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NATIONAL AERONAUTICS & SPACE ADMINSTRATION

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REACTOR ASSEMBLIES FOR NON NUCLEAR TEST SYSTEMS (SIMULATORS)

(Title Unclassified)

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REACTOR ASSEMBLIES FOR NON-NUCLEAR TEST SYSTEM (SIMULATORS)

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SUMMARY

Engineering studies on non-nuclear reactor assemblies (simulators) were made as follows:

Reactor Simulator for Startup Development (RSSD)

This simulator duplicates stored heat capacity and flow impedance of the reference reactor during an initial startup and restart transient. RSSD is to be a part of the Cold Flow Development Test System (CFDTS), which is in the planning stage of Aerojet-General Corporation's effort in propellant feed system control development.

Reactor Simulator for ETS Flow Test

This simulator is to be a part of E-engine simulator which would be used to check out installation details and to test flow interaction of the engine and the test stand facility (piping and ejector systems) at ETS-1 and 2. The reactor simulator is similar to RSSD except that the restart capability is not required.

Instrumentation and Control (I & C) Systems Checkout Device at ETS

The joint efforts of WANL and AGC on I & C checkout device are in progress under a separate task. The WANL work program is covered by Project 2200.

Reactor Simulator for Remote Assembly and Disassembly Study

Postponed until the further details of E-engine reactor are available.

Non-Nuclear Test Assembly (NNTA)

The non-nuclear test assembly is an exact duplicate of a reactor except the core section, where either non-fueled or depleted fuel graphite was used. The primary objective was to duplicate and study the interaction, displacement, vibratory motions, and stress of reactor components under the flow and thermal conditions of the reactor startup transient. This was not included in the original work program. However, the necessity of this device for NERVA reactor development became evident and the study is included in this report.

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RECOMMENDATIONS

The following recommendations are made:

1. Incorporate the RSSD into the AGC test program of CFDTS.
2. Continue further study of the reactor simulator for ETS Flow Test and a reactor simulator for training of personnel at the E-MAD building for remote assembly and disassembly of the reactor as soon as more detailed information on the ETS and E-engine are available.
3. Continue further study of the NNTA and incorporate results into the NRX-A and E-series test programs.

I. SIMULATOR STUDIES

INTRODUCTION

Project 1391, Reactor Assemblies for Non-Nuclear Test Systems (Simulators), was established under the Contract No. NP-1, Tasks Item 1.3 for Contract year 1963. The project was scheduled for the four month period from October 1, 1962 to January 31, 1963. The project was established because of the high cost of actual hardware, and was intended in response to the following Work Request:

"1. PROJECT TITLE: REACTOR ASSEMBLIES FOR NON-NUCLEAR TEST SYSTEMS (SIMULATORS)"

"2. PURPOSE AND OBJECTIVES: To provide for the engineering study to determine nuclear subsystem requirements for simulators (reactor flow path and heat capacity mockup assembly for the cold flow development test system, a functional reactor mockup assembly for the NERVA engine hard functional mockup, and a core assembly mockup for training purposes in the E-MAD building)."

"3. RELATED WORK OR BACKGROUND: The assemblies to be studied in this task are intended to meet several needs. A reactor assembly is required for the Generation II, Mod. 2 and Mod. 3 Simulator at the AGC Liquid Rocket Plant for transient cold flow testing. This assembly must simulate flow path and heat capacity characteristics of the NRX-A reactor assembly. A hard functional reactor mockup is required at NRDS for installation testing, flow testing, control and instrumentation checkout, and general handling studies. This mockup will be used on ETS-1, ETS-2 and possibly the RIFT test stand. The training mockup for the E-MAD building is a dimensional and weight simulation of the reactor for checkout of handling procedures and personnel training. Hardware procurement of the simulator assemblies will not be initiated during the study period. These design studies will be coordinated with related studies to be performed by AGC."

"4. DESCRIPTION OF WORK PROGRAM:

Perform an engineering study to assist in the definition of the simulator test plan and to:

a. Define the functional requirements of a reactor and shield assembly to serve as a flow and heat capacity mockup in the cold flow development test system, Generation II, Mod. 2 and Mod. 3. Adapt the NRX-A mechanical design and select materials to meet the functional requirements at minimum cost. Prepare preliminary layout drawings, preliminary procurement cost estimates and schedules.

b. Define the functional requirements of a nuclear subsystem assembly to serve as a component in the NERVA engine hard functional mockup. Adapt the NRX-A mechanical design and select materials to meet the functional requirements at minimum cost. Prepare preliminary layout drawings and preliminary cost estimates and procurement schedules.

c. Define the functional requirements of a nuclear subsystem mockup to provide dimensional and weight simulation of the NERVA engine for E-MAD training purposes. Prepare preliminary layout drawings and preliminary cost estimates and procurement schedules."

This report was prepared after the work required to satisfy the above Work Request was completed. It is divided into two parts. The first part discusses four particular simulators. (1) presents the engineering study of a reactor simulator for start-up development covering mechanical, flow, thermal aspects, instrumentation, estimated cost, procurement time, and test capabilities; (2) presents a brief discussion of a reactor simulator for ETS checkout; (3) presents the requirements for Instrument and Controls Checkout Device at ETS-1 and ETS-2 and provides a brief outline of similar work covered in Project 2200; and (4) constitutes a feasibility study on a non-nuclear test assembly for study of reactor mechanical component interaction. The second part (Appendix) includes technical data and information on the reference reactor components on which

RSSD Design was based. The reference reactor design is one of the earlier versions of the NRX-A reactor design, and its thermal and flow impedance characteristics remain unchanged from those of NRX-A reactor. The Appendix was added for expediency in comparing the reference reactor components with the simulator reactor components studies in Section I.

1.0 - REACTOR SIMULATOR FOR START-UP DEVELOPMENT (RSSD)

The primary objectives for the Reactor Simulator for Start-Up Development were as follows:

1. To evaluate the initial start-up transient characteristics of the NERVA hot bleed engine such as temperature and pressure distributions versus time.
2. To evaluate the re-start transient characteristics of the NERVA hot bleed engine.
3. To determine the minimum net positive suction pressure (NPSP) and boot-strap start capabilities of the turbo pump.
4. To determine the optimum position of the turbine power control valve.
5. To determine the operating characteristics of available control system components and instrumentation.
6. To correlate analytically determined values with test results.

These objectives could have been attained by using an actual reactor with U-238 fuel. There were several disadvantages to this proposition such as excessive costs, loss of time in the program, and introduction of difficulties due to radiation hazards. On the other hand, a rather inexpensive simplified simulator consisting merely of a few load valves to simulate fluid friction and an appropriate quantity of material to simulate heat capacity could have been constructed. However, this concept would have involved a great deal of analytical work. Unfortunately, the mechanism of two phase flow and the complexity of the problem made this approach appear unreliable. In addition it would not have provided an independent check of theory against experiment.

A third proposition which was considered briefly was to represent the reactor by a reasonably accurate reproduction of a 1/6 segment with a simple representation of the remaining 5/6 of the reactor. However, it probably would have been difficult to achieve identical conditions in both portions of the simulator. Since an important objective is to test boot-strap capabilities, accurate simulation of flow in the whole reactor was required.

The simulator proposed for this program is one which will accomplish the required objectives with emphasis on a minimum cost. In order to keep costs to a minimum, components were simplified as much as possible without compromising their effectiveness.

The objectives could be achieved if flow and thermal characteristics matched those of the reference reactor with sufficient accuracy. Therefore, flow passages through the majority of the components were not changed appreciably. However, changes dictated by economy, such as a reduction of the number of flow holes from 3888 to 384 in the dome end outer reflector support, were investigated analytically and the flow hole diameters adjusted to match flow impedance.

Thermal characteristics are determined by such parameters as specific heat, density, volume, and coefficient of heat conduction. Analytical studies indicated that heat conduction is of less importance than the other parameters since rate of heat transfer is determined largely by the conductivity properties of the gas boundary layer film. Therefore, the rule of thumb for material substitution was the requirement to match total heat capacity.

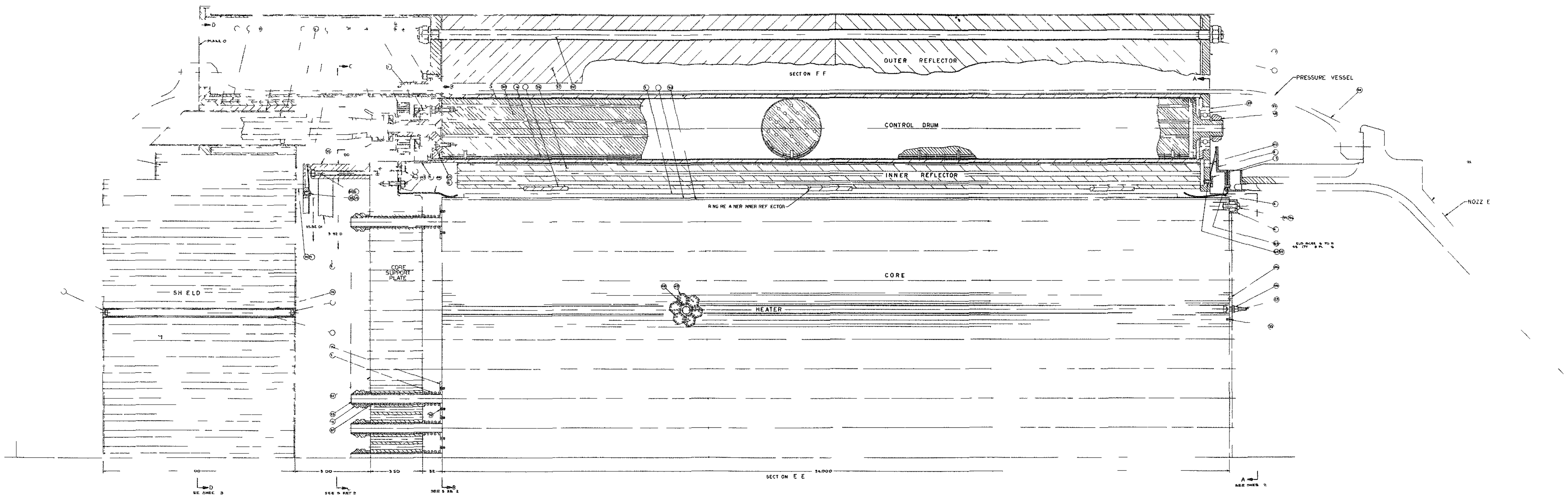
1.1 - Mechanical Design Adaptation

Major components of the RSSD consists of (a) outer reflector assembly made of 12 aluminum segments and includes 2 simulated control drums, (b) graphite inner reflector assembly made from 66 segments with 6 aluminum shim pieces, (c) shield assembly which utilizes stainless steel tube insert to simulate the heat capacity of lithium hydride, and (d) core assembly which is made from unfueled graphite elements and include provisions for the heat input of about 200~250 KW to simulate various initial conditions of the reactor startup and restart. The lateral support of the core assembly is provided by a corrugated cylinder which is drawn tightly around the assembly. The nozzle end core seal is substituted by a twin layer split leaf type seal, attached to the nozzle and a secondary seal, Belleville spring washer type, attached to the reflector assembly.

The following paragraphs describe the mechanical details of the reactor simulator. Mechanical assembly layouts of RSSD are shown on Figures 1, 2, and 3. For comparison with the reference reactor, see Figure 4 and appendix.

1.1.1 - Pressure Vessel and Nozzle

These two components would be supplied by the Aerojet General Corporation. No major modifications of the NRX-A vessel or nozzle design are anticipated. However, the pressure vessel may require reinforcing bosses where it is pierced by instrumentation probes.



REQD	ITEM NO	NOMENCLATURE OR DESCRIPTION	CODE IDENT NO	PART OR IDENTIFYING NO	MATERIAL	SPECIFICATION	UNIT WT	ZONE
30	96	INSERT, HELI-COIL		MS-124736				
30	95	SCREW RD HD 250 28 00			STEEL			
	94	PRESSURE VESSEL						
	93	NOZZLE						
	92	R NG, SEAL			STEEL			
2	9	ELEMENT, RREGULAR			GRAPH TE			
2	90							
2	89							
2	88							
2	87							
2	86							
2	85							
2	84							
2	83							
2	82							
2	8							
2	80							
2	79							
6	78	ELEMENT, IRREGULAR			GRAPHITE			
278		SPR NG CLUSTER			STEEL			
254	76	PLATE CLUSTER			CRES			
	75	P N, P ANO H NGE			STEEL			
	74	H NGE, PIANO			STEEL			
3	73	RING, RETAINER INNER REFLECTOR			STEEL			
278	72	NU SE F OCK NG 750 6			STEEL			
240		CAPSULE EXTENDED, SH ELD			CRES			
240	70	TUBE EXTENDED, SHIELD			CRES			
160	69	SCREW FLAT HD 250 28 15			STEEL			
8	68	NUT, SELF LOCK NG 115 2			STEEL			
24	67	NUT, SELF LOCK NG 615 8			ALUM			
278	66	NUT, SELF LOCKING 250 28			STEEL			
48	65	SCREW FLAT HD 10-32 x .00						
96	64	SCREW, FLAT HD 0-32 50						
4	63	BO T SOC HD 250-28 25						
104	62	BO T, SOC HD 250 28 x 75			STEEL			
AS REQD	6	SCREW LOCK NSERT		MS2 09 4 20				
48	60	BO T, SOC HD 250 28 x 3.00			STEEL			
96	59	SCREW LOCK NSERT		MS21209 F 5				
96	58	SCREW PAN HD 10-32 x 31			STEEL			
2	57	SECTOR, OUTER REFLECTOR			ALUM			
0	56	SECTOR OUTER REFLECTOR			ALUM			
0	55	PLATE, SIMULATED CONTROL			ALUM			
0	54	BLOCK, F LLER			ALUM			
	53	HEATER, BUS BAR		707J858				
	52	BARREL, CORRUGATED, CORE			CRES			
	5	BARREL CORE			CRES			
	50	INSULAT ON, CORE						
374	49	ELEMENT, REGULAR CLUSTER			GRAPHITE			
278	48	ELEMENT CENTRAL, CLUSTER			GRAPH TE			
	47	R NG, RREGULAR SUPPORT			STEEL			
253	46	PLATE, CLUSTER, SUPPORT			STEEL			
	45	RING, NOZZLE END SEAL			STEEL			
	44	SEAL CORE DOME END			CRES			
2	43	R NG, SEAL, SUPPORT						
	42	R NG, SEAL, SUPPORT						
	4	SEAL, CORE, NOZZLE END						
	40	SEAL REFLECTOR NOZZLE END			CRES			
2036	39	BUSHING, ELEMENT LOCATING			STEEL			
2	38	SPR NG, SAFETY			CRES			
2	37	HOUS NG CONTROL DRUM			A UM			
2	36	PLATE CONTROL DRUM			A UM			
2	35	SHAFT CONTROL DRUM DRIVE			CRES			
4	34	BEAR NG		963B274				
2	33	HOUS NG BEAR NG			CRES			
2	32	STOP CONTROL DRUM			CRES			
2	3	COUPLING CONTROL DRUM			CRES			
2	30	CYLINDER CONTROL			ALUM			
	29	SPR NG, INNER REFLECTOR			CRES			
AS REQD	28	SHIM, INNER REFLECTOR, SECTOR			ALUM			
2	27	SECTOR, NNER REFLECTOR			ALUM			
66	26	SECTOR NNER REFLECTOR			GRAPHITE			
278	25	TUBE END			INCONNEL X			
278	24	SPACER			CRES			
278	23	TUBE CLUSTER SUPPORT			NCONNEL X			
	22	PLATE CORE SUPPORT			STEEL			
	2	SUPPORT CORE			STEEL			
2	20	ROD TIE OUTER REFLECTOR			STEEL			
	9	R NG OUTER REFLECTOR			CRES			
	8	SUPPORT OUTER REFLECTOR						
	7	SEAL						
	6	SUPPORT, SEAL SH ELD						
5040	5	PLUG CAPSULE, DOME END						
4820	4	PLUG, CAPSULE, NOZZLE END						
3068	3	TUBE, FULL CAPSULE						
828	2	TUBE 3/4 LG CAPSULE						
924		TUBE 1/2 LG CAPSULE						
3068	0	CAPSULE FULL, SH ELD						
828	9	CAPSULE 3/4 LG, SH ELD						
924	8	CAPSULE 1/2 LG, SH ELD						
2	7	BLOCK F LLER SH ELD						
2	6	BLOCK F LLER, SH ELD						
2	5	BLOCK F LLER SH ELD						
2	4	BLOCK F LLER SH ELD						
2	3	TUBE, DRUM DR VE PORT						
2	2	PORT, DRUM DR VE						
		SUPPORT SH ELD			CRES			

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Figure 1 - Reactor Simulator Start-up Development (RSSD) (Longitudinal Section)

