EURAEC 277

GEAP-3771-3-AEC

INFORMAL USAEC - EURATOM
RESEARCH AND DEVELOPMENT REPORT
TID 4500 (16th Edition)
511-TP-2

HIGH PERFORMANCE UO_2 PROGRAM

THIRD QUARTERLY PROGRESS REPORT

October - December 1961

Prepared for the U.S. Atomic Energy Commission and Euratom

by

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Under Contract AT(04-3)-189

Project Agreement Number 17

January 2, 1962

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511-T102E

ACKNOWLEDGEMENT

This Research and Development Program, sponsored by the USAEC and Euratom, is being conducted by the General Electric Company. The following listed persons contributed to the project during this quarter:

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SECTION I

INTRODUCTION

1.1 Program Purpose

The primary purpose of this joint USAEC-Euratom program is to obtain a better understanding of the maximum achievable operating characteristics of UO_2 as a reactor fuel. During the program work will be performed in two areas that have been of concern to reactor core designers for a long time; namely, fission gas release and central melting in fuel rods.

1.2 Fission Gas Release

The rate of fission gas release of a fuel rod will be measured by a direct method, while the rod is resident in the Vallecitos Boiling Water Reactor (VBWR). A suitable transducer system will be developed for this purpose. Fuel rods containing sintered pellets of different densities (95 per cent and 90 per cent) will be tested at a temperature near the UO_2 melting point (2740 C) and also at 1500 C. At the lower temperature, no considerable amount of UO_2 mass transfer is expected to occur, nor is an appreciable amount of grain growth anticipated. Fuel rods fabricated by swaging arc-fused UO_2 powder will be tested concurrently with those rods containing pellets of corresponding density (90 per cent). These tests will provide information regarding pressure build-up in the reactor during the transient period, as well as during steady-state operating conditions.

1.3 Central Melting in Fuel Rods

The second area with which this program is concerned is the amount of central melting that can be tolerated in a UO_2 fuel rod which is in use in an operating reactor. Fuel rod design has been, and still is, arbitrarily limited by the attainment of a central temperature well below the melting point of UO_2. Originally this limitation existed to avoid the release of fission gases from the UO_2 with a resultant build-up of pressure in the tube. There is then the possibility of eventual fuel rod failure due to rupture of the cladding caused by high internal pressure developed during extended irradiation. Recently consideration has been given to fuel rods designed with a plenum chamber, or other means of reducing internal pressure from fission gas release. With such a fuel rod it may be possible to operate UO_2 fuel rods with a higher central temperature than used previously.

1.4 Central Temperature Limitation

The central temperature limitation also imposes a limit on the specific power that can be attained for a given fuel geometry. Because specific power can influence fuel costs, a better understanding of the limiting central temperature for UO_2 fuel could result in a lower fuel cost. During the program, UO_2 fuel will be irradiated in the General Electric Test Reactor (GETR) Pressurized Water Loop (PWL), with the central temperatures becoming progressively higher. To attain different central temperatures, a series of four fuel assemblies will be irradiated at heat fluxes of 600,000, 800,000, and 1,200,000 Btu/hr-ft^2. The extent of central melting will of course vary directly with the increase in heat flux. At the highest heat flux, as much as one-quarter to one-half of the fuel cross section may be molten.

It is a primary purpose of this phase of the program to obtain information on the relationship between the extent of central melting and the length of time before the fuel rod fails as a result of interaction between the fuel and cladding. Steps will be taken to minimize the probability of failures from causes external to the rod. Flow and thermal conditions existing during fuel irradiation in the PWL have been simulated in an out-of-pile loop to obtain a burn-out safety factor. This safety factor will be employed to eliminate failure of fuel rods from burn-out during irradiation. Similarly, precautions will be taken to maintain coolant chemistry leading to low corrosion rates and crud formation. These measures should also reduce the possibility of fuel failure from these external causes.

1.5 Tasks and Objectives

The three major tasks of the program and the related objectives are:

TASK I - Measurement of Fission Gas Pressure in Operating Fuel Elements

Objective: Direct measurement of fission gas pressure in UO_2-filled fuel rods, as functions of temperature and fuel configurations. Measurements to be made over an extended period of time during transient and steady-state reactor operation.

TASK IIA - Loop Modification

Objective: Design, fabrication and installation of GETR Pressurized Water Loop modifications required by the Task IIB experimental program.

TASK IIB - Performance of UO_2 Fuel

Objective: Obtain a relationship between the amount of fuel rod central melting and the burn-up that can be attained before fuel-cladding interaction results in rod failure.

SECTION II

SUMMARY

Work performed during the past quarter is summarized as follows:

2.1 TASK I - Direct Measurement of Fission Gas Pressure

1. A fuel rod containing 98 per cent dense UO_2 pellets at 3.9 per cent enrichment is being irradiated in the Vallecitos Boiling Water Reactor (VBWR). Reasonable pressure readings were being obtained until operational difficulties rendered the readout system inoperative.

2. A fuel rod containing 98 per cent dense UO_2 pellets at 7.0 per cent enrichment will be inserted in the VBWR during the January reactor shutdown.

3. Fabrication is proceeding on the rods containing arc-fused UO_2 powder and UO_2 pellets with a density of 90 per cent.

