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APRIL 1968

MASTER

**SEFOR INSTRUMENTED FUEL
ASSEMBLY DESIGN AND DEVELOPMENT**

BY
E.R. CRAIG

U.S. ATOMIC ENERGY COMMISSION
CONTRACT AT (04-3) -540

ADVANCED PRODUCTS OPERATION

GENERAL ELECTRIC

SUNNYVALE, CALIFORNIA

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SECTION I

INTRODUCTION

The Southwest Experimental Fast Oxide Reactor (SEFOR) is a 20 MWt fast-spectrum reactor fueled with $\text{PuO}_2\text{-UO}_2$ and cooled with sodium. The reactor will have characteristics similar to the large, soft spectrum fast breeder reactors fueled with mixed $\text{PuO}_2\text{-UO}_2$. It will be used to obtain physics and engineering data at fuel compositions, temperatures, and crystalline states characteristic of power reactor operating conditions. SEFOR is particularly designed for the systematic determination of the Doppler coefficient of reactivity at temperatures up to the vicinity of fuel melting.

The project consists of two major parts: the design and construction of the reactor and a related research and development program. Funds for the design and construction of the facility are being provided by the Southwest Atomic Energy Associates (a group of 17 investor-owned utility companies located in the South and Southwest parts of the United States), together with the Karlsruhe Laboratory of West Germany, Euratom, and the General Electric Company.

The United States Atomic Energy Commission is supporting the research and development program. The R and D Program consists of two phases:

Phase I - Preoperational Research and Development

Phase II - The reactor test program after the start of reactor operation.

This report describes work performed in Phase I of the Research and Development Program under Task 4.5, Other Core Instrumentation.

The work included the design and testing of a prototype Instrumented Fuel Assembly and handling fixtures. In addition to the Instrumented Fuel Assembly, the work included design and testing of the associated Electrical Connector Assembly, the thermocouple lead wire and specification of a constant temperature reference junction, (the 20 pin connector portion of the Electrical Connector Assembly design and testing was completed and reported under Task 4.4, Reference 1). Fuel thermocouple development is reported in Reference 2. The designs and tests are discussed in the following sections. At the time of writing this report, the Instrumented Fuel Assemblies were being fabricated by General Electric's Vallecitos Nuclear Center.

SECTION II

DESIGN OBJECTIVES

2.1 DESIGN CRITERIA

The criteria cover six Instrumented Fuel Assemblies scheduled for insertion in the first SEFOR core. Basic design requirements for instrument sensors, special fuel rods, sensor leads, lead connectors, and Instrumented Fuel Assembly handling fixtures are included. Figure 2-1 shows the Instrumented Fuel Assembly installed in the SEFOR core.

Instrumented fuel assemblies will be used to obtain information necessary to verify the physics and thermal analysis calculations of the core behavior during the planned tests. To accomplish this objective, a number of core parameters will be monitored during startup, steady state and transient core operation. (See Reference 2 for material temperatures and allowable stress limits.)

2.2 GENERAL REQUIREMENTS

1. Sensors and associated components will operate under the following conditions:

- (a). Steady state reactor operation 0 to 20 MWt.
- (b). Transients up to 10^5 MWt.

2. All components in the core shall be designed to occupy a minimum volume.

NOTE:-
 A. FOR NOZZLE SCHEDULE SEE DWG. 175A 8512.
 B. FOR ASSEMBLY NOTES NUMBERED B-1, B-2, ETC., SEE DWG. 175A 8511.
 C. FOR ASSEMBLY DETAILS OF FIELD ASSEMBLED PARTS, SEE THE APPLICABLE PART DRAWING.

FIGURE 2-1. REACTOR ARRANGEMENT AND ASSEMBLY

3. Assemblies shall be connected and disconnected for replacement or repair in the refueling cell environment (argon atmosphere) during normal shutdown conditions.

4. Allow for refueling without disturbing the IFA, connector, or leads.

5. Design for high reliability, up to 3 years of operation.

2.3 SPECIFIC REQUIREMENTS

2.3.1 Fuel Center Temperature Sensor

Two rods per assembly, two thermocouples per rod will be used for fuel temperature measurements.

(a). Tungsten-rhenium thermocouples will be located at the center of the fuel pellet at the high flux and at the position of 75% average flux (approximately).

The general test conditions and requirements are:

	<u>Mild Ramp</u>	<u>Prompt Excursion</u>	<u>Static Measurement</u>	<u>Oscillator Measurement</u>
(b). Range (°F)	Up to 4700	Up to 4700	400 to 4700	400 to 4700
(c). Accuracy (% of point)	---	---	± 10	± 10
(d). Sensitivity (% of change)	$\pm 10^{**}$ (ΔT max. 200°F)	$\pm 10^{**}$ (ΔT max. 650°F)	$\pm 10^{**}$ (ΔT 200 to 400°F)	$\pm 10^{**}$ (ΔT 20 to 400°F)
(e). Response (time constant)(sec.)	0.5 to 0.10	0.05 to 0.10	0.5 to 1.0	0.5 to 1.0
(f). Thermocouples will be arranged within the fuel rods so that no more than 2 inches from the junction will see temperatures greater than 3000°F.				

** Or a minimum of $\pm 10^\circ\text{F}$.

2.3.2 Channel Inlet and Outlet Temperature Sensors

(a). Chromel-alumel thermocouples are located above and at the bottom of the fuel zone in the channel sodium flow. Two thermocouples will be above the core, at the core outlet, and one thermocouple will be located at the bottom of the core, at the coolant inlet.

