Do not use
[illegible]

DESIGN AND DEVELOPMENT OF COMPONENTS FOR THE SRE

~~PREPRINT 79~~

William E. Parkins

North American Aviation, Inc., Downey, California

Contributed by

American Society of Mechanical Engineers

2P /PRESENTED ~~for presentation~~ at the Nuclear Engineering and Science Congress, ~~sponsored by Engineers Joint Council,~~ December 12-16, 1955, at Cleveland, Ohio./ ~~Publication rights are reserved by the contributing society. Opinions expressed are not necessarily those of the contributing organization or Engineers Joint Council.~~

RECEIVED

JAN 15 1968

LMIC

Published on behalf of the Nuclear Engineering and Science Congress by

AMERICAN INSTITUTE OF CHEMICAL ENGINEERS

25 West 45 Street, New York 36, New York

Price: 30 cents

LM-02837

DESIGN AND DEVELOPMENT OF COMPONENTS FOR THE SRE

Wm. E. Parkins
North American Aviation, Inc.

ABSTRACT

The engineering of the Sodium Reactor Experiment, has been confronted with a number of problems, many of them new to the reactor field. A general design arrangement has been worked out which appears to offer practical solutions to these problems. In many instances it has been necessary to conduct experiments to obtain information on materials behavior or to test components. The results of this design and development work are described in some detail for the reactor portion and cover the fuel elements, moderator and reflector, control elements, safety elements, other special core elements, reactor tanks, and shielding.

I. Introduction

The Sodium Reactor Experiment (SRE) is a reactor facility being constructed as a part of the five-year program for the development of nuclear power. It will be the principal tool for the development of the technology associated with the sodium-cooled, graphite-moderated type of reactor. Design of the SRE for construction was undertaken in June, 1954, with the completion of a contract between the Atomic Energy Commission and North American Aviation, Inc. As of June, 1955, the design of the SRE with its associated facilities is approximately 60 per cent complete and field installation is well underway. Construction is scheduled for completion early in 1956.

The engineering for the SRE has included, in addition to the actual design work, an experimental program for component development. It is the purpose of this paper to describe some of the components of the SRE and certain problems encountered during their design and development. The discussion is limited to portions of the reactor and no attempt is made to cover components in the sodium heat removal system. The features of the SRE which are described represent the contributions of many members of the Nuclear Engineering and Manufacturing Division of North American Aviation.

II. General Description

The SRE is designed for the production of nominally 20,000 kw of heat. No provision is being made in the initial installation for a steam cycle and the production of electrical power. Steps are being taken, however, which will permit such an addition at a later date. The reactor is cooled by sodium, which circulates in a primary system and becomes radioactive. This primary sodium transfers its heat to a secondary, non-radioactive sodium system in intermediate heat exchangers. The secondary sodium rejects its heat to the atmosphere in air-cooled heat exchangers. Both the primary system and secondary system have two separate circulating loops; a main loop, capable of the transfer of 20,000 kw of heat, and an auxiliary loop capable of the transfer of 1,000 kw heat. This arrangement, as well as the temperatures and flows for normal operation, is shown in the simplified diagram in Fig. 1.

An artist's view of the equipment arrangement is shown in Fig. 2. The reactor is located below grade, with the upper surface of its top shield at floor

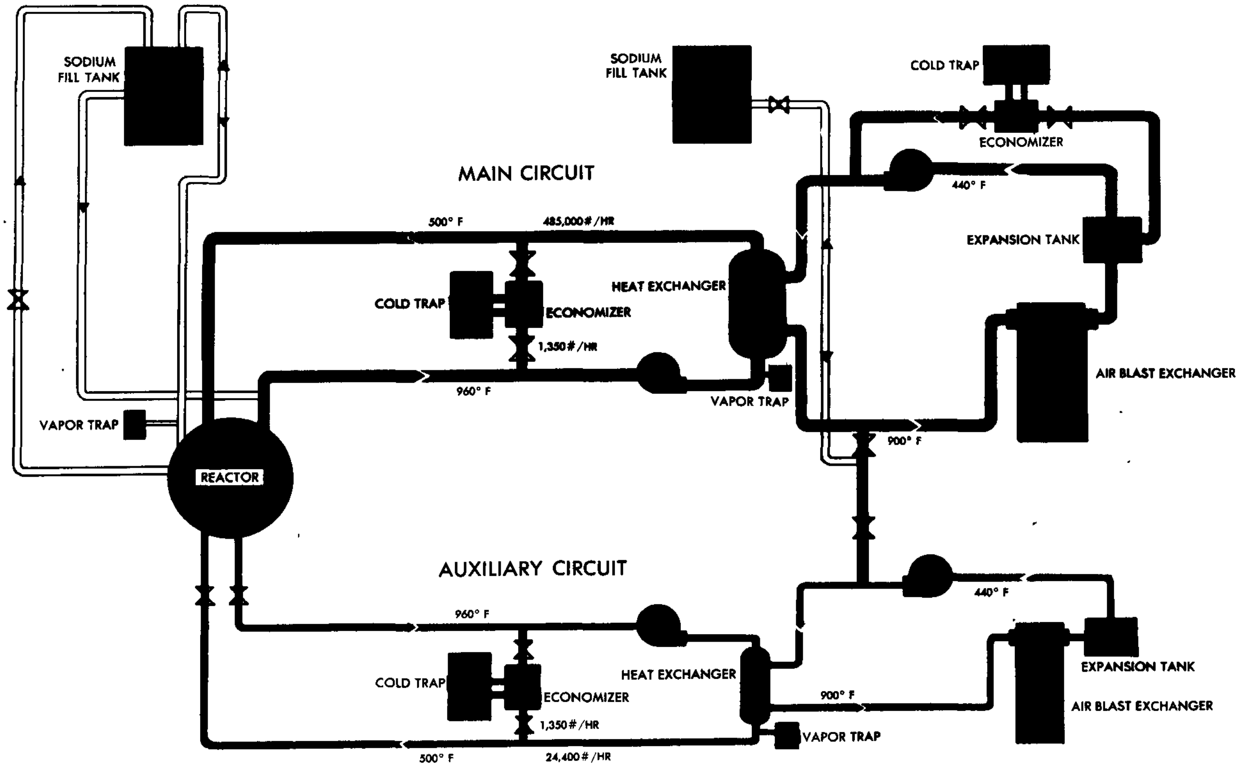
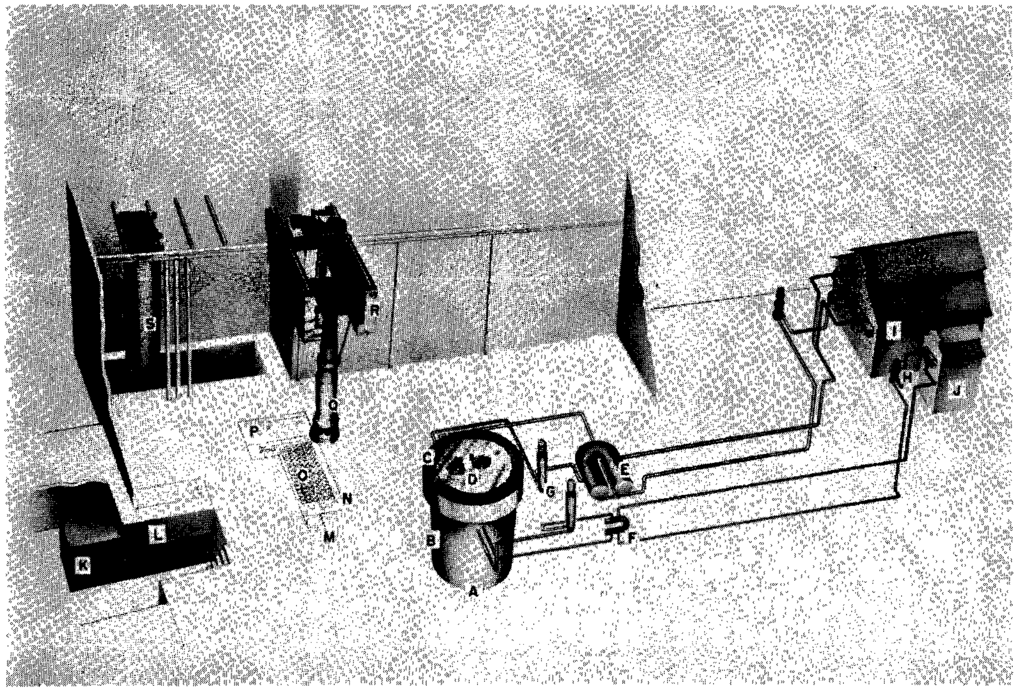