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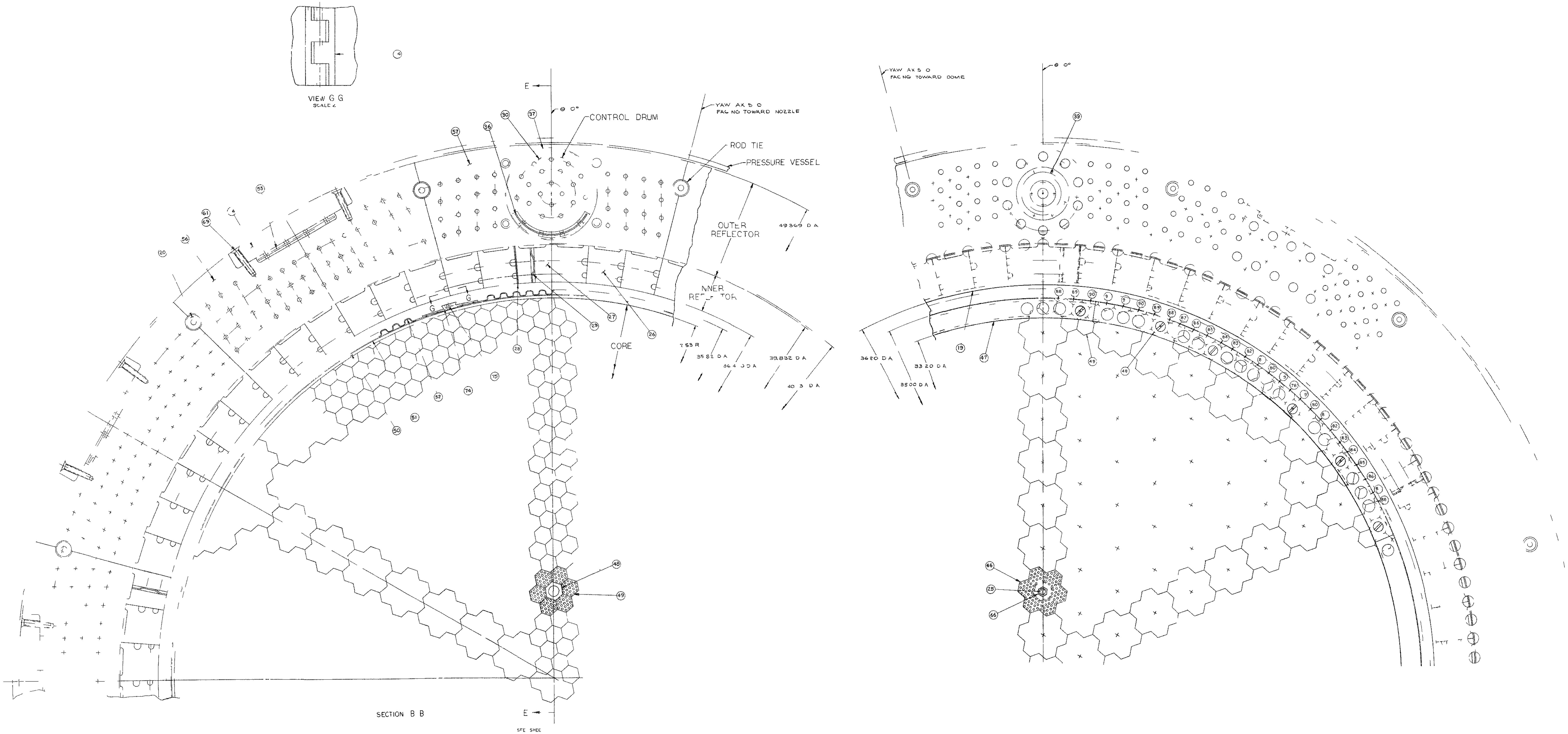
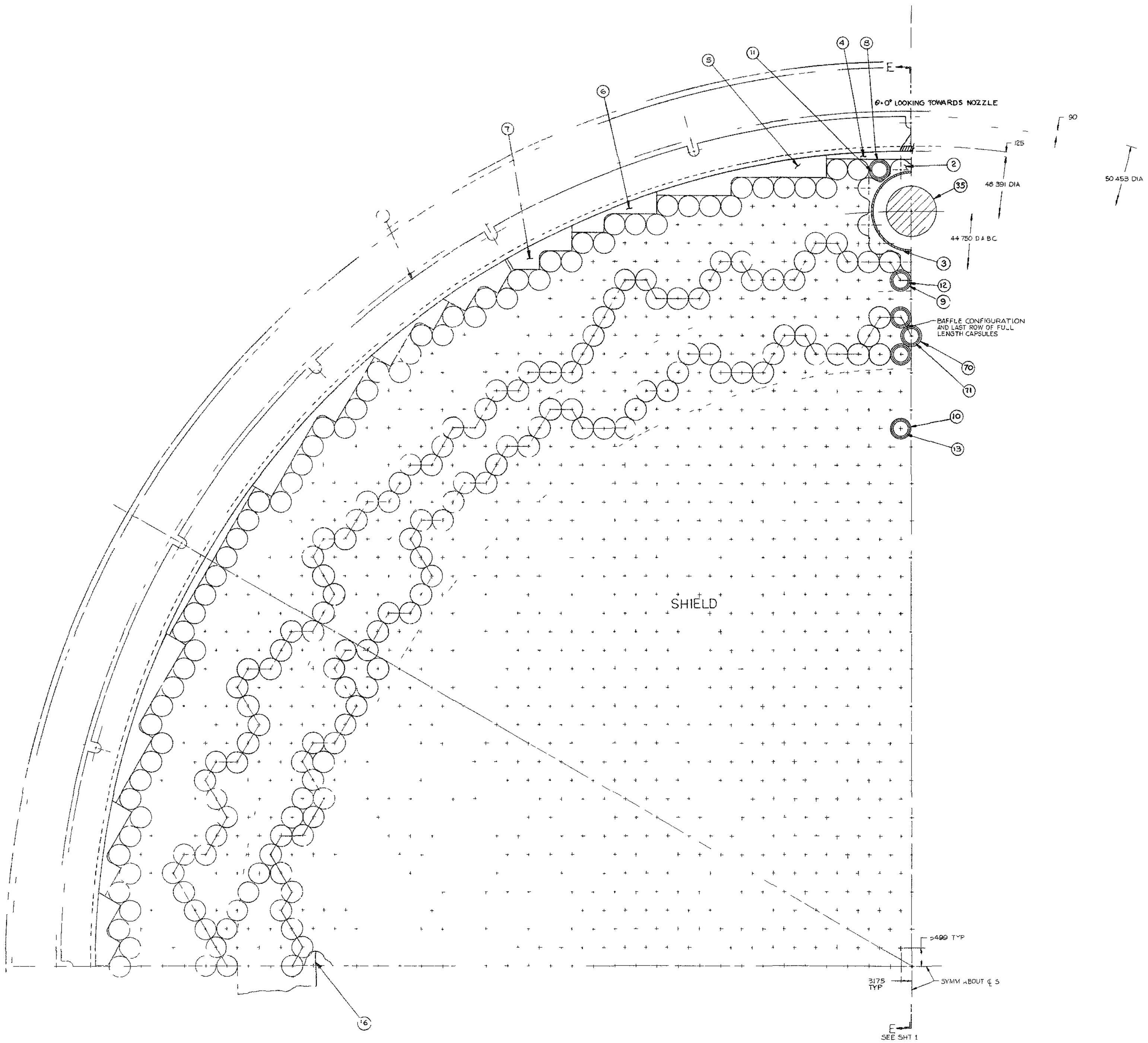


Figure 2 - Reactor Simulator Start-Up Development (RSSD) (Transverse Section)



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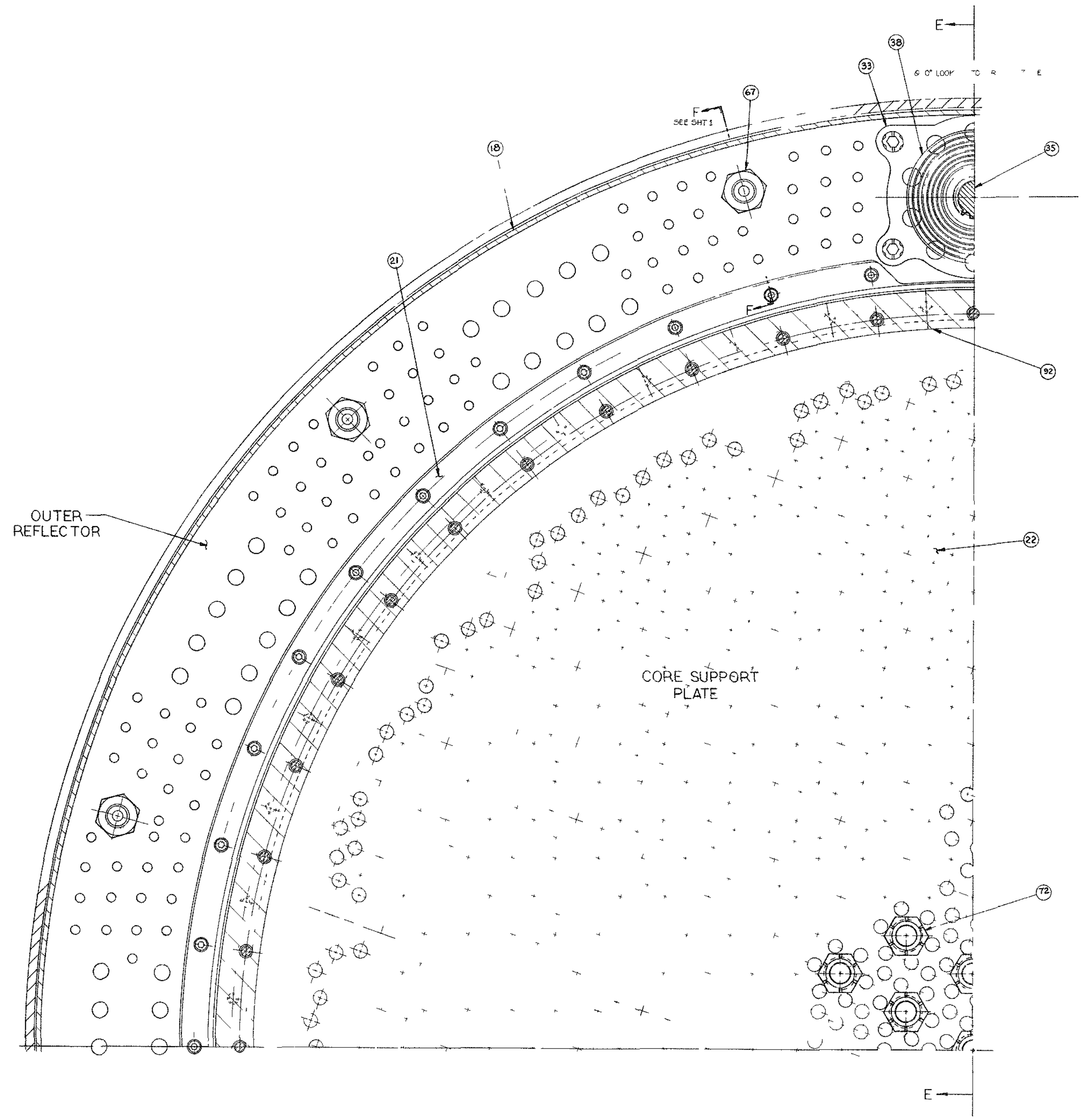

SECTION CC

Figure 3 - Reactor Simulator for Start-Up Development (RSSD) (Transverse Section)

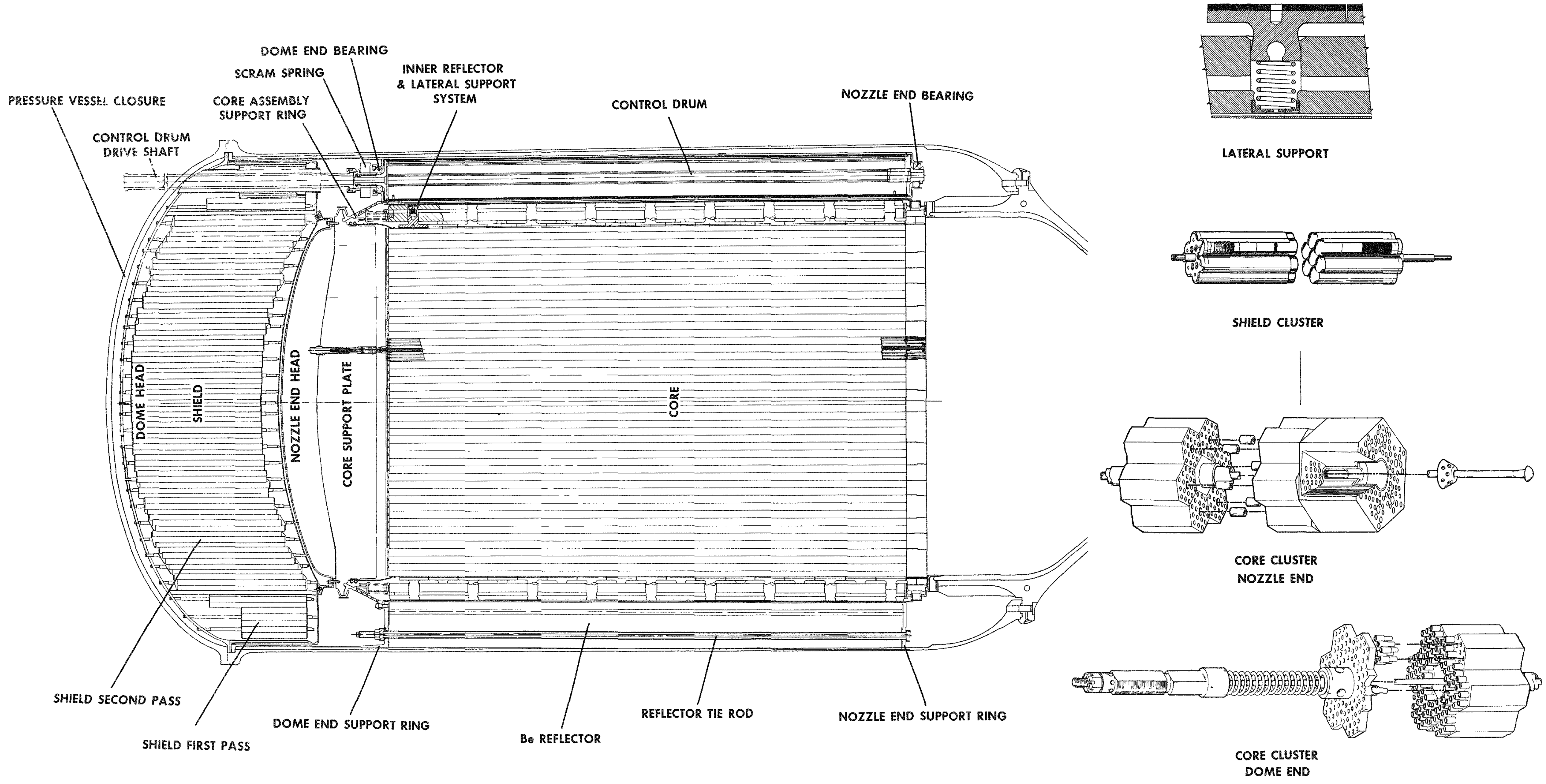

Figure 4 - Reference Reactor Assembly

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1.1.2 - Outer Reflector

The outer reflector in the simulator consists of a segmented aluminum barrel held together by means of axial tie bolts through end plates. The substitution of aluminum for beryllium permits considerable cost savings without significant changes in the thermal properties over the temperature range involved.

The segmented barrel is divided into 30° segments with the inner and outer diameters, remaining unchanged. However, each 52-in. long segment has been cut into two parts 26 in. long. It is anticipated that this will result in a considerable saving in the cost of deep hole drilling of the axial flow holes. The saving in cost of deep drilled holes must be balanced against the additional cost of interface machining and sealing.

The number and size of flow holes remains unchanged; however, cost savings can be realized by omission of the shim rod holes and by making 10 of the 12 control drums integral with the barrel segments. Since the shim rod holes in the reference reactor are plugged with either aluminum or beryllium shim rods, no significant change in flow or heat capacity will result by their omission.

Flow passages around the poison plates in the integral control drums were simulated by passages which are of the same area, length, and thickness but which are straight instead of curved. These were located far enough from the periphery to prevent leakage problems into the inner or outer annuli. The flow holes simulating the control drum flow holes were relocated slightly to accommodate the above changes. The effect of these hole relocations was investigated and found to be of little consequence since the thermal conductivity is high.

The nozzle end support plate was simplified by replacing 1488 flow holes by 384 flow holes. The flow hole diameters were changed such that the flow impedance of the smaller number of holes would match that of the larger number. Machining would be facilitated and material costs reduced if steel were substituted for titanium. The elimination of the bearing housing bosses simplifies machining considerably.

The dome end support plate with the integral cylindrical and support ring was simplified by changing from a one piece machining to a three piece welded assembly. Machining of these parts would be facilitated and material costs reduced by substitution of steel for titanium. The 3888 flow holes were replaced by 384 flow holes and the diameters were adjusted to match the impedance.