2.2 TASK IIA - Loop Modifications

1. Completion of the loop modification has been delayed because the high pressure valves were not delivered on schedule.

2. Shakedown of the loop through the facility tube bypass is scheduled to start not later than January 22, 1962.

3. Installation and shakedown of the facility tube is scheduled for the shutdown of the General Electric Test Reactor (GETR) on February 5, 1962.

2.3 TASK IIB - Performance of UO_2 Fuel

1. The PWL Fuel Assembly design was completed. The assembly will contain four fuel rods, each within its own concentric flow tube.

2. The hydraulic performance of a lead-filled, dummy Zircaloy rod assembly was obtained, to confirm the adequacy of the fuel assembly design. The dummy assembly will also be useful during the PWL shakedown, and for testing transfer equipment.

3. The temperature profile that will exist in the fuel rods during operation at the scheduled heat fluxes, has been calculated.

4. A capsule containing 20 per cent-enriched UO_2 pellets, was irradiated for 20 minutes in the GETR Trail Cable Facility, at an average heat flux of 600,000 Btu/hr-ft^2. Post-irradiation examination of pellets, at the point of the average heat flux and at ~800,000 Btu/hr-ft^2, is in progress.

5. Fabrication is proceeding on the pelleted fuel assemblies that will operate at 600,000 Btu/hr-ft^2, 800,000 Btu/hr-ft^2, and 1,200,000 Btu/hr-ft^2.

SECTION III

TASK I - DIRECT MEASUREMENT OF FISSION-GAS PRESSURE

3.1 Introduction

This experiment has as its objective the measurement, during operation, of the fission gas pressure existing in typical UO_2-filled fuel rod segments. Pressure is measured by means of a Booth-Cromer pressure sensor attached to each fuel rod in question. The details of the apparatus for operation of the pressure read-out equipment have been reported previously, but by way of recapitulation, the Booth-Cromer sensor is a differential device of negligible volume which compares fuel rod gas pressure with a secondary balancing pressure. The value of the secondary pressure is recorded when the two are equal.

3.2 Experimental

Six fuel rods equipped with pressure sensors are to be irradiated. These will contain UO_2 in the form of compacted powder and of pellets. Fission gas pressure is to be measured and related to density, power level, and burnup.

To date, one fuel rod, containing 98 per cent dense UO_2 pellets of 3.9 per cent enrichment, has been installed and is being irradiated in the VBWR. The pressure transducer attached to this rod became non-functional because of a shorted electrical lead connection, before the reactor was brought to power. Operation of the pressure-sensing system was subsequently restored temporarily by repairing the electrical lead connection. Operation of the system stopped shortly thereafter because of a malfunction of the data printer as a result of excessive humidity within the reactor enclosure. The electrical components of the read-out instrumentation are being moved into the reactor control room to eliminate this problem.

During the period in which the read-out instrumentation was operative, gas pressures ranging from 13 to 18 psig were observed as the reactor power varied from 15 to 26 megawatts. These values are consistent with the reactor operating temperature since the fuel rod was sealed off at one atmosphere and it was too early for appreciable fission gas to have been generated.

A fuel rod containing 98 per cent dense, 7.0 per cent enriched UO_2 pellets is being prepared for insertion during the next reactor shutdown. Two rods containing 90 per cent dense pellets, one with 3.9 per cent enriched and the other with 7.0 per cent enriched UO_2, are being prepared for a subsequent insertion in the reactor.

Two rods containing arc-fused UO_2, one with low enrichment and the other with high enrichment, are also being fabricated to a bulk density of 90 per cent.

SECTION IV

TASK IIA - LOOP MODIFICATIONS

4.1 Task Objectives

Modifications to the existing pressurized water loop in the General Electric Test Reactor (GETR) will be designed, fabricated, and installed to permit the experimental objectives of Task IIB. The modifications will be checked and shakedown runs will be made in the loop before the start of the experimental program.

4.2 Over-all Status

Modification effort is in the fabrication phase, but it has been hampered by delays in the receipt of high pressure valves.

Fabrication of the main loop piping is approximately 80 per cent complete, and is now awaiting the receipt of the in-line valves. Because of the position of the welds and the radiation exposure within the cubicle, the valves and piping will be prefabricated in the shop. The piping sections, including valves, will then be moved to the cubicle and interconnected.

The best estimated delivery for the valves is January 5, 1962. On a "best effort" basis, and with a minimum of fabrication and assembly difficulty, it is anticipated that the loop will be ready for shakedown through the facility tube bypass by January 22, 1962. The facility tube will then be installed during the reactor outage, commencing February 5, 1962. Further loop shakedown tests must be completed through the facility tube before the loop can be fueled.

4.3 Decontamination System

Fabrication of the decontamination system is approximately 70 per cent complete. The decontamination pump, standby cooling pump, standby cooling heat exchanger, and the interconnecting piping have been installed. The decontamination pump is located outside the main loop cubicle, and will be locally shielded with lead brick. Interconnecting piping, from the decontamination pump to the standby system and the main loop, runs through the cubicle wall. The chemical mix tank will be located on the third floor of the reactor, and interconnected to the decontamination pump.

