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Chief, Reactor, Space and Technology Branch
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STRUCTURE OF REACTOR-

PART 2 OF THE TORY II-C PROGRAM

AEC RESEARCH AND DEVELOPMENT REPORT

Livermore, California

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Livermore, California

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STRUCTURE OF REACTOR — PART 2 OF THE TORY II-C PROGRAM

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C. E. Walter

September 27, 1962

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FOREWORD

This is Part 2, "Structure of Reactor," of the 10-part report UCRL-7036. A list of all 10 parts, including titles and major subheadings, appears on the opposite page.

STRUCTURE OF REACTOR — PART 2 OF THE TORY II-C PROGRAM

C. E. Walter

Lawrence Radiation Laboratory, University of California
Livermore, California

September 27, 1962

INTRODUCTION

The Tory II-C reactor consists of a reflected core, internal structural components, and a reactor duct. The overall dimensions of the reactor are those of the reactor duct, which is a flanged cylinder $8\frac{1}{2}$ feet long and 4-3/4 feet in diameter. Sketches of the reactor are given in Figs. 1 and 2. The gross reactor volume is 150 ft^3. During peak operation an average of $3\frac{1}{4}$ MW/ft^3 of power will be transferred from the reactor to the approximately one ton of air per second passing through it. The volume of uranium-containing BeO is such that the peak power density in a fueled tube is $27\frac{1}{2} MW/ft^3$.

About 55% of the gross reactor volume contains hollow hexagonal beryllium-oxide tubes. These comprise the homogeneously fueled moderator and most of the reflectors making up the reflected core. There are approximately 465,000 tubes having an average length of $3\frac{1}{2}$ inches, either unfueled or loaded to various degrees with highly enriched uranium dioxide. The hollow tubes are close-packed to provide a honeycomb pattern of about 26,000 parallel flow channels running the length of the reactor. Heat released in the fission of U 235 is conducted to the channel walls and transferred by convection into the air passing through the channels. The ratio of the fueled channel flow area to the overall cross-sectional area of the reactor is 1/3.

The reactor is designed for flight capability at low-altitude, hot-day, Mach-3 conditions for periods of 3-10 hours. It must sustain a thrust load of 275,000 pounds due to air flow, air pressure up to 350 psia, lateral maneuver loads as high as 4 g's, and a not yet clearly defined vibration environment. This force picture appears in a high temperature environment where metal temperatures range to 2300°F and ceramic temperatures to 2850°F. All cooling is accomplished with ram air, the temperature of which is 1060°F.

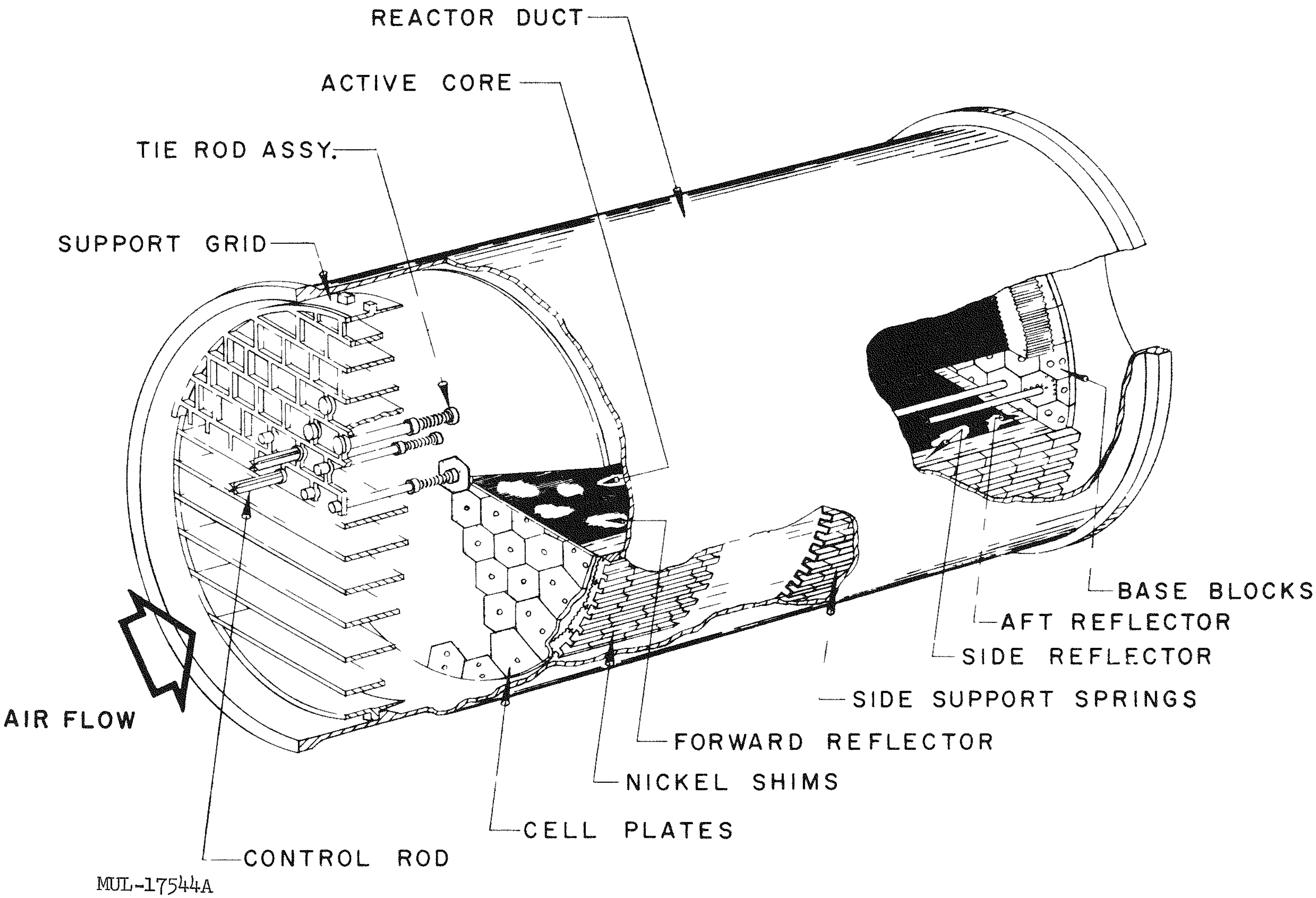


Fig. 1. Artist's conception of Tory II-C reactor indicating most components.