Fig. 1. Sodium Flow Diagram for SRE Cooling System.



A - REACTOR
B - CORE TANK
C - RING SHIELD
D - ROTATABLE FACE SHIELD
E - MAIN SODIUM HEAT EXCHANGER
F - AUXILIARY SODIUM HEAT EXCHANGER
G - PUMP
H - PUMP
I - MAIN SODIUM-AIR HEAT EXCHANGER
J - AUXILIARY SODIUM-AIR HEAT EXCHANGER
K - METALLURGICAL HOT CELL
L - PRIMARY HOT CELL
M - SHIPPING COFFIN CELLS
N - MODERATOR CAN STORAGE CELL
O - FUEL STORAGE CELL
P - FUEL CLEANING CELL
Q - FUEL HANDLING COFFIN
R - HANDLING BRIDGE
S - MODERATOR HANDLING COFFIN

Fig. 2. General Arrangement of Components

level in the reactor room. Two primary loops are also below floor level and are installed in separate concrete-walled galleries. Motors for the mechanical sodium pumps and for the control rod drives are located above floor level for easy maintenance. The secondary sodium lines extend from the intermediate heat exchangers to locations above ground level and outside the reactor building to where the air-cooled heat exchangers are situated.

A 75-ton handling bridge is designed to move within the reactor room and be capable of supporting lead-shielded coffins used for the removal of radioactive elements from the reactor core. At one end of the reactor room special facilities are installed, again below floor level, for the cleaning and storing of these elements. For the purposes of the experimental program, especially that associated with the fuel development, a hot cell is installed below grade with access holes to receive elements from the handling coffin.

In addition to the sodium coolant and graphite moderator, the SRE will initially use fuel elements fabricated from slightly enriched uranium, containing 2.80 atom per cent U^{235}. These elements, as well as all others penetrating the reactor core, are suspended from small plugs in the top shield. The reactor elevation is shown in Fig. 3.

The entire core is contained in a stainless steel vessel, 19 feet deep and 11 feet in diameter. The graphite moderator is supported and located on a stainless steel grid plate near the bottom of this core tank. The graphite is in the form of cell-sized hexagonal prisms, placed on a triangular lattice 11 inches between centers. Each prism is 10 feet in height and is clad with thin zirconium sheet. The 10-foot height includes 6 feet for the moderator and an additional 2 feet at the bottom and at the top for reflector. The graphite assemblies making up the core region contain an axial zirconium tube, in which fuel elements are suspended.

Inlet lines from the main primary and auxiliary primary loops enter the core tank above the graphite assemblies and extend vertically downward in double-walled pipes, in order to discharge into a plenum between the bottom of the core tank and the grid plate. This sodium at a temperature of 500° F then passes up through the axial tubes, cooling the fuel elements and discharging into a pool 6 feet deep, having a mean temperature of 960° F. Separate outlet pipes for the two primary loops are also located in the core tank above the graphite assemblies.

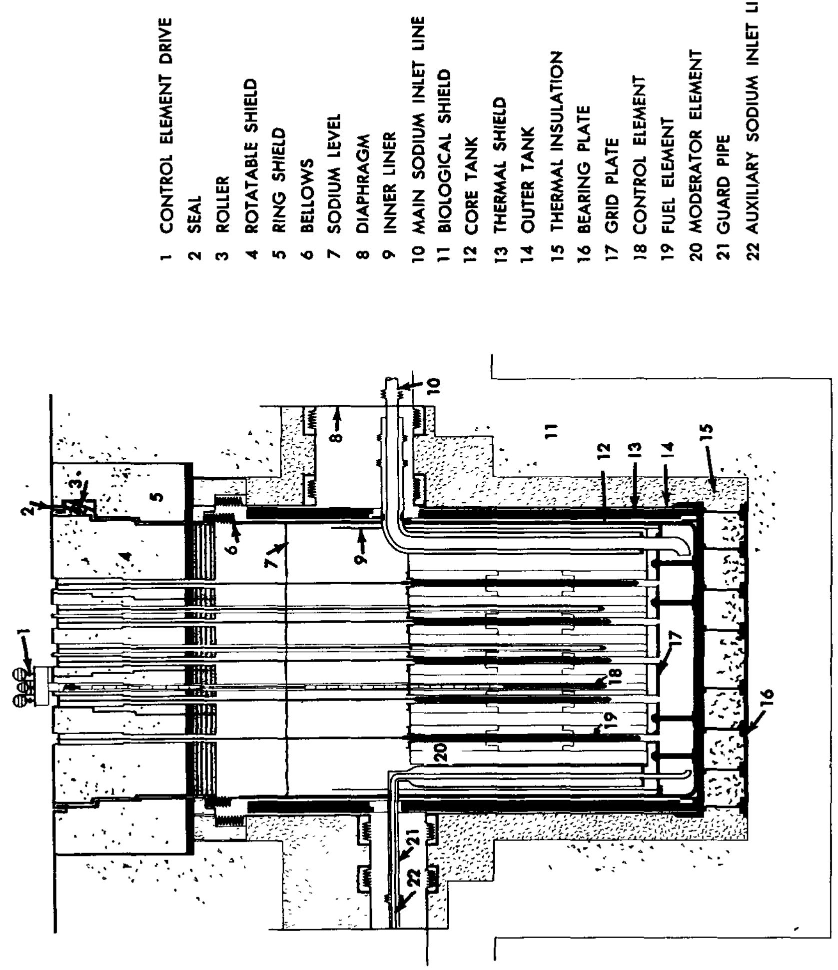


Fig. 3. Reactor Elevation.