A draft of the decontamination procedures has been issued for review.

4.4 Facility Tube

Facility tube fabrication is complete, and ready for installation. Photographs of the facility tube, taken during fabrication, are shown in Figures 4-1A and 4-1B.

4.5 Sample Station - D. Danielson

The loop water sample station, shown in Figure 4-2, is 95 per cent complete; the only work which remains to be done are the final connections of sample points and the air duct to the sample station.

The sample station is designed for routine measurement of conductivity and dissolved oxygen, and provides access points for withdrawing samples for analysis of pH, chlorides, fission products, and gas concentration. Two sample points are normally used: one located at the ion exchanger inlet (SSV-80), representative of the main recirculating loop water; and the other one located at the ion exchanger effluent

Figure 4-1A FACILITY TUBE.

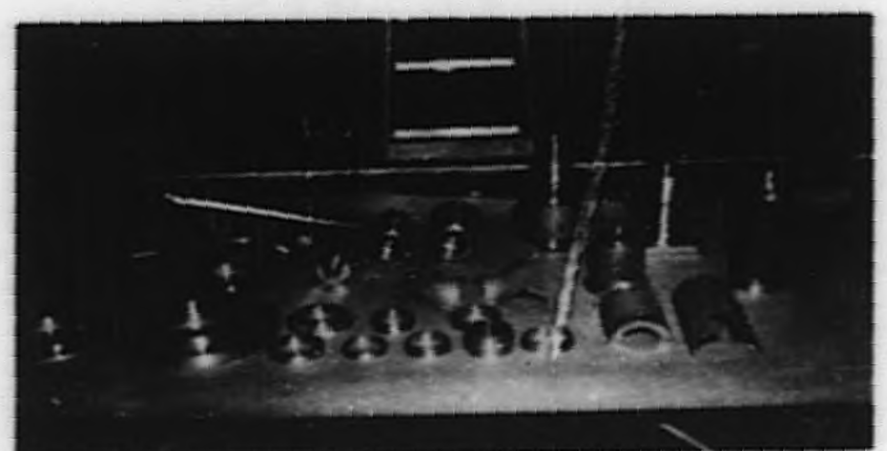

Figure 4-1B FACILITY TUBE CONNECTORS - FITTINGS.