	<u>Mild Ramp</u>	<u>Prompt Excursion</u>	<u>Static Measurement</u>	<u>Oscillator Measurement</u>
(b). Range (°F)	700 to 900	700 to 1150	300 to 800	300 to 800
(c). Accuracy	$\pm 2\%$	$\pm 2\%$	$\pm 2\%$	$\pm 2\%$
(d). Sensitivity (% of change)	$\pm 2^*$	$\pm 2^*$	$\pm 2^*$	$\pm 2^*$
(e). Response (time constant)(sec.)	0.10	0.10	0.10	0.10
(f). Core inlet and outlet temperatures will be used to evaluate thermal shock problems in addition to use in the above test.				

* Or a minimum of $\pm 3^\circ\text{F}$.

2.3.3 Channel Flow Sensor

	<u>Mild Ramp</u>	<u>Prompt Excursion</u>	<u>Static Measurement</u>	<u>Oscillator Measurement</u>
(a). Range (%)	100 to 120*	100 to 120*	20 to 120*	20 to 120*
(b). Accuracy (%)	± 5	± 5	± 5	± 5
(c). Sensitivity (%)	± 2	± 2	± 2	± 2
(d). In addition to use in the above test, flow data will be used to evaluate the effectiveness of the various orifice plates in the channels.				

* Based on channel flow as follows, center of core 26,000 lb/hr, average power radius 17,000 lb/hr and core periphery 12,000 lb/hr.

2.3.4 Instrument Lead Connector

(a). The instrument lead connectors (see Figure 2-2) were specified for the following conditions or requirements:

- (1). Vibration per MIL-C-26482, para. 4.6.11
- (2). Shock per MIL-C-26482, para. 4.6.12
- (3). Engagement Force, max. 25 lbs., min. 4.5 lbs.

(b). Pin inserts and socket inserts must meet the following requirements:

- (1). Minimum insulation resistance - 50,000 megohms at 500 volts DC at 70°F.
- (2). Maximum leakage - 4×10^{-8} standard cc/sec of helium at 1 atmosphere differential pressure.
- (3). Proof pressure of 1000 psi at 70°F.
- (4). Minimum operating life radiation level of 1.4×10^{17} nvt neutron fluence and 1.6×10^5 R/hr gamma flux.
- (5). Temperature requirements:

Operating (continuous): 0°F to +900°F.

Limits (30 minutes maximum at temperature in a non-reducing or inert atmosphere): 0°F low limit, +1000°F high limit.

FCF 191X642

GROUP NO. AND QUANTITY																	PART NO.	NAME	DRAWING NO., DESCRIPTION, MATERIAL, WEIGHT	
3	2	G16	G15	G14	G13	G12	G11	G10	G9	G8	G7	G6	G5	G4	G3	G2	G1	1	PIN ASM.	THIS DWG GR. 3
																		2	SOCKET ASM.	THIS DWG GR. 4
3	2																	3	PIN INSERT	112C3015G1
																		4	SOCKET INSERT	112C3017G1
		1	1		1	1			1	1								5	BACKSHELL	129B3723P1
		2	2		2	2			2	2								6	CLAMP	129B3724P1
2	2	2	2		2	2			2	2			2	2				7	SOCKET HEAD CAP SCREW	NO. 2-56 UNC-2A X 7/16 LG SST
																		8	PIN ASM.	THIS DWG. GR. 7
																		9	SOCKET ASM.	THIS DWG. GR. 8
																		10	PIN INSERT	112C3015G2
3	2																	11	SOCKET INSERT	112C3017G2
																		12	PIN ASM.	THIS DWG. GR. 11
																		13	SOCKET ASM.	THIS DWG. GR. 12
																		14	PIN INSERT	112C3015G3
3	2																	15	SOCKET INSERT	112C3017G3
																		16	PIN ASM.	THIS DWG. GR. 15
																		17	SOCKET ASM.	THIS DWG. GR. 16
																		18	PIN INSERT	112C3015G4
3	2	1																19	SOCKET INSERT	112C3017G4

SPEC. CONTROL DWG.

- NOTES:
- ELECTRICAL CONNECTOR MUST MEET THE FOLLOWING CONDITIONS:
 - VIBRATION PER MIL-C-26482 PARA 4.6.11.
 - SHOCK PER MIL-C-26482 PARA 4.6.12.
 - ENGAGEMENT FORCE MAX 25 LBS, MIN 4.5 LBS.
 - PIN INSERT (P3) AND SOCKET INSERT (P4) MUST MEET THE FOLLOWING REQUIREMENTS:
 - MIN INSULATION RESISTANCE - 50,000 MEGOHMS AT 500 VOLTS D.C. AT 70° F.
 - MAX LEAKAGE 4×10^{-8} STD CC/SEC OF HELIUM AT 1 ATMOSPHERE DIFF. PRESSURE.
 - PROOF PRESSURE - 1000 PSI AT 70° F.
 - MINIMUM OPERATING LIFE AT RADIATION LEVEL OF 1.4×10^{17} NVT NEUTRON 1.6×10^5 R/hr GAMMA.
 - TEMPERATURE REQUIREMENTS:
 - OPERATING (CONTINUOUS) 0°F TO +900°F.
 - LIMITS (30 MINUTES MAX AT TEMPERATURE IN A NON-REDUCING OR INERT ATMOSPHERE). 0°F LOW LIMIT, +1000°F HIGH LIMIT.
 - CLAMP (P6) WILL PROVIDE CLAMP PRESSURE ON WIRE BUNDLES OF $\frac{11}{32}$ TO $\frac{7}{16}$ DIA.
 - CONOSEAL FLANGE NOT REQUIRED - REFERENCED ONLY TO INDICATE FINAL USE OF CONNECTORS.