Surrounding the core tank is a steel thermal shield 5-1/2 inches thick. Immediately outside of the thermal shield is the outer tank which is intended as as emergency means of containing sodium in the event that a leak should develop in the core tank. The outer tank is surrounded by approximately a foot of thermal insulation. This, in turn, is contained in a tank called the cavity liner. The function of the liner is to serve as a form for the concrete foundation and to aid in the removal of heat from this region. Steel pipe is tack-welded to the outside surface of the cavity liner to provide a means of circulating a fluid for removing the small smount of heat developed in the concrete, together with that conducted through the layer of thermal insulation. The fluid circulated is tetralin, furnished from a special cooling system intended for many components around the reactor where there might be some conceivable possibility of contact between this fluid and the sodium coolant.

The concrete foundation extends up to the biological shield at floor level, where it is planned to use a special grade of concrete made with magnetite iron ore aggregate. As a closure for the reactor vessel there is a ring shaped shield supported on a ledge in the cavity liner, and a circular (or rotatable) shield supported on steps on the inside of the ring shield. All of the small plugs permitting access for the core components are located within this rotatable top shield. Large diameter bellows provide a gas seal for the core tank atmosphere and for the atmosphere between the core tank and the outer tank. Separate bellows and diaphragms seal the galleries from the atmosphere of the various pipes penetrating this region.

III. Fuel Elements

The fuel elements planned for initial operation in the SRE are fabricated in the form of clusters of seven rods, as shown in Fig. 4. Each rod consists of a 6-foot high column of 6-inch uranium slugs in a thin-walled stainless steel jacket tube, thermally bonded by NaK alloy. The slugs are 0.750 inch in diameter, the jacket tube 0.010 inch in wall thickness, and the NaK annulus 0.010 inch in average thickness. The stainless steel jacket material is type 304 and is closed at each end by a welded stainless steel plug. The NaK bonding alloy extends a few inches above the slug column to a free surface above which is helium gas at atmospheric pressure (when at room temperature).

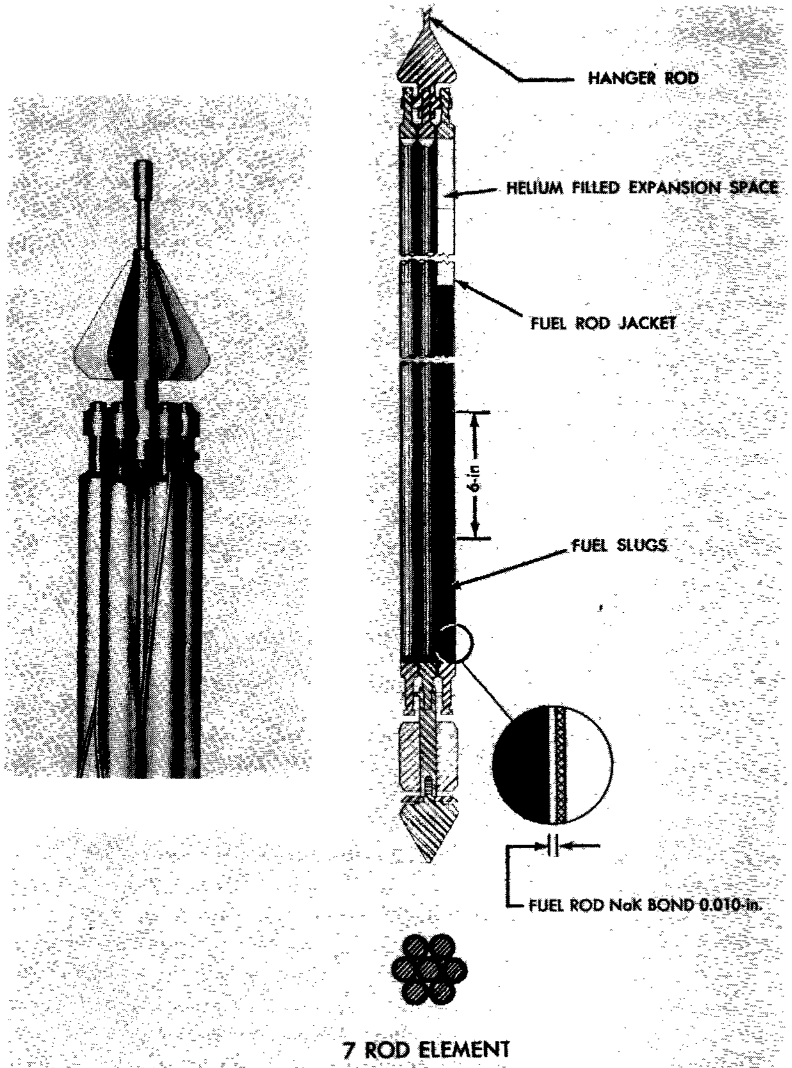


Fig. 4. Seven-Rod Fuel Element.

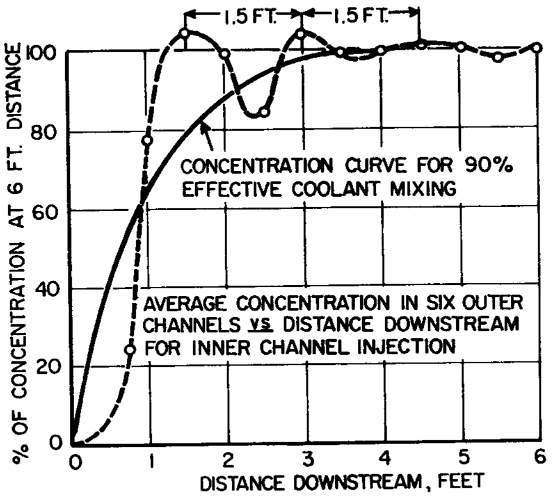


Fig. 5. Results of Chemical Injection Experiment for Fuel Element.