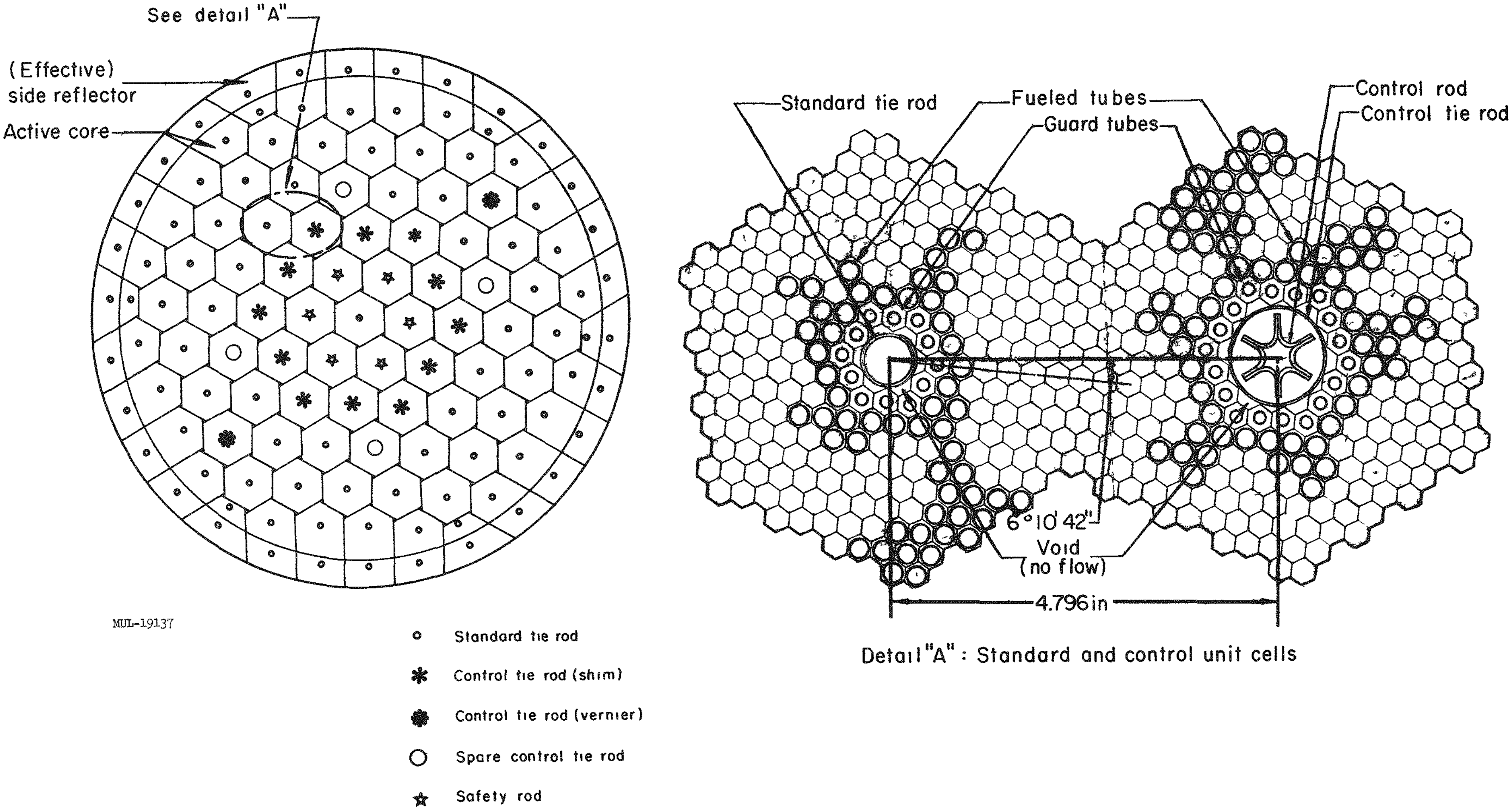


Fig. 2. Schematic cross section (looking downstream) of the reflected core showing unit cells and control and safety rod locations. Except at the periphery, a unit cell is associated with each tie rod assembly.

The forces are accommodated and the reflected core integrity maintained by side and axial support systems located in a high pressure duct. The side support system occupies an annulus between the reflected core and the duct. It consists of 31 bands of corrugated springs which exert a uniform radial compressive force on the reflected core. In order to maintain a stable geometry, the irregular boundary formed by the hexagonal tube columns is transformed to a regular boundary by the use of thick nickel shims. The flexibility of the corrugated springs holds the nickel shims in place and accommodates thermal expansion of the reflected core. Transverse inertia loads on the reflected core are transferred to the duct by means of 30 support rails, bolted to the inside of the duct, which engage "valleys" of the springs. The springs engage fingers in the nickel shims in a similar manner.

Axial loads are reacted at the front (cooler) end of the duct. Here a support grid spans the duct and is pinned to an interrupted ledge on the inside of the duct. Over a hundred tie rods attached to the support grid pass through the reflected core and attach to base blocks at its rear. A nominal axial compression is applied to the reflected core at each tie rod location by coil springs compressed between the support grid and the front of the reflected core. Thus, the bundle of almost one-half million parts comprising the reflected core is held in the desired position and geometry by side spring pressure and prestressed "hangers" or tie rods. Almost all structural parts operate at relatively low temperatures, permitting the use of superalloys. The exceptions are the base blocks at the rear of the reflected core. Their operating temperature will be as high as 2300°F.

A general appreciation of the components and materials in the reactor may be gained from the summary in Table I. The components are separately discussed in detail below.

Reflected Core

The reflected core is a right circular cylinder 63.08 inches long and 53.42 inches in diameter. It consists of the active core and the forward, aft, and side reflectors as shown in Fig. 3.

The side reflector is made up of a 2-inch thickness of BeO tubes next to the active core and an average thickness of 1 inch of nickel shims. These nickel shims provide a geometrical transition between the BeO tube array of the reflected core and the corrugated spring of the side support system (see Fig. 12). In addition, it was determined

Table I. General summary of components and materials in Tory II-C.

Component	Materials	Weight (lb)	Weight (%)
Reflected Core			
Ceramic tubes, Nickel shims, Nickel tubes	BeO, BeO-OyO_2[a]-Y_2O_3-ZrO_2, Ni, Cr-MgO, Pt-Rh	10,300[b]	56.0
Base Blocks	F-48	450	2.0
Tie Rod Assemblies			
Tie rods, Reflector inserts, Cell plates, Compression springs, Spring adapters	René 41, R-235, SS 410, Hastelloy C, Pt-Ru	700	4.0
Support Grid	René 41, Hastelloy C	1,000	5.5
Control Rods	Hafnium	100	0.5
Side Support System			
Springs, Rails and wipers	René 41,Hastelloy C	1,900	10.0
Reactor Duct	Hastelloy C	4,000	22.0
		18,450lb	100 %

[a]Oy is uranium highly enriched (93.5%) with the isotope U^{235}.

[b]Includes about 50 kg of OyO_2.

through experiment that their 99.5% pure nickel in this location and amount has the same neutronic worth as an equivalent volume of BeO.

About 1000 shims are assembled to form 1062 axial flow passages, most of which are 0.130 inch in diameter. BeO tube holes in the side reflector are 0.093 inch in diameter. There are 3876 axial flow passages of this diameter in the side reflector. The total flow porosity of the nickel reflector material is 9.9%, and of the BeO side reflector tubes 8.4%. The flow passages in the nickel shims lie inside a 52.88-inch circle. Within this circle the flow porosity in the shims is 14.1%. Porosity in the side reflector has been chosen in such a way that the temperature is reduced to 1500°F at the nickel-BeO interface.

The reactor's ceramic tubes have the shape of a regular hexagonal prism with an axial circular hole as shown in Fig. 4. Fueled tubes and forward reflector tubes measure 0.296 inch, and tie rod guard tubes measure 0.295 inch. For the purpose of calculating reflected core diameter, cross-flats dimensions of the ceramic tubes are assumed to be 0.0004 inch greater than their actual measured average. This necessary "buildup" allowance was determined experimentally.

There are about 293,000 fueled and about 16,000 unfueled tubes within the active core, where the average power density is about 10 MW/ft^3. All fueled tubes have a flow passage diameter of 0.227 inch. The spatial distribution of fuel loading is shown in Fig. 5. It is intended to provide a flat radial power and temperature distribution and constant power axially over the first half of the active core. In the latter half of the active core the power falls off due to constant axial fuel loading. The design peak wall temperature in the fueled tubes is 2500°F. Temperature excursions to 2850°F can be tolerated by structural components under certain conditions.

Over 80% of the fueled tubes are 3.925 inches long. The remainder vary in length in order to achieve the proper tube column lengths and to provide a staggered arrangement between adjacent columns. Figure 6 shows the stagger arrangement of the tube columns.

The ceramic tubes surrounding the tie rods (i.e., "guard" tubes) are unfueled and have smaller holes than the fueled tubes, being 0.130 inch in diameter. With this size hole, a reasonably low tie rod temperature is maintained without producing an excessively high thermal gradient in the adjacent rings of fueled BeO tubes. The flat-to-flat dimension is reduced (to 0.295 inch) to allow thermal bending of these guard tubes without breaking.