1.1.3 - Inner Reflector

The simulated inner reflector consists of a segmented barrel made from 66 graphite segments of 5° each and six special aluminum segments made narrower to provide for shimming and to accommodate springs to maintain circumferential compression. The outer surface of the segments is assembled against a split sheet metal drum which lines the inner surface of the outer reflector. In order to ensure that the segments fit tightly against the outer reflector, three split expansion rings (similar to piston rings) are installed against the inner surface. Deep hole drilling of 144 flow holes is eliminated by simulating the flow holes by grooves as shown' in Figure 2. The flow annulus between the inner and outer reflector is simulated by a flat groove on the outer surface of each segment. The heat conduction area across the annulus can be reduced, if necessary, by additional machining to leave only intermittent contact instead of continuous axial contact. The lower support plate which provides support for the outer reflector was widened to provide support for the inner reflector segments.

1.1.4 - Shield

The simulator shield consists of stainless steel tubes with steel tube inserts to simulate the lithium hydride heat capacity. Analysis showed that this double walled construction was necessary to match heat transfer rate and heat capacity.

The tubes are plugged at both ends with machined plugs. All the tubes may be bundled together and furnaced brazed, thus eliminating the need for module assemblies, tie plates, baffle and enclosure domes. However, alternate assembly techniques were investigated. The machined plugs are brazed in during the braze cycle and vent holes are later welded closed to form hermetically sealed tubes to avoid entrapment of gases. Construction was further simplified by making the shield flat instead of elliptical and by eliminating all but two of the drum control drive ports. The screen below the shield has tentatively been eliminated, but if more refined flow analysis later shows that more impedance is required, a suitable screen can be added.

1.1.5 - Core Support Plate

Steel was substituted for aluminum to allow for high temperatures which might occur during heating of the core to 1600°R prior to simulated restart. The integrated heat capacity from 100° to 530°R was made to match aluminum by an appropriate change of volume. The design was simplified by making both sides flat.

The number and size of flow holes remain unchanged. However, the support ring was simplified by making it a simple bolted-on section rather than a conical ring (see Fig. 1). This tool was changed to steel.

The double thickness split fabricated sheet metal seal is very similar in design to the reference reactor except for a change of material to steel and method of attachment. It is bolted to the support plate rather than being shrunk on.

1.1.6 - Lateral Support System

The function of the lateral support system in the simulator is the same as in the reference reactor; namely to bundle the core and to provide insulation for the restart condition.

The lateral support system in the simulator consists of an 1/8-in. layer of Transite insulation adjacent to the core covered by an 0.032-in. split steel cylinder with an 0.032-in. axially corrugated steel sheet around the outside. The corrugated sheet is joined together by a piano hinge to form a cylinder. Pre-tension in the cylinder bundles the core. The bundled core thus acts as its own lateral support system.

1.1.7 - Core

Various material substitutions for the core were investigated; however, difficulties were encountered in matchining the heat capacity over the temperature range desired. A comparison of material thermal properties and costs indicated that unfueled, uncoated graphite was the most economical and satisfactory means of simulation.

The over-all dimensions of the simulator reactor core are the same as the reference reactor core. The length of the individual elements, however, were increased approximately 2 in., and the nozzle end support blocks were reduced in thickness a corresponding amount.

The simulator clusters have the same cross sectional shape as the reference reactor and will be assembled using the same components. A few of the components such as bushings, sleeves, insulators, tie rod holders, etc., were eliminated for simplification. The parts which make up the simulator clusters are described in the following paragraphs.

The simulator core elements can be extruded from a less expensive graphite than reactor grade and need not be coated. The tolerances on the elements have been relaxed to reduce costs. The hole in the center element was enlarged to permit the insertion of a tubular tie bolt. Since the simulator is essentially an unfueled reactor, no shimming is required. Consequently, the axial holes in the center element of the reference reactor have been eliminated. Each of the satellite elements will have nineteen 0.095-in. diameter axial holes extruded in it. These will be located and spaced as are those in the reference reactor core fueled elements.

The steel tie rod tubes have a heavy wall sleeve brazed to one end which will be threaded and flanged such that a nut can be turned on to the tube and torqued against the shoulder after the tubes are inserted in the core support plate. Plugs with a threaded stem will be brazed to the opposite end of the tubes. Holding devices will be machined on the stems so that the tubes can be restrained while the nuts completing the cluster assemblies are being torqued. The inside diameter of the tie rod tubes is large enough to accept electrical heater elements.

The support plates located on either end of the cluster assemblies are approximately 1/8-in. thick. They have a shape similar to the cross section of the cluster assemblies and have small counter-bored center holes for the satellite elements. These counterbored holes, in company with bushings, are utilized as locating devices when assembling the elements into clusters. The center element is located and held captive in the cluster assemblies by the satellite elements. Eighteen additional orifice holes will be drilled and countersunk in the cluster support plates to provide exhaust paths for the coolant from the elements. These holes are equally spaced on a triangular pattern following the hexagonal contour of the elements.

Shouldered bushings will be pressed into the counterbored holes in the support plates such that the legs protrude from the counterbored side of the plate. These are devices for locating the satellite elements in the clusters. They also restrain the clustered elements in a transverse direction, thereby easing handling and assembly procedures. The bushings in the dome end support plate have orifice holes drilled through them.

The satellite elements are located on the dome end support plates by placing the center hole over the bushings in the plates. The center elements are located and held captive by the satellite elements in each cluster. The dome end support plate is fitted to the cluster assembly in the same manner.

Coiled springs with flat ground ends are placed over the long ends of the tubular tie bolts and seated on the shoulder of the thick wall sleeves brazed to the opposite ends prior to inserting the tiebolts in the center elements. Nuts are then placed on the plugged and threaded ends of the tie bolts until they are seated. Thus, each cluster assembly in the simulator core is an individual sub-assembly. There are 253 cluster assemblies, 24 of which are irregular clusters around the periphery.

The reactor core support plate is held in a fixture while the simulator core is being assembled. The open end of the tubular tie rod extending from the cluster assemblies (the spring end) is inserted in the core support plate from the nozzle end side and secured with locknuts.

The core assembly is placed in 1/8-in. thick split cylinder of an insulating material. A thin gage sheet metal split cylinder will be placed over insulator, and a third cylinder hinged axially with a piano hinge and having a number of axial corrugations, goes over the second cylinder.

The corrugated cylinder is drawn tight around the assembly springing the corrugations until a pin can be inserted in the hinge. The spring action of the corrugations was calculated to maintain a radially compressive load on the core assembly.

Approximately two hundred 1-Kw electrical heaters will be placed in the tubular tie bolts from the dome end side of the core support plate and electrically connected to a bus bar which is also secured to but insulated from the plate. The electrical leads from the bus bar are connected by flexible straps to external terminals. These heaters are capable of raising the core temperature to approximately 1600^{o}R.

1.1.8 - Nozzle End Core Seal

The nozzle end core seal in the simulator, in conjunction with the shield to core support plate seal, prevents the coolant entering the pressure vessel from mixing with the coolant flowing through the core.

The seal is a circumferential type, fastened to the engine nozzle assembly and sealing against the outer diameter of the simulated core. A secondary seal is fastened to the reflector assembly nozzle end support plate. It bears against the core seal retaining ring and limits the amount of coolant flowing between the core and the inner reflector.

The nozzle end core seal is a barrel shaped double thickness sheet metal part, contoured to provide easy lead-on around the outside diameter of the core. Both thicknesses are split axially at staggered locations so that the core will expand the parts at assembly providing a zero clearance seal. The seal is backed up by a steel ring which is fastened to the nozzle assembly with screws.

The secondary seal is a steel sheet metal part shaped to resemble a large Belleville spring washer. It is backed up and held captive by a steel ring which is fastened to the reflector assembly nozzle end support plate. Sealing is effected when the part is deflected against the nozzle end core seal retaining ring at assembly.

The nozzle end core seal is fastened to the nozzle assembly as already described, and the secondary seal is fastened to the reflector assembly nozzle end support plate. The entire reactor assembly is placed in the pressure vessel from the dome end direction. The nozzle assembly is brought into position from the opposite direction, expanding the attached core seal around the core assembly. The secondary seal is seated against the core seal retaining ring when the nozzle assembly closure flange is fully engaged.

1.2 - Thermal and Fluid Flow Considerations

Initial studies of the heat transfer characteristics of a reactor simulator were concentrated on the possibility of substituting materials in areas where such substitution would reduce problems of procurement time, fabrication difficulties, and cost. Arrangement of the material is in order of the components as they are physically located in the flow path.

1.2.1 - Nozzle

The use of a reactor simulator for any experiments involving startup of the reactor implies that conditions unique to the use of a converging-diverging nozzle be properly simulated.

A substitute for a real nozzle configuration was investigated to simplify fabrication problems. One approach considered involved simulating the tube side of the nozzle with a venturi type flow path or an assembly of variable flow area nozzle tubes connected in parallel between tube sheets or plenums. Further study indicated that this simplification would result in a lack of simulation in several areas, including the following:

1. A venturi type flow device cannot accurately simulate flow resistance due to simultaneous area change and frictional pressure drop. Improving accuracy of simulation requires an increasingly larger number of very small devices, thus approaching the multiple tube, variable flow area concept.
2. The multiple tube concept does not adequately simulate flow resistance unless the tubes are bent to the same curvature as the nozzle flow path.
3. Adequate simulation of pressure drop and heat transfer in the nozzle during the startup flow transient requires that the heat capacity of the tubes and heat transfer of stored heat from the tube backing be properly simulated. Furthermore, normal startup schedules do not result in an appreciable reduction of gas temperature at the core exit. As a result, gases which would normally pass over the nozzle tubes during a startup do not drop appreciably below ambient temperature. At the same time, fluid temperatures on the coolant side of the nozzle are extremely low resulting in temperature differences between the propellant paths of the order of 400°R. Heat transfer across the nozzle and

its resultant effects on fluid density in the nozzle, reflector, and core inlet temperatures cannot be adequately simulated without providing the proper geometry for the heat transfer to take place.

4. Pressure levels in the reactor, gas densities, and pressure drops must be properly simulated. Use of a valve at the core exit to simulating the effect of the nozzle on pressure level was considered. However, the technique for varying valve resistance to simulate the nozzle in both unchoked and choked flow regimes was considered unreliable.

The use of a nozzle of the same configuration as will be used in the actual reactor presents certain distinct advantages:

1. Provisions for simulation of the shape of the nozzle on the gas side would permit studies of the effects of flow separation in the nozzle at low flow rates under back pressure influence. This would provide information on the influence of any vibrations of flow pulsing resulting from the nozzle configuration.
2. The problem of improper flow distribution between nozzle tubes resulting from a non-uniform entrance condition at the nozzle inlet could best be studied with the proper nozzle configuration.

For the above reasons, it is recommended that a nozzle employing the same configuration as that anticipated for actual reactor be provided for the simulator work.

1.2.2 - Reflector

The principal heat transfer problem in supplying a reflector to provide adequate startup simulation was the selection of a suitable alternate material (aluminum is recommended for reasons presented below) to replace beryllium as an outer reflector. High costs of the base material and long procurement times associated with machining beryllium, made an adequate substitute desirable. In addition to mechanical considerations the substitute material was required to a good representation of the rate of cooldown of the beryllium during the startup transient and its corollary — the rate of change of coolant temperature at the reflector exit.

Assuming a reflector substitute of approximately the same configuration, the two physical properties which affect this area of performance are the thermal diffusivity and volumetric heat capacity of the material.

1.2.2.1 - Thermal diffusivity: Table 1 lists the individual properties of interest at room temperature. It can be seen by inspection that the thermal diffusivity values do not vary so widely from the value for beryllium as do the individual properties, density, conductivity, and specific heat. Furthermore, the thermal conductivity of beryllium is sufficiently high that, in the reflector, it is not so important a thermal lag as the coolant film.

1.2.2.2 - Volumetric heat capacity: Most of the materials shown in Table 1 have volumetric heat capacities of the same order as beryllium. There are, then, two important criteria for the selection of a material on this basis. The first is that the total heat which can be supplied by the material to the coolant in chilling down from ambient temperature to about 100^{o}R should be approximately the same as beryllium for a reasonable simulation to take place. The second is that the total heat per unit volume available on the above basis should be equal to or greater than that for beryllium in order to permit an accurate geometric configuration. If this vlaue is smaller, a substitute reflector cannot supply sufficient heat within the volume defined by the reflector design. If the available heat per unit volume is higher, material can be removed.

Debye* has shown that the heat capacity for different materials varies with temperature in a fashion which permits a normalization of the data for most materials based on a different critical

*See Slater, J. C. McGraw Hill, 1st Ed., 1939, p. 236, "Introduction to Chemical Physics"

TABLE 1

PHYSICAL PROPERTIES AT ROOM TEMPERATURE

Material	K $(\frac{BTU}{Hr\ Ft^oR})$	$\rho (\frac{lb}{ft^3})$	$C_p (\frac{BTU}{lb\ ^oR})$	$\alpha (\frac{Ft^2}{Hr})$	$C_p (\frac{BTU}{Ft^3\ ^oR})$
Aluminum	128	169	0.217	3.48	36.7
Beryllium	92	113	0.52	1.57	58.8
Graphite	90	138	0.165	3.95	22.8
Copper	228	560	0.092	4.42	51.5
Iron	44	490	0.110	0.81	54.0
Lead	20	708	0.031	0.91	22.0
Magnesium	92	109	0.25	3.38	27.3
Nickel	53	555	0.105	0.91	58.2
Silicon	48	145	0.162	2.04	23.5
Sodium	77.5	60.5	0.295	4.34	17.9
Tantalum	31.5	1040	0.036	0.84	37.4
Tin	39	455	0.054	1.59	24.5
Titanium	4.7	283	0.126	0.13	35.7
Tungsten	116	1200	0.032	3.00	38.4
Zinc	65	445	0.0915	1.60	40.7
Zirconium	12	405	0.066	0.45	26.7

temperature for each material. Table 2 lists the integrated heat available (normalized to 1.00 for beryllium) from 540° to 100°R based on Debye's theory. Theory and experiment agree well on this basis for most materials with the exception of graphite. Graphite values were computed from measured properties.

It can be seen that the material most closely approximating beryllium in terms of the total volumetric heat availability between these temperature limits is aluminum. It also has a slightly higher value. A plot of the heat supplied per unit volume as beryllium and aluminum are cooled down from room temperature as shown in Figure 5. Since aluminum offered the most promise for good simulation, possessed attractive mechanical properties, and is readily obtainable, it was singled out for further investigation. The time-temperature dependence of the material and coolant were therefore examined using the WANL transient code. Aluminum and beryllium tubes equivalent in geometry to a unit cell of the reference beryllium reflector were taken as models and the transient response of material and coolant during a chilldown was examined for the case of constant inlet pressure for a time period of one minute. The results are shown in Figure 6. Generally speaking, the aluminum cooled down faster in the initial stages of the chilldown and, as can be noted from Figure 6, there was a temperature crossover near the latter stages of the cooldown. This is as would be expected from examination of Figure 5. It is encouraging to note that the average temperature deviation between the two materials and between the coolant temperature in these areas was never more than about 40°R, the maximum error in coolant temperature being about 10%. Especially encouraging is the fact that the temperatures agreed well at about 200°R. This would essentially permit a reasonable simulation to take place to relatively low temperatures. In view of the above, it was decided that aluminum would provide the most satisfactory substitute material for beryllium, more accurate simulation being possible only by use of beryllium itself.

1.2.3 - Shield

A problem of material substitution exists in the region of the shield which is somewhat similar to the one in the reflector. It would be desirable to replace the lithium hydride pellets with a

TABLE 2

Material	Thermal Diffusivity (540°R)*	Heat Storage (100 - 540°R)*
Aluminum	2.22	1.06
Beryllium	1.00	1.00
Graphite	2.51	0.56
Copper	2.82	1.65
Iron	0.51	1.56
Lead	0.58	0.89
Magnesium	2.15	0.87
Nickel	0.58	1.77
Sodium	2.77	0.67
Tantalum	0.54	1.29
Titanium	0.08	1.11
Zinc	1.02	1.43
Zirconium	0.29	0.90

*Values normalized to 1.00 for beryllium.