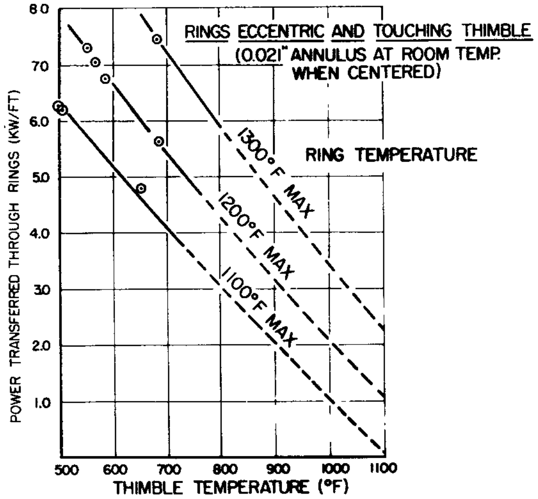


Fig. 6. Results of Heat Transfer Experiment for Control Element.

The seven rods forming each cluster are retained at their ends. Support is provided by the fixture at the top, while individual expansion of the rods is permitted by the fixture at the bottom end. Also at the bottom of the assembly is a locating guide and an orifice plate for controlling the flow of the sodium, as required for each particular coolant tube. In order to prevent the rods from touching each other or the coolant tube, the six outside rods forming the cluster are spirally wrapped with an 0.092 inch diameter stainless steel wire with a pitch of approximately 10 inches. The direction of wrap is arranged such that adjacent rods are wrapped in counter directions. In order to determine the temperature of the exit sodium from any coolant tube, a thermocouple is inserted down the inside of the stainless steel tube supporting the entire cluster from its plug in the top shield. The junction of this thermocouple is located just above the fixture at the top of the fuel element cluster.

To prove out the operational characteristics of this fuel element a considerable amount of analysis was devoted to determining radial and axial temperatures within the individual rods. This analysis was based on the assumption that all sodium passing a particular elevation in any one channel would be at uniform temperature. Mixing of the sodium as it flows upward tends to produce this condition. In order to obtain more quantitative information experiments were undertaken.

The measurements for this purpose were performed by W. J. Freede and T. T. Shimazaki using a hydraulic model. The degree of mixing was determined not by attempting to simulate the heating pattern in the fuel element and making temperature measurements, but by the use of a chemical injection method. In its simplest form manganous chloride solution was simultaneously injected into each of the six inner passages surrounding the central rod of a full sized fuel element at an elevation near its upstream end. The resultant concentration of the manganous chloride was then measured in samples tapped off at various heights and locations within the element. An example of results obtained during simulation of the flow within a fuel tube near the center of the core is shown in Fig. 5. A parameter giving the effectiveness of the mixing was determined both by analyzing the particular concentrations obtained at various locations and by noting the pitch of rotation of the coolant from average results of the type given in Fig. 5. Here a pitch of 18 inches for the fluid motion is apparent. This is slightly greater than the pitch of 10 inches used for the wire wrap around the individual fuel rods. These experiments clearly showed the advantage of wrapping the wire in counter directions on adjacent rods so that the fluid is forced outward from an inner passage and inward from an outer passage in alternate openings around the ring of six rods. The results of the mixing experiments indicated that the fuel element design described is adequate as to cooling conditions.

Other aspects of the flow pattern were investigated on the hydraulic model. With a plastic pipe functioning as the coolant tube and sawdust dispersed in the circulating water, local effects in the flow pattern were photographed using high speed equipment. The sawdust employed for this purpose was weighted by soaking in carbon tetrachloride to give a density nearly that of water. The results of these tests were useful in designing the orifice plate and fuel element end fixtures to prevent eddying and assure proper circulation of the coolant.

Another important question investigated was that of fuel rod vibration. For this purpose a full scale fuel element was fabricated in complete detail except for the substitution of kerosene in place of the NaK alloy. In this way the proper mechanical mock-up was achieved without introducing the hazard of a possible leak in a rod jacket which would bring NaK and water into contact. Vibration conditions were investigated by the use of electrical strain gauges. No appreciable vibration was detected in spite of the fact that the design incorporates no provision for securing the cluster of rods along its length.

IV. Moderator and Reflector

The graphite in the SRE moderator and reflector is protected from contacting the sodium coolant by zirconium sheet fabricated into individual can assemblies. An example of such an assembly for the core region is shown in Fig. 7. As designed, 0.035-inch thick sheet will be used on the side panels of each hexagonal column of graphite, and 0.10-inch thick stock will be used for the bottom and top can heads. The distance across the flats of each can assembly is slightly less than the 11-inch center-to-center spacing of the triangular lattice. This reduction from 11 inches is sufficient to provide for an average gap between cans of approximately 0.170 inch during normal operation. Such a gap in the form of a thin, flat channel is necessary to permit some heat removal at the can wall by the sodium coolant. Sodium for this purpose enters the core tank in a separate pipe, branching from the main inlet sodium stream and accounting for a total flow of approximately 7 per cent of that in the main stream. This branch line discharges its sodium into a low pressure