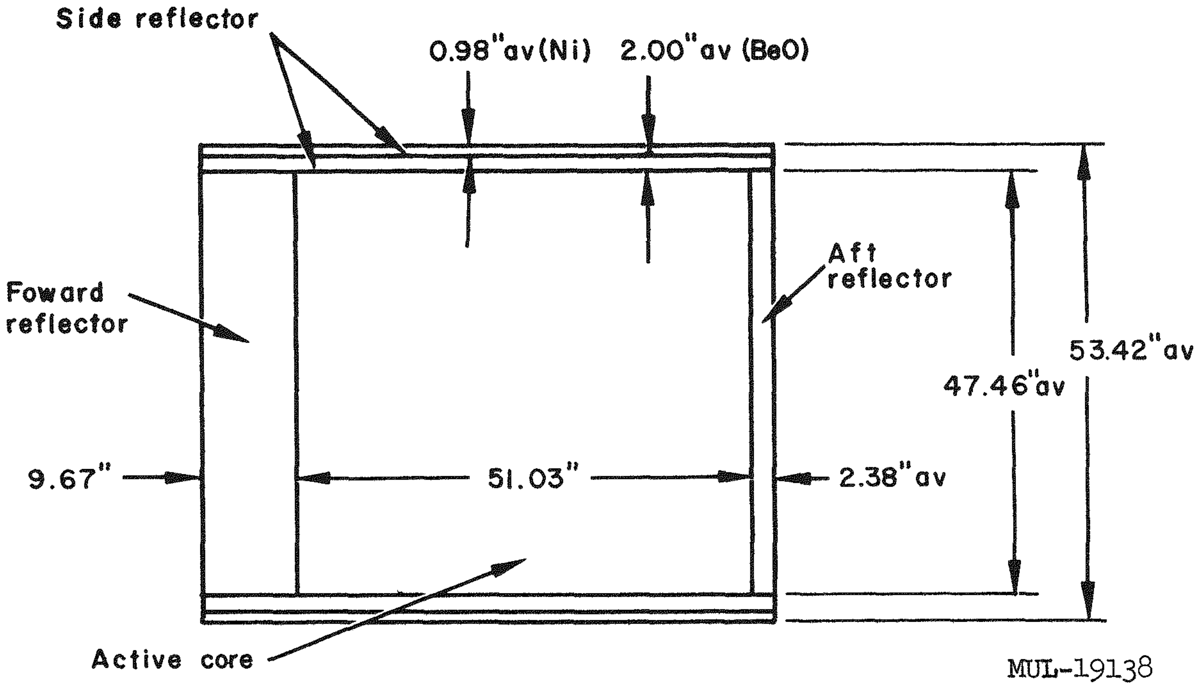


Fig. 3. Reflected core dimensions.

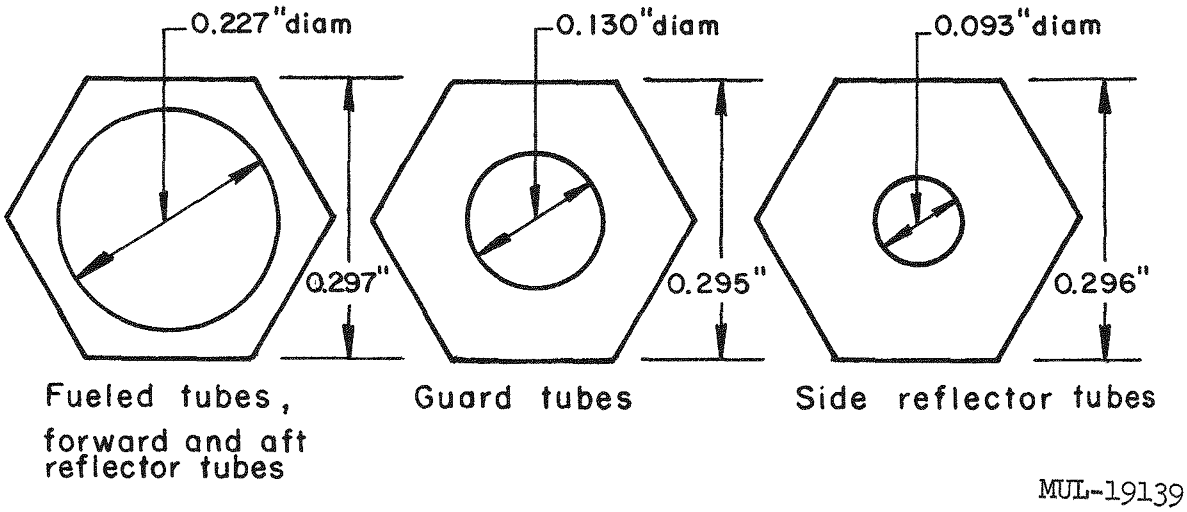
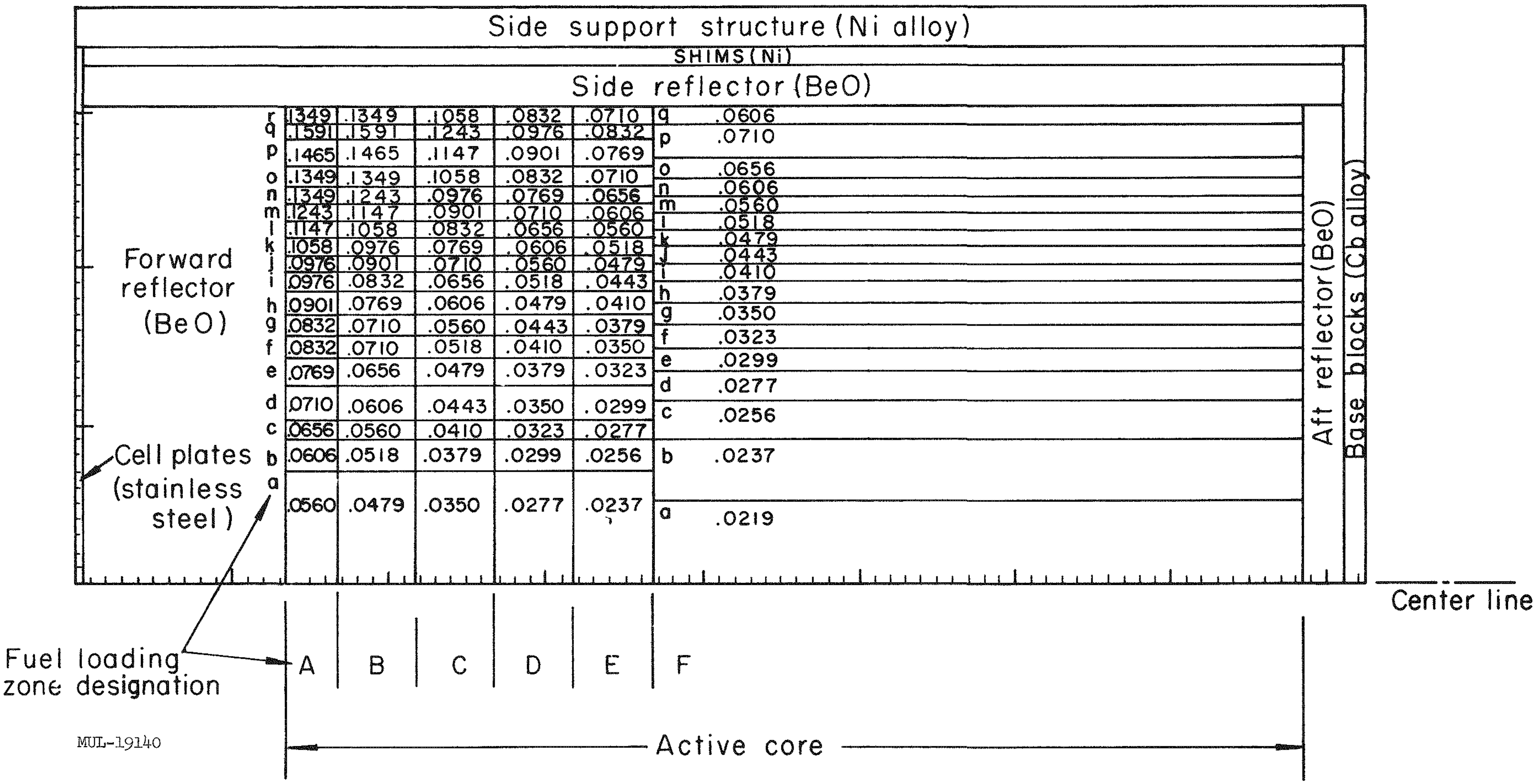


Fig. 4. Ceramic tube dimensions.