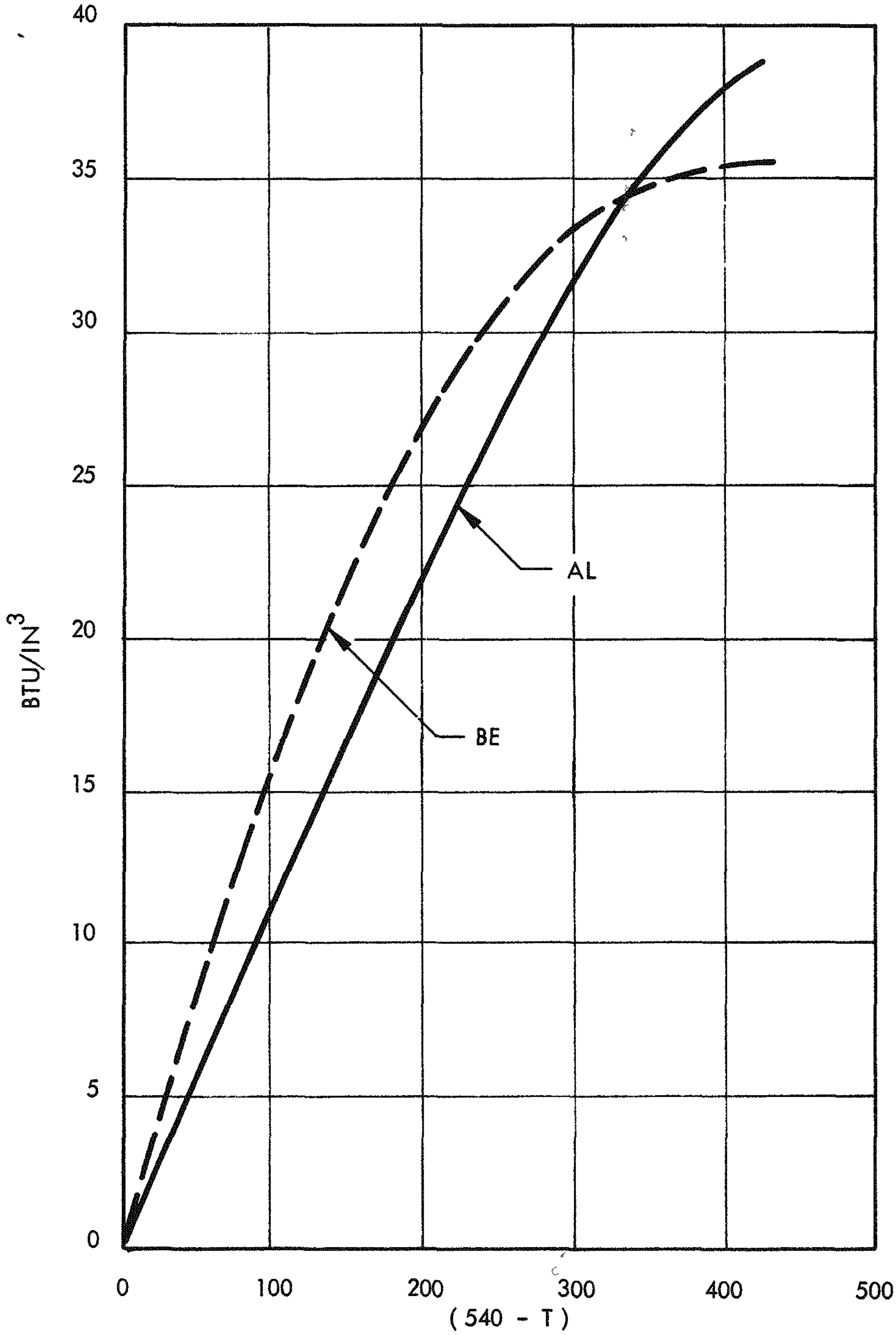


Fig. 5 - Comparison of Beryllium and Aluminum Heat Capacities.

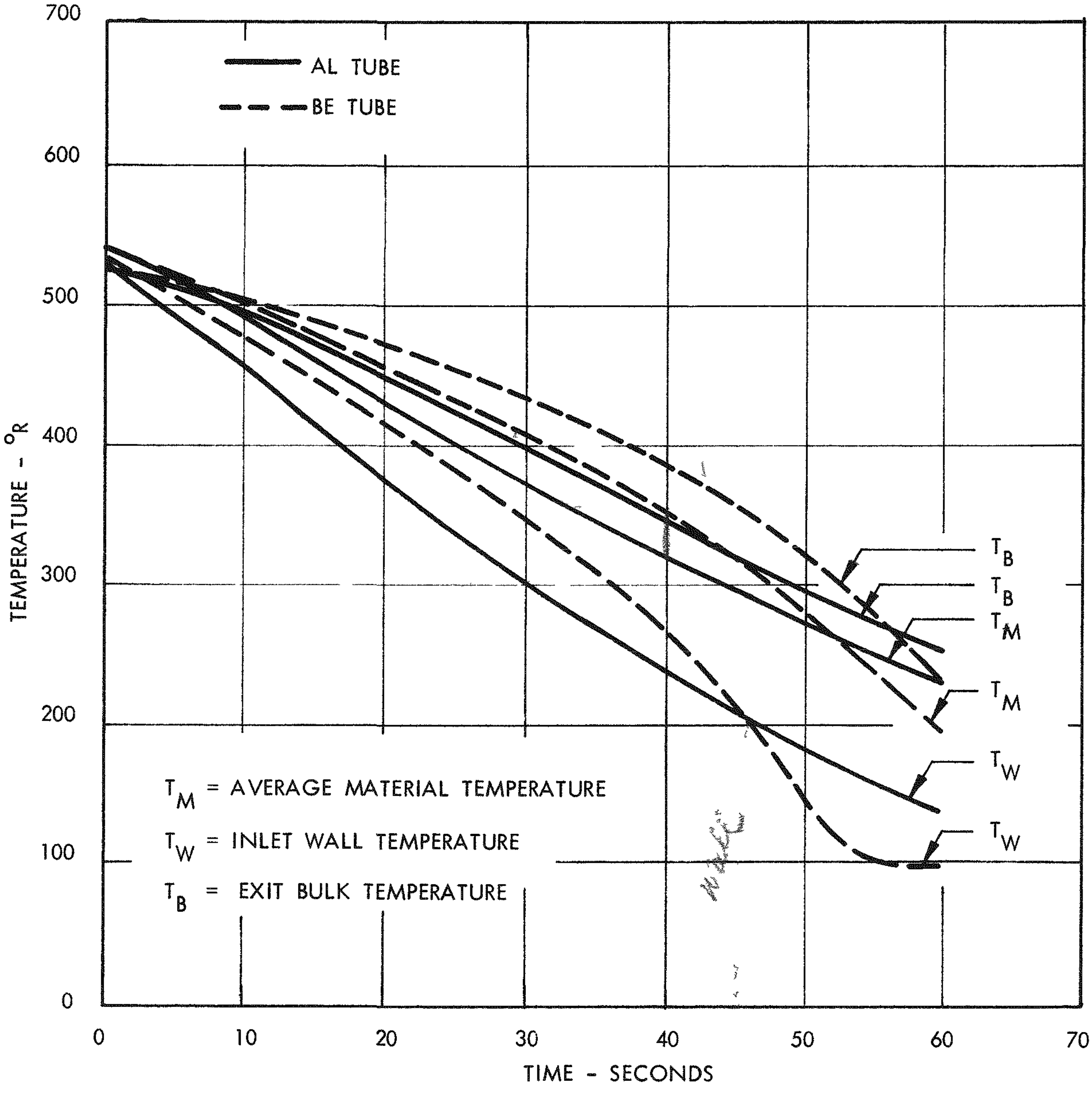


Fig. 6 - Comparison of Beryllium and Aluminum Childown.

material which would provide approximately the same steel cladding temperatures and coolant temperatures during chilldown as would the lithium hydride itself. Oak wood has approximately the same specific heat and density as lithium hydride, but it was ruled out because of the high temperature encountered during core preheat. Lithium hydride also has a very high coefficient of thermal expansion, and in replacing this material it is very difficult to match all the variables involved. For this reason, the possibility of replacing the hydride with a stainless steel tube of the same outside dimensions was considered, the inside diameter of which would be adjusted to provide approximately the same total heat capacity.

A steel tube with a 0.584-in. OD and a 0.420-in ID appeared to meet the necessary requirements. A transient chilldown analysis similar to that made on the reflector yielded results shown in Figures 7 and 8. Figure 7 shows the response of the actual shield under these conditions. The dashed line shows the expected temperature response of the stainless steel cladding if no material were present inside it. A comparison of this curve with the actual cases makes it obvious that filler material is needed for an adequate simulation. Figure 8 compares the temperature response between the stainless steel cladding with the lithium hydride filler and the cladding having the steel tube insert. The agreement is quite good over the entire temperature history thus indicating that a substitution of this type could be accomplished to provide reasonable simulation.

1.2.4 - Core Reheat

Mechanical and cost considerations made extruded graphite elements the best material choice for the core. These reasons were outlined previously. However, in the case of the Reactor Simulator for Startup Development, it was decided to examine the possibility of providing a method of heating the core to temperatures expected during an engine cooldown. This would permit experimentation under circumstances similar to those existing at engine restart.

Electrical heaters were proposed for this purpose, and two types were examined to determine if they could operate safely in the graphite within their temperature limitations.

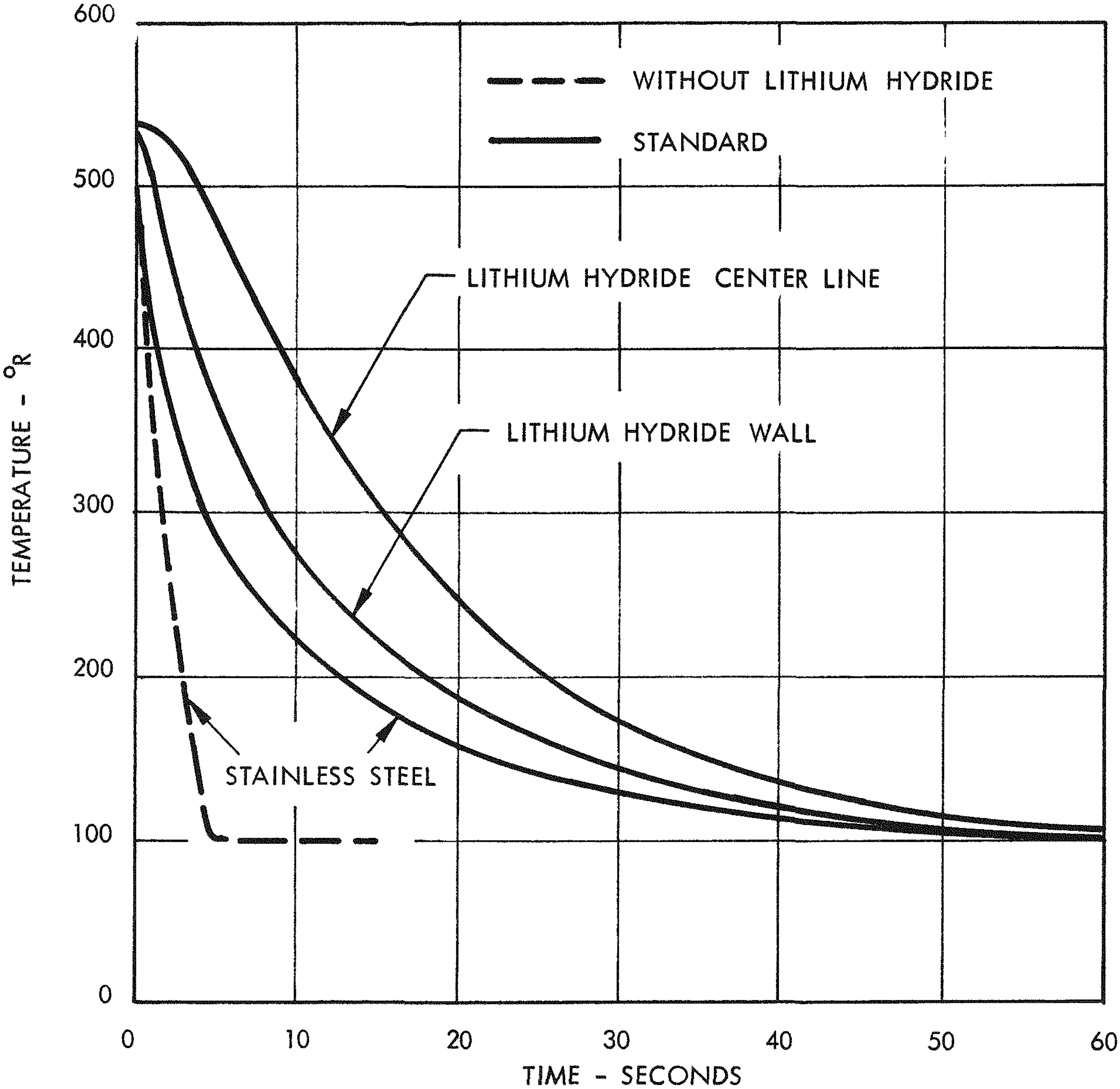


Fig. 7 - Effect of LiH on Chill Down of Shield

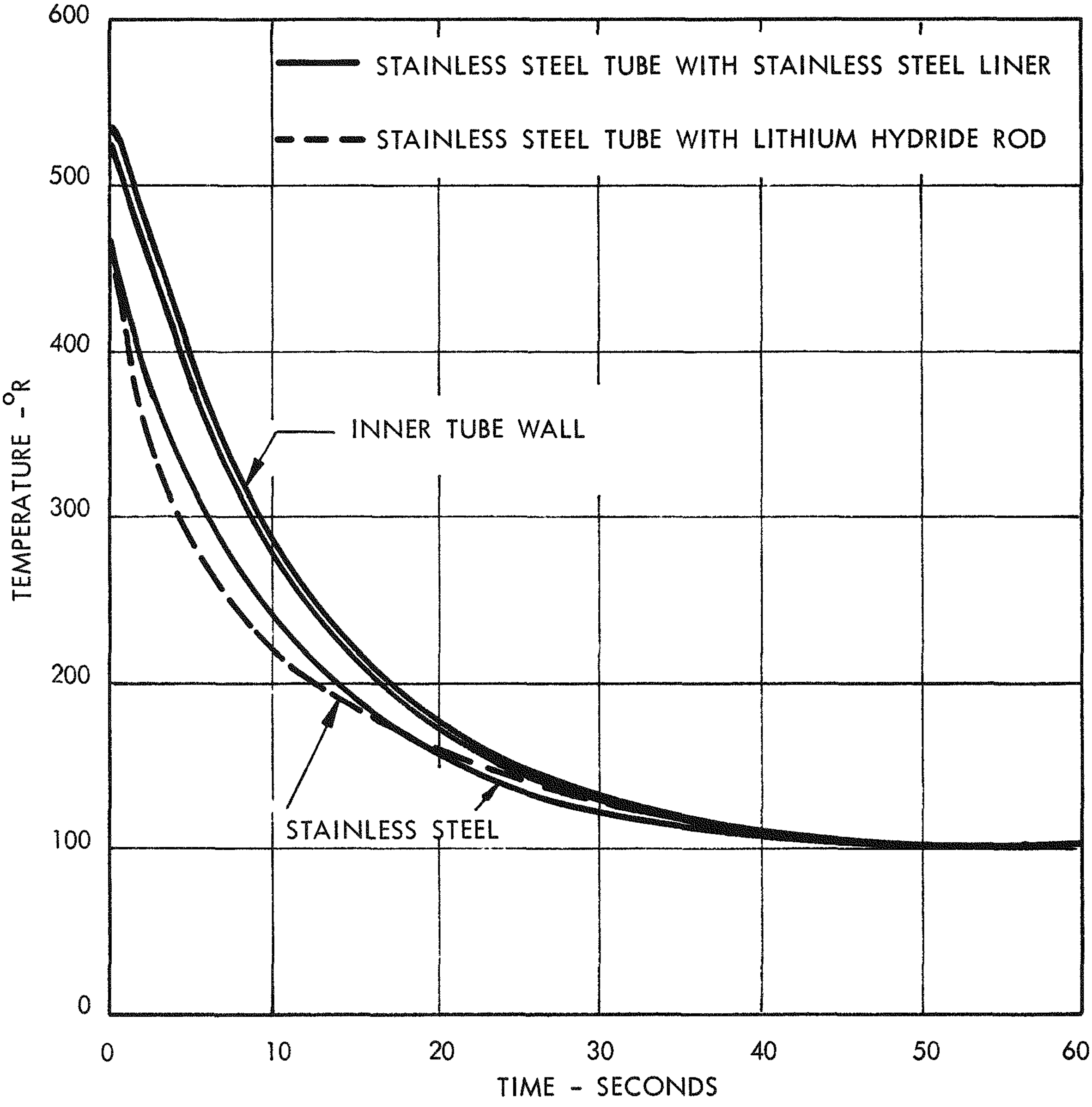


Fig. 8 - Shield Temperatures with Stainless Steel Liner

It was assumed that the heaters would be placed directly in the core in spaces normally used for tie rod support structure. To obtain an estimate of the worst possible temperature difference between the heater and the surrounding graphite, it was assumed that air surrounded the heater, and a gap of 0.017 in. on the diameter existed between heater and graphite. (This was the gap expected for the cold condition: it would actually be smaller during the hot condition due to higher expansion coefficient of the heater.) Assuming no heat loss, it would be possible to heat the core to 1600°R in about 80 minutes with 200 Kw of power. The first type of heater examined had an 0.500-in. OD and would supply 1 Kw of power. It was assumed that 200 of these could be inserted into the core in the support channels.