FIGURE 2-2. ELECTRICAL CONNECTOR

2.3.5 Other Specific Requirements

(a). Fuel pellets arranged so that the fuel thermocouple hot junction will not be in or move through a pellet interface during any anticipated reactor test operation. This will require one long pellet (approximately 1-1/8 inch) in each rod center section at the thermocouple hot junction.

(b). The total fuel zone has been limited to 37-1/8 inches for the IFA.

(c). The spring load on each segment of fuel will be 2 G's $\pm$ 1/4 G in the cold condition.

(d). For thermal expansion design, three extreme conditions have been considered. Room temperature, 1000°F temperature without reactor power, and greatest planned reactor power transient with the fuel going to 4700°F (see Figure 2-3).

(e). The following table shows fuel column characteristics for the IFA fuel and regular fuel:

	<u>IFA Fuel Rod 3-Segment Design</u>	<u>Regular Fuel Rod 2-Segment Design</u>
Core Height (inches)	37.125	35.812
Total Fuel Height (inches)	30.375	33.812
Total Fuel Volume (cu.in.)	17.844	20.295
Percent of Regular Fuel Volume	88	100

FIGURE 2-3. INSTRUMENTED FUEL ROD

	<u>IFA Fuel Rod 3-Segment Design</u>	<u>Regular Fuel Rod 2-Segment Design</u>
Fuel Segment Length: Upper (in.)	10.125	13.188
Center (in.)	6.188	--
Lower (in.)	14.062	20.625
Fuel Loss (percent) due to TC Hole, (.140 dia. thermocouple):		
Upper (in.)	4.6	--
Center (in.)	1.6	--
Lower (in.)	0	--
Fuel Loss due to Using 3-Segment Design Rather than 2-Segment Design	5.8	

Note: Values are for IFA fuel rods of 3 segments in all cases (necessary to provide 2 thermocouples per rod). Regular fuel volume based on 1.76% loss due to the use of dished pellets.

IFA fuel height was set at the length nearest to regular fuel without dividing a pellet.

SECTION III

EQUIPMENT DESIGN

3.1 GENERAL DESCRIPTION

The Instrumented Fuel Assembly, Figures 3-1 and 3-2, houses thermocouples to measure fuel and coolant temperatures and a magnetic flowmeter to measure coolant flow rate through the assembly. The assembly consists of two instrumented fuel rods and a center BeO-filled tightener rod. The three rods are attached at both the top and the bottom to form an integral unit. The overall length of the assembly, including the lead connector at the top of the assembly is 12 feet 4 inches. Four regular fuel rods are loaded in the same core channel with the instrumented fuel assembly to complete the normal fuel assembly loading of six rods and a center BeO-filled tightener rod. The two instrumented fuel rods each contain two tungsten-rhenium thermocouples positioned at the center-line of the fuel pellet - one located at midplane of the core and the other at an axial position closer to the top of the core (at a position which is approximately 75% of the average power density). (See Figure 3-1)

A magnetic flowmeter is mounted at the bottom of the assembly. The flowmeter signal leads, together with the leads from the thermocouple measuring the coolant inlet temperature, pass to the top of the assembly through the center tightener rod. The leads of the two coolant outlet thermocouples, enter the tightener rod 14 inches above the top of the core (approximately 59 inches above the core support plate) and also pass to the top of the assembly through the center tightener rod. The coolant thermocouples consist of grounded chromel-alumel junctions (0.012 inch diameter wire), MgO insulation and Inconel sheathing (0.062 inch outside diameter x 0.009 inch wall thickness), the thermocouples are specified to have a time constant of less than 0.1 second.

FIGURE 3-2. IFA PROTOTYPE

See Reference 2 for description of thermal-hydraulic design, structural design and materials evaluation.

3.2 DESIGN FEATURES

3.2.1 General Considerations

Three major considerations contributed to the basic features of the design: (1) The necessity of remotely handling the assembly and making instrument lead connections in the vessel, (2) the desirability of being able to refuel surrounding fuel rods without first removing and hence disturbing the instrumented fuel, and (3) the advisability of providing redundancy of measurements to minimize reactor shutdown for replacement and to improve reliability of the measurements.

The remote handling and connection features were provided by incorporating the instrumentation components and signal lead system into one assembly. The assembly is handled remotely by attaching a lifting fixture with solenoid operated grapples to two lugs mounted on the top of the assembly. The lifting fixture is suspended from the Master Grapple on the SEFOR refueling cell bridge crane. Positioning the assembly in the core also positions the instrument lead connector located at the top of the assembly to its mating component mounted at the side of the reactor vessel. Bolts, remotely tightened with a hand operated extension wrench, secure the two halves of the connector. These remote handling operations have been performed in the refueling cell mockup and in general have worked quite well.

The ability to leave the instrumented fuel assembly, including the signal leads, in place when handling surrounding fuel rods is accomplished by placing the lead wires in a thin ribbon of stainless steel structure which is formed to fit between rows of fuel assemblies, as shown in Figures 3-3 and 3-4.

FIGURE 3-3: LEAD WIRE RIBBON

FIGURE 3-4. LEAD WIRE RIBBON

The ribbon is approximately 3/16 inch in thickness, 3-5/16 inches in height, and has appropriate length for each of the three different radial locations of the instrumented assemblies in the core. At the edge of the core, the leads leave the ribbon and enter into a vertical pipe which extends to the connector at the top. At the point where the sheathed leads leave the ribbon structure and enter the vertical pipe, an expansion loop provides for the thermal expansion and misalignment of the core channel in relationship to the reactor vessel.