	A	B	C	D	E
r	.1349	.1349	.1058	.0832	.0710
q	.1591	.1591	.1243	.0976	.0832
p	.1465	.1465	.1147	.0901	.0769
o	.1349	.1349	.1058	.0832	.0710
n	.1349	.1243	.0976	.0769	.0656
m	.1243	.1147	.0901	.0710	.0606
l	.1147	.1058	.0832	.0656	.0560
k	.1058	.0976	.0769	.0606	.0518
j	.0976	.0901	.0710	.0560	.0479
i	.0976	.0832	.0656	.0518	.0443
h	.0901	.0769	.0606	.0479	.0410
g	.0832	.0710	.0560	.0443	.0379
f	.0832	.0710	.0518	.0410	.0350
e	.0769	.0656	.0479	.0379	.0323
d	.0710	.0606	.0443	.0350	.0299
c	.0656	.0560	.0410	.0323	.0277
b	.0606	.0518	.0379	.0299	.0256
a	.0560	.0479	.0350	.0277	.0237

	F
q	.0606
p	.0710
o	.0656
n	.0606
m	.0560
l	.0518
k	.0479
j	.0443
i	.0410
h	.0379
g	.0350
f	.0323
e	.0299
d	.0277
c	.0256
b	.0237
a	.0219

Fig. 5. Radial and axial distribution of fuel loadings. The numbers in each zone of the active core are in units of 10^{-4} g of OyO_2 per inch of fueled tube length.

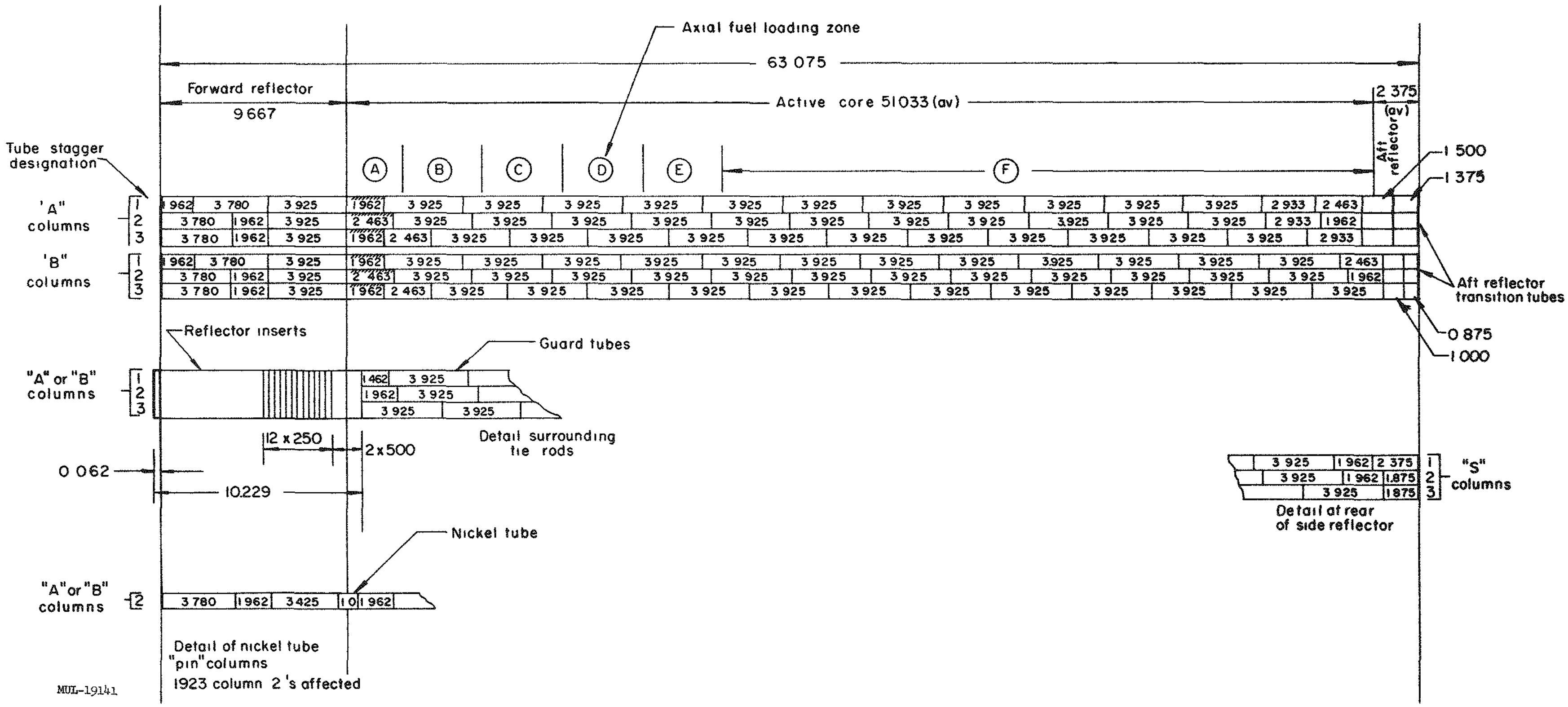


Fig. 6. Stagger arrangement of tube columns (dimensions in inches).

The forward reflector is 9.67 inches thick and consists primarily of BeO tubes. Its cross section is the same as that of the active core except adjacent to the tie rods. Here metal inserts are used to replace the ring of tie rod guard tubes. These reflector inserts create an annular space around each tie rod which permits the tie rod to deflect to accommodate differential expansion between the ceramic tube array and the support grid. The insert adjacent to the active core face fits closely around the tie rod to restrict air flow between the outside of the tie rod and the surrounding unfueled tubes.

The planar interface between the forward reflector and the active core would permit shearing displacement were it not for about 1900 nickel tubes which act as pins. The displacement could be large owing to a severe temperature difference (600-2000°F) which exists between the active core and the forward reflector under certain operating conditions.

The nickel tubes are 1 inch long and replace $\frac{1}{2}$ inch of unfueled BeO tubes of the forward reflector and $\frac{1}{2}$ inch of fueled BeO tubes of the active core. The nickel tubes are located in the interface in a regular pattern to limit the displacement of front reflector tubes with respect to corresponding active core tubes. No radial force is applied to the 4-inch length of front reflector BeO tubes adjacent to the active core. The corrugated springs, although present in this region, transfer their load through their corresponding shims to nickel shims located fore and aft of this region. Gross displacement at the interface 4 inches upstream of the active core interface is prevented by the tie rod reflector inserts.

In the aft reflector a transition between the active core's flow channels and the larger holes in the base blocks is required. In general, each base block hole receives the flow from a cluster of seven active-core flow channels. The central tube in the cluster is supported by a platinum cap set into six special BeO tubes, as shown in Fig. 7. The average thickness of the aft reflector is 2.375 inches. However, the length of the aft reflector in a given cluster is either 1.875 or 2.875 inches. The two lengths provide a means of registry for the flow passages from the active core into the slightly cooler aft reflector. As in the case of tube stagger, pressure loss due to offsets in the flow channels is minimized in this manner. An alternate design for the transition section involves the use of a one-piece cartridge to replace the six special BeO tubes and the platinum cap. These cartridges are made of Cr-5 MgO material. Whether they will be used depends on their availability at the time of reactor assembly.