The temperature difference which would exist between this heater and the 1600°R graphite was calculated to be 126°R in air. This would result in a heater temperature of 1726°R which was acceptable in view of a maximum sheath temperature capability of about 1900°R.

A second type of heater was examined which would supply 4 Kw and have an OD of 1.5 in. Although only 50 of these heaters would be necessary, their larger diameters would make it necessary to replace an entire seven-module cluster to accommodate each heater and its graphite adaptor. The gap temperature rise was not significantly larger than that for the smaller heater - only 168°R - permitting operation at 1768°R which was still a safe temperature. However, in view of the modifications required to accommodate the larger heater, the smaller type was chosen.

The heatup time to 1600°R was examined to take into account heat leakage from the core during the heatup time. A cylindrical model of the core surrounded by an insulator equivalent in resistance to the pyrographite used in the actual reactor was employed. The graphite reflector, beryllium reflector, and pressure vessel temperatures resulting from core heat leakage were also computed as a function of time.

Figure 9 is the result of such a computation using the TOSS Computer Code. The radial temperature profile is shown for various times after start of core heating from room temperature. Temperature profiles are given for each 20-min time increment. It can be seen that a temperature of 1600°R is reached in the core after about 90 min of heating at 200 Kw. Since the energy storage can be accomplished with no losses in about 80 min, the process is quite efficient, having a net loss of only about 11% during the heatup time. Since the aluminum temperatures do not exceed 800°R during this time, it may not be necessary to cool the reflector during the heatup until the start of the experimental run. At this time it may be desirable to first reduce the reflector temperature to a low value of the order of 100 to 200°R to simulate flight restart conditions. This could be accomplished by cooling with a cold gas such as vaporized nitrogen and bypassing the core by venting the gas through the vessel dome.

A closer study of this reflector cooldown process might indicate that it would be possible to permit the cooling gas to pass through the core without materially reducing the core temperature by the time the reflector is sufficiently cooled.

1.2.5 - Startup Study of Simulated Reactor

To demonstrate the degree of simulation which could be achieved on an over-all basis with the changes outlined in the previous sections, a comparison of startup (actually childown) performance was made between the actual reactor configuration and the simulator. This was done by applying a multi-channel transient heat transfer code to a 7 channel model made up of the following sections:

Channel	
1	Divergent nozzle section coolant side
2	Convergent nozzle section coolant side
3	Reflector
4	Shield
5	Top support plate
6	Fueled core channel
7	Tie rod channel

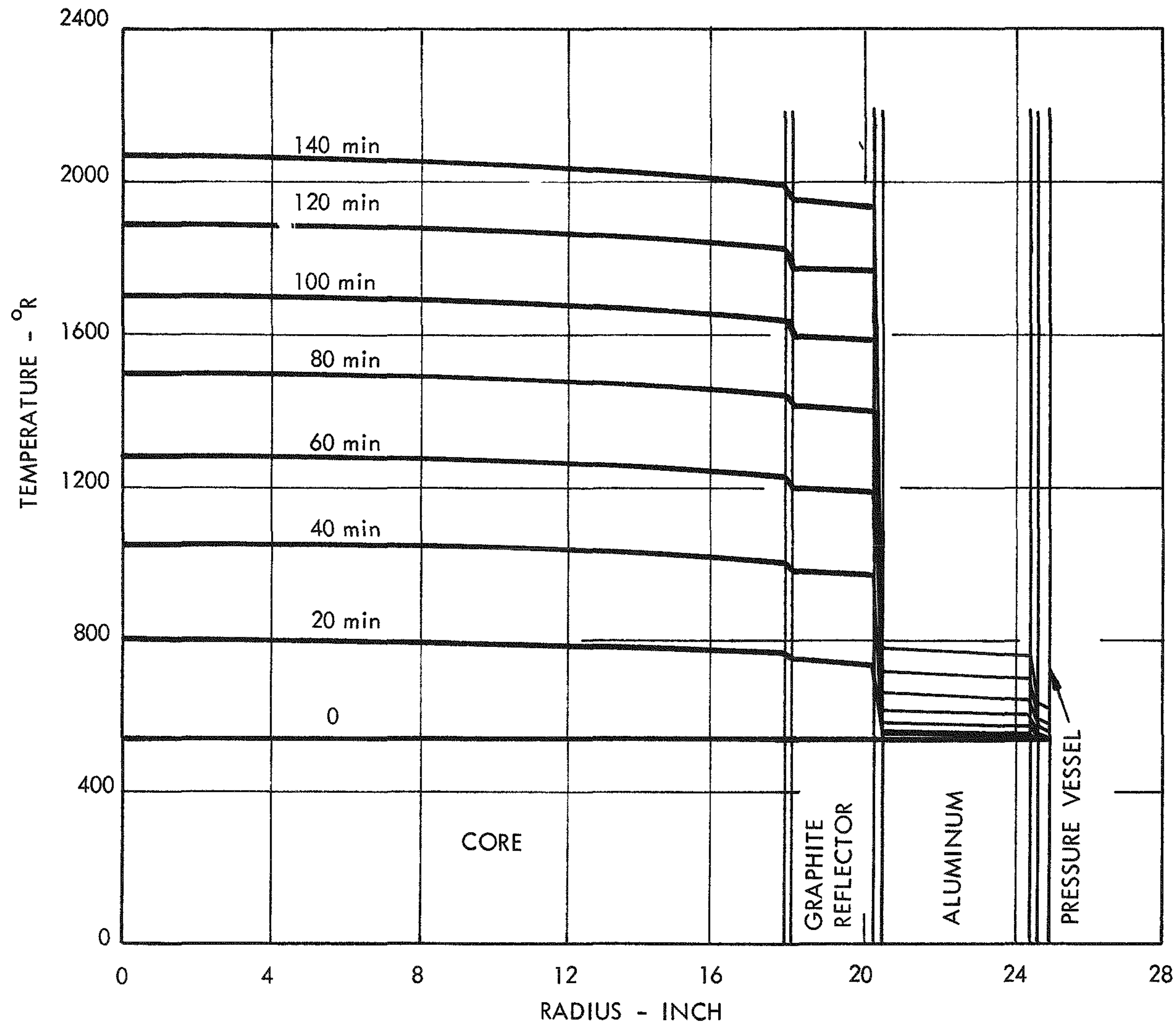


Fig. 9 - RADIAL Temperature Profile at Reactor Station ⌿ 26

A flow schedule similar in nature to the type expected for a reactor startup was used (Figure 10). While it is not possible to state with certainty that this would be the schedule used for engine startup, it is approximately correct and would provide a valid comparison of performance.

The exit temperature for the various components is shown in Figure 11 for both the reactor configuration and the simulator. The simulator cooled down faster than the reactor. It appears that the reactor has a time lag of approximately 1 1/2 seconds due to different shapes of the specific heat as a function of temperature for beryllium and aluminum.

1.3 - Instrumentation and Heating Provision

1.3.1 - Instrumentation

The RSSD simulator is a simplified thermal and hydraulic replica of the reference reactor. Transd cers for sensing internal component temperature and pressure relationships would be built-in within the internal components. These sensors would be kept to a minimum consistent with simulator objectives, which principally involve fluid temperature and pressure distribution during flow startup transients.

Sensors for flow, vibration, linear motion, and acceleration are not included here as internal instrumentation because the RSSD simulator is not mechanically representative of the NRX-A nor a NERVA type reactor. Addition of suitable external sensors for these additional parameters should be included as test rig instrumentation.

During detailed design, consideration would be given to inclusion of an optimum numbers of removable sensors to permit pre- and post-calibrations which could be adapted to the majority of the flow stream measurements (except those in the core and reflectors) with suitable vessel, head, or nozzle penetrations. While all sensors listed in Table 3 may not be used during each test, the complement of sensors listed is recommended as a minimum for RSSD. Four (4) C/A thermocouples are included in the tabulation for use with recorder-controllers for the protection

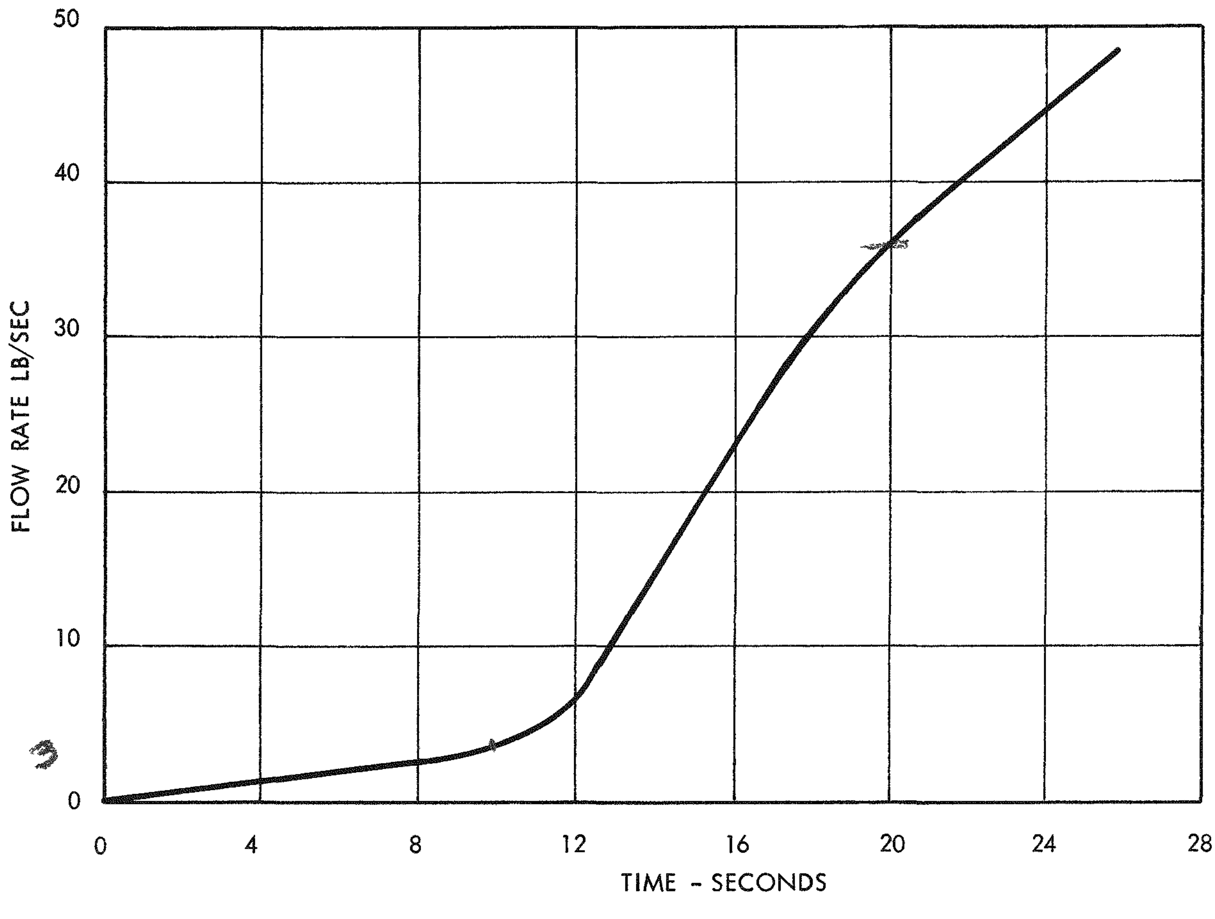


Fig. 10 - Flow Rate Vs Time

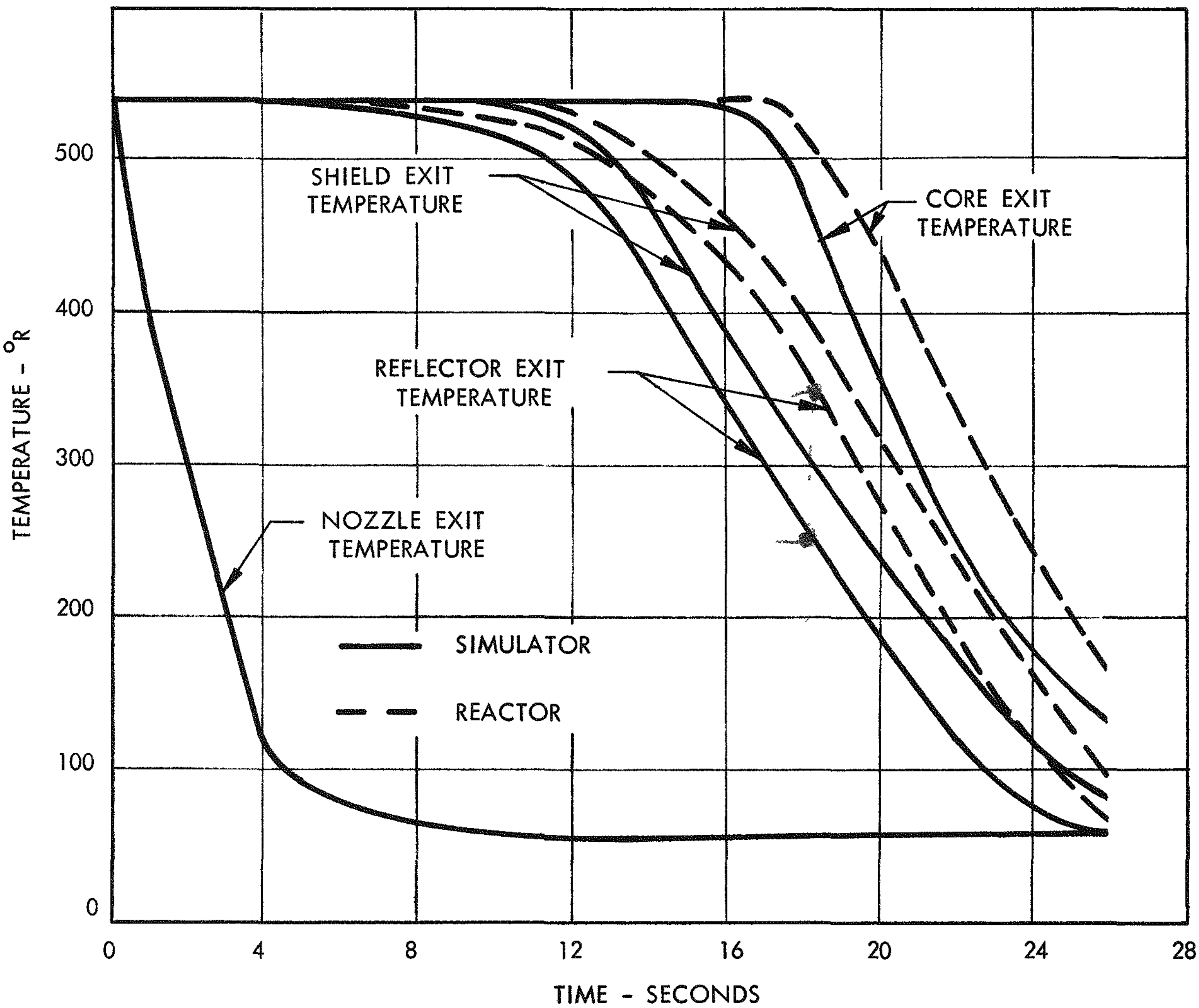


Fig. 11 - Exit Fluid Temperatures Vs Time

TABLE 3

INTERNAL SENSORS, RSSD SIMULATOR

LOCATION	TYPE	QUANTITY C/C	QUANTITY C/A	QUANTITY P	QUANTITY D/P	USE
Shield, Upper Surface	T/C, C/C	3				Shield Surface Temperature
Shield, Lower Surface	T/C, C/C	3				Shield Surface Temperature
Shield Area, Fluid Temp.	T/C, C/C	30				Shield Temperature Distribution
Shield	D/P				3	Shield Differential Pressure
Shield	Press.			12		Shield Press. Distribution
Support Plate	T/C, C/C	6				Plate Temperature
Core Inlet, Fluid	T/C, C/C	12				Core Inlet Temp. Distribution
Core, 36.5" Plane	T/C, C/A		6			Core Temperature Distribution
Core, 61.5" Plane	T/C, C/A		6			Core Temperature Distribution
Core, Inlet to Outlet	D/P				3	Core Pressure Drop
Core, Modules	Press.			8		Core Pressure Di Distribution
Inner Reflector	T/C, C/C	12				Reflector Temp. Distribution
Lateral Support Area	T/C, C/A		12			Lateral Supp. Area Temp.
Lower Seal Area	T/C, C/A		6			Seal Outlet Temperature

TABLE 3 (Cont)

LOCATION	TYPE	QUANTITY C/C	C/A	P	D/P	USE
Outer Reflector	T/C, C/C	42				Reflector Temp. Distribution
Outer Reflector	Press.			8		Reflector Press. Distribution
Outer Reflector	D/P				4	Reflector Differential Press.
Core Modules	T/C, C/A		4			Heater Overheat Control
		108	34	28	10	

C/C - Copper-Constantan Thermocouple
C/A - Chromel-Alumel Thermocouple
P - Pressure Transducer
D/P - Differential Pressure Transducer

of the immersion type heaters; these controls would only be used during a core heatup cycle (see Fig. 12).