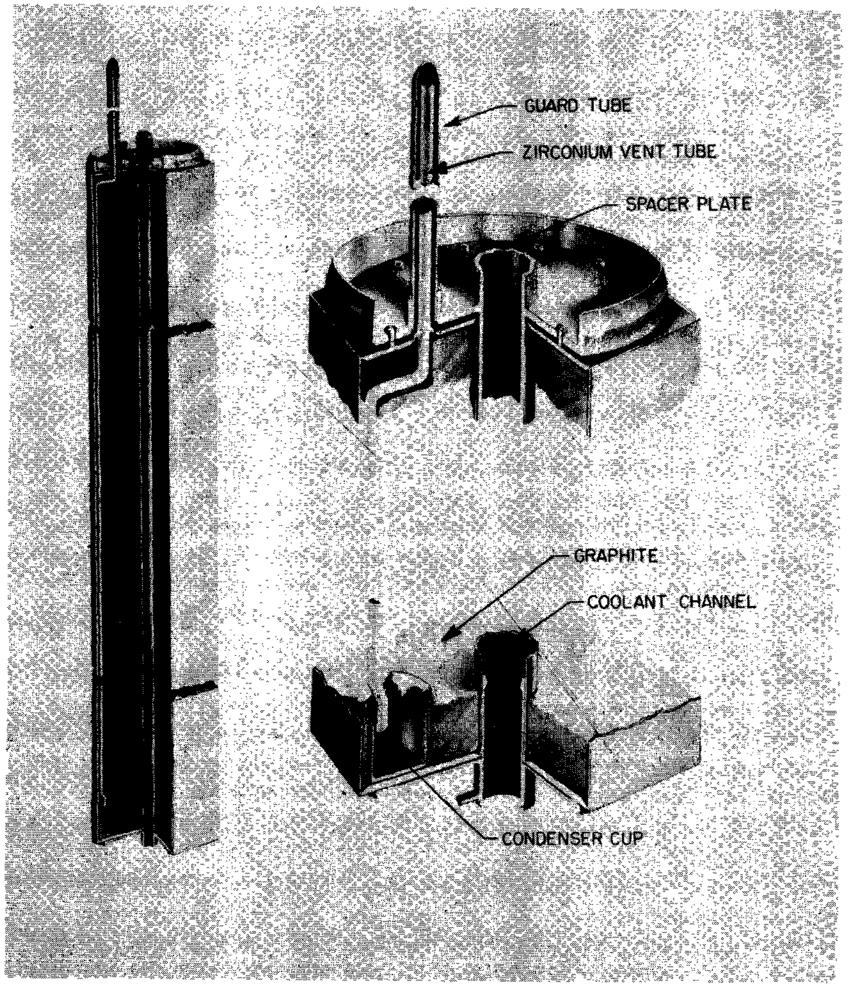


Fig. 7. Zirconium Canned Graphite Assembly

plenum above the grid, but below the graphite assemblies. This sodium is then free to seep upward through the passages between cans and through special channels provided for core elements other than the fuel elements. It removes heat from these core elements, from the cans, and from the tanks and shielding at the sides of the reactor. Average flow is to be adjusted so that this sodium exits into the pool at approximately 960° F.

Each graphite assembly is bolted by means of zirconium studs to a supporting pedestal at the base of the can and to a spacer plate at the top. Both the pedestal and spacer plate are fabricated from type 405 stainless steel. The spacer plates from adjacent cans nest together and are maintained in place by a clamping band around the outside. The zirconium canned graphite assemblies which make up the side reflector do not have axial channels. Each assembly in the core region is penetrated along its axis by zirconium tube 0.035 inch thick and 2.80 inches in inner diameter, welded to both the bottom and top heads. Such a tube normally contains a fuel element and receives sodium coolant through a cylindrical passage along the axis of its supporting pedestal.

One of the problems in canning the graphite is the question of gas pressure which might be produced as a result of long operation at elevated temperature in the radiation field. Considering the can design just described, the side panels are of thin material which will only permit operation with some external pressure collapsing them against the graphite. At the time of assembly, the top head is spaced very close to the top of the graphite column, but as the temperature increases during operation, the zirconium expands away from the graphite, necessarily leaving the head unsupported. This makes possible flexibility which is required when the reactor is "scrammed", and the axial tube contracts relative to the sides of the can. However, at the temperatures involved it is imperative that with the unsupported head only a small pressure difference exist between the sodium on the outside of the can and the gas atmosphere on the inside. Since the outgassing properties of the graphite during operation are not fully known and since it is extremely difficult to predict the average temperature of the graphite which will determine the pressure buildup inside any sealed can assembly, provision is being made to control the pressure on the inside by means of a vent tube extending from the bottom of the assembly out through the top head and to the helium atmosphere above the free surface of sodium in the core tank pool. This vent tube is 1/4 inch in outside diameter and is protected by a vertical stainless steel guard tube attached to the spacer plate. At the bottom of the

vent tube and resting on the bottom can head is a small cup to accept any sodium which enters during the lifetime of the unit, as a result of diffusion of sodium vapor and pressure fluctuations.

A number of different aspects of the design of the zirconium canned graphite assemblies have been investigated experimentally. One of these is the problem just mentioned of the diffusion of sodium vapor down the vent tube. A mock-up of this arrangement was made and operated by S. Bain. After exposing the end of the vent tube to helium containing saturated sodium vapor at 1200° F for a period of seven weeks, a total weight of 2.2 grams of sodium was found to be collected in the tube. At this rate the collector cup, having a volume of 400 cm^3, would not be filled for more than 20 years of operation even at this exessively high temperature. Breathing,because of pressure and temperature variations within the core tank,represents another mechanism for the transport of sodium vapor but has been calculated to be a less important effect than the pure diffusion mechanism. This point is also being checked by experiment.

The problem of outgassing the graphite is not completely solved by the use of the vent tube described above. The gases which may be released by the graphite, consisting principally of nitrogen, hydrogen, and carbon oxides, are readily absorbed at reactor operating temperatures by zirconium. In sufficient quantities and at temperatures which might permit the diffusion of the zirconium compounds formed, this effect may deteriorate the physical properties of the zirconium. To obtain more complete information, experiments have been conducted to measure the quantity and types of gases released at different temperatures and for different initial treatments given to the graphite. An example of this, from the work of R. L. Carter, is shown in Fig. 8. Here the total analysis for the gases released from a grade of Speer graphite is given for outgassing temperatures up to 1800° C. The effect of absorption of such gases by zirconium at elevated temperatures has been studied in separate experiments. It was decided advisable to decrease the quantity of such gases available for release during the operation of the SRE. For this purpose, the large diameter graphite logs from which the hexagonal columns are machined are being maintained in a helium atmosphere in the graphitizing furnace during the cooling process until the temperature is lowered to 1200° C or less. Also, special provisions are being made for the protection of this graphite following machining and before its insertion into the can structure. Tests have been conducted showing that by such treatment, the maximum gas content at STP available for release is approximately 0.3 of the total graphite volume.