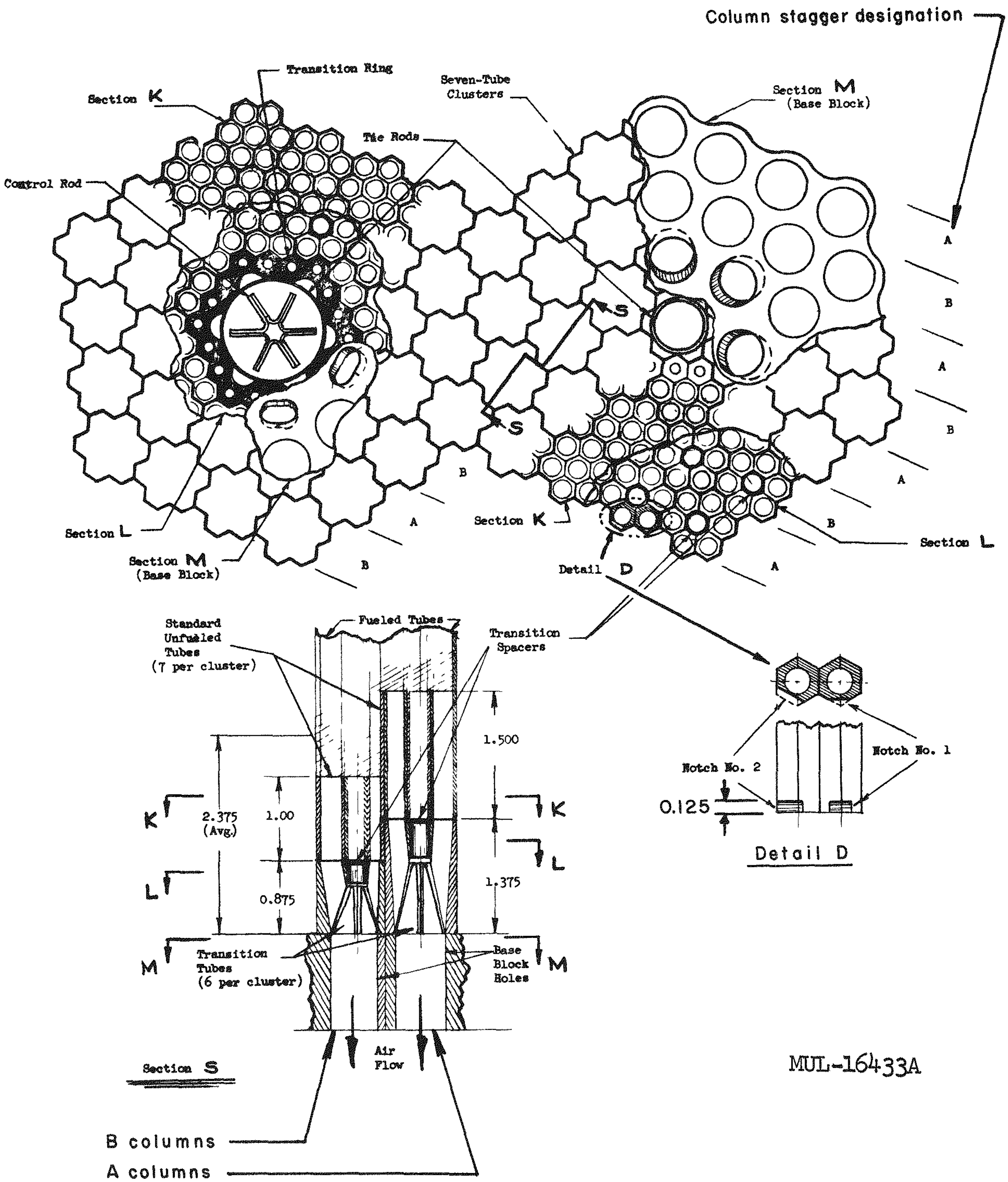


Fig. 7. Aft reflector flow transition details.

The critical stress in the ceramic tubes is thermal. Calculated thermal stresses are in general lower than calculated thermal stresses in the Tory II-A reactor. Judging from preliminary results of the Tory II-A experiments, the ceramic tubes that crack due to thermal stress do not affect performance of the reactor.

Base Blocks

The axial load due to the pressure drop force on the reactor is sustained at the aft end by 91 base blocks. These are made of F-48, a columbium base alloy, and are coated to provide oxidation resistance at operating temperatures. The coating is a two-cycle diffusion coating of silicon and chromium-ferroboron. The maximum thickness of the coating is 0.004 inch. Air flow tests indicate that the operating life of coated base blocks is in excess of 10 hours at 2300°F. Base blocks are 1.110 inches thick and when assembled form a roughly hexagonal array across the aft face of the reflected core. A standard base block, shown in Fig. 8, is about 4.8 inches across flats.

The maximum calculated mechanical stress in the base block is 8000 psi. The yield strength for this material at 2200°F is in excess of 25,000 psi.

In the region of the active core the majority of base block holes are about 0.6 inch in diameter, or large enough to accommodate the flow of seven active-core flow channels. This produces some mixing of the air and minimizes the effect of "hot spots" in the core on local base block temperature. The use of large base block holes also simplifies the ducting of air in the flow channels adjacent to the tie rods and greatly reduces problems of aligning holes in the base blocks with those in the reflected core.

In the 30 base blocks at the periphery of the reflected core, there are two tie rods per base block, one in the active core region and one in the side reflector. In the side reflector region, base block holes are 0.136 inch in diameter, one per flow channel. The problems encountered in using small base block holes in the active core region are not prominent in the side reflector region due to the smaller flow channel diameter and lower exit air temperature.

Tie Rod Assemblies

A total of 121 tie rods transmit axial loads from the base blocks to the support grid. The tie rods are long hollow tubes, cooled on the inside with ram air. A standard tie rod is shown schematically in Fig. 9. Both the