1.3.2 - Core Heating Provisions

Design considerations reveal that up to 204 heaters can be conveniently accommodated in the simulator core. As an illustration, Figure 13 depicts the connection arrangement for 192 heaters which give a reasonable balance for phase loading of 440-volt, 3-phase power. The stainless steel tubing supports for the core modules provide the wells for heater insertion.

Power terminals of a proven design would be provided for connection of the 3 phase power. The external terminal design shown has been proof tested to 2500 psi. Suitable adapting pads on the pressure vessel are necessary to apply this type terminal. It is also possible to adapt the terminals to the vessel head (or dome) rather than the vessel side as shown in Figure 13.

Several heater designs, power ratings, and arrangements were considered. Good heat distribution and balance of phase loadings can be obtained. For example, with an assumed core weight of 2500 lb and heating from 500 to 1600°R,

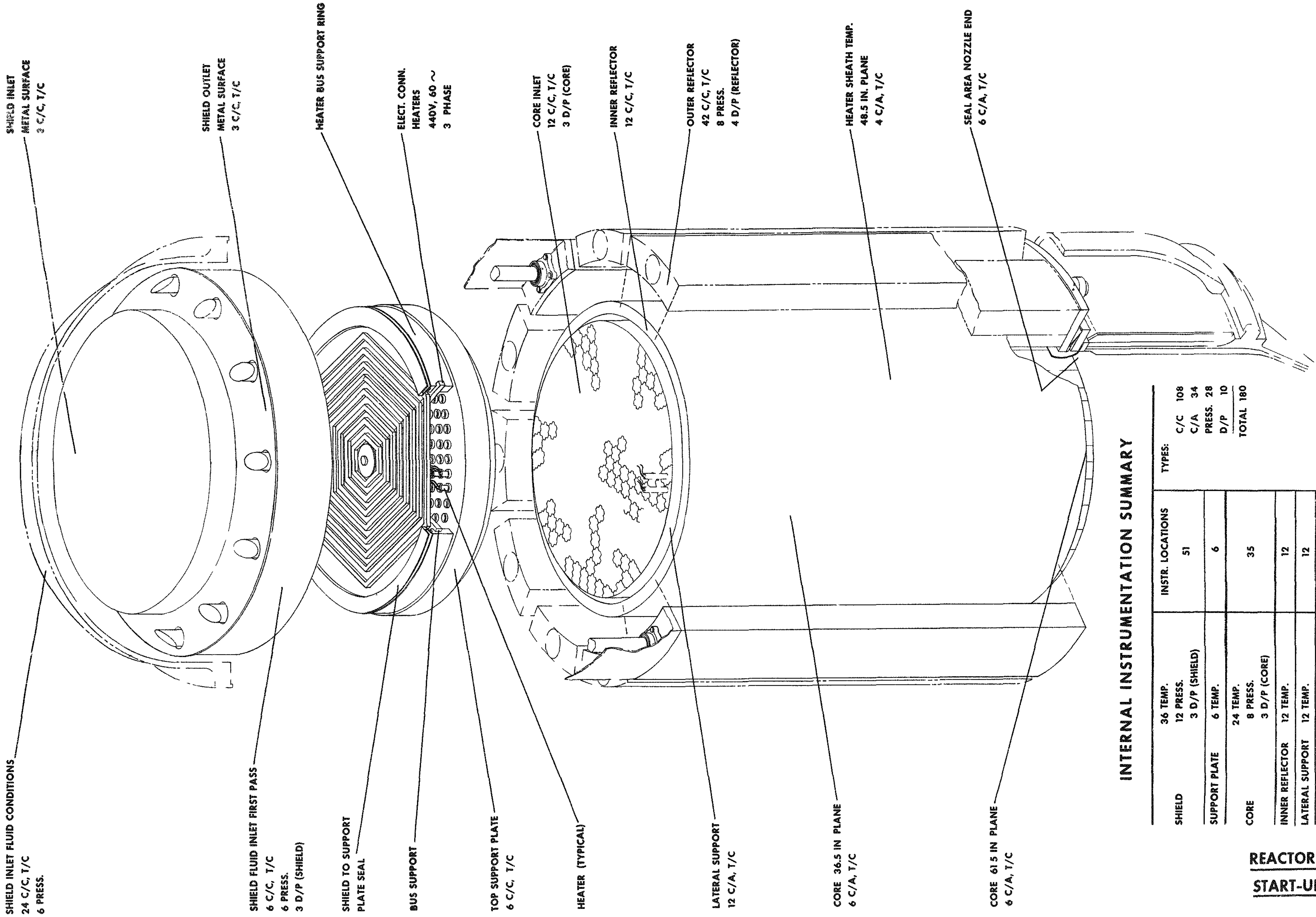
$$\text{Required Heat, KW-Hr.} = \frac{\text{Weight} \times \text{Sp. Ht.} \times \Delta T \times 2.93 \times 10^{-4}}{\text{Heating Efficiency}} = (0.231 \frac{\Delta T}{EFF})$$

$$= \frac{254}{\text{Heating Efficiency}}.$$

Then, with an assumed heating efficiency of 90%, required heat input is 282 Kw-Hr (see Fig. 14). Using a 1-Kw heater and a 192-Kw capacity installed as shown in Figure 13.

$$\text{Heating Time} = \frac{282}{192} = 1.47 \text{ hr.}$$

A simple on-off overheat control may be necessary to limit heater sheath temperature to a value below burnout. Heater off time naturally will increase the total heating time; likewise, heating efficienty below an assumed 90% will increase heating time.



INTERNAL INSTRUMENTATION SUMMARY

		INSTR. LOCATIONS	TYPES:
SHIELD	36 TEMP. 12 PRESS. 3 D/P (SHIELD)	51	C/C 108 C/A 34 PRESS. 28 D/P 10 TOTAL 180
SUPPORT PLATE	6 TEMP.	6	
CORE	24 TEMP. 8 PRESS. 3 D/P (CORE)	35	
INNER REFLECTOR	12 TEMP.	12	
LATERAL SUPPORT	12 TEMP.	12	
LOWER SEAL	6 TEMP.	6	
OUTER REFLECTOR	42 TEMP. 8 PRESS. 4 D/P (REFLECTOR)	54	
HEATER CONTROL (CORE)	4 TEMP.	4	

REACTOR SIMULATOR FOR START-UP DEVELOPMENT (RSSD)

Fig. 12 - RSSD Instrumentation Summary

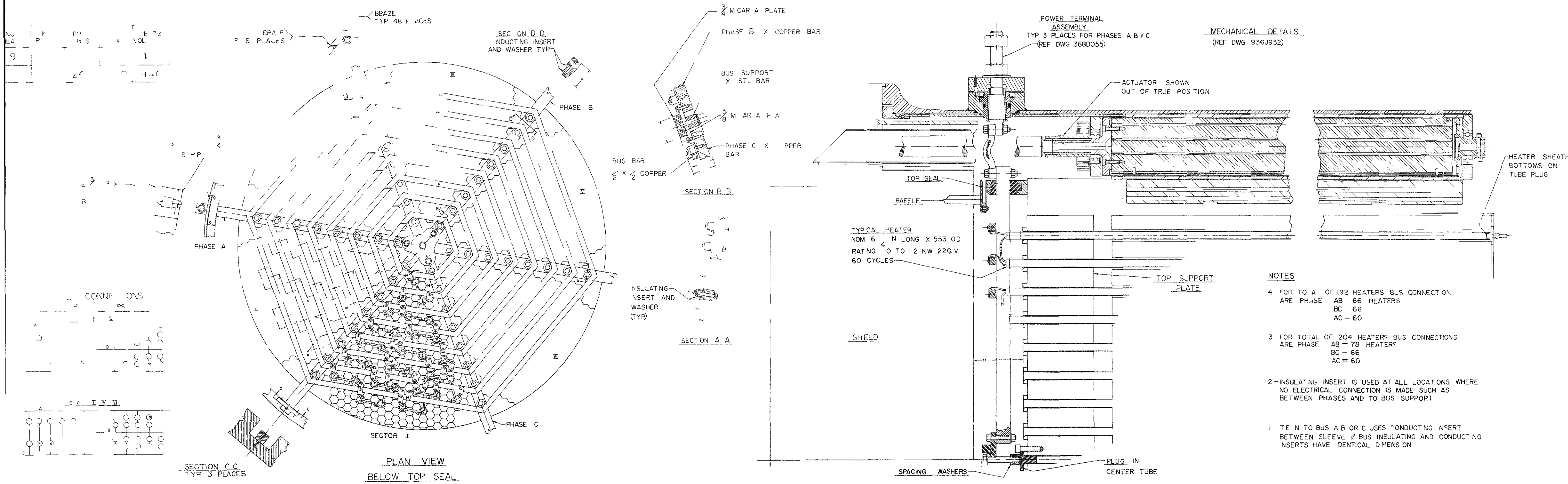


Fig. 13 - RSSD Heater Arrangement

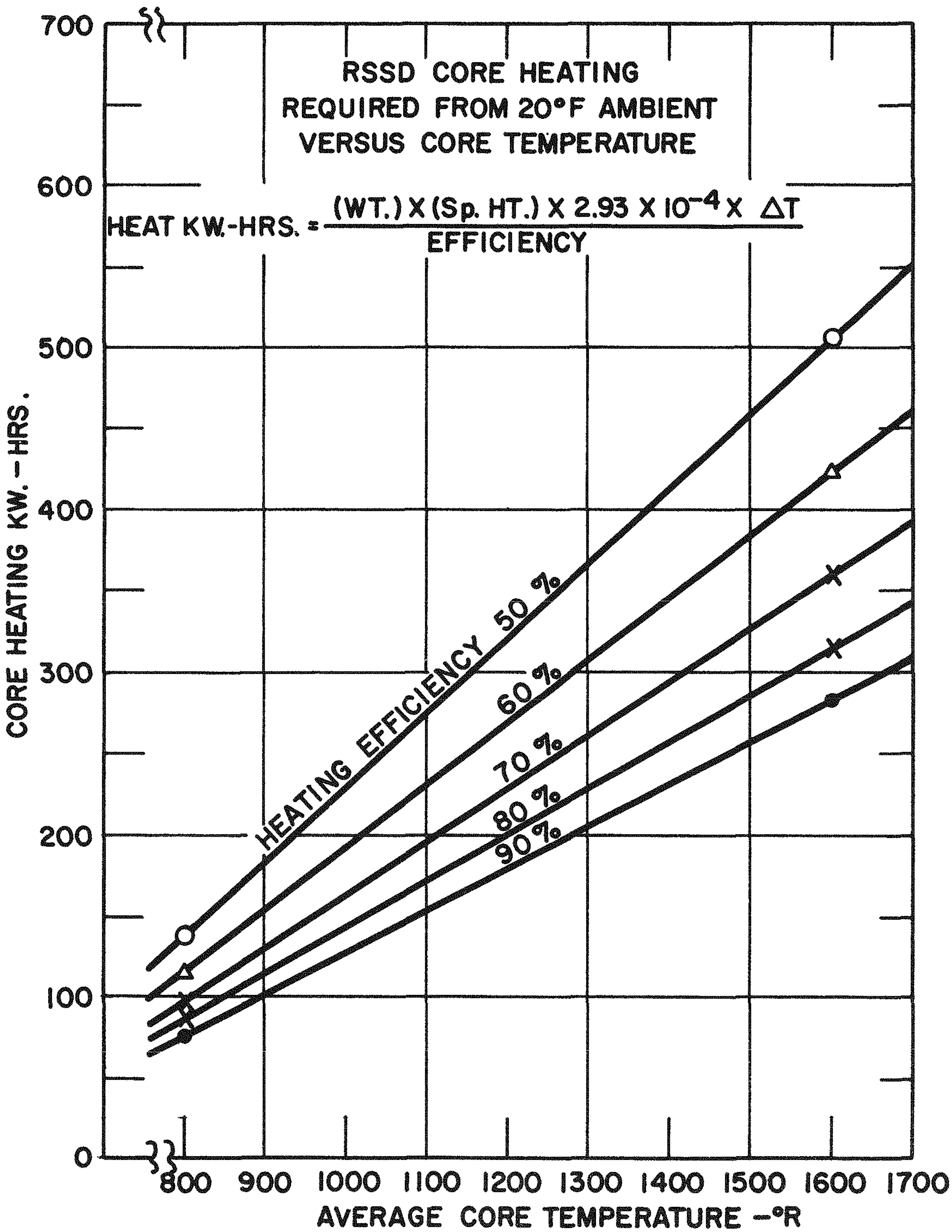


Fig. 14 - Curve of "Core Heating Kw-Hrs vs Average Core Temp."

The bus bar and terminal assemblies would be amply sized so as not to contribute any significant heat. Bus bars and terminals would be plated to be oxidation resistant.

1.3.3 - Heater Design

Heaters are to be a standardized cartridge type of proven design and connected for 440-volt, delta, 3-phase, 60-cycle operation. Individual heaters are rated about 1.0 to 1.2 Kw each at 220 volts, with two heaters connected in series across 440 volts. The heater sheath is incoloy metal and approximately 61 1/4 in. in over-all length (including approximately 1 1/4 in. for the hermetic seal at the top end). Internally, heater elements are insulated with magnesium oxide and ceramics. The hermetic seals chosen are designed for operating temperatures to $1000^{\circ}F$ ($1480^{\circ}R$) and should give good service for the life of the assembly.

The standardized 0.553   0.005 inch sheath outside diameter may be slightly oversized for the inside diameter chosen for heater wells; however, during detailed design the well and heater sizing will be made compatible.

1.4 - Test Capability

The CFDTS is a simulation of the NERVA hot bleed engine system. At present, AGC plan to incorporate an overhead LH_2 tank, a Mark III pump-turbine assembly (LH_2 lubricated), a NERVA nozzle (probably area ratio of 1:25), and an ejector system to provide high altitude environment at the nozzle exit and turbine exhause line. Also, the pressure vessel may be made of titanium rather than aluminum. Many details of bleed ports at reflector inlet and core exit chamber, mixing chamber (or valve) and flow control system at the mixing chamber are not yet firm. The tank shutoff valve (TSOV) and the turbine power control valve (TPCV) are prototype hardware.

RSSD is designed to provide a reasonably close simulation of thermal and flow characteristics of the reference reactor during the initial startup transient and a restart transient at the end of a cooldown period.

1.4.1 - Initial Startup Transient.

AGC's Generation II, Model I test results indicate that the reflector inlet temperature reached about 200°R at about 30 sec after TSOV was opened, and the reflector outer temperature remained at about 450°R. The Gen. II, Mod. I simulator did not have the cold side of the nozzle represented: consequently the temperature at the reflector inlet may remain above 200°R longer than 30 sec. Since the RSSD outer reflector presents a close simulation of the temperature response of the reference reactor reflector until temperature reaches about 100°R at inlet, it is reasonable to expect that the RSSD can simulate chilldown period (5-20 sec) and the initial few seconds of pump bootstrap startup. Once the pump bootstraps and flow increases, the reflector temperature will drop rapidly and the difference between aluminum and beryllium thermal response will diverge.

Since the RSSD shield and core thermal responses are nearly identical with those of the reference reactor for the whole range of operation, the RSSD outer reflector and the lack of internal heat generation sets the limit on simulation.

Although the heating elements are located in the core section primarily to simulate restart condition, the same heaters can be utilized to simulate various startup conditions. At present, the NERVA startup sequence has not been established. Studies indicate that the TSOV opening and flow initiation could take place anywhere within a power range of 0.1% and 10% and during an elapsed time from zero to seconds or minutes after reactor power levels out at a selected value.

For example, as a preliminary consideration, flow can be initiated any time within 80 sec after nuclear power reaches the 1% level; on the other hand, flow must be started within a few seconds after nuclear power reaches 10%. In order to select an optimum startup sequence, consideration must be given to various limitations set by maximum allowable temperature and thermal gradient, heating rate, heat transfer rate, etc., throughout the reactor components. Provisions for adding stored heat enables simulation of various startup conditions to investigate these problems.

1.4.2 - Restart Transient

Heating elements are installed within the core section of the simulator to simulate the thermal condition of the reference reactor prior to restart. The required preheating time depends on the temperature level of the core exit region selected. Since a relatively long period of preheating is required, temperature will be fairly even throughout the entire core, and reflector temperature will be considerably higher than room temperature. In order to simulate the axial temperature gradient within the core and a relatively low temperature at the reflector section, flow of cold gas through the simulator must be used. This cooling process during the preheating period can be either pulse or steady flow. The actual mode of cooling must be studied analytically and determined by means of trial and error. At present, analysis is not available; however, a thorough study must be made when the detail design of the RSSD is undertaken.

