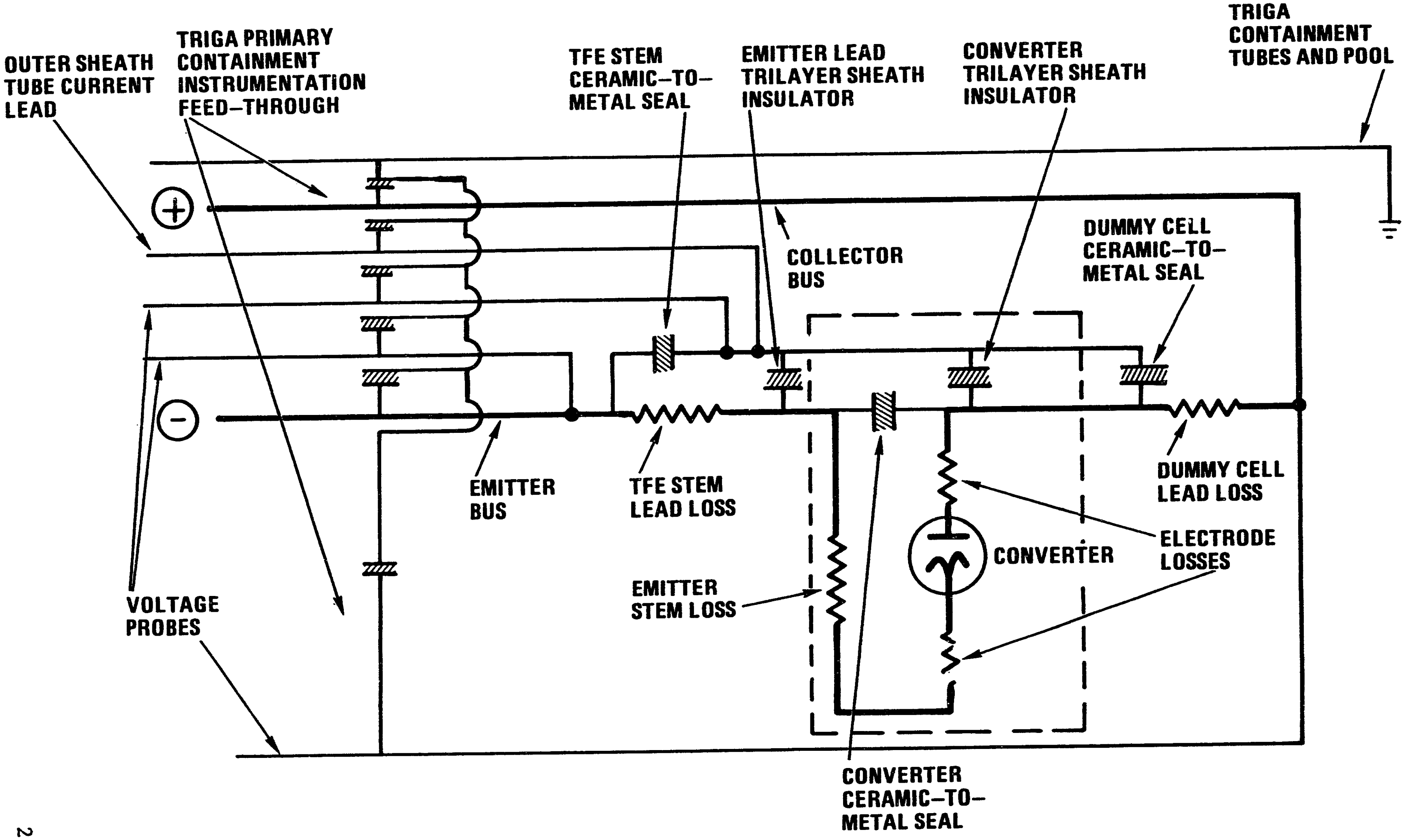

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Fig. 11 - TFE electrical schematic

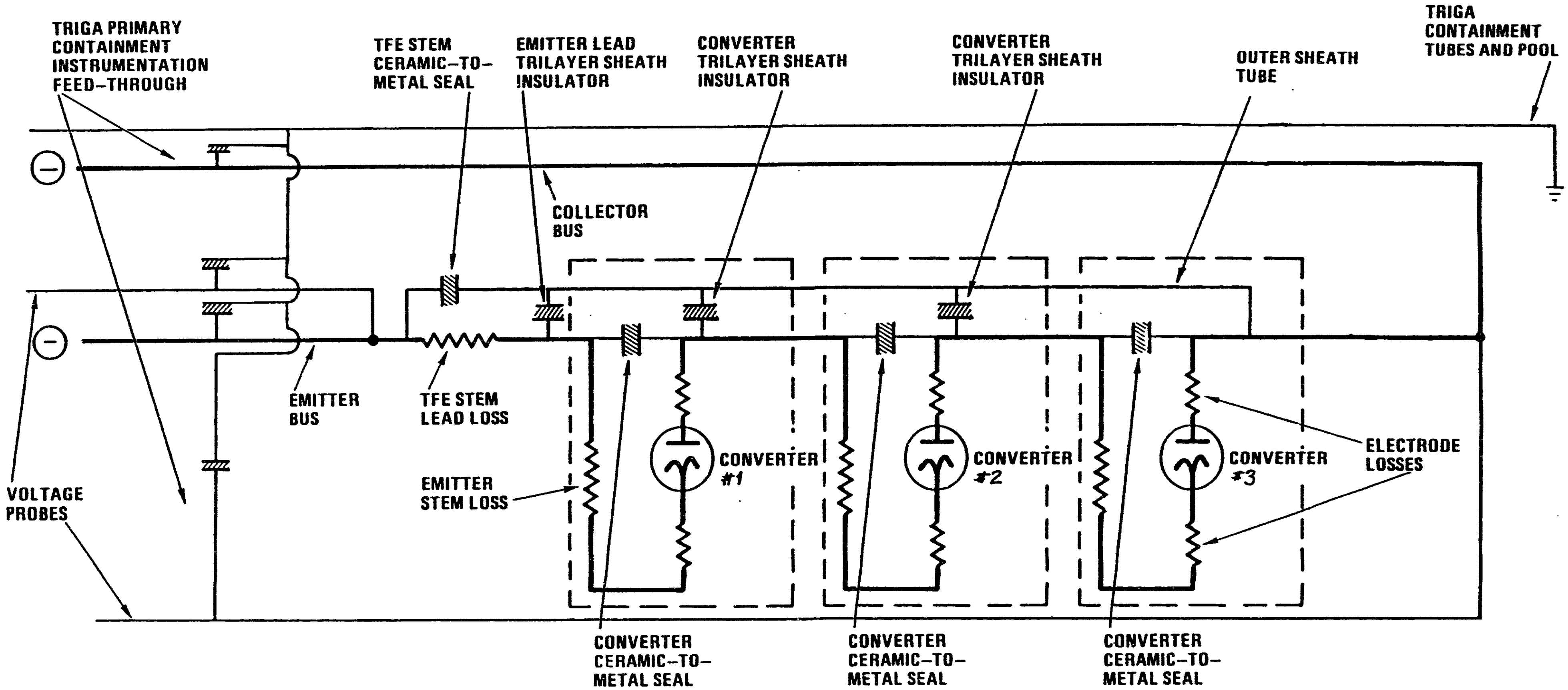

Fig. 12 - 3H TFE electrical schematic

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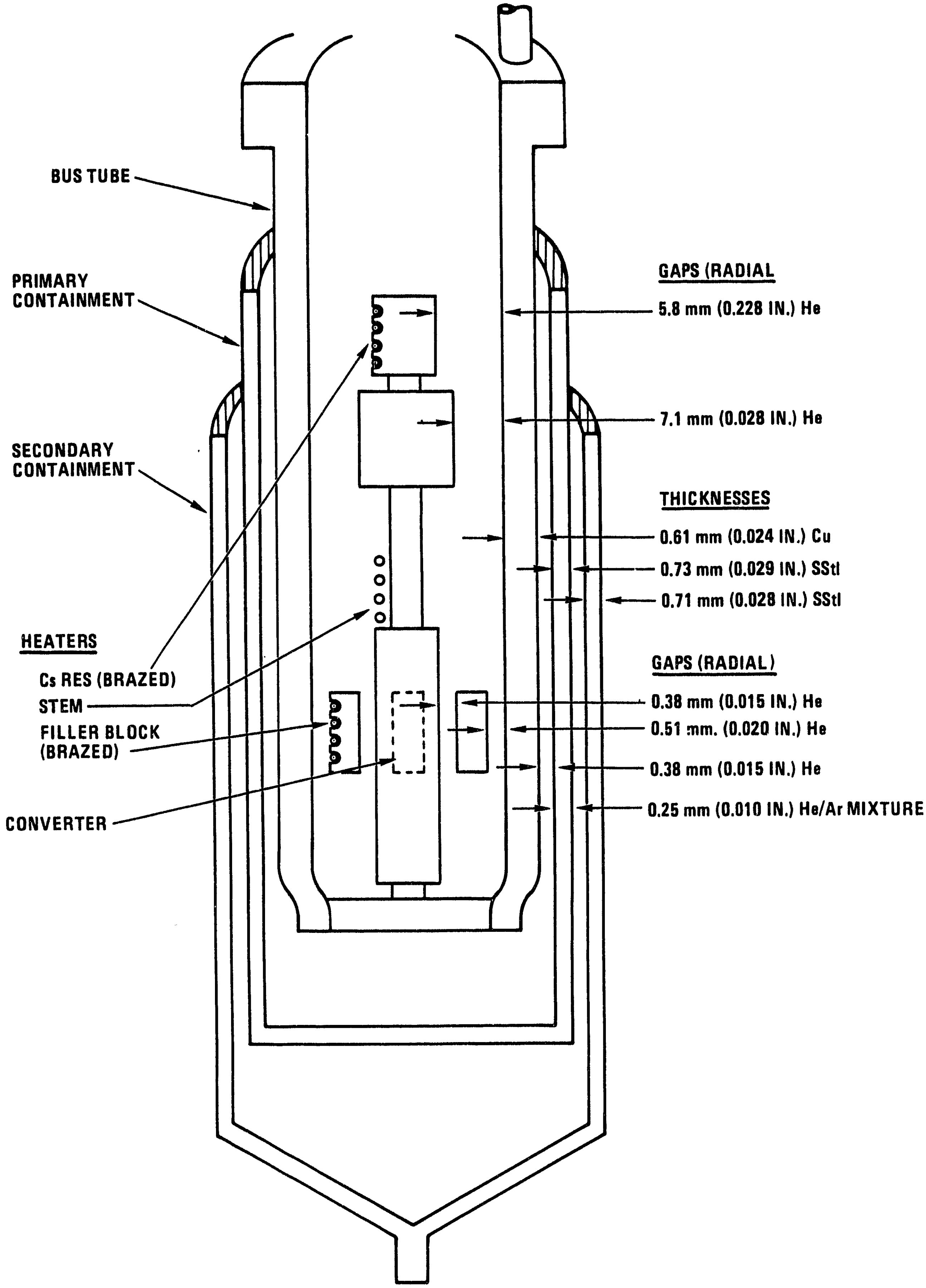