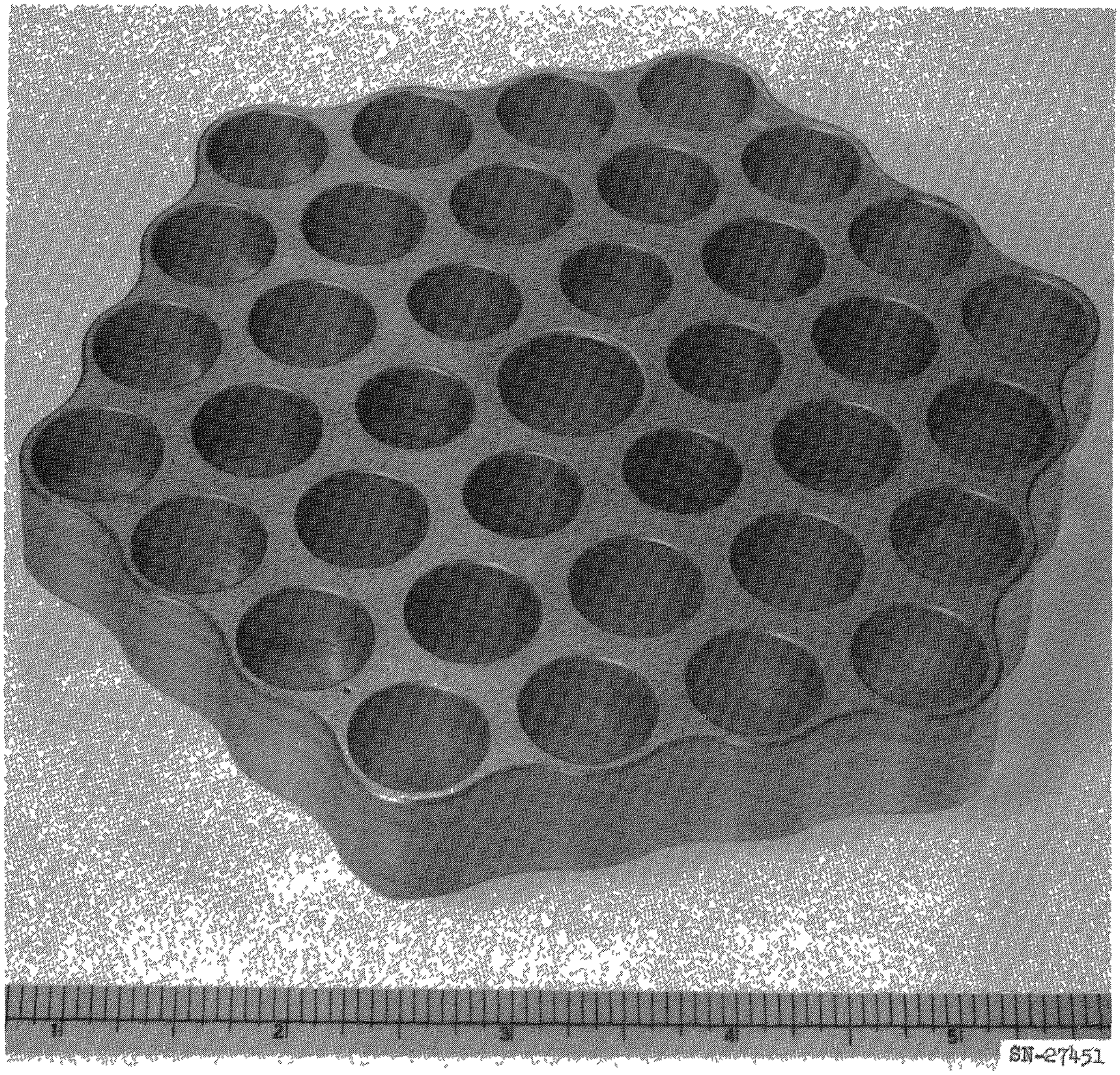


Fig. 8. Standard base block.

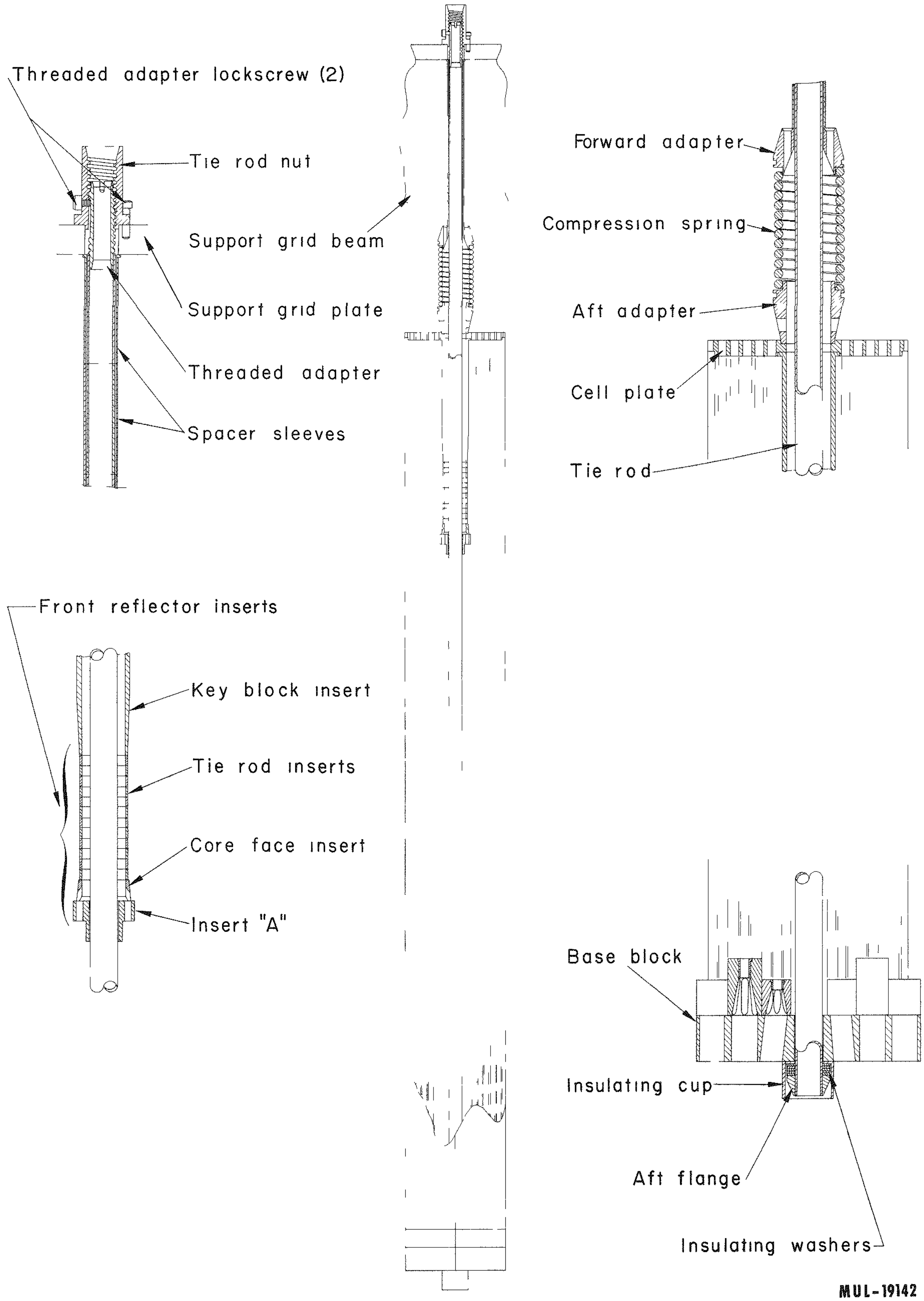


Fig. 9. Standard tie rod assembly.

threaded adapter at the front end and the aft flange are brazed to the tie rod. The assembly is bolted to the front plate of the support grid with a flanged nut. The inside diameter of the threaded adapter is less than the inside diameter of the tie rod. This is made necessary by the depth of thread required and assembly restrictions on the outside diameter. The diameter is not sufficiently reduced, however, to choke the flow of ram air. There are 103 standard tie rods having a 0.670-inch outside diameter and a 0.043-inch wall. The length of a tie rod assembly is about 81 inches. There are 18 control tie rods with a 1.22-inch outside diameter and a 0.030-inch wall. These permit insertion of control rods.

Roughly two-thirds of all tie rods are made of René 41 and one-third of Hastelloy R-235. Both materials are nickel base alloys; however, René 41 contains much more cobalt (11% vs 1%). The proportion of tie rods of each alloy may be varied to adjust reactivity of the reactor during the preliminary critical experiment. Since these alloys cannot withstand reactor exit air temperatures, a platinum-5% ruthenium cup and a series of Hastelloy C washers are used to insulate the aft flange of the tie rods. The maximum temperature expected in the tie rod is 1520°F. The calculated stress in the tie rod due to the average thrust load is 25,000 psi. At 1520°F the 10-hour rupture stress for Hastelloy R-235 is 40,000 psi. René 41 is stronger.