This ribbon lead feature has the obvious advantage of facilitating fuel handling operations. In addition it is believed that, based upon past experience with in-pile testing of instrumented fuel capsules, the lifetime of the instrumentation will be substantially enhanced if left undisturbed.

Redundancy of measurement is provided for in several ways. First, each fuel assembly has duplicate thermocouples to measure fuel and coolant outlet temperatures. Secondly, two assemblies are located at each of three different radii across the core. The radial positions include center, mid-radius, and periphery of the core (see Figures 3-5 and 3-6) to obtain measurements at the different rates of power generation across the core.

3.2.2 High Temperature Fuel Thermocouples

It will be desirable during the experimental program in SEFOR to be able to measure fuel temperature up to the vicinity of fuel melting temperature (approximately 5000°F), which is the planned operating limit for the fuel in SEFOR. The fuel thermocouples will have response times small compared to the heat transfer time constant of the fuel rod (approximately 30 seconds).

FIGURE 3-5. CORE LOCATION ARRANGEMENT

THIS DWG FOR INFORMATION ONLY

FIGURE 3-6. INSTRUMENTED FUEL ASSEMBLY THERMOCOUPLE RELATIONSHIP

Experience from previous programs indicated it was feasible for the design conditions to be met; however, additional information was needed to properly design and specify the thermocouples. An extensive program, involving both in-pile and out-of-pile testing, was carried out to obtain the necessary information (Reference 3 and 4).

The following thermocouple designs were selected for use in the SEFOR fuel elements based upon the experimental results from the SEFOR program and the work of other programs. The wires will be made of W5Re/W26Re and the sheathing of W26Re. Most of the thermocouples will use BeO insulators and the remainder will use ThO₂. Three different junction sizes will be used: (Shown on Figure 3-7)

0.140 inch O.D. sheath with 0.010 inch diameter wires,
0.063 inch O.D. sheath with 0.005 inch diameter wires,
Bare 0.010 inch diameter wires.

Note that both BeO and ThO₂ insulation will be used. The BeO has performed well not only in these experiments but other investigators also report good results up to the melting point of BeO (4658°F), which falls short of the target temperature. ThO₂ has a higher melting point and the shunting effects which develop above 4200°F can be corrected for in the calibration of the thermocouple. However, an unexplained porosity in the tungsten-rhenium sheathing was observed in ThO₂ insulated thermocouples which was not found in any BeO insulated, tungsten-rhenium sheath thermocouple. The porosity was observed both after in-pile and out-of-pile but did not affect the thermocouple signal within the experimental measurement accuracy of ± 0.3 millivolt. Hence, for the purposes of SEFOR, BeO will be relied upon up to temperatures near its melting point, and on ThO₂ for temperatures above this temperature.

FIGURE 3-7. FUEL THERMOCOUPLES

The bare wire thermocouples is expected to have a response time approaching 100 milliseconds, and the sheathed thermocouples will have a response time in the vicinity of 3 seconds. Although the 0.063 inch thermocouple has a somewhat better response time than the 0.140 inch thermocouple, some 0.140 inch thermocouples will be installed because it is thought that the large thermocouples should be inherently more rugged and, hence, should have longer life.

3.2.3 Coolant Thermocouples

With the thermocouples located in the sodium coolant channel stream before and after the reactor core it will be possible to monitor particular fuel channels for coolant temperature increase or if coolant flow is considered channel power may be determined. The thermocouples are required to operate in the liquid sodium environment under steady state and transient conditions from 400°F to 1200°F. The time constant for the thermocouples will be less than 0.1 second. Thermocouples of similar design and specification have consistently performed well in past programs.

The Inconel 600 ASTM SB-163 sheath has similar expansion properties to Hoskins Types 3-G 179 Chromel-Alumel wire. Magnesia with a density of 85 to 88% of theoretical will match expansion properties of the Chromel-Alumel wire. It will at the same time prevent the gripping action between wire and sheath experienced in high density, insulated, sheathed thermocouples.

3.2.4 Dummy Thermocouples

Measurements at pulsed reactors have shown some unexplained results from sensors where the output is in the millivolt range.

The Philips Petroleum Company (at NRTS, Idaho Falls) have reported radiation induced signals on thermocouples, strain gauges, and cables which interfere with the actual signal during reactor transient tests. Among other measurements they performed a test series with about 60 different cables at TRIGA (Reference 5). A typical result: 20 μ A radiation induced current at 10^7 rad/sec gamma pulse.

When running an excursion experiment at SEFOR similar effects might occur in the instrumented fuel assemblies, where the gamma dose rate is in the order of 10^8 rad/sec at 10^3 MW. Assuming 100 Ohm impedance and the above given induced current at 20 millivolt radiation induced signal would be imposed, which is the same order of magnitude as the actual temperature signal.

"Dummy" thermocouples having wires both made of W26/Re will be used in 2 of the possible 24 thermocouple positions in the core (one at midplane and one at a position of approximately 75% fuel rod average power. Similar alumel, alumel "dummy" thermocouples will be used in 2 of the possible 18 locations adjacent to the coolant thermocouples. These sensors will be inside the tightener rod as close as possible to one of the coolant thermocouples (inlet and outlet).