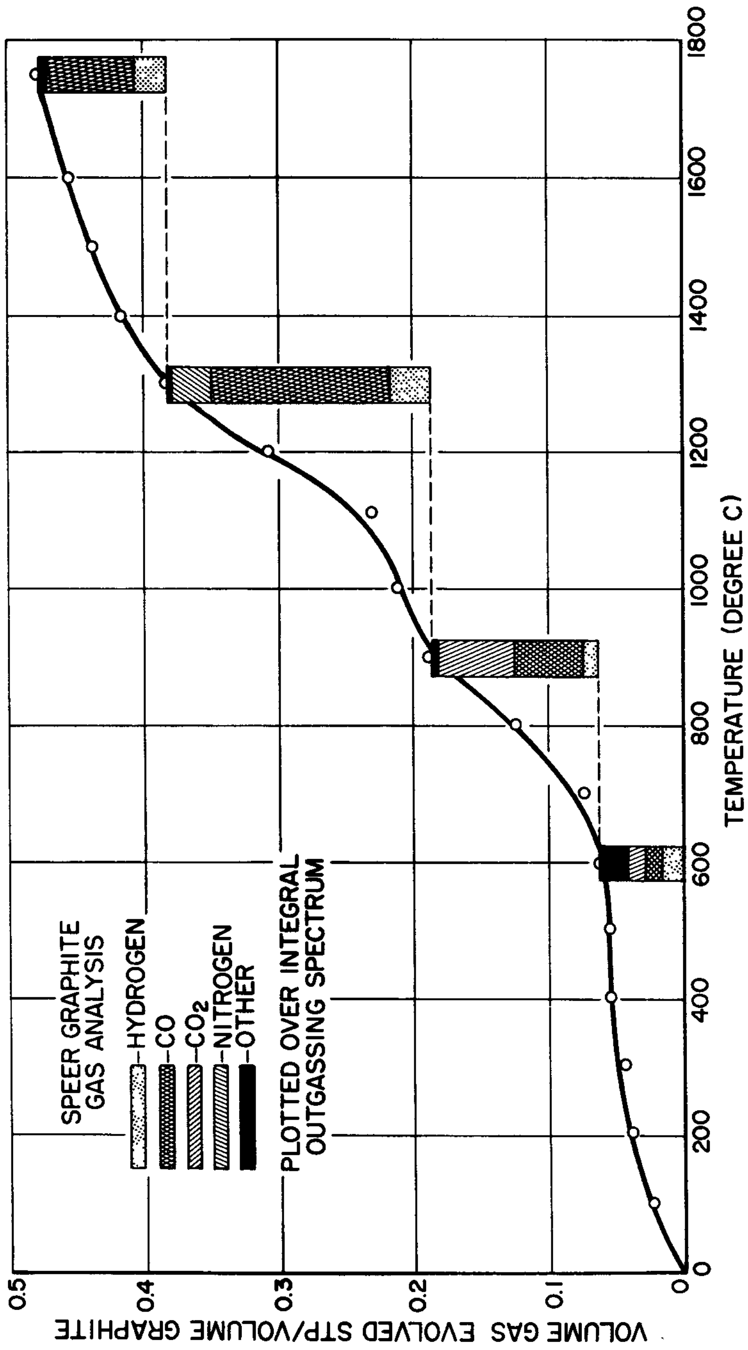


Fig. 8. Mass Spectrograph Analysis of Gases Evolved from Graphite.

Considerable experimental work has been conducted relative to the properties of the zirconium sheet. This material is being rolled from ingots of zirconium sponge. Strength and creep measurements have indicated the rather low stresses to which this material can be safely subjected at the maximum operating temperatures expected. Work on the zirconium welding has indicated the need for carefully controlled processing of the zirconium during the various phases of its manufacture. Otherwise excessive amounts of gas can be absorbed which result in the production of bubbles in the heated material at the time of welding. The welding process must also be carefully specified to obtain sound and ductile weld material. The initial surface preparation, arc conditions, rate of welding, degree of chilling at the weld, and inert gas coverage are all factors which have been found to be important in the production of high quality welds.

In the SRE, some of the hexagonal zirconium can assemblies are shaped at their corners to provide circular passages extending down to the grid plate. Each of the circular channels is formed by 120 degree-shaped corners in three adjacent assemblies making a passage approximately 3-1/4 inches in diameter. These extra channels are necessary for the insertion of control elements, safety elements, a neutron source, and other special units. The only means of heat removal at these locations is that of the moderator cooling sodium which seeps up through all the interstices at the outside surfaces of the zirconium can assemblies. Since there is no provision for orificing this sodium flow from one passage to the next, proper control of the flow is dependent upon thermal convective effects. If the temperature of the sodium in one channel is increasing more rapidly than the average in other channels, the accompanying decrease in density automatically increases the flow rate in that particular channel. As a result, a nearly uniform sodium temperature is assured throughout any horizontal plane taken through the reactor. This effect has been shown analytically to be sufficiently effective provided the channels available for sodium flow are wider than some amount of the order of 1/16 inch. In the channels between cans, these gaps will be maintained by the action of the pedestals and spacer plates, but an additional precaution has been taken wherein dimples 0.045 inch in height are being rolled into the zirconium panels before can fabrication.

The pressures required to maintain the flow of the moderator cooling sodium are very low, of the order of 0.02 psi frictional drop. It has been necessary to experimentally determine if larger pressure differences might result from dynamic effects in the pool above the core due to jetting from the various fuel tubes and to the high flow rate at the discharge nozzle into the main primary loop. A hydraulic model of 1 to 3.5 scale in which these conditions could be observed was constructed and operated by W. J. Freede and C. R. Davidson. No difficulties were encountered which required the addition of baffle plates to minimize pressure variations in the upper pool. For example, pressure variations in the pool were determined to be approximately 25 per cent of the maximum estimated to be permissible without interference with the flow determined by the thermal convective effects described above.

There are other areas of technology in which information is required for proper design of the zirconium canned graphite assemblies. Examples are effect of sodium on zirconium, effect of sodium on graphite, effect of irradiation on the physical properties of graphite, and conditions which produce carburization of zirconium. Sufficient information appeared to be available from other work so that few experiments on these subjects are being performed short of tests which will be conducted during actual operation of the SRE. Analysis of the performance of the canned graphite assemblies has been carried out based upon available data, and the design as described appears to be satisfactory.

V. Control Elements

There are four control elements in the SRE core, located as shown in Fig. 9. Each control element is contained in a thimble assembly which extends from the top of the rotatable shield to a point just below the core, a total distance of 23-1/2 feet. The thimble material is type 304 stainless steel and in the core region it has a wall thickness of 0.049 inch. This arrangement makes possible a self-contained control rod assembly in which no sodium or its vapor contact the moving mechanical parts. See Fig. 10.

The poison column is made up of a series of eighteen rings of a boron-nickel alloy suspended on a "pull-tube". Each ring is 2-1/2 inches in outside diameter, 3/8 inch in annular thickness, and 4 inches long. The boron concentration in the alloy is approximately 2 weight per cent. Control rod motion is obtained by a ball-nut screw arrangement wherein the pull-tube is attached to the nut and a motorized drive mechanism above the top shield turns the screw. The nut is prevented from rotating by guides which move in flutes machined into the inside surface of the heavy wall of the upper portion of the thimble. Suitable