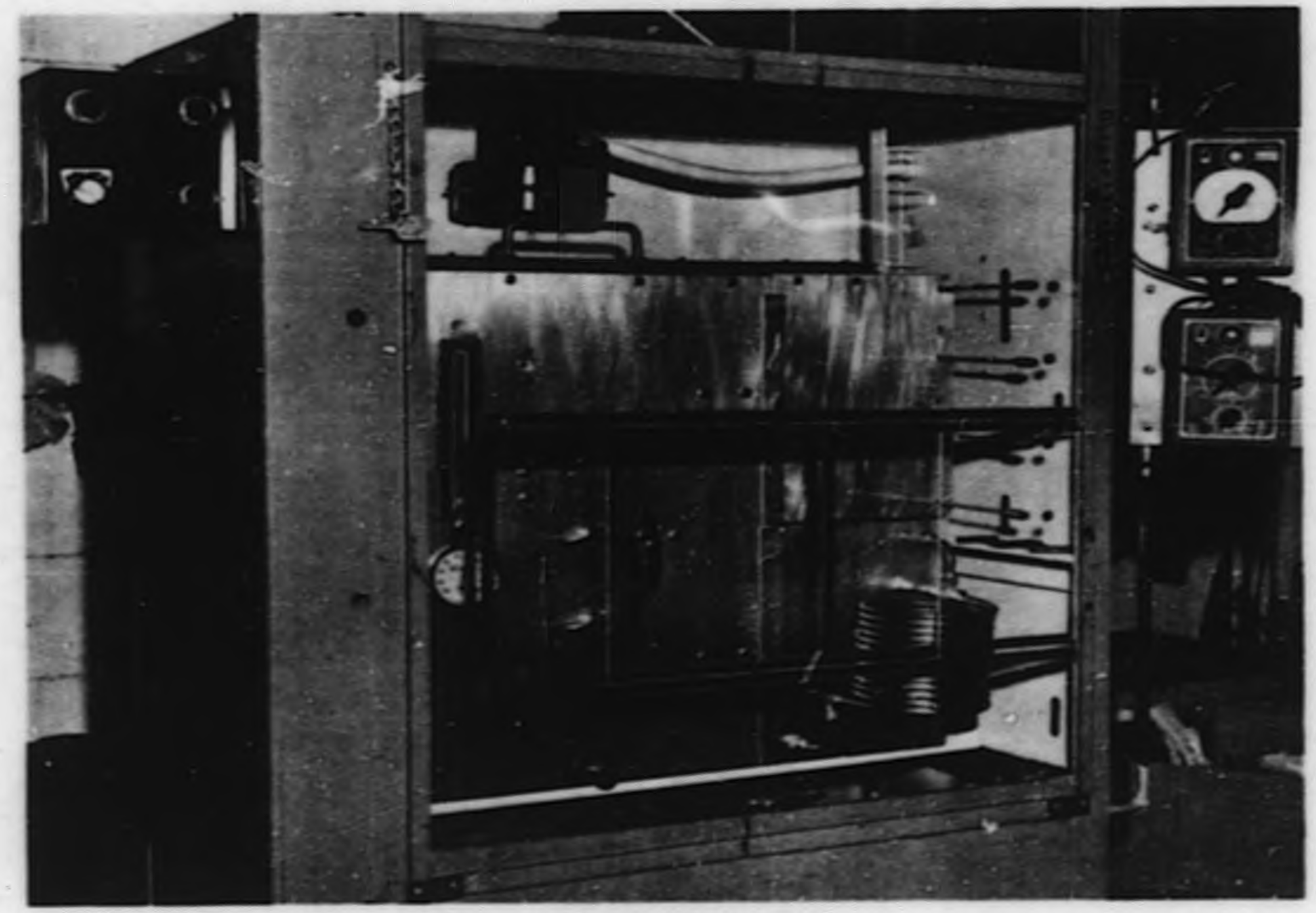

Figure 4-2 SAMPLE STATION.

(SSV-81), for use in monitoring the operation of the ion exchanger. Additional sample points are provided for sampling the makeup water and the pressurizer steam phases. The chemistry equipment panel consists of three conductivity cells, four selector valves, a thallium column, a temperature gage, a flowmeter, and two ion exchangers.

To obtain the best accuracy in the conductivity and dissolved oxygen measurements, a sample cooler is provided for lowering the sample temperature to approximate the ambient temperature. Temperature compensation over a limited range is provided on the instrumentation; however, the most reliable results can be obtained with a stable temperature close to the reference temperature of 77 F.

4.6 Instrumentation and Electrical

All modifications to the control panel and motor control centers are essentially complete. The five-channel radiation monitoring system, differential temperature system, and numerous control switches for the decontamination system have been installed in the main control panel.

The remaining work, consisting of final tie-in from the loop to various sensors and transmitters, cannot be completed until the major portion of the piping spools are installed.

4.7 Decontamination Development - S. Siegel

Detailed operating procedures were prepared for decontamination of the PWL facility. These procedures designate the course of action to be followed from the time a fuel failure is first recognized, to the point where the facility tube can be charged with the new fuel element and the loop returned to service. Complete instructions are included for the preparation of all chemical solutions, the operating limits pertaining to their application, and chemical and radiation safety guides.

Fabrication was essentially completed on the coupon holder, with a full charge of test coupons. The coupons are made of the key alloys used in PWL components, and will be used to conduct control tests for identifying the optimum decontamination treatment conditions. These tests will not start until the test specimens have been exposed for one or two reactor cycles. Some preliminary testing will be done on coupons exposed in the HAPO in-pile loops.

SECTION V

TASK IIB - UO_2 FUEL PERFORMANCE

5.1 PWL Test Assembly Design

The design of the PWL fuel assembly has been completed, as shown in Figure 5-1. The assembly will be installed in the PWL facility tube, with the lifting tee at the upper end. The assembly rests on, and is supported by, a 45-degree annular seat built into the facility tube 8 inches below the bottom of the GETR core. Coolant flow enters from above the assembly, thereby exerting a downward force that holds the assembly in position. Each of the four fuel rods is contained in its own concentric flow tube to maximize flow velocity and minimize flow variations between rods and around individual rods. Approximately 95 per cent of the coolant flow passes down through the fuel rod annuli, while the remaining 5 per cent is bypassed around the outside of the assembly to cool the externally-insulated PWL facility tube wall.

The maximum OD of the assembly is governed by the minimum OD of the PWL facility tube, plus some clearance to permit easy insertion down the 11-ft length of the facility tube to the operating position. The maximum length of the assembly is determined by the requirement that the assembly fit within a leak-tight can for transfer when defected. The can, in turn, must fit within the largest available transfer cask at the GETR.

One of the basic objectives of the design was to permit the removal of individual rods in the event of a rod failure, and the replacement