Although the oxidation damage of core material at 1600°R is probably negligible under insufficient supply of fresh air, the hermetic seal, the sleeve of the heater elements, and the bus bar may deteriorate rapidly at and about 1000°R. Consequently, inerting of the entire core and shield region of the simulator is recommended during the preheating period.

1.5 - Cost and Procurement Estimates

Based on the preliminary design layouts as shown on Figures 1, 2, 3, 12, and 13, approximate cost estimates of RSSD hardware are made. This estimate does not include supporting manpower costs, i.e. design, quality control, procurement, and program control, etc.

RSSD Hardware Cost

Item	Material	Labor	Tooling	Total
Core Assembly*	$39,375	$64,640	$30,320	$134,215
Outer Reflector Assembly	31,250	133,775	7,225	172,250
Inner Reflector Assembly	4,450	31,530	18,500	54,480
Shield Assembly	15,300	7,500	7,600	30,400
Instrumentation & Miscellaneous	30,000	8,000	1,500	39,500
			Grand Total	$430,845

The overall procurement time is estimated at the minimum of 8 months, assuming the maximum accelerated effort.

* Fuel elements are assumed to be G.F.E.

2.0 - REACTOR SIMULATOR FOR ETS FLOW TEST

It is recognized that an ETS cold flow simulator would be very helpful in development of mechanical reactor-engine details and for checkout of the flow systems of the ETS-1 and ETS-2 test stands.

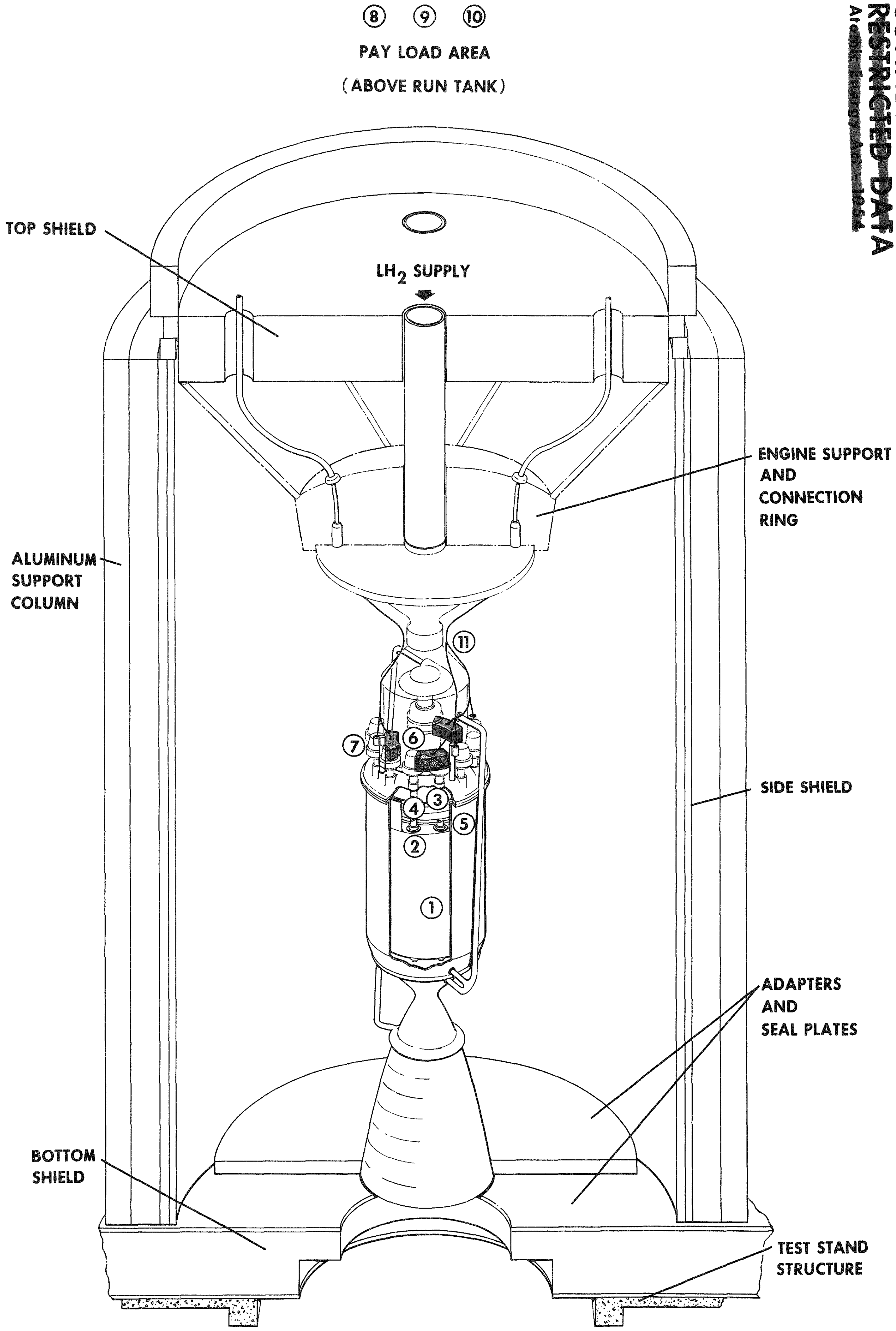
A reactor simulator is required to reproduce the stored heat capacity and flow impedance of the reference reactor during the chilldown and the initial few seconds of the startup transient. This simulator is to be a component of an E-engine simulator designed to allow detailed study of the following:

1. Flow interaction between the test facility piping and the engine assembly.
2. Operating characteristics of the ejector system in conjunction with the engine system for startup transient.
3. Fit up of engine piping, mechanical support to the test stand, control and instrumentation cabling, harnesses, and other plugable connections.
4. Evaluation of operating characteristics of available flow control system.
5. Training of operating personnel with the operational procedures of E-engine system.

Figure 15 shows engine installation in the proposed ETS test stand shield. WANL supplied components are listed in the figure. The test stand outline is based on AETRON Dwg. No. 3350-S101.

AGC personnel were contacted with regard to the E-engine simulator; however, they had not yet begun study of it at the time. In addition, sufficient details of the ETS test stand were not available, and many major changes in test stand and E-engine details are expected prior to the scheduled operation of ETS in 1964. Consequently, no further study was made on the E-engine simulator.

To satisfy the test objectives mentioned above, the reactor simulator required would be very similar to the one described in Section 1 of this report (RSSD) but without heaters. Instrumentation needed and test capability are also similar to RSSD. On the other hand, the objectives of the flow test at ETS may be expanded to include evaluation study of interaction, vibration, and stress conditions of the reactor components during the liquid hydrogen startup transient. This will require a reactor simulator which is an exact mechanical duplicate of an actual reactor except for core fuel for which would be substituted either a structural graphite or depleted fuel. Discussion on this type of simulator is presented in Section 4 of this report.



1. REACTOR CORE
2. REFLECTOR ASSEMBLY
3. SHIELD ASSEMBLY
4. CORE TRANSDUCERS
5. SHIELD, SUPPORT AND REFLECTOR TRANSDUCERS
6. NEUTRON DETECTORS AND AMPLIFIERS
7. ROD ACTUATORS
8. POWER AND TEMPERATURE CONTROLLER
9. REACTOR PROTECTION CHASSIS
10. CONTROL LOGIC CHASSIS
11. CONNECTORS, CABLES AND HARNESSES

Fig. 15 - Westinghouse Supplied Components (E-engine Series)

Astronuclear

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3.0 - SIMULATORS FOR INSTRUMENTATION AND CONTROL SYSTEM CHECKOUT

The study program to determine the need for I & C simulation equipment at ETS-1 & 2 was made on the basis of anticipated needs over and above those to be built-in as part of test cell I & C systems or being planned by other activities.

3.1 - Definitions of Function

The I & C checkout equipment should be capable of simulating parameters of temperature, pressure, flow and nuclear characteristics of the E-Reactor-Engine for checkout of facilities I & C systems prior to each engine test. The equipment should be readily available for use by plug-in or switch-in means whether or not an engine is at the cell. Additionally, the equipment should be compatible with installed test cell equipment and with reactor engine-control equipment furnished by WANL and REON.

3.2 - Simulator Components and Relationship to Other I & C Checkout Equipment

The ETS flow simulator, covered in Section 2.0, is instrumented to provide a cold flow path representative of the NERVA reactor, and with external details approximating the exact physical arrangement of the E-engines. Transducer ranges used in this simulator do not necessarily duplicate the E-engine because only cold flow conditions are involved. The ETS flow simulator would be used both at ETS-1 and ETS-2 for initial checkout of the test stand flow systems and low temperature ranges of installed I & C instrumentation.

Other components for I & C checkout are being planned as "built-in" equipment at the test cell. The test cell I & C contractor, working to REON instructions, will be responsible for the general checkout equipment being built-in for facilities controls, data systems, and other I & C systems not part of the Remote Engine and Engine Controls systems. Those components associated with the Remote-Engine and Engine Control Systems will be the responsibility of control groups at WANL and AGC REON. For Reactor subsystem checkout, special components such as simulation equipment for drum actuators and the reactor systems are required; however, these would be supplied by Project 2200 for WANL supplied components. Project 2200 equipment is defined as special equipment of an electrical or electronic nature needed for checkout and/or calibration of control and instrumentation associated with the reactor subsystem. Similar checkout equipment for the engine systems will be supplied by AGC.

Table 4 compares the components recommended for full range and cold flow testing.

3.3 - Conclusions of Study and Recommendations

No additional simulation equipment is required for ETS I & C systems other than that already in planning. While the cold flow simulator will provide nominal amounts of instrumentation useful in I & C checkouts, the bulk of the equipment needed would be on a continuing basis and is to be either built into the cell equipment or provided from other sources (such as Project 2200 and a similar Aerojet task).

The cold flow simulator would provide an equivalent mechanical model for fit-up of cabling, connectors, harnesses, etc., which are related to the I & C systems.

4.0 - NON-NUCLEAR TEST ASSEMBLY

During the study it became evident that there was a need for a non-nuclear test assembly that could be used for reactor component interaction development, under cold flow operating conditions. A test assembly of this type will permit the use of instruments to a fuller advantage in the study of problems associated with the over-all mechanical, thermal and fluid flow designs. Therefore, a brief feasibility study was made to define this need. No attempt has been made here to completely design such a test assembly. The idea has only been introduced and its advantages outlined.

TABLE 4

E-ENGINE I & C SYSTEMS SIMULATION

(Including Hard Mockup) WANL Supplied Components

	DYNAMIC PERFORMANCE SIMULATION			
	Full Range Test (Test Cell Equipment)		Cold Flow Test (Hard Mock-Up)	
WANL Supplied Components	Active	Passive	Active	Passive
1. Reactor Core	X			X
2. Reflector Assembly	↑			↑
3. Shield Assembly	(Included)			(Included)
4. Core Transducers				
5. Refl., Shield & Supp. Transducers	↓			↓
6. Rod Actuators	X		X	X
7. Neutron Det. & Amplifier	X			X
8. Pwr. & Temp. Cont. Chassis	X			
9. Reactor Prot. Chassis	X			
10. Control Logic Chassis	X			
11. Connectors, Cables, Harnesses			X	X

Active - Electrically or Electronically active or actively simulated.

Passive - Physical arrangement details simulated.

4.1 - Configuration

A non-nuclear test assembly for component interaction development (cold-flow machine) would be designed and built to the exact specifications of the actual reactor. Departure from actual design would occur only in the core where either unfueled graphite elements or depleted fuel would be used. All other design characteristics such as flow paths, thermal capacities, mechanical designs and supports would remain the same. The actual flow nozzle pump assembly, and piping would be incorporated in the assembly. The pressure vessel would be the same as that to be used on the actual reactor, except that provisions would be made for hand-holes, pads and connectors to allow for installation, mounting, and connection of special instrumentation.

4.2 - Instrumentation

Figure 16 shows some of the areas of concern, and a possible method for the installation of the instruments. All the instruments shown could be installed and leads brought out to terminals mounted on, or external to the pressure vessel. These types of instruments called for in most cases, have been subjected to cryogenic temperatures and have performed satisfactorily under the conditions they would have to endure in a non-nuclear, cold flow test.

4.2.1 - Instrumentation for Mechanical Analyses

The proper use of linear displacement transducers, accelerometers, strain gages, vibration pick-ups, angular displacement and torque indicating transducers, and thermocouples could help define reactor component interaction.

4.2.1.1 - Linear Displacement Measurements: The movement of the core, lateral supports, inner and outer reflectors and pressure vessel could be determined as shown in Figure 16, View E Linear displacement transducers could be mounted in the inner reflector with one sensor extending to the outer surface of the core and the other to the back surface of the lateral support, thus providing indication of movement of the core and the lateral support in relation to the inner

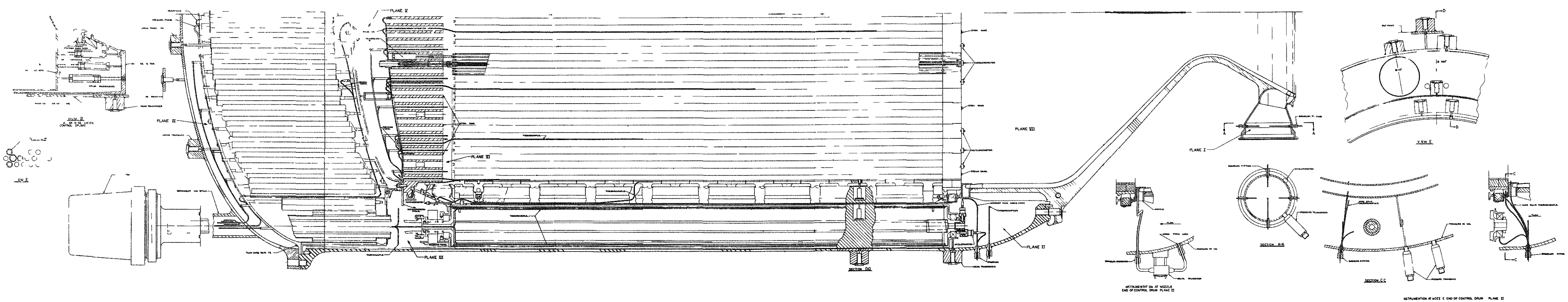

Fig. 16 - Non-Nuclear Test Assembly (NNTA) Instrumentation Study

reflector. A similar displacement transducer mounted directly in the outer reflector with its sensor on the outer periphery of the inner reflector would show movement of the inner reflector relative to the outer reflector. A similar attachment on the pressure vessel could indicate movement of the outer reflector relative to the pressure vessel. Arrangements of this type could be located strategically, both circumferentially and axially to determine the movement and modes of deflection with time and temperature.

Linear displacement transducers are also shown which would sense motion between the reflector and shield, pressure vessel and dome end of shield, nozzle end of shield and core support plate and other locations where relative motion is expected during operation.

4.2.1.2 - Amplitude and Frequency of Vibration Measurements: Accelerometers are shown mounted on a special adapter and fitted to the nozzle end of a typical drum rotor. Accelerometers would transmit the amplitude and frequency, in three directions (axial, radial, and tangenial), experienced by the drum at any time during operation. Accelerometers could be mounted in many areas within the reactor (e.g., in the dome end of the shield, accelerometers could be installed as shown in Figure 16, giving a pattern of the deflection and frequency over the shield during a test run).

4.2.1.3 - Strain Gages Measurements: Although there is difficulty in attaching strain gages to graphite under hot conditions, it is possible to attach them for a test such as would be made on a non-nuclear cold-flow test assembly. It would be possible to attach strain gages to many sections of the assembly to measure and record strain under static or dynamic conditions. The transition ring and clamp that ties the core support plate to the transition ring is an area of concern (see Fig. 16, View B). Under cold conditions, a gap is expected to occur between the faces of the core support plate and the transition ring where they are clamped together. At the same time a sizable deflection will take place in the transition ring. It can be assumed therefore, that the holding clamp will be highly stressed under these conditions. Strain gages mounted in this area would be quite helpful in understanding any stress problems. Other areas of concern would be on

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the dome and nozzle ends of the shield, core support plate areas within the core and on the fuel element support blocks.

4.2.1.4 - Seal Leakage Detection: One possible method of determining seal leakage would employ a combination of thermocouples and ΔP transducers placed in close proximity to and around the seal on both sides. For example, at cold flow start-up conditions the nozzle-end seal may be subjected to a 300°R temperature difference. If this seal should experience any sizable leak during this period, bare-bead thermocouples placed around the area should be capable of sensing the temperature change that would occur (see Fig. 16, Section C-C). Displacement transducers which would sense motion between the seal and nozzle could be instrumental in determining the amount of separation that takes place between them.

4.2.1.5 - Material Temperatures Measurements: Thermocouples extending into various areas of the reflectors, lateral supports, shield, core support plate, and core could reflect temperature changes with time. This would give a good correlation of cooldown rates under actual conditions as well as correlating the deflections with temperature changes.