Fig. 13 - TFE with liquid reservoir-containment details

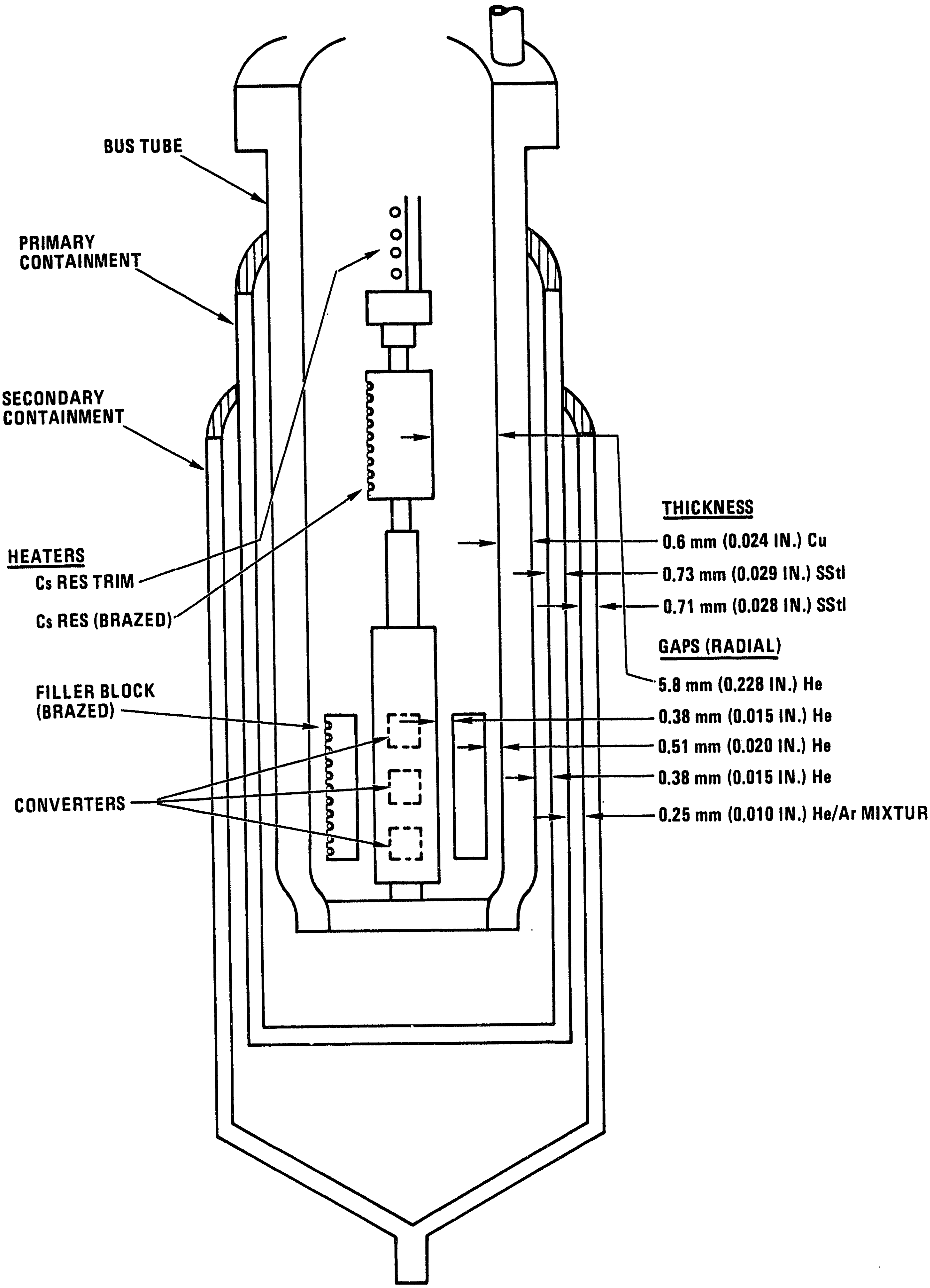

Fig. 14 - TFE with graphite reservoir-containment details

TABLE 1

LOCATIONS OF THERMOCOUPLES AND PROBES - TFEs 1H1 and 1H3

Thermocouple Number*	Location	Purpose
12	Top of Cs heater block	Cs heater feedback
11	Top of Cs reservoir block	Reservoir (top) end loss
10 9	In Cs reservoir block at approximately liquid level	Redundant temperature for Cs pressure
8	TFE stem just below reservoir	Reservoir bottom end loss
7	TFE stem seal	Monitor seal
6	TFE stem between seal and cell	Estimate cell top end loss and feedback to step heater
5	TFE outer sheath opposite emitter lead trilayer	Infer emitter temperature
4	In filler block at emitter midplane	Filler heater feedback
3 2	} TFE outer sheath at emitter midplane	Collector temperature and TRIGA reactor trip signal on high temperature
1	TFE outer sheath opposite dummy	Cell bottom end loss
Voltage Probe #1	Bottom of dummy cell at bus tube connection	Estimate collector voltage
Voltage Probe #2	Cs reservoir block	Emitter voltage
Voltage Probe #3	TFE stem adaptor just above joint to sheath	Sheath voltage
Current Probe	TFE stem adaptor just above joint to sheath	Impose voltage differential from sheath to emitter and collector

* Sheaths of T/Cs 1 thru 6 are at TFE sheath potential;
Sheaths of T/Cs 7 thru 12 are at emitter potential.

TABLE 2

LOCATIONS OF THERMOCOUPLES AND PROBES - TFE 1H2

Thermocouple Number*	Location	Purpose
12	Top of TFE on pinchoff tubes inside heater	Heater feedback (potential cold spot)
11	Top of TFE in lead cap	Alternate heater feedback
10	Reservoir envelope/heater at top end	Cs reservoir temperature uniformity
9, 8	Reservoir midplane	Cs heater feedback, Cs reservoir temp.
7	Reservoir envelope/heater at bottom end	Cs reservoir temperature uniformity
6	TFE stem between seal and cell	Cell top end loss
5	TFE outer sheath opposite emitter lead trilayer	Infer emitter temperature
4	In filler block at emitter midplane	Filler heater feedback
3, 2	TFE outer sheath at emitter midplane	Collector temperature and TRIGA reactor trip signal on high temperature
1	TFE outer sheath opposite dummy	Cell bottom end loss
Voltage Probe #1	Top of dummy cell under alignment insulator	Collector voltage
Voltage Probe #2	Cap above stem seal	Emitter voltage
Voltage Probe #3	TFE stem adaptor just above joint to sheath	Sheath voltage

* Sheaths of T/Cs 1 thru 6 are at TFE sheath potential;
Sheaths of T/Cs 7 thru 12 are at emitter potential.

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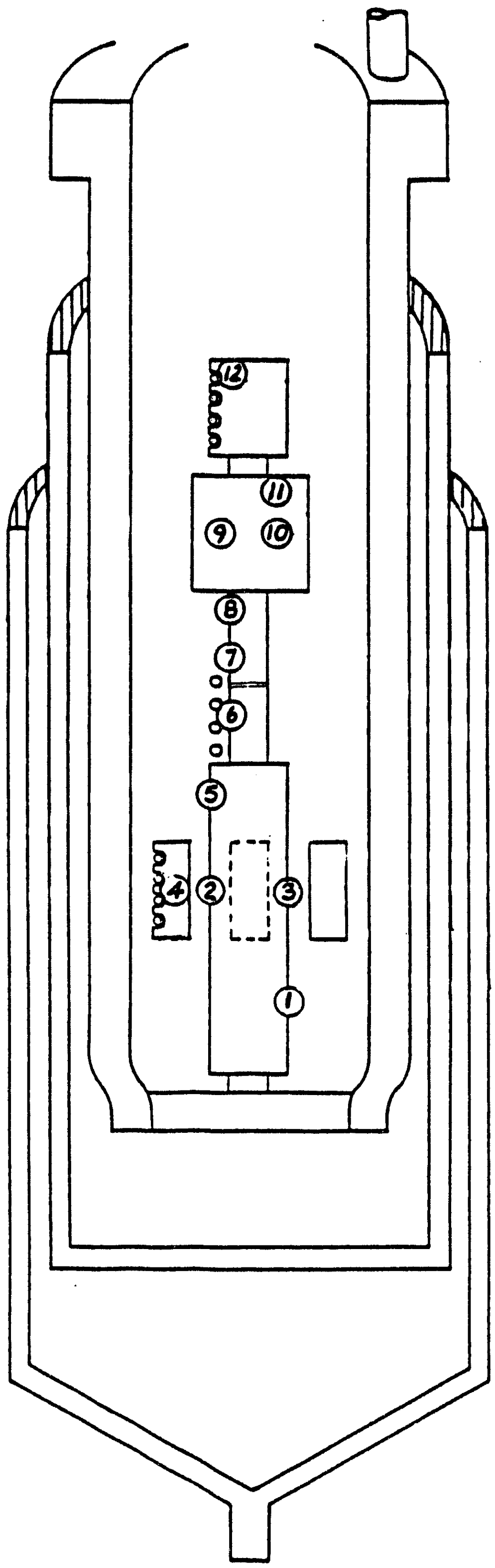