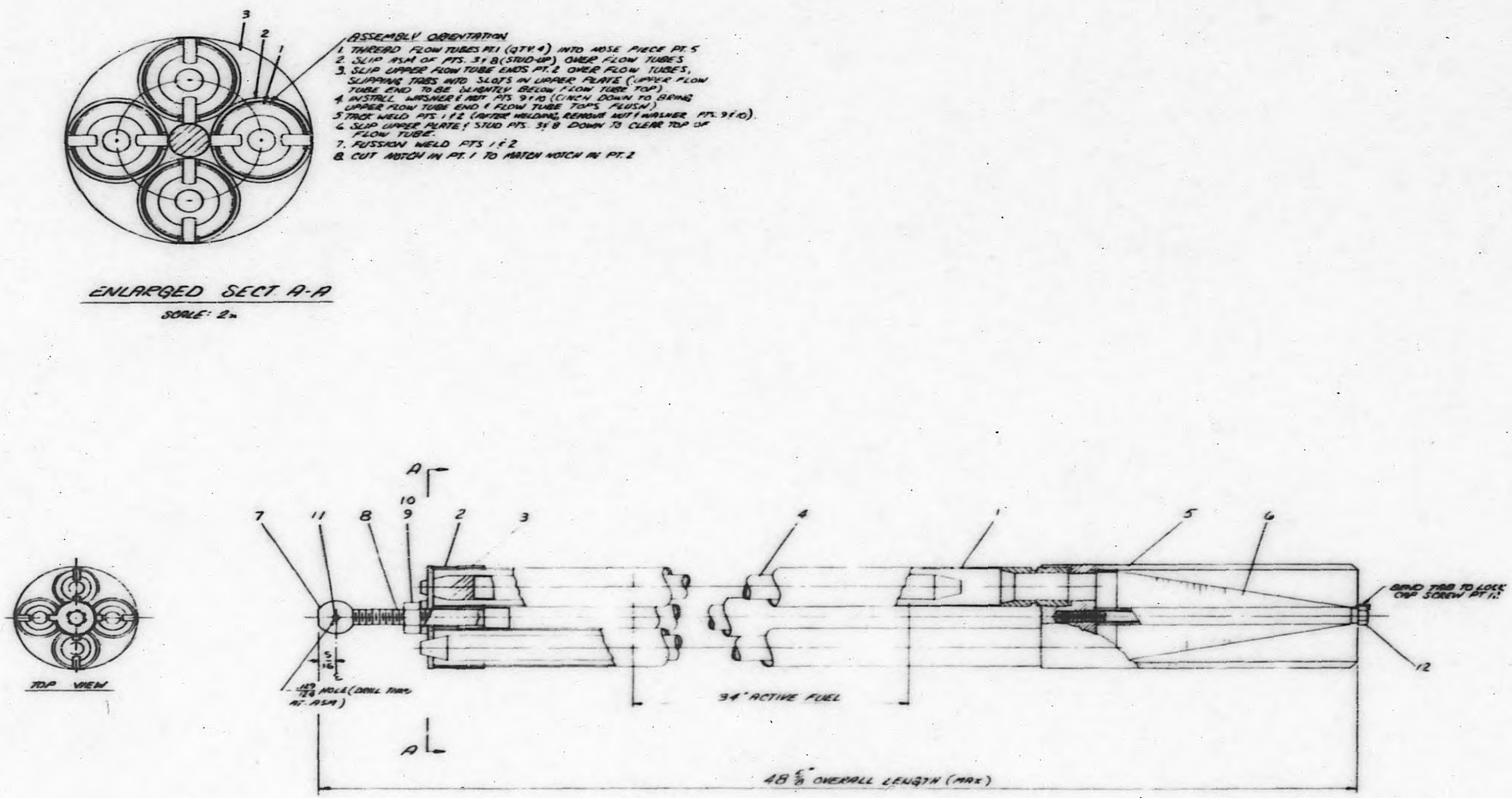

FIGURE 5-1 PWL FUEL ASSEMBLY

with a spare rod to allow continued operation. To accomplish this, each rod is supported only at the top of the flow tube, by a cross pin through the fuel rod end plug; thus the rod is free to expand axially downward from this point. The cross pin meshes with notches cut in the flow tube ends. The inside ends of the cross pins from all four rods are locked down in place by a nut and washer on the assembly lifting stud. Lateral spacing of the fuel rods within the flow tubes is performed by semi-circular wire spacers mounted in the flow tube wall at three axial locations. Four wire spacers are provided at each axial location, 90 degrees apart, with the plane of the spacers parallel to the flow. Thus, removal of an individual fuel rod can be accomplished by merely loosening the top nut and backing it off, lifting the rod sufficiently for the cross pin to clear the notches, rotating the rod 90 degrees, and then withdrawing it from the flow tube. In the event the rod becomes wedged in the flow tube, provision has been made for removing both the rod and flow tube together, and replacing both.

A filter has been included at the bottom of the fuel assembly to trap fuel particles released in the event of a serious clad rupture, preventing their spread throughout the loop. The filter, which is removable, is basically a cone formed from 60-mesh, stainless steel, wire cloth.

Fabrication of the hardware for the initial five fuel assemblies was started about December 1. The hardware is now about 60 per cent complete, with all individual parts fabricated. Welding of subassemblies is now under way. No difficulty is anticipated in completing the hardware for three assemblies by the middle of January, as required in the current schedule.

5.2 Fuel Rod Design

The use of spacers on the flow tube, as described in Subsection 5.1, also allows the use of an unsegmented fuel rod design for the PWL assemblies (see Figure 5-2). This straight-through type of rod design minimizes flux peaking within the fuel zone, and also permits the use of a single fission gas plenum at the coldest zone at the top of the rod. An Inconel-X spring is included in the plenum region to keep the pellet column intact during handling prior to irradiation.

The 3-in. plenum shown in Figure 5-3 is sufficient to accommodate 100 per cent fission gas release from a rod running at 1.2×10^6 Btu/hr-ft^2 peak surface heat flux for three 28-day cycles in the GETR. If irradiation plans are revised for longer term irradiations, the plenum volume will be increased by reducing the fuel column height. As designed, the bottom of the fuel rod pellet column is even with the bottom of the GETR core during operation, and the top of the column is 2 inches below the top of the GETR active core zone.