It is necessary, in order to maintain axial integrity of the reflected core, to provide an axial preload on the reflected core. This is accomplished with a cell plate, spacer sleeves, springs, and adapters between the support grid and the reflected core, in each tie rod assembly as shown in Fig. 9. The cell plate is 0.375 inch thick and contains holes corresponding to the flow channels it covers. The plates are arranged in a hexagonal array similar to that of the base blocks. Upstream of the cell plate there is a compression spring between two spring adapters. A stack of spacers between the spring and the front plate of the support grid completes the assembly. The tie rod is used to keep the components aligned. The preload force which 121 springs exert is about 7200 pounds. The springs are made of Inconel X. The sleeves, adapters, and cell plates are made of stainless steel.

Support Grid

The support grid transfers axial loads to the reactor duct. It consists of a ring, a front plate, and 12 beams as shown in Fig. 10. The beams are 0.5 inch thick, a maximum of 7.75 inches deep, and run horizontally across the reactor duct about 6 inches forward of the reflected core. The spacing of the beams varies between 3.2 and 4.7 inches. Their ends rest in slots in the ring. The ring is about 55 inches in diameter and has 96 external support lugs which rest on a similar interrupted ledge on the inside of the aft reactor duct. This method of mounting the support grid is used to provide cooling air passages in the annulus between the ring and the duct. The grid and duct are locked in position by 12 radial pins.

The front plate containing the holes into which the tie rods are mounted is bolted to the ring and beams. It is 0.75 inch thick and has a flow porosity of 0.74. The beams and plate are made of René 41 while the ring is of Hastelloy C. No structural welds are employed in the fabrication of the support grid. The maximum stress, 48,000 psi, occurs in the beams. At the operating temperature of 1300°F, the 10-hour rupture strength of René 41 is over 80,000 psi.

Control Rods

There are 12 shim control rods attached to 4 actuators, and 2 vernier control rods each connected to its own actuator. The actuators are located in the forward reactor duct. All control rods are made of hafnium sheet welded to form the asterisk-like cross section shown in Fig. 11. The span of shim rods is 1.0 inch; the vernier rods may be slightly smaller. The length of the control rods is $63\frac{1}{4}$ inches, while their length of travel is 40 inches. In the full out position the tip of the control rod is at the interface between the cell plates and the forward reflector. Four additional shim control rods may be used by adding an extra rod to each actuator. The control rods travel in the 18 control tie rods provided for this purpose.

Side Support System

A series of "square wave" corrugated springs and 30 support rails provide lateral support to the reflected core in the aft reactor duct. A typical section is shown in Fig. 12. The system must provide stability of the ceramic tube matrix while allowing the reflected core to function in an environment of

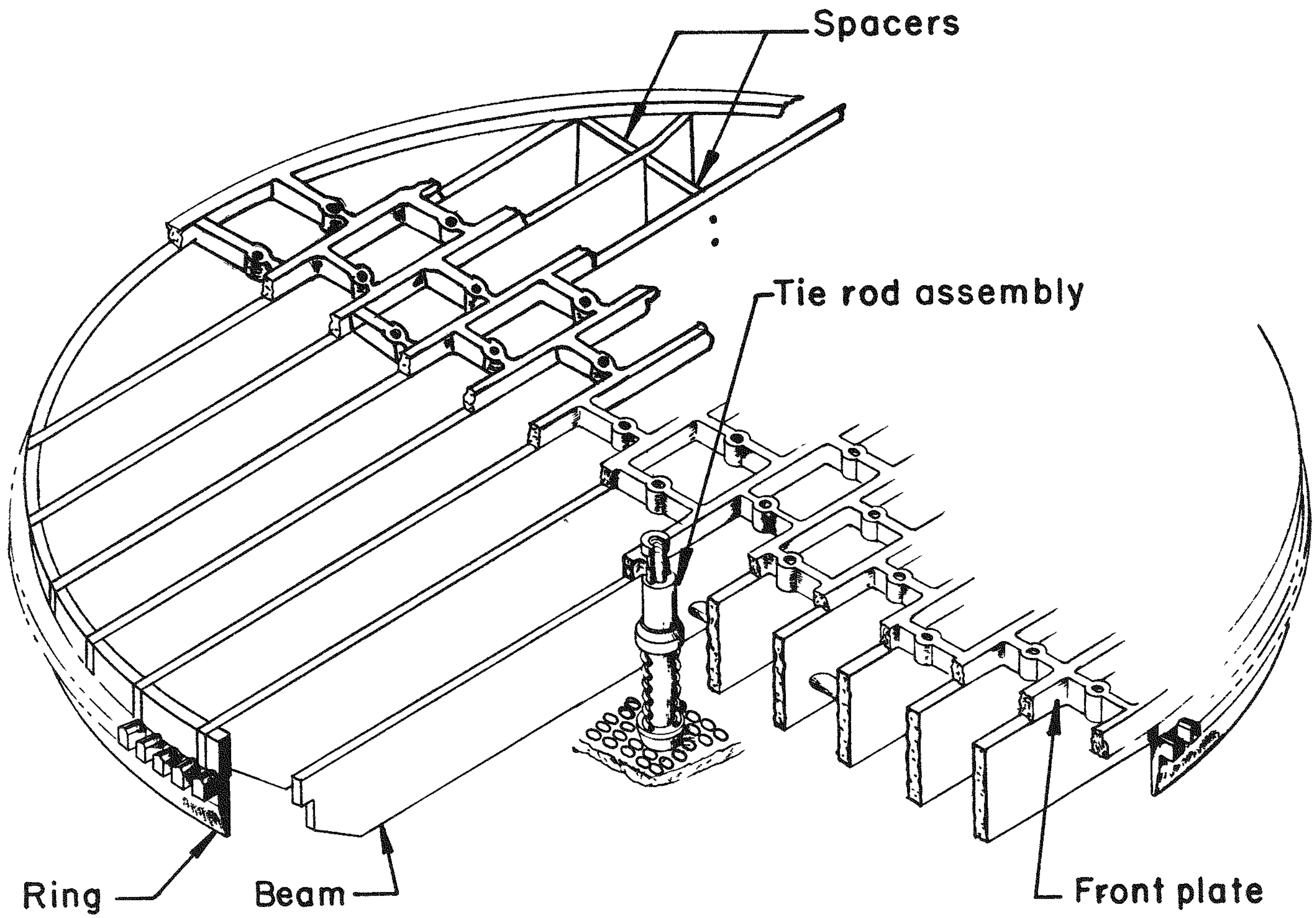


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Fig. 10. Artist's conception of support grid.