3.2.5 Magnetic Flowmeter

The magnetic flowmeter (see Figures 3-8 and 3-9) is located on the end of the instrumented fuel assembly and will extend through the core support plate when inserted in the reactor core. The flowmeter will measure channel flow at inlet core coolant conditions. The throat of the flowmeter will be sized to provide the same flow restriction as a normal channel flow orifice in the same core flow zone. Bypass leakage around the flowmeter body is prevented by a thin

FCF 197 R 243

Q2/G1	PT. NO.	NAME	DESCRIPTION
1	1	FLANGE	B50YP1A2 OR B2 304 SST
1	2	FLANGE	
1	3	END	
1	4	END	B50YP1A2 OR B2 304 SST
1	5	TUBE	1.803 ± .005 I.D. X .020 ± .001 WALL X 4 3/4 LG. B50YP33A2 OR B2 304 SST-SEE NOTE-2
1	6	TUBE	.997 ± .002 O.D. X .020 ± .001 WALL X 4 1/16 LG. B50YP33A2 OR B2 304 SST-SEE NOTES 2&3
1	7	TUBE	.707 ± .002 O.D. X .020 ± .001 WALL X 4 1/16 LG. B50YP33A2 OR B2 304 SST-SEE NOTES 2&3
1	8	TUBE	.125 O.D. X .035 WALL X 1/2 LG B50YP6A1 OR A2 304 SST
1	9	STOP	ASTM A 276 TYPE 304 SST
2	10	WIRE	.032 DIA. STK. 302 OR 304 SST
2	11	LEAD CABLE	211A 6701 PI
1	2	12	MAGNETRING 129 B 3022 P3
1	2	13	MAGNETRING 129 B 3022 P4
2	14	SPACER	ASTM A 29 STEEL
2	15	SPACER	ASTM A 29 STEEL
1	1	16	INS. TUBING 1/32 O.D. X .020 I.D. CAT. NO. ARST020132 MC DANIEL RETRACTORY PROCESSING CO. OR EQUIV. APPROVED EQUIVALENT

NOTES:

1. FLOWMETER TO BE IN ACCORDANCE WITH SPEC. 22 A1666.
2. SHARP EDGES ON P5, 6 & 7 TO BE .002 X 45° CHAM. MAX.
3. PREPARE TUBE O.D. P6 & P7 AS FOLLOWS:
A. SAND BLAST TUBE OUTSIDE DIA. SURFACE ONLY. TUBE NOT TO EXCEED THE FOLLOWING VALUES AFTER SAND BLASTING:
.993 O.D. MIN. (P6)
.703 O.D. MIN. (P7)
.018 WALL MIN.
B. COAT TUBE USING METCO 105 (METCO INC, 1101 PROSPECT AVE., WESTBURY L.I., N.Y. OR ENGR. APPD. EQUIV.) WITHIN AREAS SHOWN AS FOLLOWS:
.003 MIN. COATING THK
1.004 (P6) MAX. TUBE O.D.
.714 (P7) AFTER COATING

FIGURE 3-8. MAGNETIC FLOW METER

FIGURE 3-9. MAGNETIC FLOW METER

metal seal that will deflect to conform to the surface condition at the interface between the flowmeter and the bottom of the channel.

Since the channels are free to move $1/8$ inch in any lateral direction relative to the holes in the core support plate, the connection between the flowmeter and the spider support part of the instrumented fuel assembly allows a similar lateral movement. The flexible sheathed signal lead between the tightener rod and the flowmeter is protected against vibration induced from the coolant flow velocity by being enclosed in a $1/4$ inch protective sleeve. The flowmeter consists of a cylindrical magnet canned on the inside and outside with 0.020 inch thick stainless steel tubes. The inlet nose piece is rounded and the down stream end is expanded over a distance of about 3 inches to minimize pressure loss. The meter has an overall length of 7 inches and an outside diameter of 1.84 inches. Other throat sizes will be used to conform with the orificing pattern across the core radius. The flowmeter was designed for flow rates ranging from 12 to 72 gallons per minute. In conventional magnetic flowmeters, flat pole pieces are used to produce a uniform flux field in the liquid flow tube. In the Instrumented Fuel Assembly, space limitation precluded this approach and the magnets instead consist of two-pole rings. The magnet material is cast ALNICO VI (8% Al, 15% Ni, 24% Co, 3% Cu, 1.5% Ti, Bal Fe), and the measured strength of the magnet tested was found to be 648 gauss at 700°F. (Reference 6)

3.2.6 Instrumented Fuel Connector

To provide maximum reliability for the Instrumented Fuel Assemblies in the SEFOR core, an instrument lead and connector (see Figures 3-10 and 3-11) system was designed which could remain undisturbed while the reactor vessel refueling head was removed and any uninstrumented fuel rod changed. This design approach required an instrument lead connector which would operate inside the reactor vessel, sealed from the sodium and the sodium vapor, during reactor operation. During reactor shutdown, with the vessel head removed for removal or insertion of an instrumented fuel assembly, the connector would be open. The open connector is required to withstand exposure to sodium vapor in argon up to 400°F for periods

GR.1-WIRING DIAGRAM		
PT. NO.	WIRE MATL	ELEC. CONN. CONTACT LTR.
11	ALLOY 405	R
	ALLOY 426	S
11	ALLOY 405	N
	ALLOY 426	P
11	ALLOY 405	T
	ALLOY 426	U
11	ALLOY 405	V
	ALLOY 426	W
8	CHROMEL-P	L
	ALUMEL	M
8	CHROMEL-P	J
	ALUMEL	K
9	ALUMEL	C
	ALUMEL	D
8	CHROMEL-P	A
	304 SST	B
10	304 SST	E
	304 SST	F
9	ALUMEL	G
	ALUMEL	H

GR.2-WIRING DIAGRAM		
PT. NO.	WIRE MATL	ELEC. CONN. CONTACT LTR.
14	ALLOY 405	R
	ALLOY 426	S
14	ALLOY 405	N
	ALLOY 426	P
14	ALLOY 405	T
	ALLOY 426	U
14	ALLOY 405	V
	ALLOY 426	W
12	CHROMEL-P	L
	ALUMEL	M
12	CHROMEL-P	J
	ALUMEL	K
12	CHROMEL-P	A
	ALUMEL	B
13	304 SST	E
	304 SST	F
12	CHROMEL-P	C
	ALUMEL	D
17	ALUMEL	G
	ALUMEL	H