4.2.2 - Instrumentation for Fluid Flow Investigation

One of the main problems associated with the NERVA engine is the complete understanding of the flowing fluid, liquid hydrogen. Two-phase flow, one of the uncertainties, is expected to appear during the start-up period. The distance the liquid front travels downstream and whether or not liquid will corry-over into the core is not known. A flow schedule under which the system can operate without liquid carry-over is being sought.

Pressure transducers, differential pressure transducers, and thermocouples located in the areas shown, would provide a comparison between computed values and actual state points. Pressure drops across each component and stream temperatures would be known at any time during the cycle. Pressure pulses or surges and the extent of their attenuation along the flow stream could be evaluated, and it might be possible to ascertain whether these are caused by flow or the pump. Thermocouples imbedded in the metals can give a running record of temperature changes with time in each component.

Since reactor performance depends to a large extent on the inlet conditions to the core, a non-homogeneous mixture (drops or slugs of liquid) at this point could cause serious reactivyty controlling problems. Slugs of liquid introduced into a hot core could also cause serious stress problems.

As a requirement for the non-nuclear test assembly, additional instrumentations would be included for fluid flow analysis. Figure 16 shows the planes selected for the installation of instruments.

Plane I - Nozzle Inlet Plenum: Thermocouples mounted on the inlet flange and around the plenum, together with pressure transducers would give the state of the fluid entering the nozzle cold side. Vibration transducers mounted on the entrance piping would measure that vibration being transmitted to the assembly which might be caused by the pump or flow.

Plane II - Reflector Inlet Plenum: Thermocoupled located on equal area circles around this plenum would indicate the temperature at this point and give an indication of flow distrubution into the reflector. Pressure transducers could be mounted individually around the circumference or manifolded together. Pressure drop transducers could be mounted between Planes II and III to indicate the pressure drop across the reflectors.

Plan III - Reflector Discharge Annulus and First Pass Shield Inlet: Thermocouples located on equal area circles would indicate both temperature and flow distribution. Pressure transducers would measure the pressure level in this annulus, and ΔP transducers would measure the pressure drop between Planes III and IV.

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Plane IV - Second Pass Shield Inlet: Thermocouples located in six or seven equal area zones would give a good indication as to the flow distribution entering the shield. Pressure transducers would indicate the pressure level in this area as well as ΔP between Planes IV and V.

Plane V - Shield Outlet: Thermocouples located in equal area zones with pressure and ΔP transducers would describe the state point in this area and ΔP across the core support plate.

Plane VI - Core Inlet: Thermocouples located in equal area zones with pressure transducers would describe the state point of the fluid as it enters the core.

Plane VII - Core Exit Chamber: Thermocouples and pressure transducers would describe the state point of the fluid as it leaves the core.

A majority of the instruments could be mounted directly within the test assembly, assuring fast signal response. A test assembly of this type, properly instrumented, combined with an adequate data acquisition and processing system, would permit comparison of the mechanical and fluid flow performance of the reactor at any given instant.

4.3 - Data Acquisition and Process System Required

The data system described in Figure 17 is proposed for testing the Non-Nuclear Test Assembly. This system would have the capability of measuring analog voltages with a band width of up to 5000 cps for 360 channels and would have the capability of measuring 400 channels with a sampling rate of up to 75 samples per second. It would be possible to reproduce the data from the wide band channels through the analog to digital system and prepare a digital tape for the IBM 7094 computer. For a five minute run it would take approximately two hours to reduce the data from the wide band recorders. Therefore, any data recorded on this system would be ready for computer analysis within a few hours.

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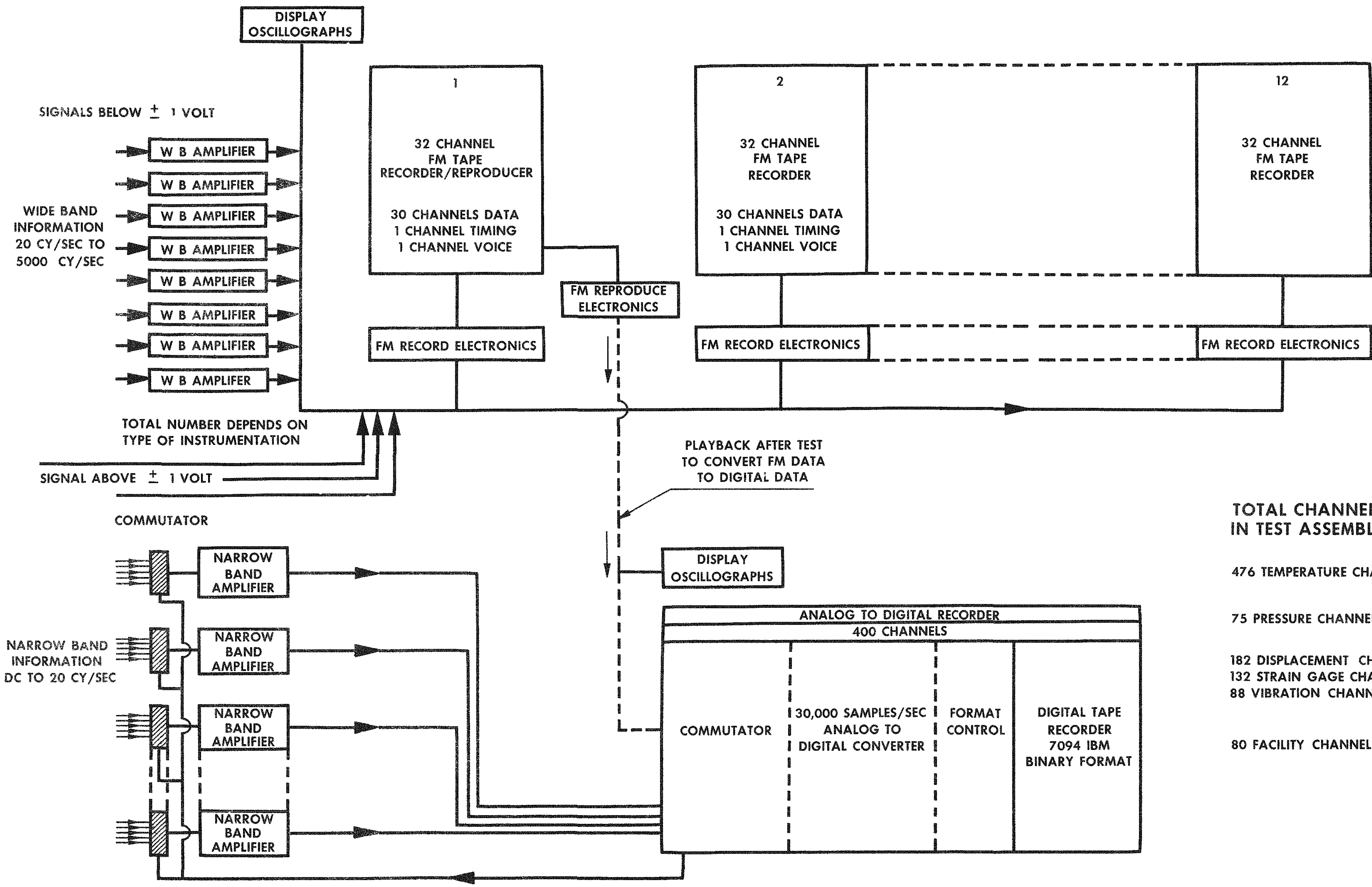

TOTAL CHANNELS IN TEST ASSEMBLY	EXPECTED FREQUENCY RESPONSE		CHANNELS TO BE RECORDED ON ANY ONE TEST
476 TEMPERATURE CHANNELS	236	10 CY / SEC	160
	240	20 CY/SEC	160
75 PRESSURE CHANNELS	75	100 CY/SEC	50
182 DISPLACEMENT CHANNELS 132 STRAIN GAGE CHANNELS 88 VIBRATION CHANNELS	402	300 CY/SEC	300
			670
80 FACILITY CHANNELS	80		80
			750

Fig. 17 - Proposed Recording System for Non-Nuclear Test Assembly.

It would also be possible to monitor and make a permanent recording of selected channels during the operation of the test. A permanent recording could be made of any of the wide band instrumentation channels for analysis at the test site during the period that the information is being digitized.

Table 5 lists the measurements and the band width of the requirement measurements of the Non-Nuclear Test Assembly.

It is not known at the present time where the Non-Nuclear Test Assembly would be tested, but if the Test Cell A area at NRDS were used, the digital system now installed at this site would be capable of measuring the 476 temperature channels with a sampling rate of 40 samples per second and an accuracy of approximately 1-3%. If all wide band instrumentation now being procured by LASL is available for Test Cell A, approximately 100 channels of wide band instrumentation will be available. Since the digital data system installed at NRDS does not produce an IBM compatible tape, it would have to be converted. Approximately four to five days are needed to convert the data to a form suitable for entry into an IBM 7094. LASL does not have the facilities for converting the data from the wide band instrumentation to a digital form; therefore, it would be necessary to do this at some other facility such as AGC Sacramento or Westinghouse Air Arm. The time required for converting this data is not known at the present time, but it should not take much longer than converting the digital tapes. Therefore, it would be possible to gather approximately 500 channels of information from Test Cell A and have the information available for the IBM 7094 in approximately one week.

TABLE 5

Total Measurements Required in Non-Nuclear Test Assembly	Bandwidth Required		Measurement Required in any One Test	Accuracy Req. of Data System
476 temperature channels	236	10 cps	160	1/4% to 1/2%
	240	20 cps	160	
75 pressure channels	75	100 cps	50	
182 displacement channels				
132 strain gage channels	402	300 cps	200	3% to 5%
88 vibration channels				
80 facility channels				

II. APPENDIX: REFERENCE REACTOR DESIGN DESCRIPTION

This Appendix presents brief descriptions of the reference reactor on which the simulators' designs were based. The reference reactor is one of the earlier versions of NRX-A reactor design.

Outer Reflector

The outer reflector consists of a segmented beryllium barrel held together by means of axial tie bolts through end plates as shown in Figure 4. The segmented barrel is 52 in. long with an OD of 49.369 in. and an ID of 40.131 in. and is divided into 12 segments of 30° each. There is a total of 384 axial flow holes, 216 axial shim holes, 12 axial tie rod holes, and 12 axial holes for the control drums.

The control drum consists of an aluminum tube with a wall thickness of 0.050 in. closely fitted over a beryllium cylinder. The beryllium cylinder contains 19 flow holes and a slot around one side of the periphery which contains the poison plate.

The nozzle end support plate is a circular titanium ring containing 1488 flow holes. Configuration is complicated by the raised bearing housing bosses.

The dome end support plate consists of a ring which has a "Z" shaped section. The vertical portion of the ring is a cylinder 16 in. high with an outside diameter of 40.131 in. and a wall thickness which varies between 0.1 and 0.2 in. The horizontal portion is a plate with a maximum thickness of 0.50 in. containing 3888 flow holes.

Inner Reflector

The inner reflector is located between the core and the outer reflector. The inner reflector consists of a graphite cylinder 52 in. long with an OD of 39.83" and an ID of 36.44" enclosed in an aluminum drum. Cooling is provided by 144 full length axial flow holes. The graphite inner

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reflector is enclosed in a 0.032 in. thick aluminum drum which fits outside of the graphite with a nominal clearance of 0.025 in. A nominal gap of 0.090 in. between the aluminum drum and the outer reflector provides a flow annulus. Lateral loads are transmitted across the annulus by axial spacer blocks which are located every 5° around the periphery. The graphite reflector is pierced by approximately 600 radial holes of 1.00 in. diameter which house the lateral support block plungers. These radial holes are tapped at their outer ends to receive threaded plugs which retain the lateral support springs.

The inner reflector is supported on a ring which rests on the nozzle. The dome end is supported by springs attached to the core support plate ring.

Shield

The shield is located in the reactor pressure vessel between the reactor core support plate and the dome end of the pressure vessel. The purpose is to reduce the radiation in the propellant tank to an acceptable level. It is instrumented with pressure probes and thermocouples for evaluation purposes.

The shield consists of lithium hydride powder compacted into pellets and encapsulated in 5/8-in. diameter stainless steel tubes. The capsules are gathered into bundles of seven, called modules, and welded together with tie plates. There are approximately 700 modules, each of which consist of six satellite capsules and one center capsule. Stems on the center capsule provide a means of welding the modules to elliptical shells of revolution called enclosure domes. Due to the varying distance between the comes and special requirements around the periphery approximately 100 different module assemblies are required. The shield is pierced by 12 drive shaft ports and 7 instrumentation ports.

The capsules are arrayed in an equilateral triangular pattern which provides flow passages between the capsules. These passages vary as a function of the capsule clearance, which is a nominal of

0.0065, but may vary between a minimum of 0 and maximum of 0.015 in. Flow passages through the enclosure dome are provided by approximately 8000 holes. A 0.010-in. thick baffle zig-zags between modules to form an approximately circular barrier so that flow can be directed toward the dome through the outer part of the shield and toward the nozzle through the center ports.

Core Support Plate

The core support plate is located between the core and the shield. Its function is to provide support for the reactor core elements. Each cluster of elements is supported by an axial tie bolt which is fastened to the support plate by a tie rod holder nut.

The core support plate is a circular plate which is flat on the surface adjacent to the core. However, the surface adjacent to the shield is elliptically shaped. The plate is pierced by approximately 2000 axial flow holes of 0.375-in. diameter, and 283 axial holes are drilled and counterbored from each side for attachment of the core cluster tie rod holders.

A quick disconnect flange and pilot on the outer diameter serves as a locating device and a support for the plate. The plate is supported in the assembly by a conical shaped ring which is piloted to the inner diameter of the outer reflector. Flow holes in the ring permit gas to flow from the inner reflector to the outer reflector plenum.

A double thickness, split fabricated, aluminum sheet metal seal shrunk on the outside diameter of the support plate extends skirt-like beyond the flat surface of the plate. The skirt slides over the outside diameter of the core at assembly to provide a seal between the reflector plenum and the core.

Lateral Support System

The lateral support system is located around the core between the core and the inner reflector and extends the full length of the core.

The function of the lateral support system is to bundle the core elements together, to provide lateral support for the core and to provide a thermal insulation around the core.

The lateral support system consists of approximately 600 pyrographite tiles, each of which is spring loaded to produce 3 to 5 psi on the core. The pyrographite tiles are rectangular plates 3 in. high, 3 in. wide and 0.12" thick and are curved to conform to the outer radius of the core. Each tile is glued and pegged to a lateral support block. An integral plunger-like protrusion on the support block slides in a radial hole in the graphite inner reflector. This plunger rests against a coil spring which is retained in the radial hole. The spring is trapped by a steel plug which is tapped into the radial hole.

Core

The core is a cylinder approximately 36 in. in diameter and 52 in. long consisting of 253 clusters, 24 of which are irregular clusters around the periphery. Each regular cluster consists of six hexagonally shaped fueled elements and one center, hexagonally shaped, unfueled graphite element. Coolant flow is provided by 19 axial holes of 0.10-in. diameter in each satellite fueled element and one large hole in the center of the unfueled element. Coolant flow is metered into the fuel elements by orifice bushings which fit into the flow holes and are retained by a perforated cluster plate.

Each cluster is supported by an Inconel X tie rod which runs through the flow hole in the center unfueled element. The nozzle end of the tie rod is shouldered to a molybdenum cone which seats in a pyrographite washer and cup through a transition cone. The cone supports a graphite support block which in turn supports the cluster. The dome end of the tie rod is threaded into a locking device and the cluster plate reacts negative g loading. It has the additional function of holding the cluster together, particularly before final core assembly. The satellite elements are retained in the cluster subassembly by a special orifice bushing which is pressed into both the element and the cluster plate at the dome end and by a similar bushing pressed into the element and the support block at the nozzle end.

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Tie rod temperatures are maintained at acceptable levels by means of coolant flow around the tie rod and by means of pyrographite insulating tubes which line the flow hole. The pyrographite tubes are protected from flaking and chipping by a thin walled inner steel tube.

Nozzle End Core Seal

The purpose of the nozzle end core seal in conjunction with the shield-to-core support plate seal is to prevent the coolant entering the pressure vessel from mixing with the coolant flowing through the reactor core. Thus, the coolant entering the pressure vessel must pass through the reflector and control assemblies as well as the shield assembly prior to entering the reactor core and exhausting through the engine nozzle.

The seal is located axially and held captive between the nozzle and the inner reflector assembly. It is located radially by the core nozzle and support blocks and an aluminum cylinder which spans the length of the core separating the inner and outer reflector assemblies.

The seal consists of three segmented graphite rings backed by spring operated plungers. The segments are located with respect to each other by shouldered steel pins. The major sealing surface of the assembly is faced with pyrolytic graphite tiles which are also located by steel pins. Steel plunger housings pressed into a steel seal carrier ring contain graphite cloth springs which activate the plungers when the graphite segments are built into the assembly.

The nozzle end core seal is fitted on the core-reflector assembly, and tabs on the aluminum support cylinder are bent into position to hold the seal axially prior to placing the entire reactor assembly in the pressure vessel shell from the dome end direction. The engine exhaust nozzle seats on the seal carrier ring when it is brought into position.