Fig. 15 - TFE 1H1 and 1H3 thermocouple locations

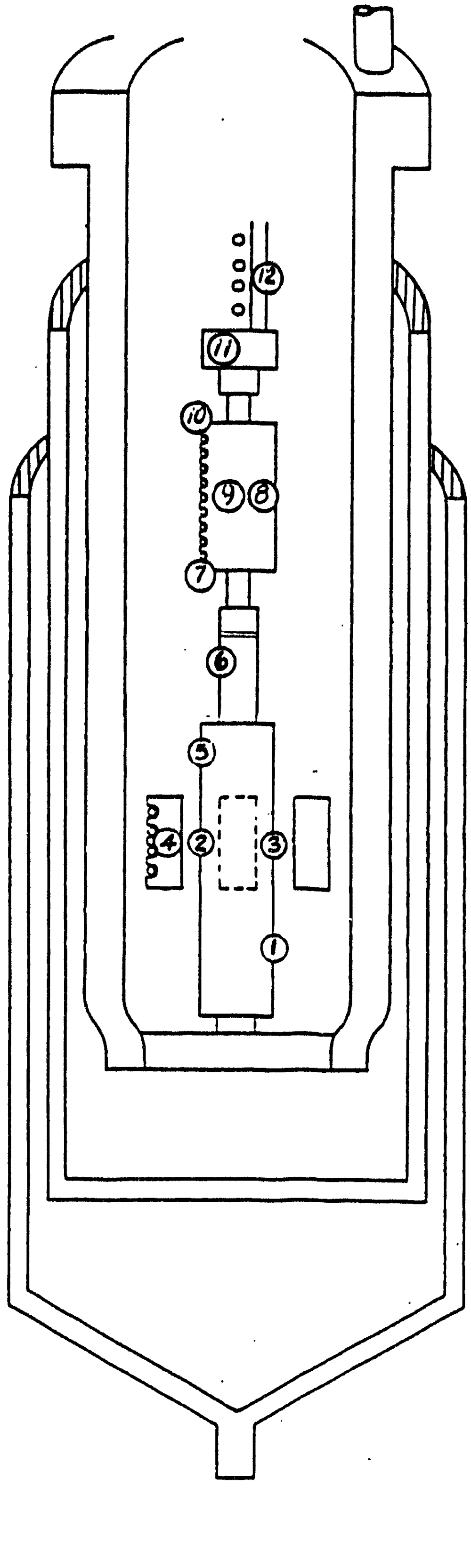

Fig. 16 - TFE 1H2 thermocouple locations

TABLE 3

LOCATIONS OF THERMOCOUPLES AND PROBES - TFE 3H1

Thermocouple Number*	Location	Purpose
16	Top of TFE on pinchoff tubes inside heater	Heater feedback (potential cold spot)
15	Top of TFE in lead cap	Alternate heater feedback
14	Reservoir envelope/heater at top end	Cs reservoir temperature uniformity
13, 12	Reservoir midplane	Cs heater feedback, Cs reservoir temp.
11	Reservoir envelope/heater at bottom end	Cs reservoir temperature uniformity
10	TFE outer sheath opposite emitter lead trilayer	Infer emitter temperature at top cell
9, 8	TFE outer sheath at emitter midplane, top cell	Collector temperature
7, 6	In filler block at TFE midplane	Filler heater feedback
5	TFE outer sheath at emitter midplane, middle cell	Collector temperature and TRIGA reactor trip signal on high temperature
3	TFE outer sheath at emitter midplane, bottom cell	Collector temperature
1	Bottom of bottom cell collector	Cell bottom end loss
Voltage Probe #1	Bottom of bottom cell collector	Collector voltage
Voltage Probe #2	Cap above stem seal	Emitter voltage

* Sheaths of T/Cs 1 thru 10 are at TFE sheath potential;
Sheaths of T/Cs 11 thru 16 are at emitter potential.

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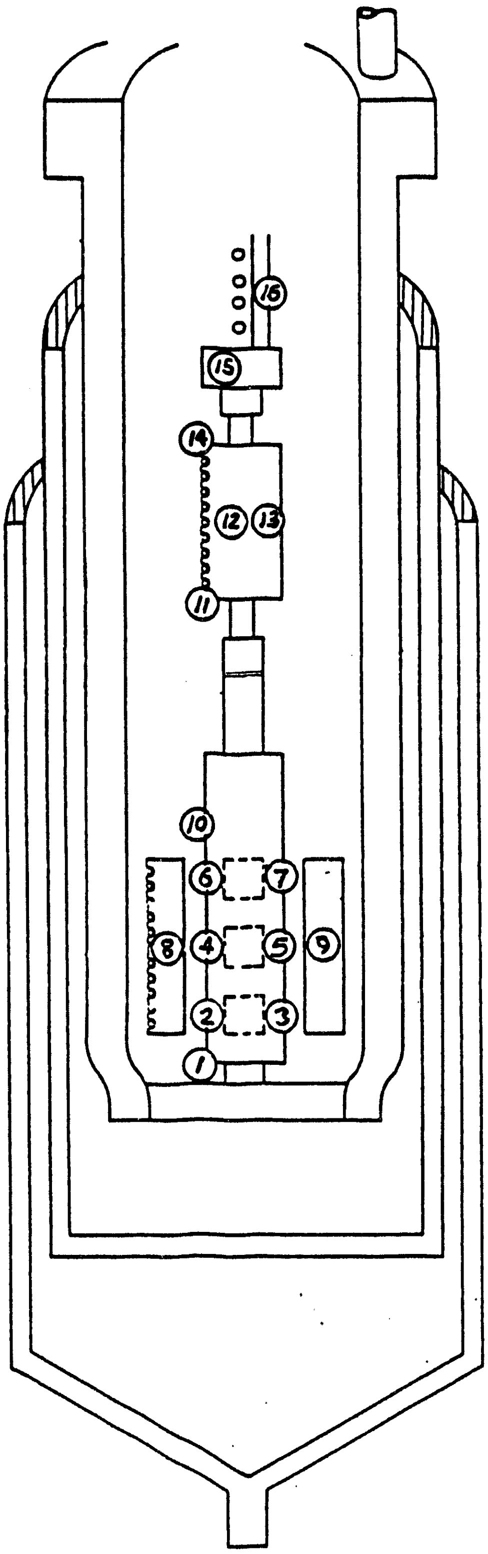
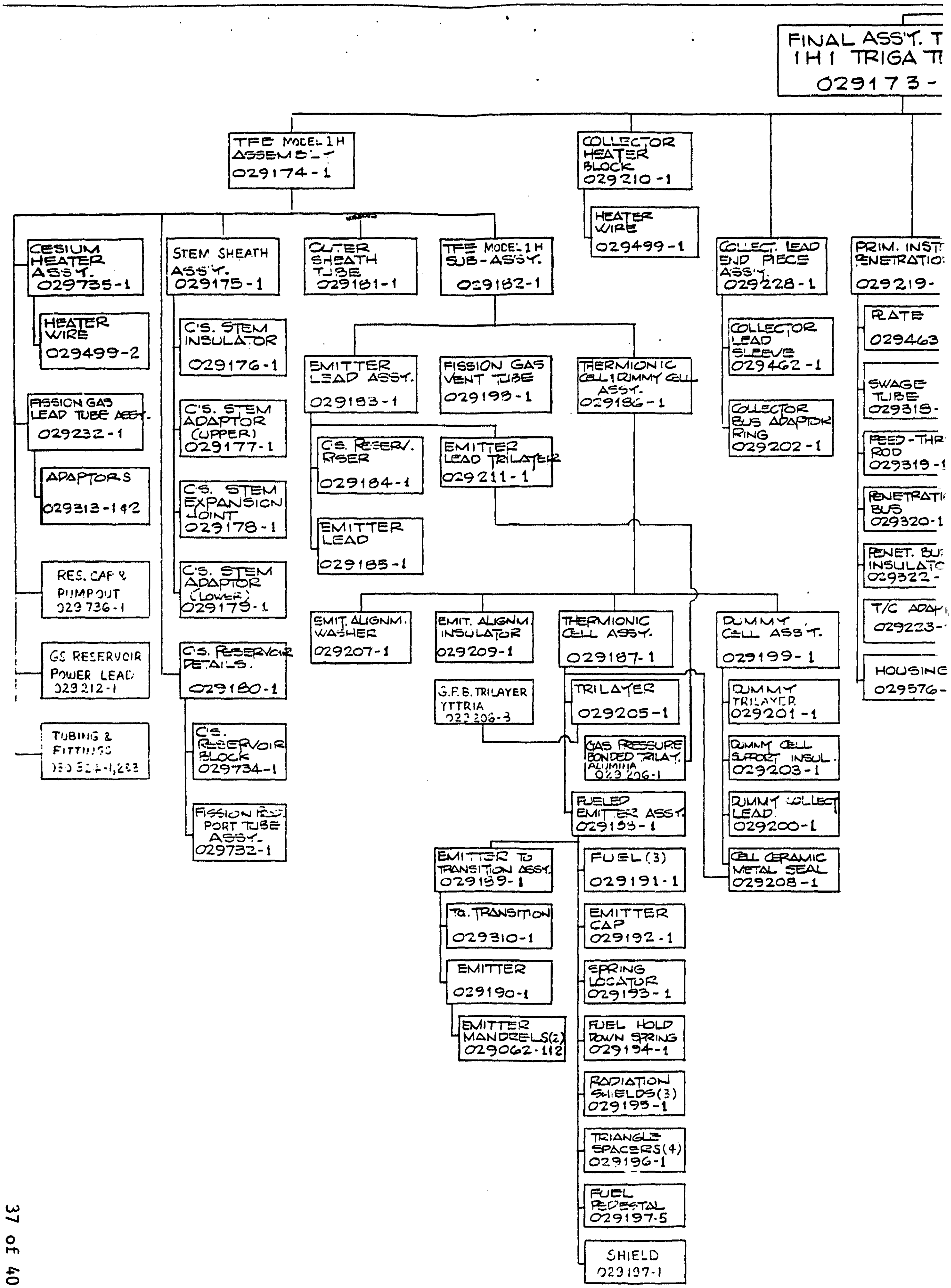