Pressing of fuel pellets for the four different enrichment fuel assemblies has been completed, and the pellets are presently being sintered. Sufficient pellets are being made for seven rods of each enrichment. Four rods will be initially installed in the assembly, and the remaining three rods will serve as spares for installation in the event of defects. Sample pellets of each enrichment have been submitted for isotopic, O/U, and emmission spectrographic analysis. A metallographic specimen of a sintered pellet from each enrichment will be made.

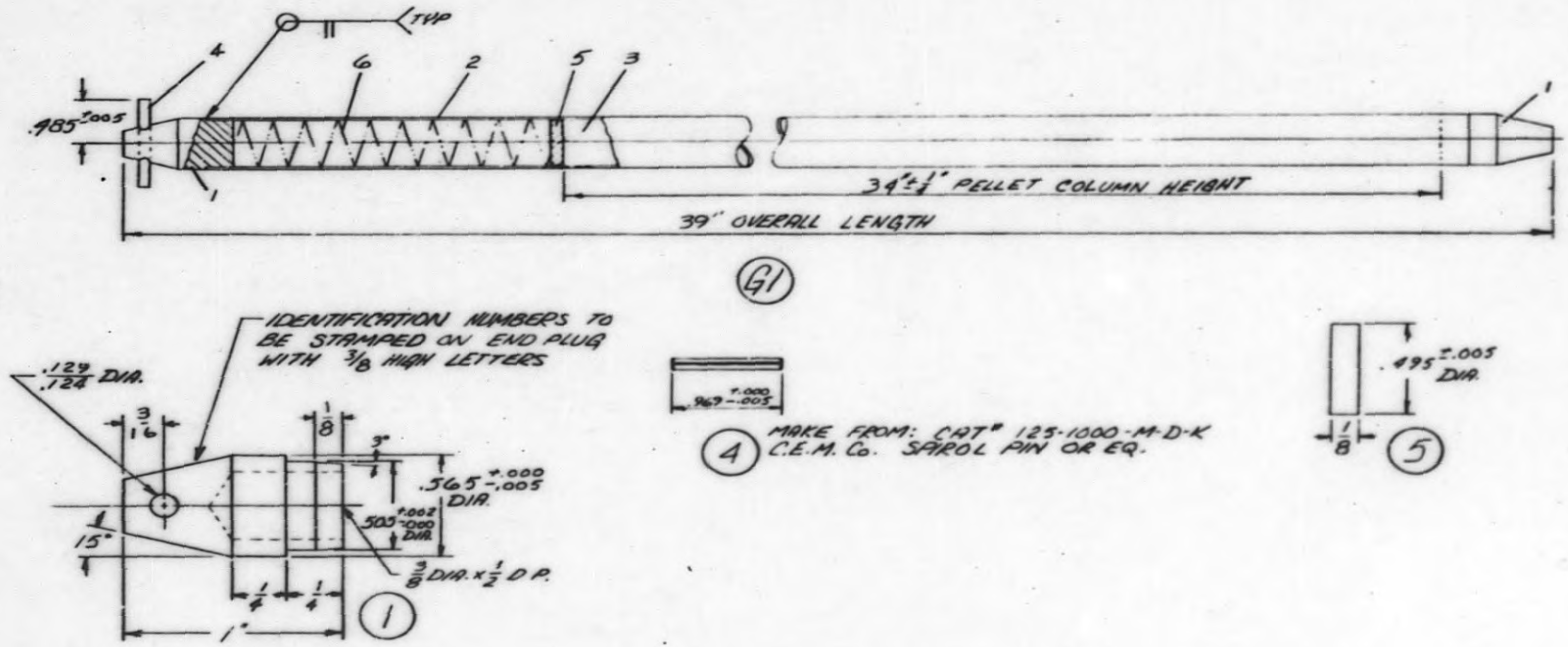

FIGURE 5-2 FUEL ROD DESIGN

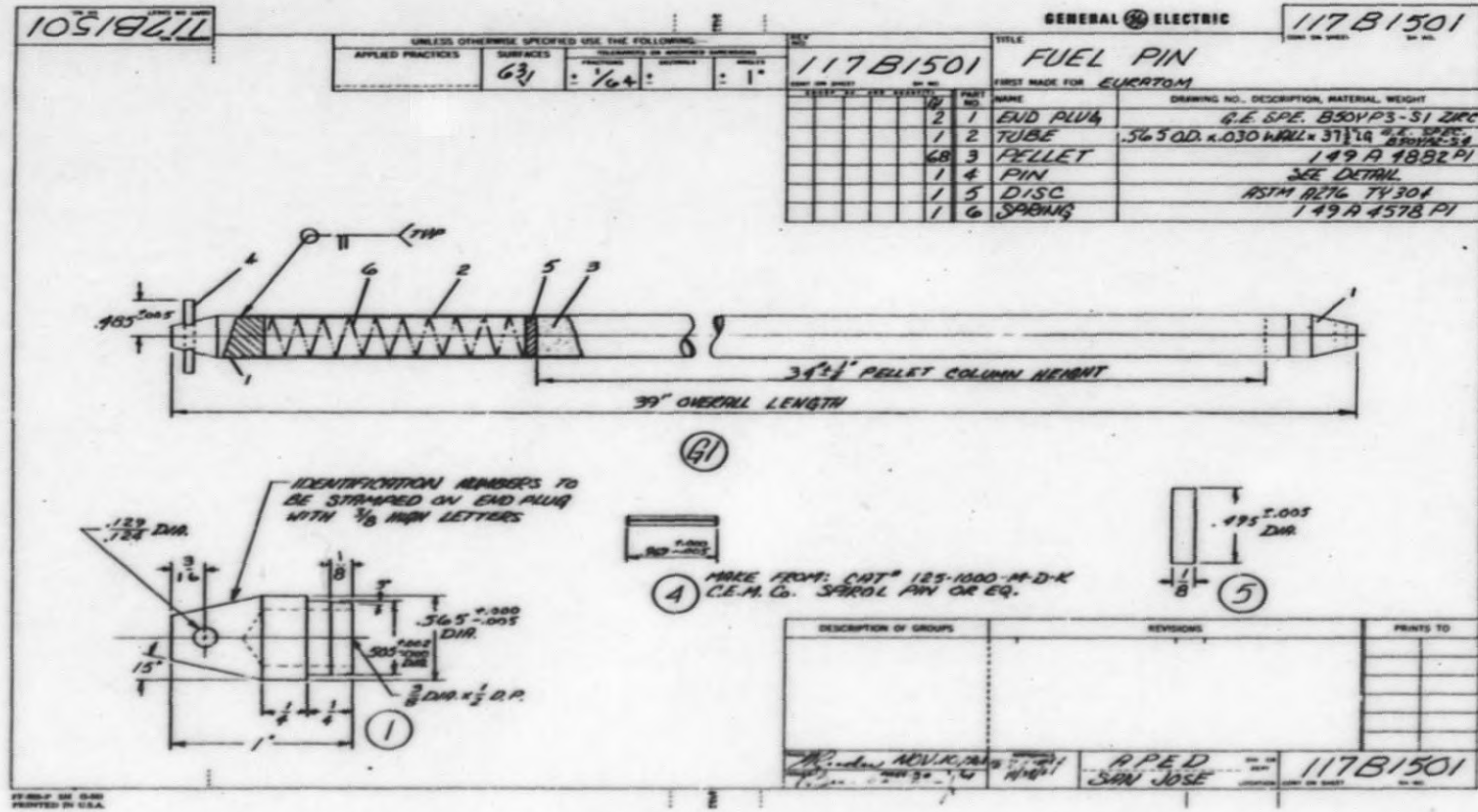

FIGURE 5-3 FUEL PIN

The cladding for the pellet-filled rods is presently being ultrasonically tested. The cladding will then be machined to length, and samples will be taken from each tube for chemical and metallographic analysis. End plugs and internal hardware for the fuel rods have been completed; assembly of the rods will start after the completion of pellet grinding.

5.3 Dummy Assembly

In addition to the fueled assemblies described in the previous paragraphs, a dummy PWL assembly containing lead-filled, Zircaloy-clad rods, has been fabricated for the performance of hydraulic and structural tests of the assembly design. Figure 5-4 is a photograph of the completed dummy assembly.

The assembly will be installed in a test loop in San Jose, and operated at design flow rates to allow the measurement of pressure drops and the assembly bypass flow rate. The bypass flow around the assembly must be at least ~5 gpm to adequately cool the PWL facility tube walls. On the other hand, excessive bypass flow would reduce the flow available for fuel rod cooling and, consequently, the operating safety margins. The actual bypass flow cannot be measured during operation in the PWL loop.

Following approximately a week's testing in the San Jose test loop, the assembly will be transferred to the GETR and installed in the PWL loop during the loop shakedown operation. Operation of the dummy assembly in the loop will permit further checking of the assembly pressure drop, detecting of any plugging tendencies in the