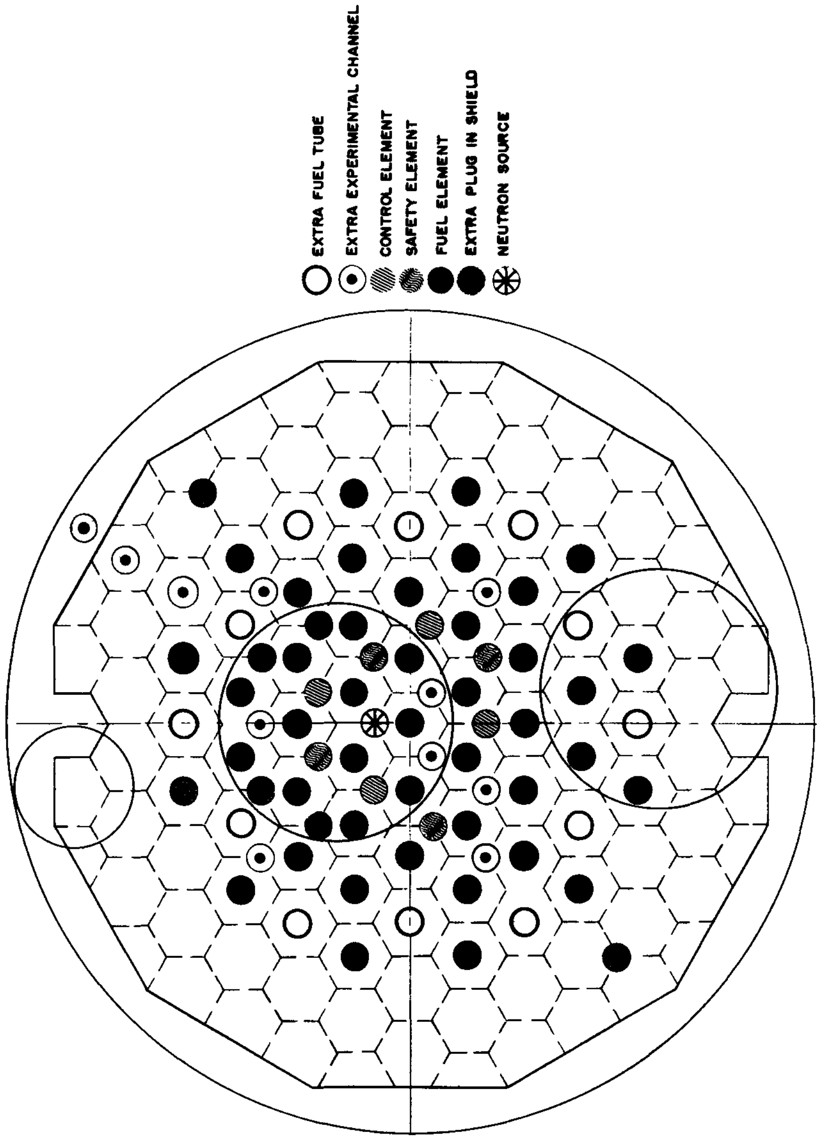


Fig. 9. Loading Pattern

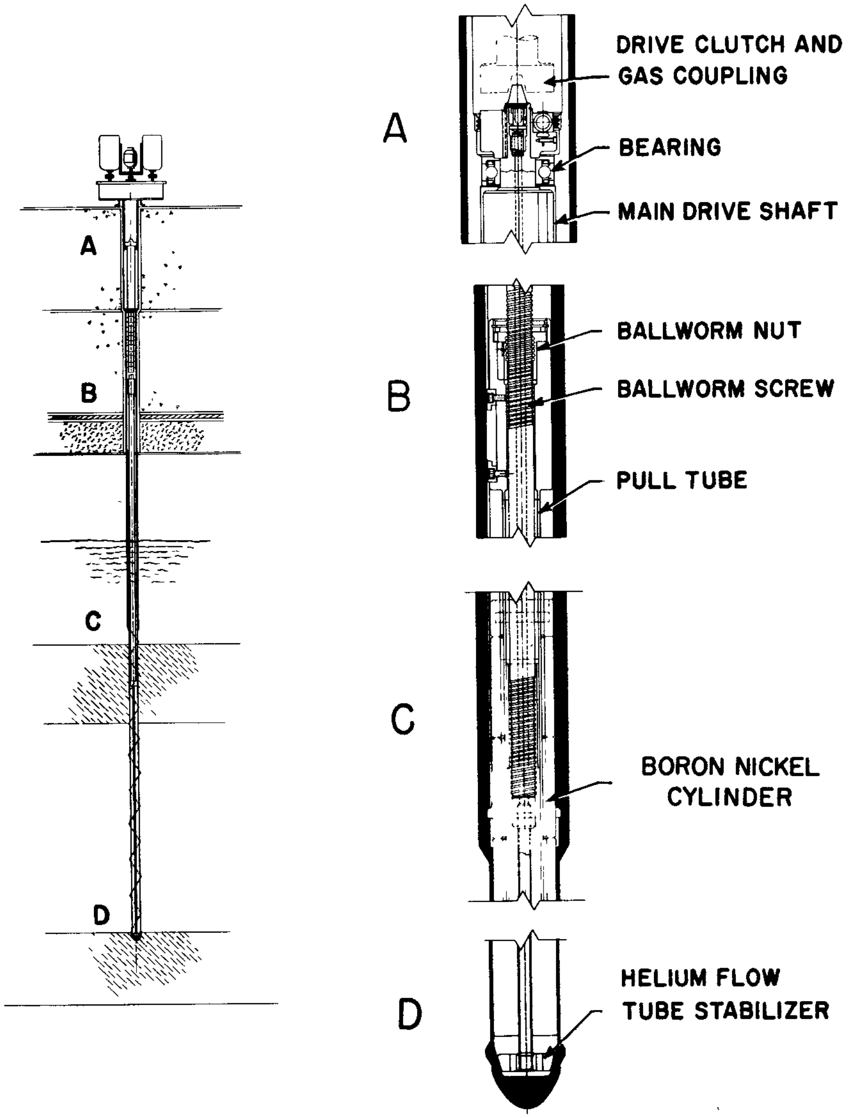


Fig. 10. Control Element.

shielding is provided within the thimble in the neighborhood of the top shield. The motor drive units rest on the top shield and engage at a clutch several inches below the top surface of the shield. Limit switches and Selsyn motors indicate the control rod positions at all times.

One of the problems with the thimble arrangement is that of transferring the heat generated in the poison material to the sodium coolant on the outside of the thimble. To prevent excessive temperatures in the boron-nickel, helium gas at about 16 psig is used as an atmosphere within the thimble and relatively close clearances are maintained between the rings and the thimble. Experiments by J. D. Howell have been conducted to establish these conditions. An electrical heater placed inside of a short column of the boron-nickel rings was operated to reproduce various heat generation rates expected within the rings during reactor operation. The experimental rings were contained inside of a tube simulating the control rod thimble with a reservoir of NaK at its outside surface to establish the temperature of the tube at a determined high value. This NaK was cooled in turn at the outside surface of its reservoir by Dowtherm circulated in a heat removal loop. Thermocouples were used to establish temperatures and measurements were conducted at various operational conditions including different locations of the rings inside the thimble tube. Figure 6 gives some results for design conditions for the situation where the rings are eccentric and touching the thimble. The extrapolated region for higher thimble temperatures is known to be reliable from other earlier measurements in this temperature range. In the SRE, a maximum heat generation rate of about 8 kw per foot is expected and, according to the results shown, should give maximum ring temperatures of approximately 1300° F.

The most successful method of fabricating the boron-nickel rings has proved to be centrifugal casting followed by machining. Rings fabricated in this way were tested for stability under the most extreme temperature gradient and thermal cycling conditions expected. The maximum distortion measured as a result of this treatment was inappreciable, of the order of 0.002 inch on the diameter.