Fig. 17 - TFE 3H1 thermocouple locations

TABLE 4

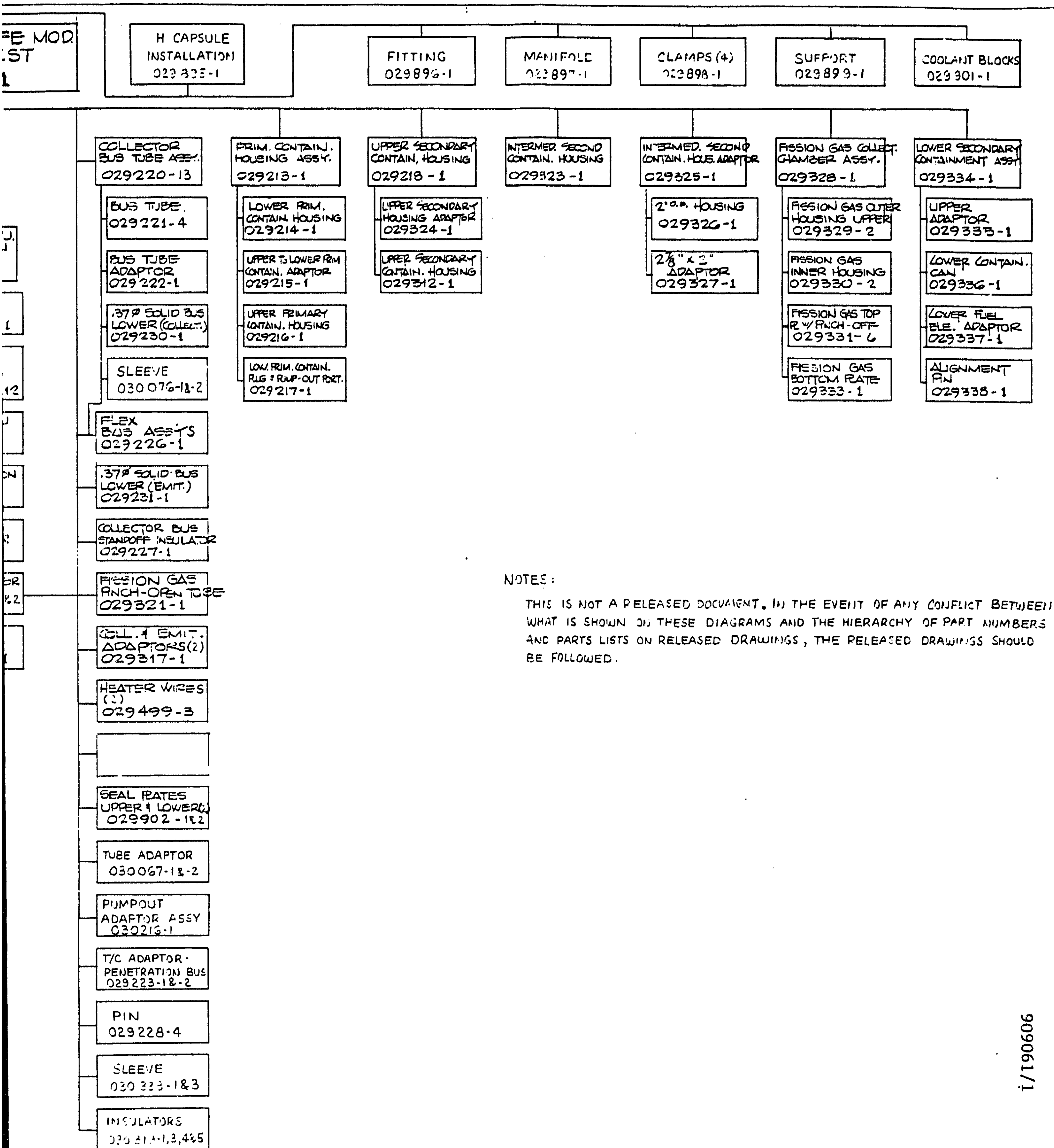
TFE DESIGN FEATURES DIFFERING BETWEEN TESTS

	1H1	1H2	1H3	3H1
Converter(s)				
Number of converters	1	1	1	3
Mixed cesium and fission product spaces	No	No	Yes	No
Solid fission product trap in emitter(s)	No	No	Yes, but not prototype	Yes, but not prototype
Alignment configuration	Loose ceramic & single coned washer spring	Loose ceramic & single coned washer spring	Loose ceramic & single coned washer spring	Bonded ceramic and welded double washers
Converter trilayer ceramic	Y_2O_3	Al_2O_3	Al_2O_3	Al_2O_3
Fuel support pedestal	2-piece	1-piece	1-piece	1-piece
TFE Above and Below Converter(s)				
Cesium reservoir	Liquid	Graphite	Liquid	Graphite
Thicker lead trilayer lead section	No	Yes	No	Yes
Dummy at bottom end (and floating potential)	Yes, long	Yes, long	Yes, short	No
Test Vehicle				
Number of voltage probes	3	3	3	2
Number of thermocouples	12	12	12	16
Fission product collection chamber gauge	No	No	No	Yes
Primary containment length	Short	Long	Long	Long
Heater wire o.d. [mm (in.)]	1.8 (.070)	1.8 (.070)	1.8 (.070)	1.6 (.062)



FINAL ASS'Y. T
1H1 TRIGA T
029173-
TFE MODEL 1H ASSEMBLY
029174-1
COLLECTOR HEATER BLOCK
029210-1
HEATER WIRE
029499-1
COLLECT. LEAD END PIECE ASS'Y.
029228-1
PRIM. INST PENETRATIO
029219-
CESIUM HEATER ASSY.
029735-1
STEM SHEATH ASSY.
029175-1
OUTER SHEATH TUBE
029181-1
TFE MODEL 1H SUB-ASSY.
029182-1
HEATER WIRE
029499-2
C'S. STEM INSULATOR
029176-1
EMITTER LEAD ASSY.
029183-1
FISSION GAS VENT TUBE
029198-1
THERMIONIC CELL & DUMMY CELL ASSY.
029186-1
COLLECTOR LEAD SLEEVE
029462-1
RATE
029463
SWAGE TUBE
029318-
FISSION GAS LEAD TUBE ASSY.
029232-1
C'S. STEM ADAPTOR (UPPER)
029177-1
C'S. RESERV. RISER
029184-1
EMITTER LEAD TRILAYER
029211-1
COLLECTOR BUS ADAPTOR RING
029202-1
FEED-THR ROD
029319-
APAPTORS
029313-1&2
C'S. STEM EXPANSION JOINT
029178-1
PENETRATI BUS
029320-1
EMITTER LEAD
029185-1
PENET. BU INSULATO
029322-
RES. CAP & PUMP OUT
029736-1
C'S. STEM ADAPTOR (LOWER)
029179-1
T/C ADAP
029223-
EMIT. ALIGNM. WASHER
029207-1
EMIT. ALIGNM. INSULATOR
029209-1
THERMIONIC CELL ASSY.
029187-1
DUMMY CELL ASS'T.
029199-1
CS RESERVOIR POWER LEAD
029212-1
C'S. RESERVOIR DETAILS.
029180-1
HOUSING
029576-
G.F.B. TRILAYER YTTRIA
029206-3
TRILAYER
029205-1
DUMMY TRILAYER
029201-1
TUBING & FITTINGS
TUBING & FITTINGS
C'S. RESERVOIR BLOCK
029734-1
GAS PRESSURE BONDED TRILAY. ALUMINA
029206-1
DUMMY CELL SUPPORT INSUL.
029203-1
FUELED EMITTER ASSY.
029188-1
DUMMY COLLECT LEAD
029200-1
FISSION PRODUCT PORT TUBE ASSY.
029732-1
EMITTER TO TRANSITION ASSY.
029189-1
FUEL (3)
029191-1
CELL CERAMIC METAL SEAL
029208-1
Ta. TRANSITION
029310-1
EMITTER CAP
029192-1
EMITTER
029190-1
SPRING LOCATOR
029193-1
EMITTER MANDRELS (2)
029062-1&2
FUEL HOLD DOWN SPRING
029194-1
RADIATION SHIELDS (3)
029195-1
TRIANGLE SPACERS (4)
029196-1
FUEL PEDESTAL
029197-5
SHIELD
029197-1

Fig. 18 - TFE



NOTES:

THIS IS NOT A RELEASED DOCUMENT. IN THE EVENT OF ANY CONFLICT BETWEEN WHAT IS SHOWN ON THESE DIAGRAMS AND THE HIERARCHY OF PART NUMBERS AND PARTS LISTS ON RELEASED DRAWINGS, THE RELEASED DRAWINGS SHOULD BE FOLLOWED.