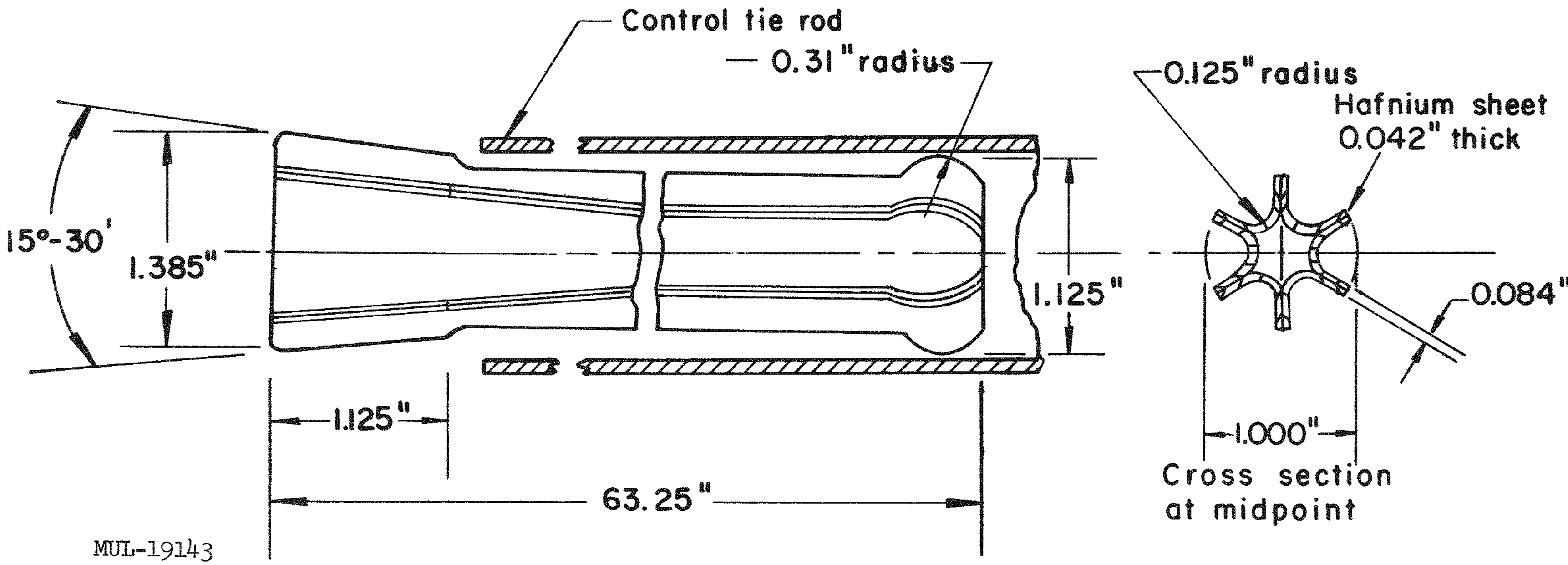

Fig. 11. Control rod.

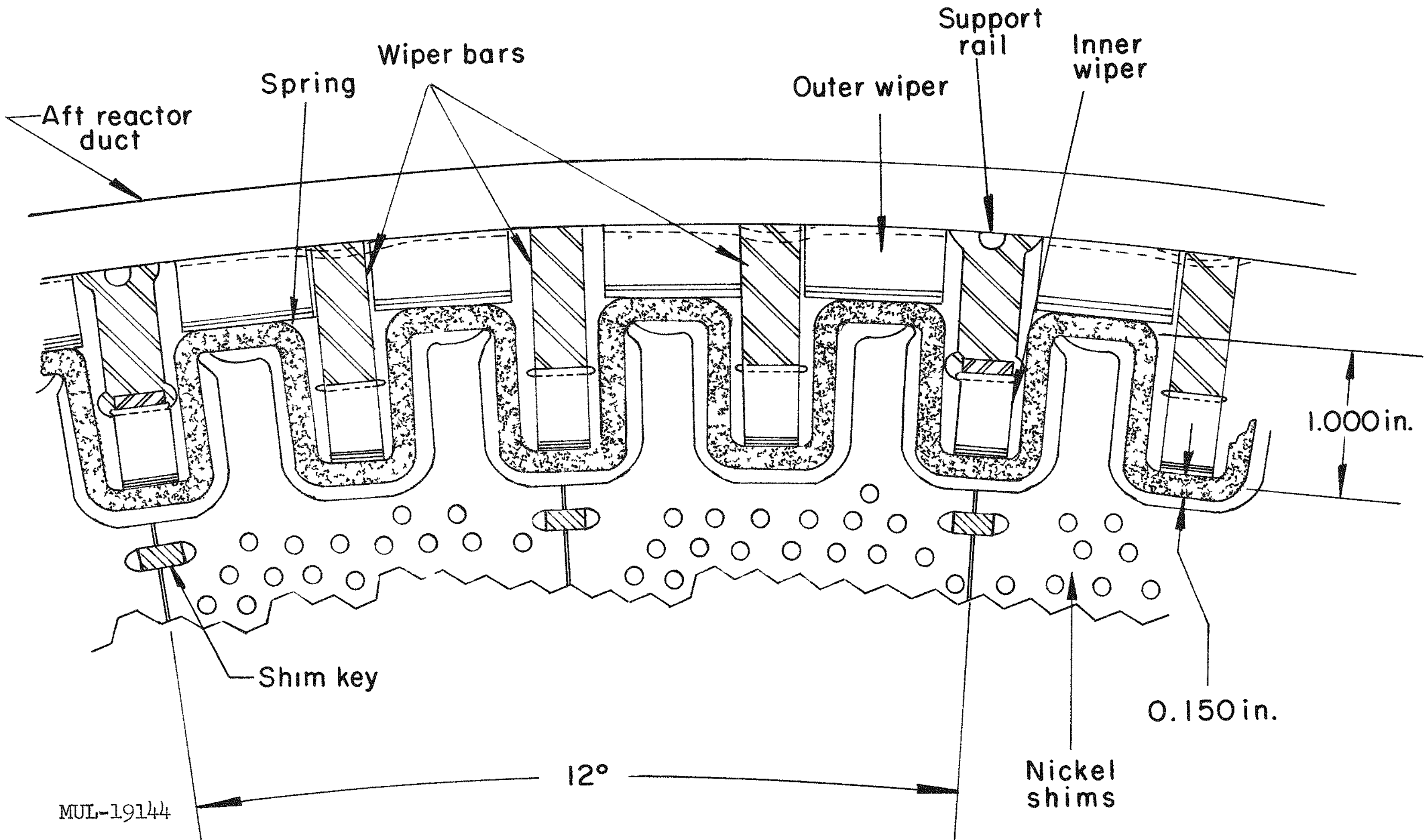

Fig. 12. Typical section of the side support system.

vibration, thermal expansion, and the lateral loads induced by missile maneuvers.

The spring is made of René 41, 0.150 inch thick. Its circumference contains 120 corrugations with a pitch of about 1.4 inches. The width of each spring is about 2.0 inches. When assembled in the reactor, adjacent springs are in contact with each other. Inertia loads from the reflected core are transmitted to the spring through the fingers of the nickel shims which fit into the spring's corrugations. These forces are transmitted to the duct through the support rails bolted to the inside of the duct. Support rails are made of short lengths of René 41.

There are 90 wiper bars in the spring corrugations interspersed between the support rails. These are made of Hastelloy C and serve both to reduce the radiation heat load in the duct and to provide flow blockage in the area between the spring and duct. To further control the cooling air flow, René 41 wipers, about 0.030 inch thick, are placed between the duct and the corrugated springs and between the rails or wiper bars and the springs. The wipers are sized to produce a net compressive force on the reflected core due to the difference in pressure of the air flowing in the reflected core and in the side support annulus. Thirty of the wiper bars, equally spaced, extend to the rear end of the duct in order to provide a mounting for the shroud.

Reactor Ducts

Aft Portion

The aft reactor duct is made of Hastelloy C. It is 103 inches long and has a 57.25-inch outside diameter. Its wall thickness at the reflected core is 0.438 inch. Ninety-six support lugs which correspond to external lugs on the support grid are located around the inside of the duct 13 inches downstream of the duct's forward flange. Fifty-six bolts in 60.25-inch bolt circles in each flange join the aft reactor duct to the forward reactor duct and nozzle. A number of pass-through glands at each end of the duct provide a means of carrying instrumentation wiring out of the duct.

In order to keep the aft portion of the reactor duct at a suitably low temperature, a shroud is installed between the aft face of the reflected core and the nozzle. Inlet air, after passing through the side support system, passes between the duct and the shroud, thus cooling these components.

Forward Portion

The forward reactor duct is 60 inches long and is made of Hastelloy C with flanges the same as those of the aft reactor duct. Internally it contains mounting and aligning structures for the control system actuators. Six electropneumatic supply packages, one for each control actuator, are mounted externally on the duct. A reactor safety mechanism is also installed in the forward reactor duct. This system is mechanically actuated from outside the duct. The safety system permits insertion of six 0.4-inch-diameter rods containing high density $(B^{10})_4C$ into the center ring of reactor tie rods. The safety system is used during checkout operation of the control actuators or as a secondary shutdown mechanism in the event that one of the control actuators fails in the rod withdrawn position. The system may only be used at very low reactor power since the safety rods seriously retard coolant flow through the corresponding tie rods.

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