GR.3-WIRING DIAGRAM		
PT. NO.	WIRE MATL	ELEC. CONN. CONTACT LTR.
11	ALLOY 405	R
	ALLOY 426	S
11	ALLOY 405	N
	ALLOY 426	P
15	ALLOY 426	T
	ALLOY 426	U
11	ALLOY 405	V
	ALLOY 426	W
8	CHROMEL-P	L
	ALUMEL	M
8	CHROMEL-P	J
	ALUMEL	K
8	CHROMEL-P	A
	ALUMEL	B
10	304 SST	E
	304 SST	F
8	CHROMEL-P	C
	ALUMEL	D
9	ALUMEL	G
	ALUMEL	H

GR.4-WIRING DIAGRAM		
PT. NO.	WIRE MATL	ELEC. CONN. CONTACT LTR.
14	ALLOY 405	R
	ALLOY 426	S
14	ALLOY 405	N
	ALLOY 426	P
14	ALLOY 405	T
	ALLOY 426	U
16	ALLOY 426	V
	ALLOY 426	W
12	CHROMEL-P	L
	ALUMEL	M
12	CHROMEL-P	J
	ALUMEL	K
12	CHROMEL-P	A
	ALUMEL	B
13	304 SST	E
	304 SST	F
12	CHROMEL-P	C
	ALUMEL	D
17	ALUMEL	G
	ALUMEL	H

GR.5-WIRING DIAGRAM		
PT. NO.	WIRE MATL	ELEC. CONN. CONTACT LTR.
14	ALLOY 405	R
	ALLOY 426	S
14	ALLOY 405	N
	ALLOY 426	P
14	ALLOY 405	T
	ALLOY 426	U
14	ALLOY 405	V
	ALLOY 426	W
12	CHROMEL-P	L
	ALUMEL	M
12	CHROMEL-P	J
	ALUMEL	K
12	CHROMEL-P	A
	ALUMEL	B
13	304 SST	E
	304 SST	F
12	CHROMEL-P	C
	ALUMEL	D
17	ALUMEL	G
	ALUMEL	H

FIGURE 4-10. IFA CONNECTOR

of several hours and not be adversely affected. The connector was designed using known technology. Socket and pins are the type commonly used in high temperature connectors. High integrity ceramic inserts approximately 0.125 inch diameter surround the 0.040 inch diameter stem of each pin and socket. The body of the connector is designed for a precision fit into the flange and at the same time provide a "lip" for seal welding to maintain the helium leak-tight joint. The weld "bead" can be seen on Figure 3-11.

The pin insert shell and the socket insert shell material is Inconel to facilitate the joining of the ceramic insulators. An overlaying ring of 347 stainless steel in the region of the seal weld "lip" facilitates welding the connector into the instrumented fuel assembly flange.

Makeup of the vessel connector flange (Figure 3-11) and the instrumented fuel assembly flange is accomplished in 3 stages: (1) the nose of the lead conduit part of the instrumented fuel assembly enters the slotted guide tube of the vessel connector flange; (2) the dowel pins of the instrumented fuel assembly flange enter the mating holes in the vessel connectors precisely positioned by the dowel engagement; and (3) flange bolts are made up.

3.2.7 Transport Fixture

The instrumented fuel assembly requires a special strongback or support for handling when not installed in the reactor or held in the lifting fixture used for reactor insertion. This strongback or transport fixture (see Figures 3-12 and 3-13) also serves as a launching pad for the instrumented fuel assembly in the reactor refueling cell for pickup by the lifting fixture.

FIGURE 3-11. IFA CONNECTOR

FIGURE 3-12. IFA IN TRANSPORT
FIXTURE

FIGURE 3-13. INSTRUMENTED FUEL TRANSPORT FIXTURE

It is required that the instrumented fuel assembly be installed in the transport fixture for all time between fabrication and positioning in the reactor refueling cell to protect the expansion "loop" of the sheathed leads between the "ribbon" lead traverse above the core channel walls and the lead conduit portion of the instrumented fuel assembly. This flexing or expansion loop between these two parts of the assembly must be restrained within the limits of the design.

3.2.8 Lifting Fixture

Insertion of the instrumented fuel assembly in the reactor core will be accomplished with the aid of the lifting fixture (see Figure 3-14) supported from the crane by the master grapple. The lifting fixture is a remotely controlled special grapple which can be preset to accommodate any one of the three different core radii positioned instrumented fuel assemblies. The lifting fixture will be used to remove the instrumented fuel assembly from the transport fixture after the transport fixture containing the instrumented fuel assembly has been placed in wall brackets inside the refueling cell.

The "key" type joint between the wall bracket and the transport fixture is self-tightening and self-aligning as it is made up. The lower bracket has a large lead-in "cone" to make engagement without difficulty. Figure 3-15 shows the transport fixture hanging on the cell wall so that the lifting fixture may engage the instrumented fuel assembly. The engagement of the instrumented fuel assembly by the lifting fixture is controlled from a panel at the refueling cell window. The control panel is shown in Figure 3-16. Indicator light in Figure 3-16 indicates available power to open the failsafe solenoid latches used to engage the lifting lugs on the IFA. The 2 solenoid latches are controlled separately and the condition of each latch (engaged or disengaged) is shown by indicator lights. The lifting fixture supported from

PCF 191X655
191X643
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FIGURE 3-14. INSTRUMENTED FUEL LIFTING
FIXTURE

FIGURE 3-15. IFA CORE INSERTION

FIGURE 3-16. LIFTING FIXTURE CONTROL PANEL

the crane by the master grapple latches to the instrumented fuel assembly (after the transport fixture lifting lug and guard have been lowered) at a point on the connector flange and a point on the housing which forms the top portion of the instrumented fuel assembly enclosed in a reactor channel.