1H1 Drawing Tree

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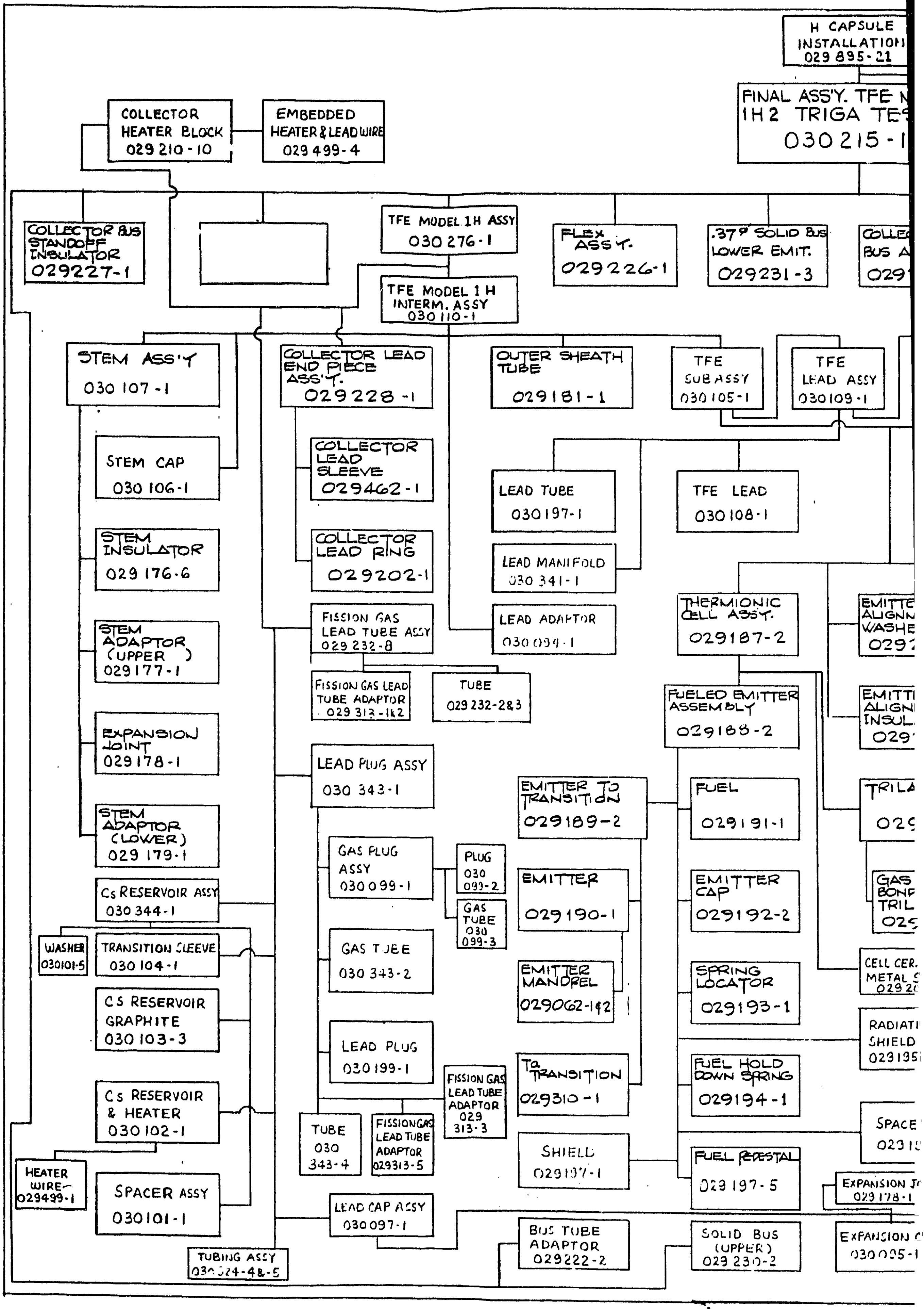
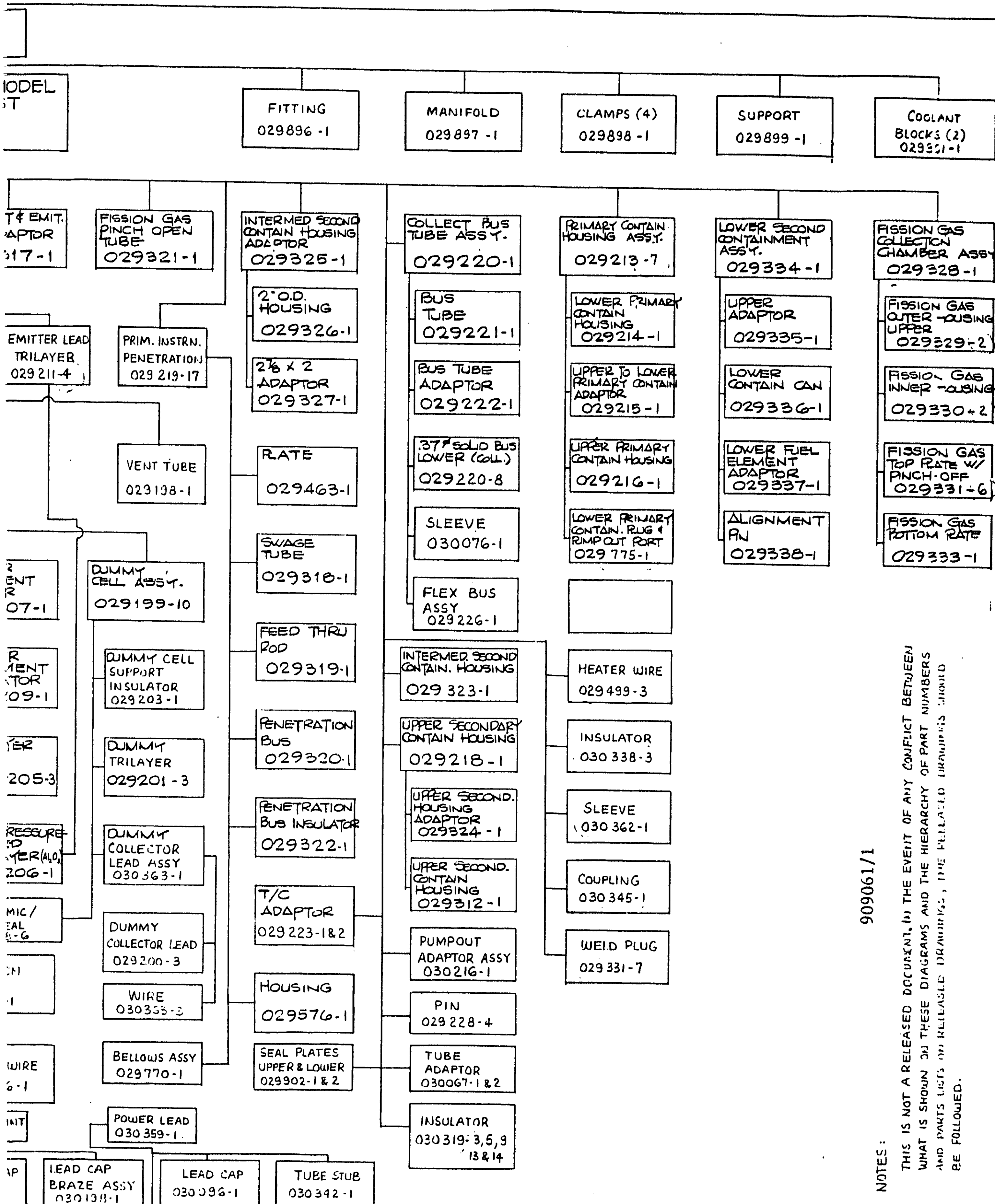

H CAPSULE INSTALLATION 029 895-21
FINAL ASS'Y. TFE N
1H2 TRIGA TES
030 215-1
COLLECTOR HEATER BLOCK 029 210-10
EMBEDDED HEATER & LEAD WIRE 029 499-4
COLLECTOR BUS STANDOFF INSULATOR 029227-1
TFE MODEL 1H ASSY 030 276-1
TFE MODEL 1H INTERM. ASSY 030 110-1
FLEX ASSY. 029226-1
.379 SOLID BUS LOWER EMIT. 029231-3
COLLEC BUS A 029
STEM ASS'Y 030 107-1
COLLECTOR LEAD END PIECE ASS'Y. 029228-1
OUTER SHEATH TUBE 029181-1
TFE SUB ASSY 030 105-1
TFE LEAD ASSY 030 109-1
STEM CAP 030 106-1
COLLECTOR LEAD SLEEVE 029462-1
LEAD TUBE 030 197-1
TFE LEAD 030 108-1
STEM INSULATOR 029 176-6
COLLECTOR LEAD RING 029202-1
LEAD MANIFOLD 030 341-1
STEM ADAPTOR (UPPER) 029177-1
FISSION GAS LEAD TUBE ASSY 029 232-8
LEAD ADAPTOR 030 099-1
THERMIONIC CELL ASSY. 029187-2
EMITTE ALIGNM WASHE 029
FISSION GAS LEAD TUBE ADAPTOR 029 313-1&2
TUBE 029 232-2&3
FUELED EMITTER ASSEMBLY 029188-2
EMITTI ALIGNI INSUL. 029
EXPANSION JOINT 029178-1
LEAD PLUG ASSY 030 343-1
EMITTER TO TRANSITION 029189-2
FUEL 029191-1
TRILA 029
STEM ADAPTOR (LOWER) 029 179-1
GAS PLUG ASSY 030 099-1
PLUG 030 099-2
GAS TUBE 030 099-3
EMITTER 029190-1
EMITTER CAP 029192-2
GAS BOND TRIL 029
Cs RESERVOIR ASSY 030 344-1
WASHER 030101-5
TRANSITION SLEEVE 030 104-1
GAS TUBE 030 343-2
EMITTER MANDREL 029062-1&2
SPRING LOCATOR 029193-1
CELL CER. METAL S 029 2
RADIATI SHIELD 029195
CS RESERVOIR GRAPHITE 030 103-3
LEAD PLUG 030 199-1
FISSION GAS LEAD TUBE ADAPTOR 029 313-3
To TRANSITION 029310-1
FUEL HOLD DOWN SPRING 029194-1
Cs RESERVOIR & HEATER 030 102-1
TUBE 030 343-4
FISSION GAS LEAD TUBE ADAPTOR 029313-5
SHIELD 029197-1
FUEL PEDESTAL 029 197-5
SPACE 0231
HEATER WIRE 029499-1
SPACER ASSY 030101-1
LEAD CAP ASSY 030097-1
EXPANSION J 029 178-1
BUS TUBE ADAPTOR 029222-2
SOLID BUS (UPPER) 029 230-2
EXPANSION C 030 095-1
TUBING ASSY 030 [illegible]24-4&-5