Figure 5-4 PWL DUMMY ASSEMBLY

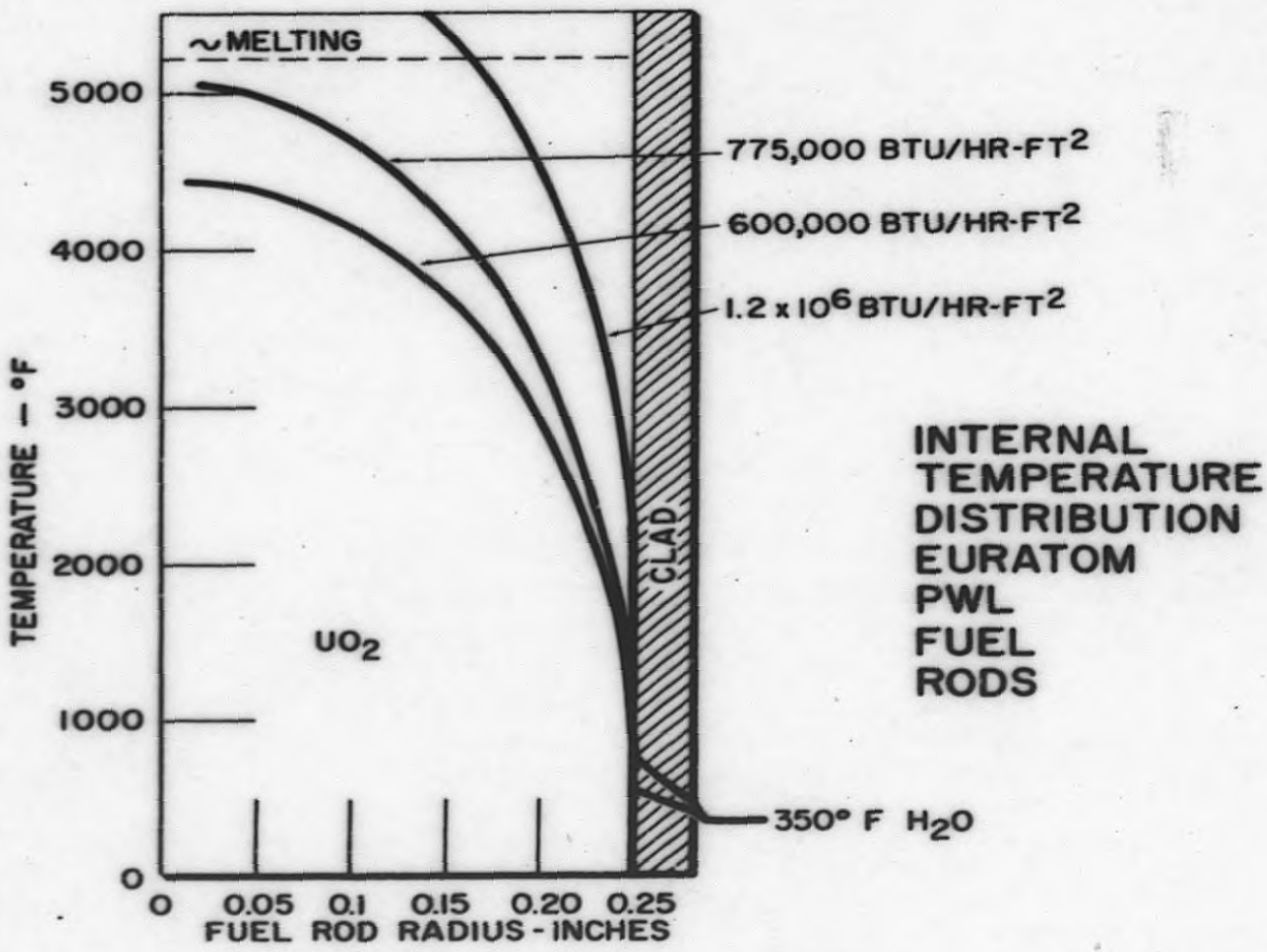

FIGURE 5-5 TEMPERATURE DISTRIBUTION - PELLET-FILLED ROD

outlet screen and vibration effects, and determining compatibility of the assembly with the facility tube during installation and with the defected element transfer equipment during removal.

5.4 Fuel Rod Internal Temperature Analysis

Calculations have been made to predict the temperature distribution within the Euratom pellet-filled fuel rods, for several operating conditions. The curves obtained for the calculated temperatures are shown in Figure 5-5. The lowest curve is for the 600,000 peak heat flux point, the middle curve for the average power generation point in the 1.2 million Btu/hr-ft^2 fuel assembly, and the upper curve is for the peak point in this assembly. The curves were calculated by assuming uniform heat generation in the UO_2, a gap coefficient of 1000 Btu/hr-ft^2, and the thermal conductivity-temperature relationship for UO_2 as given by J. L. Bates in Nucleonics, June, 1961.

While the calculations are only approximate, the basic indication of the curves is that considerably greater surface heat fluxes will be required to attain true central melting than had been believed when the irradiation program was originally planned almost two years ago. Recent experimental results, principally near 600,000 Btu/hr-ft^2 surface heat flux, at both GE-APED and at Hanford, have tended to support this fact. Since the program objective is to determine the influence of central melting on fuel rod performance, the assembly irradiation sequence will be revised if the calculated temperatures above can be confirmed experimentally. A series of capsule irradiations are being performed in the GETR Trail Cable facility, primarily in an effort to provide this confirming data.

5.5 Euratom Trail Cable Capsule Irradiations

The original capsules fabricated for these irradiations used 4.3 per cent enriched UO_2. The first capsule irradiated was found, experimentally, to be insufficiently enriched to attain the desired surface heat flux of 600,000 Btu/hr-ft^2 with the available neutron flux in the GETR Trail Cable facility.

Three new capsules were then fabricated, using 20 per cent enriched UO_2 pellets to give a 5-inch fuel section. One of these capsules was irradiated for 20 minutes at an average surface heat flux of 600,000 Btu/hr-ft^2, and at least 800,000 Btu/hr-ft^2 at a point where the neutron flux was higher than the average.

The capsule is presently undergoing examination in the RML. Metallographic specimens of cross sections at different points in the capsule will be prepared to determine thermally-induced changes in the UO_2 structure. From the changes observed, and their radial location, an estimate can be made of the UO_2 temperature attained, and compared with that predicted by calculation. A decision can be made, on the basis of these results, concerning a change in the irradiation sequence in the PWL loop. If the expected result is obtained -- i.e., no central melting at 600,000 Btu/hr-ft^2 surface heat flux -- changes will be made in the irradiation schedule to reduce the extent of irradiation at this heat flux, with a corresponding increase at the higher fluxes.

END