The latch is a collet which is actuated by a solenoid; two similar units are used on the lifting fixture. With the lifting fixture attached to the instrumented fuel assembly it is now manually released from the transport fixture by pulling the lock pins and opening the swinging brackets. This operation can be done with the same hook-type reach tool used to lower the transport fixture lifting lug and guard. The lock pins are attached to the frame by chains so that they cannot be dropped or lost.

The instrumented fuel assembly sets in a yoke bracket in the transport fixture so that the release of the lock pins may be done prior to the attachment of the lifting fixture if necessary.

The instrumented fuel assembly supported by the lifting fixture is shown in Figure 3-15. As the instrumented fuel assembly is lowered into the reactor vessel, the first engagement is the flowmeter entering the instrumented fuel position channel. Prior to this time, the lifting fixture has been adjusted in azimuth (with the master grapple) so that the nose of the vertical lead conduit will later enter the guide on the connector flange. Once the instrumented fuel assembly has been lowered into place the lifting fixture will be disengaged from the lifting lugs on the instrumented fuel assembly. This operation will be accomplished remotely from a panel at the cell window. With the instrumented fuel assembly in place in the reactor vessel, the connector flange is made up by 2 captured bolts.

With the tightener sleeve in the released condition, the four non-instrumented fuel rods will be lowered into place to complete the instrumented fuel assembly channel loading.

3.2.9 Data Acquisition and Reactor Test Operation

The purpose of the data acquisition system (DAS) is to provide accurate records of the various tests which can be conveniently used for on-site test guidance and later extensive analysis.

The DAS is computerized. Basically, the system consists of the following components:

- Solid State Scanner (multiplexer)
- Analog-to-Digital Converter (11 bits + sign)
- Computer with 8K Memory (16 bits per word)
- Teletypewriter with Paper Tape Punch and Reader
- Two Magnetic Tape Units
- Digital Incremental Graph Plotters
- Analog Recorders for on-line use (pen-type and light-beam oscillographs)

A total of 72 channels will be digitally recorded during the experiments. The sampling rate ranges from 0.1 sample per second per channel for the static measurements to 10,000 samples per second per channel for the fast transient tests. A computer-controlled digital data acquisition system (DAS) will be used for both data scanning and limited data reduction. The analog data channels are multiplexed and converted to digital form by a high speed analog-to-digital converter.

On-line data processing for the steady state and frequency response tests includes conversion to engineering units and Fourier analysis of the oscillating variables. In the fast transient tests, the data will be recorded without conversion on digital magnetic tapes.

Off-line data processing yields preliminary results enabling the operations staff to determine the next step in the program. Output devices include digital magnetic tape, punched paper tape, x-y plotter, and teletypewriter. Data are recorded on either punched paper tape or digital magnetic tape for analysis at a location remote from the test site.

For static measurements, the reactor will be operated at steady power up to 20 MWt. The variables to be recorded by the DAS are the reactor power, the core inlet and outlet temperature of the sodium coolant, the temperature within the oxide fuel elements, and the coolant flow rate through the vessel and individual fuel assemblies. Reactor power and coolant temperatures will be varied independently to establish the important static reactivity effects.

During oscillator tests, the reactor power is sinusoidally oscillated (see Reference 8) (with amplitude less than $\pm 10\%$) by a neutron absorbing rod in the reactor core; the reactor power, fuel element temperature, and coolant temperature vary simultaneously. The frequency can be adjusted over the range $0.00125 < f < 0.5$ Hz. The oscillating fuel and coolant temperatures are measured and recorded by the DAS at different levels from zero to full power. Also, key data from the process instrumentation panel will be recorded by the DAS, such as reactor power and main coolant flow rate.

During the transient tests, the critical reactor, i.e., the reactor operating at steady state, will be made supercritical by firing an absorbing rod out of the reactor core. In the fastest case, (1.0 millisecond minimum reactor period) the power increases from 0.1 MW to 10^5 MW within 50 msec, then decreases to lower power due to the inherent Doppler effect.

The neutron flux will be measured with a set of especially developed flux detectors and amplifiers located outside the reactor vessel. These instruments with a bandwidth in excess of 16000 Hz will follow the power increase with high accuracy. Again the fuel and coolant temperature will be measured. The object of this measurement is to determine the fuel Doppler reactivity feedback effect.

SECTION IV

TEST AND DEVELOPMENT

4.1 FUEL CENTER TEMPERATURE SENSORS

In addition to the test and development work described in Reference 3 and 4, thermal shock test of the sheathed lead wire and braze development for the tungsten-rhenium to Inconel sheath were carried out. The test assembly prior to installation in the thermal shock test facility is shown in Figure 4-1.

As a result of the thermal shock test performed in sodium from 800°F to 1300°F in 1 second, it was found advisable to specify sheathed lead wire insulation with a density of 84 to 88% theoretical to prevent a gripping or coupling between the lead wire and the sheath. The magnesia insulation was selected to more closely match the expansion properties of the Hoskins extension wire alloys 405 and 426 and the Inconel 600 ASTM B-163-66 sheath.