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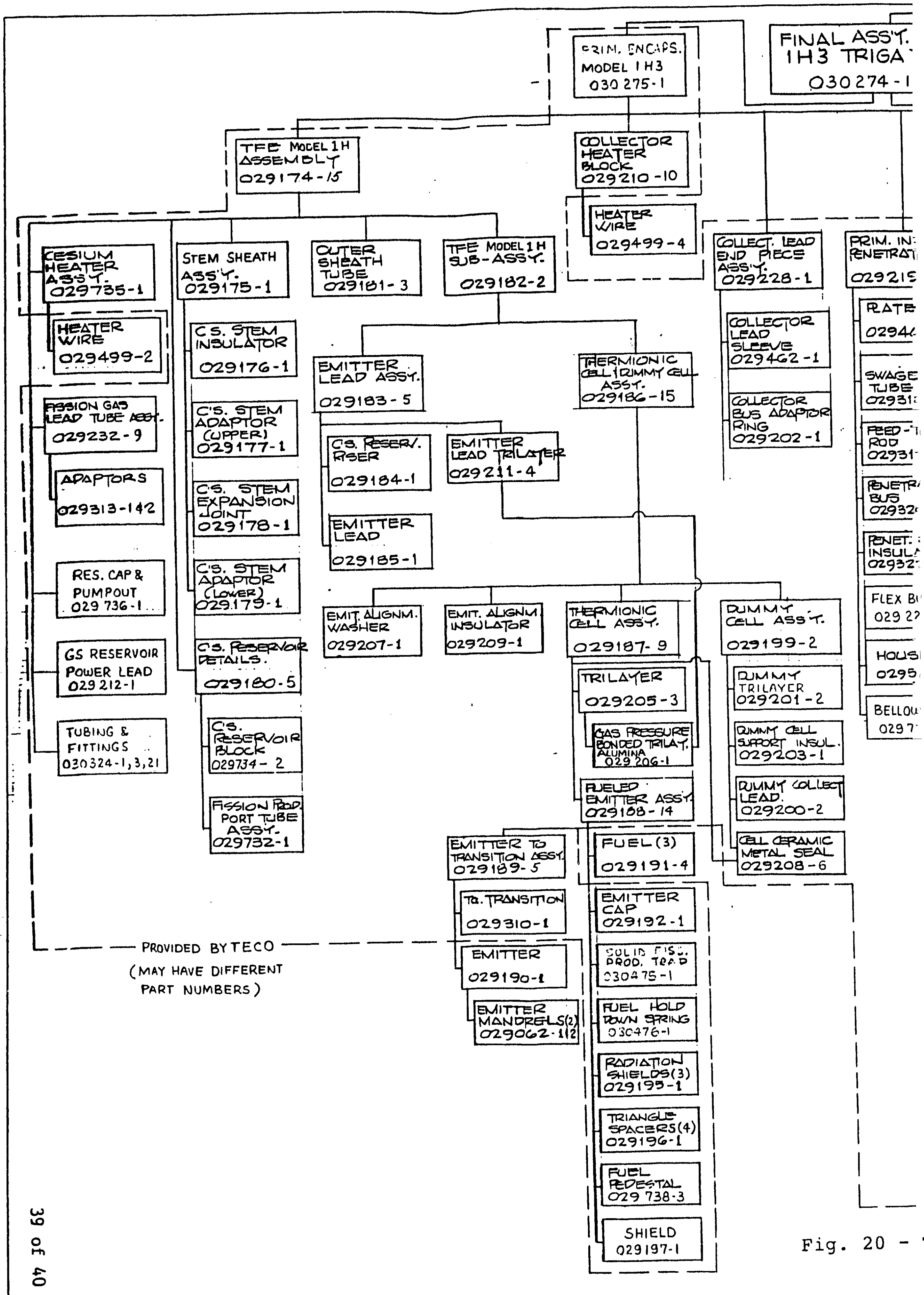
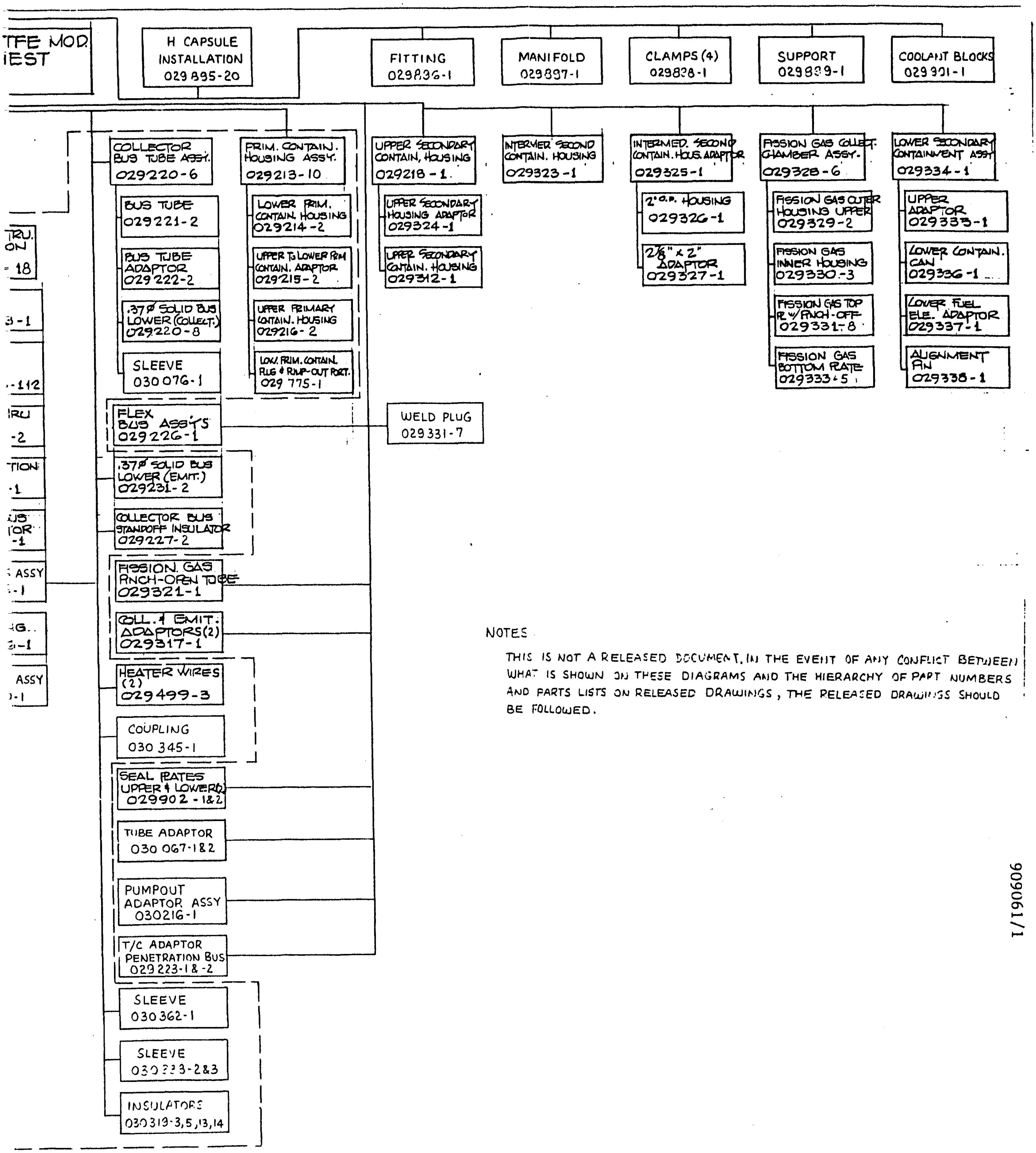
NOTES:
THIS IS NOT A RELEASED DOCUMENT. IN THE EVENT OF ANY CONFLICT BETWEEN WHAT IS SHOWN ON THESE DIAGRAMS AND THE HIERARCHY OF PART NUMBERS AND PARTS LISTS ON RELEASED DRAWINGS, THE RELEASED DRAWINGS SHOULD BE FOLLOWED.

Fig. 19 - TFE 1H2 Drawing Tree



FINAL ASSY.
1H3 TRIGA
030274-1
PRIM. ENCAPS. MODEL 1H3
030 275-1
TFE MODEL 1H ASSEMBLY
029174-15
COLLECTOR HEATER BLOCK
029210-10
HEATER WIRE
029499-4
CESIUM HEATER ASSY.
029735-1
STEM SHEATH ASS'Y.
029175-1
OUTER SHEATH TUBE
029181-3
TFE MODEL 1H SUB-ASSY.
029182-2
COLLECT. LEAD END PIECE ASSY.
029228-1
HEATER WIRE
029499-2
C.S. STEM INSULATOR
029176-1
EMITTER LEAD ASSY.
029183-5
THERMIONIC CELL (DUMMY CELL ASSY.
029186-15
COLLECTOR LEAD SLEEVE
029462-1
COLLECTOR BUS ADAPTOR RING
029202-1
FISSION GAS LEAD TUBE ASSY.
029232-9
C'S. STEM ADAPTOR (UPPER)
029177-1
C.S. RESERV. RISER
029184-1
EMITTER LEAD TRILAYER
029211-4
ADAPTORS
029313-1&2
C.S. STEM EXPANSION JOINT
029178-1
EMITTER LEAD
029185-1
RES. CAP & PUMPOUT
029 736-1
C'S. STEM ADAPTOR (LOWER)
029179-1
EMIT. ALIGNM. WASHER
029207-1
EMIT. ALIGNM. INSULATOR
029209-1
THERMIONIC CELL ASSY.
029187-9
DUMMY CELL ASS'Y.
029199-2
GS RESERVOIR POWER LEAD
029 212-1
C.S. RESERVOIR DETAILS.
029180-5
TRILAYER
029205-3
DUMMY TRILAYER
029201-2
GAS PRESSURE BONDED TRILAY. ALUMINA
029 206-1
DUMMY CELL SUPPORT INSUL.
029203-1
TUBING & FITTINGS
030324-1,3,21
C'S. RESERVOIR BLOCK
029734-2
FUELED EMITTER ASSY.
029188-14
DUMMY COLLECT. LEAD.
029200-2
FISSION PROD. PORT TUBE ASSY.
029732-1
EMITTER TO TRANSITION ASSY.
029189-5
FUEL (3)
029191-4
CELL CERAMIC METAL SEAL
029208-6
TA. TRANSITION
029310-1
EMITTER CAP
029192-1
PROVIDED BY TECO
(MAY HAVE DIFFERENT PART NUMBERS)
EMITTER
029190-1
SOLID FISS. PROD. TRAP
030475-1
EMITTER MANDRELS(2)
029062-1&2
FUEL HOLD DOWN SPRING
030476-1
RADIATION SHIELDS(3)
029195-1
TRIANGLE SPACERS(4)
029196-1
FUEL PEDESTAL
029 738-3
SHIELD
029197-1

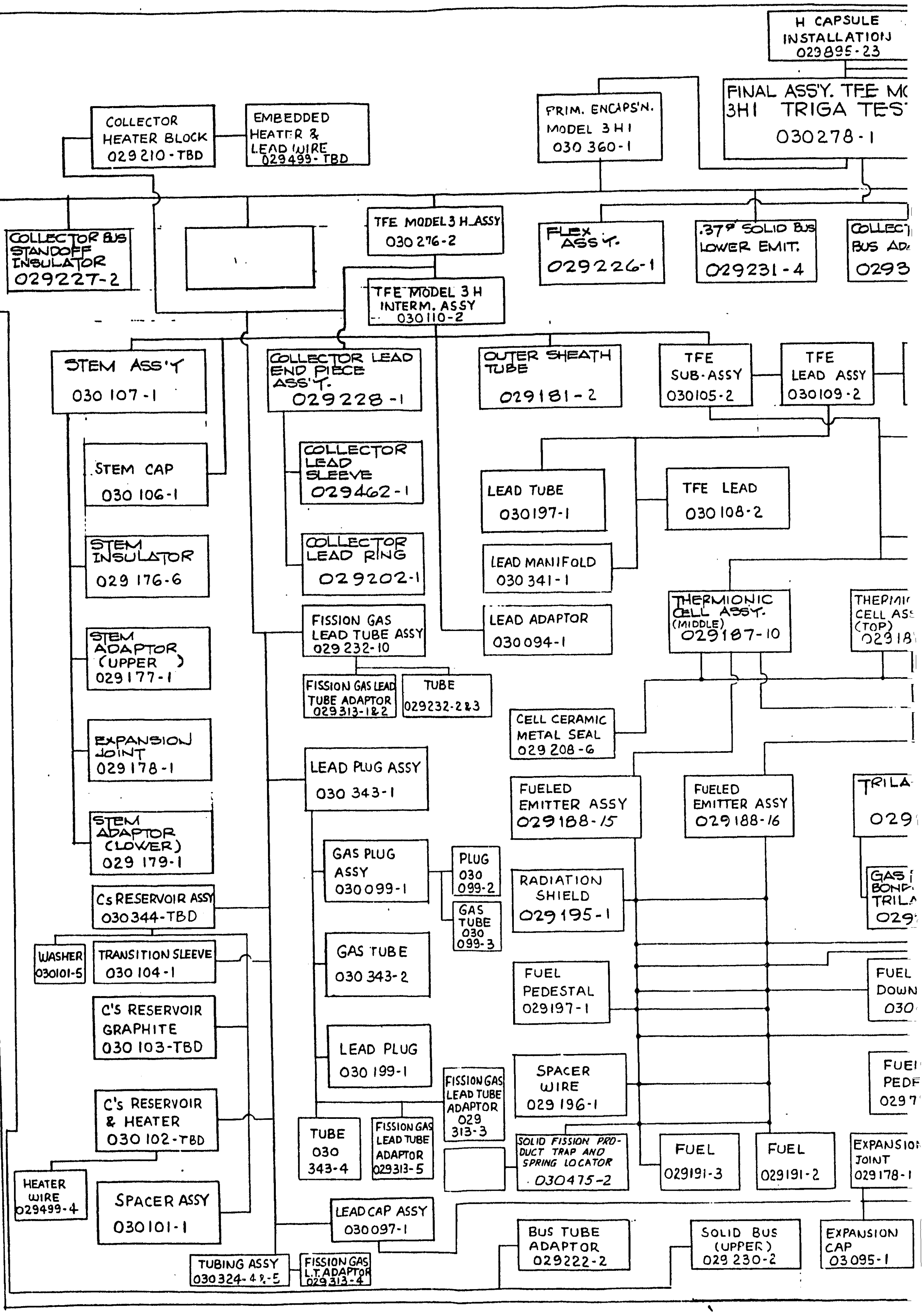
Fig. 20 -



NOTES

THIS IS NOT A RELEASED DOCUMENT. IN THE EVENT OF ANY CONFLICT BETWEEN WHAT IS SHOWN ON THESE DIAGRAMS AND THE HIERARCHY OF PART NUMBERS AND PARTS LISTS ON RELEASED DRAWINGS, THE RELEASED DRAWINGS SHOULD BE FOLLOWED.

FE 1H3 Drawing Tree


H CAPSULE INSTALLATION 029895-23
FINAL ASSY. TFE MC 3HI TRIGA TES 030278-1
PRIM. ENCAPS'N. MODEL 3HI 030 360-1
COLLECTOR HEATER BLOCK 029210-TBD
EMBEDDED HEATER & LEAD WIRE 029499-TBD
COLLECTOR BUS STANDOFF INSULATOR 029227-2
TFE MODEL 3 H ASSY 030 276-2
FLEX ASSY. 029226-1
.379 SOLID BUS LOWER EMIT. 029231-4
COLLECT BUS AD 0293
TFE MODEL 3 H INTERM. ASSY 030110-2
STEM ASS'Y 030 107-1
COLLECTOR LEAD END PIECE ASS'Y. 029228-1
OUTER SHEATH TUBE 029181-2
TFE SUB-ASSY 030105-2
TFE LEAD ASSY 030109-2
STEM CAP 030 106-1
COLLECTOR LEAD SLEEVE 029462-1
LEAD TUBE 030197-1
TFE LEAD 030 108-2
STEM INSULATOR 029 176-6
COLLECTOR LEAD RING 029202-1
LEAD MANIFOLD 030 341-1
FISSION GAS LEAD TUBE ASSY 029 232-10
LEAD ADAPTOR 030094-1
THERMIONIC CELL ASSY. (MIDDLE) 029187-10
THERMIC CELL ASS (TOP) 02918
STEM ADAPTOR (UPPER) 029177-1
FISSION GAS LEAD TUBE ADAPTOR 029313-1&2
TUBE 029232-2&3
CELL CERAMIC METAL SEAL 029 208-6
EXPANSION JOINT 029178-1
LEAD PLUG ASSY 030 343-1
FUELED EMITTER ASSY 029188-15
FUELED EMITTER ASSY 029188-16
TRILA 029
STEM ADAPTOR (LOWER) 029 179-1
GAS PLUG ASSY 030099-1
PLUG 030 099-2
GAS TUBE 030 099-3
RADIATION SHIELD 029195-1
GAS BOND TRILA 029
Cs RESERVOIR ASSY 030344-TBD
WASHER 030101-5
TRANSITION SLEEVE 030 104-1
GAS TUBE 030 343-2
FUEL PEDESTAL 029197-1
FUEL DOWN 030
C'S RESERVOIR GRAPHITE 030 103-TBD
LEAD PLUG 030 199-1
FISSION GAS LEAD TUBE ADAPTOR 029 313-3
SPACER WIRE 029 196-1
FUEL PEDE 0297
C's RESERVOIR & HEATER 030 102-TBD
TUBE 030 343-4
FISSION GAS LEAD TUBE ADAPTOR 029313-5
SOLID FISSION PRODUCT TRAP AND SPRING LOCATOR 030475-2
FUEL 029191-3
FUEL 029191-2
EXPANSION JOINT 029178-1
HEATER WIRE 029499-4
SPACER ASSY 030101-1
LEAD CAP ASSY 030097-1
BUS TUBE ADAPTOR 029222-2
SOLID BUS (UPPER) 029 230-2
EXPANSION CAP 03095-1
TUBING ASSY 030324-4 & -5
FISSION GAS L.T. ADAPTOR 029313-4