Following the development work on high temperature braze for tungsten 26 rhenium to Inconel, Palladium-Nickel (60% Pd, 40% Ni) eutectic braze was selected. Copper was selected for the nickel sleeve to tungsten-rhenium thermocouple wire braze.

A vacuum brazing process was developed to join a 304 stainless steel sleeve to the Inconel sheath as an intermediate step for lip welding into the instrumented fuel assembly. As a result of this effort, Nicro Braze 30 (Wall Colmonoy Company or equal) was specified.

FIGURE 4-1. THERMAL SHOCK ASSEMBLY

4.2 CHANNEL INLET AND OUTLET TEMPERATURE SENSORS

Thermal shock tests similar to that described above were performed and information gained was applied to the thermocouple specification calling for Inconel sheath, magnesia insulation on the chromel-alumel lead wire. Proof test of the coolant thermocouple was carried out in the "wet" cell test operating with sodium temperatures from 300°F to 1000°F. The 1000°F temperature was maintained for 5 days while the prototype instrumented fuel assembly continued to readout coolant temperatures.

4.3 CHANNEL FLOW SENSORS

Test data from several test and development efforts were used in the design of the channel flow sensor, (a) high temperature test of magnets, (b) flowmeter throat diameter sizing in the full scale water mockup, (c) flow entrance test in the one-half scale water mockup, and (3) the sodium flow test and calibration.

(a). The purpose of the high temperature magnet tests was to measure the short term flux versus temperature characteristics of the magnetic material being used and also to determine the long time magnetic flux stability at the SEFOR operating temperature of 700°F. The results obtained show that at this temperature there will be no degradation in flowmeter output signal in a one-year period.

The result of this test work is as follows:

Within the accuracy of the measuring system ($\pm 2\%$) there was no irreversible loss of magnetic field strength with time at temperature during the 9700 hours at 700°F.

The reversible flux versus temperature relationship was established including data after the 9700-hour test (see Figure 4-2).

(b). The flowmeter was tested for pressure drop in the full scale water mockup under Task 5.3 as reported in Reference 9. Dummy flowmeters with throat diameters 0.600 inch, 0.900 inch, and 1.200 inch were used to obtain orifice loss coefficients as shown in Figure 6-2 of Reference 9. This test work established the reference throat diameters for the three flow zones at 1.200 inch, 0.960 inch, and 0.670 inch. These flowmeters will match the pressure drop of the regular channel orifices in the same core flow zone.

(c). Dummy flowmeters were included in the one-half scale mockup water facility as described in Reference 10. Analysis of the data from this test shows that the extension of the instrumented fuel assemblies flowmeter through the support plate (approximately 3 inches) into the inlet plenum will not disturb the flow distribution to other core channels.

(d). A prototype flowmeter with a 1.200 inch throat diameter was installed in a flow test assembly in the sodium loop provided under Task 5.4. (Ref. 7) Flow calibration curves were obtained at 100°F intervals from 500°F to 1000°F, using a conventional magnetic flowmeter as a primary standard. The largest diameter flowmeter was used for this test since signal to flow rate will be the smallest and so this will be the least accurate of the three planned flowmeters. Figure 4-3 shows the linearity of response and the effect of temperature on the flowmeter output signal.

FIGURE 4-2. MAGNET FLUX VS. TEMPERATURE

FIGURE 4-3. FLOW METER CALIBRATION

A noise level of 0.5 millivolt was experienced in this test data. A decrease in signal noise level at the reactor installation is expected as the readout instrumentation and signal lead quality is improved. The data from this test indicated an accuracy of $\pm 5\%$ above 25 gpm and $\pm 10\%$ in the range of 10 to 25 gpm.

4.4 INSTRUMENT LEAD CONNECTOR

The design and development of the instrument lead connector is reported in Reference 1.

In addition to above reported work a number of connector design features were developed during the instrumented fuel assembly prototype fabrication. Pin and socket spade-end orientation was established. Orientation of the spades in a radial direction was necessary to provide room for the capacitance welding electrodes used to make up the terminals. Clamp action on the stainless steel sheathed cable was improved by lengthening the connector body shell. This change was the result of a problem caused by the rigid sheathed cable and the short distance between the clamping point and the connector terminations. Remote handling and connector operation in the vessel at reactor operation conditions of sodium and high temperature were demonstrated in the mockup cell test reported in more detail in paragraph 4.5.

4.5 MOCKUP CELL DRY AND WET TEST

Manual handling and remote manipulation of the prototype instrumented assembly was tested in the mockup cell. Tests were conducted with air in cell and no sodium or high temperature and also with argon in the cell,

sodium in the vessel and at temperatures up to 1000°F.

The cover gas control during transfer into the mockup cell was accomplished by placing the prototype instrumented fuel assembly mounted in the transport fixture in a plastic enclosure and sealing the plastic to the vertical transfer lock. After the plastic enclosure was purged with argon, the lock was opened and the prototype instrumented fuel assembly mounted on the transport fixture was moved into the cell attached to the lifting fixture.

Evaluation of the balance of the instrumented fuel assembly, the transport fixture and the lifting fixture in terms of insertion and removal procedure was made (see Figure 4-4). Minor interference involving the lifting fixture was corrected by cutting out a small section of the lifting fixture frame.

The prototype instrumented fuel assembly thermocouples were recorded throughout the mockup cell test. The thermocouples, the signal lead out system, and the instrument lead connector continued to function from the cold startup through the system heat up and through the 5 day wet test at 1000°F. Figure 4-5 shows the surface condition of the prototype instrumented fuel assembly as it was removed from the sodium at approximately 400°F (refueling temperature).

FIGURE 4-4. IFA CORE REMOVAL

FIGURE 4-5. IFA IN TRANSFER

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