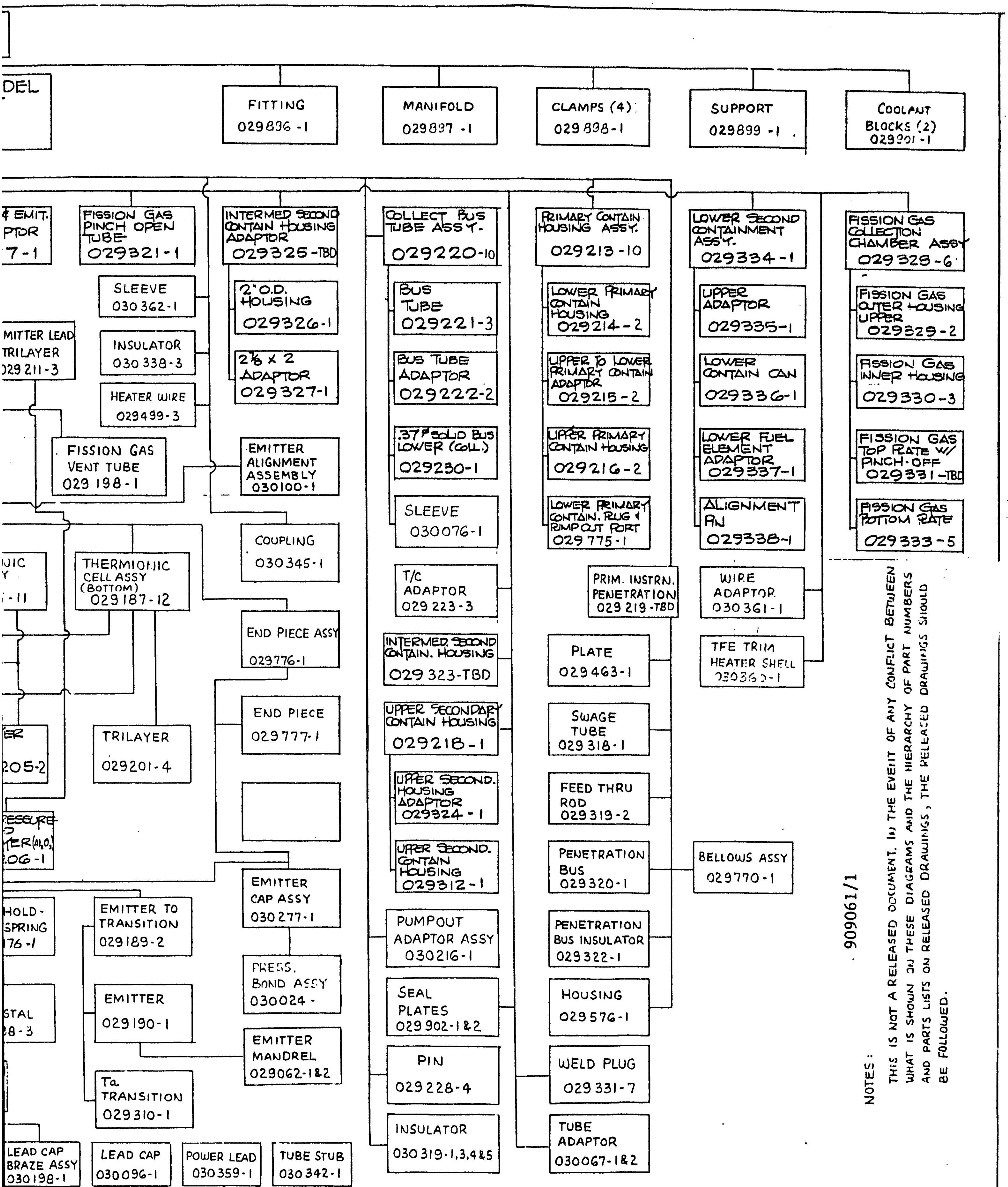


Fig. 21 - TFE 3H1 Drawing Tree

APPENDIX B

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APPENDIX C

TFE DRAWING TREES

Drawing Trees ----->	SK3450-082 Rev B	SK3450-251	SK3450-252	SK3450-239 Rev C	SK3450-240 Rev E	SK3450-283 NC
Drawing	1H1	1H2	1H3	3H1	3H5	6H1
SK3450-203				X	X	
029062	X	X	X	X	X	X
029173	X					
029174	X		X			
029175	X		X			
029176	X	X	X	X	X	X
029177	X	X	X	X	X	X
029178	X	X	X	X	X	X
029179	X	X	X	X	X	X
029180	X		X			
029181	X	X	X	X	X	X
029182	X		X			
029183	X		X			
029184	X		X			
029185	X		X			
029186	X		X			
029187	X	X	X	X	X	X
029188	X	X	X	X	X	X
029189	X	X	X	X	X	X
029190	X	X	X	X	X	X
029191	X	X	X	X	X	X
029192	X	X	X	X	X	X
029193	X	X				
029194	X	X				
029195	X	X	X	X	X	X
029196	X	X	X	X	X	X
029197	X	X	X	X	X	X
029198	X	X		X	X	X
029199	X	X				
029200	X	X	X			
029201	X	X	X	X	X	X
029202	X		X			
029203	X	X	X			
029205	X	X	X	X	X	X
029206	X	X	X	X		
029207	X	X	X			
029208	X	X	X	X	X	X
029209	X	X	X			
029210	X	X	X			
029211	X	X	X	X	X	X
029212	X		X			
029213	X	X	X	X		
029214	X	X	X	X		
029215	X	X	X	X	X	X
029216	X	X	X	X	X	X
029217	X					

Drawing Trees ----->	SK3450-082 Rev B	SK3450-251	SK3450-252	SK3450-239 Rev C	SK3450-240 Rev E	SK3450-283 NC
Drawing	1H1	1H2	1H3	3H1	3H5	6H1
029218	X	X	X	X	X	X
029219	X	X	X	X	X	X
029220	X	X	X	X		
029221	X	X	X	X		
029222	X	X	X	X		
029223	X	X	X	X	X	X
029226	X	X	X	X	X	X
029227	X	X	X			
029228	X		X			
029230	X					
029231	X	X	X	X	X	
029232	X	X	X	X	X	X
029310	X	X	X	X	X	X
029312	X	X	X	X	X	X
029313	X	X	X	X	X	X
029317	X	X	X	X	X	X
029318	X	X	X	X	X	X
029319	X	X	X	X	X	X
029320	X	X	X	X	X	X
029321	X	X	X	X	X	X
029322	X	X	X	X	X	X
029323	X	X	X	X	X	
029324	X	X	X	X	X	X
029325	X	X	X	X	X	X
029326	X	X	X	X	X	X
029327	X	X	X	X	X	X
029328	X	X	X	X	X	X
029329	X	X	X	X	X	X
029330	X	X	X	X	X	X
029331	X	X	X	X	X	X
029333	X	X	X	X	X	X
029334	X	X	X			
029335	X	X	X	X	X	
029336	X	X	X	X	X	
029337	X	X	X	X	X	
029338	X	X	X	X	X	
029462	X		X			
029463	X	X	X	X	X	X
029499	X	X	X	X	X	X
029576	X	X	X	X	X	X
029732	X		X			
029734	X		X			
029735	X		X			
029736	X		X			
029738			X	X		
029769		X	X	X	X	X

Drawing Trees ----->	SK3450-082 Rev B	SK3450-251	SK3450-252	SK3450-239 Rev C	SK3450-240 Rev E	SK3450-283 NC
Drawing	1H1	1H2	1H3	3H1	3H5	6H1
029770		X	X	X	X	X
029775		X	X	X		
029776				X	X	X
029777	X			X	X	X
029895	X	X	X			
029896	X	X	X	X	X	X
029897	X	X	X	X	X	X
029898	X	X	X	X	X	X
029899	X	X	X	X	X	X
029901	X	X	X	X	X	X
029902	X	X	X	X	X	
030024				X	X	X
030067	X	X	X	X	X	
030076	X	X	X			
030077				X		
030094		X		X	X	X
030095		X		X	X	X
030096		X		X	X	
030097		X		X	X	
030099		X		X	X	X
030101		X		X	X	X
030102		X		X	X	X
030103		X		X	X	X
030104		X		X	X	X
030105		X		X	X	
030106		X		X	X	X
030107		X		X	X	X
030108		X		X		
030109		X		X	X	X
030110		X		X	X	
030197		X		X	X	X
030198		X		X	X	
030199		X		X	X	X
030215		X				
030216	X	X	X	X	X	X
030274			X			
030275			X			
030276		X		X	X	
030277				X	X	X
030278				X	X	
030319	X	X	X	X	X	X
030324	X	X	X	X	X	X
030338	X	X	X	X	X	X
030341				X	X	X
030342				X	X	X
030343				X	X	

Drawing Trees ----->	SK3450-082 Rev B	SK3450-251	SK3450-252	SK3450-239 Rev C	SK3450-240 Rev E	SK3450-283 NC
Drawing	1H1	1H2	1H3	3H1	3H5	6H1
030344		X		X	X	X
030345		X	X	X	X	X
030359		X		X	X	X
030360				X		
030362		X	X	X	X	X
030363		X				
030475			X	X		
030476			X	X	X	X
030477		X		X	X	X
030600		X	X	X	X	X
030660					X	
030667						X
030668					X	X
030673		X		X	X	X
030682		X	X	X		
030774				X		
030867					X	X
030905		X				
030906		X		X	X	X
030960				X	X	X
030962				X	X	X
030972				X	X	X
030991				X		
030992					X	
030993				X		
030994				X	X	X
030995				X		
030996				X	X	X
030997				X	X	
030998					X	
030999				X	X	X
031054					X	X
031056					X	X
031057					X	X
031061					X	X
031068				X	X	X
031069					X	X
031071				X	X	X
031072				X		
031076				X	X	X
031077					X	X
031096				X	X	X
031108				X	X	X
031109				X	X	X
031132				X	X	X
031133				X	X	X

Drawing Trees ----->	SK3450-082 Rev B	SK3450-251	SK3450-252	SK3450-239 Rev C	SK3450-240 Rev E	SK3450-283 NC
Drawing	1H1	1H2	1H3	3H1	3H5	6H1
031230						X
031231						X
031232						X
031233						X
031234						X
031235						X
031236						X
031237						X
031238						X
031254					X	X
031270				X	X	
031292					X	X
031293					X	X
031364				X		X
031365				X		X
031375					X	
031376					X	
031377					X	
031405						X
031406						X
031407						X
031408						X
031410						X
031411						X
031423						X
031431						X
031809						X
031810						X
031811						X
031812						X
031978					X	
032058					X	
032065						X
032066						X
032077						X
032078						X

DATE
FILMED
10/19/94

END