Another problem investigated for the control rod design just described was that of the operation of the ball-nut screw under load and at temperature. In the 960° F sodium pool and with some heat generation in the mechanism due to radiation, a maximum temperature of approximately 1100° F is expected. A series of tests were carried out by A. E. Miller and E. C. Phillips to cycle ball-nut and Acme screw mechanisms fabricated from different types of hardened steel.

Without lubrication these arrangements proved uniformly unsuccessful. The addition of lubrication in the form of molybdenum disulphide improved the operation, but it was still evident that only a grade of steel capable of maintaining its hardness at this temperature could prove adequate for the number of cycles required in the control rod mechanism. Present plans call for the use of Haynes 25 alloy throughout. The ball-nut also appears to be superior to the Acme screw arrangement.

VI. Safety Elements

The SRE core uses four safety elements, located as shown in Fig. 9. The design is similar to that of the control elements in that the entire assembly is contained in a thimble extending from the top of the rotatable shield to a location below the core. The thimble material is type 304 stainless steel and in the core region has a thickness of 0.035 inch.

Rings of the same boron-nickel alloy as used in the control elements make up the poison column. Each ring is 2-5/16 inches in outside diameter, 3/16 inch in annular thickness and 4 inches long. A total of 14 rings is used, assembled in series, on an internal tube. This tube may be raised by the action of a ball-nut screw, but a latch mechanism is incorporated to release the rod at any time while it is being withdrawn or when it is in the fully cocked position. The latch is actuated by a "torque tube" flattened on two sides and extending down the center of the assembly from an actuating solenoid near the top to a position near the bottom of the thimble. The screw is driven by a motor located above the top shield as in the case of the control element. To reset the safety rod the ball-nut is driven downward by the action of the screw until engaged to the rod unit by the latch. The direction of the motor is then reversed for withdrawal. Shielding material is incorporated within the thimble in the region of the top shield. There are also electrical contacts arranged to determine the position of the rod as inserted, fully cocked or being withdrawn.

When the safety rods are released to scram the reactor, each latch is disengaged and the rod units fall freely within the thimble under gravity. In order to decelerate without the production of excessive stresses, the upper end of the tube on which the poison rings are assembled is attached to a piston within a 24-inch long cylinder. As the rod unit falls, the piston and cylinder move with the rod until it reaches a position 24 inches from the bottom of the thimble at

which time the cylinder is arrested by a shoulder and the rod unit is then decelerated as the piston is forced to move through a helium stmosphere contained in the cylinder.

In the case of the safety elements, a much larger annulus, an average of 0.125 inch, exists between the boron-nickel rings and the stainless steel thimble. This is possible since the introduction of the safety rods into the core always results in shutting down the reactor without permitting appreciable heat generation within the boron-nickel rings. The experimental work carried out for the safety elements has been restricted to mechanical tests of the various parts. These include the latch mechanism, the long torque tube and the piston and cylinder arrangement. Tests were conducted at expected operating temperatures to prove out the reliability and operating characteristics of these components. Prototype tests on the completed safety element as well as on the control element are planned for the near future.

VII. Other Core Elements

The axial tubes and the corner channels provided in the graphite assemblies which do not receive fuel, control or safety elements contain other elements of special types. One corner channel contains a neutron source element. The neutrons are produced by gamma rays from a pellet of radioactive antimony interacting with a surrounding cylinder of beryllium. For experimental purposes, some channels are to be equipped with stainless steel thimbles extending down from the top shield. Special materials or experimental assemblies may be inserted in these thimble facilities for exposure to the core radiation. It is also planned to use two corner channels for assemblies containing a series of thermocouples for measurement of the temperature of the sodium cooling the moderator. All other channels both at the corners and centers of the graphite assemblies contain "dummy" elements of graphite canned in zirconium tubes. The dummy elements occupying the axial tubes, which would otherwise be used for fuel elements, must perform the additional function of stopping off the sodium flow from the plenum below the grid plate. This is accomplished by a plug extension which rests on the lip of the pedestal supporting the can assembly.

No special problems requiring experimental tests and not sufficiently well answered by work performed on other core components are believed to be present.

Experimental verification of the operation of the special elements will depend upon experience in the SRE.

VIII. Tanks and Thermal Shield

The large tank which contains the SRE core is 1-1/2 inches in wall thickness and is fabricated from type 304 stainless steel. At the top of the core tank is a large bellows to permit vertical expansion. This bellows is approximately 18 inches high and is fabricated from stainless steel, 0.10 inch in thickness. A welded flange near the bottom of the core tank supports the 1-1/4 inches thick type 304 stainless steel grid plate. Additional support for the grid plate is provided for by means of stay-bolts arranged in three circular patterns. The inner circle of bolts is welded to the bottom of the core tank to guarantee sufficient strength against deflection of the grid plate in the event of a pressure surge in the main plenum.

One of the principal analytical problems considered was that of thermal stresses in the core tank due to a temperature gradient in the region where the upward flowing sodium enters the pool above the graphite assemblies. To reduce these stresses to tolerable levels for expected operating conditions, an inner liner was added. This liner is fabricated from type 304 stainless steel, is 1/4 inch in wall thickness, and assures a stagnant layer of sodium 2-1/2 inches thick adjacent to the inner surface of the core tank. A flange welded to both the core tank and liner at a location just above the graphite assemblies provides support. The flange has small weep holes for sodium drainage. The liner extends from 24 inches above the grid plate to the top of the core tank.

An outer tank intended to contain the sodium in the event of a leak surrounds the core tank. It is a flat bottom vessel fabricated from low alloy steel and rests on a series of four concentric cylinders 21 inches high. These cylinders rest on circular bearing plates attached to the bottom of the cavity liner, which serves as a form for the concrete foundation. Since these supporting cylinders are not welded at the bearing plates or where they contact the outer tank, there are essentially no thermal stresses as a result of the temperature gradient of approximately 400° F along the cylinders during normal operation. One important design requirement is that the core tank remain centered in spite of temperature cycling which will occur during its use. To accomplish this,

there is a skirt welded near the bottom of the core tank and which contains milled slots fitting over cleats welded to the top surface of the outer tank bottom. This arrangement constrains the core tank to only radial motion relative to the outer tank and assures that they maintain the same centerline. This principle is also used to maintain the outer tank centered relative to the concrete foundation. Narrow flanges welded to the top and the bottom of the outside surface of the outermost supporting cylinder are machined with radial notches. These notches fit over cleats welded to the outermost bearing plate and to the bottom of the outer tank, thereby constraining the outer tank to radial motion only.

On the sides, in an annular region between the two tanks, a thermal shield fabricated from low carbon steel is located. This shield consists of a series of seven rings with interlocking joints wherein the overall height of the shield assembly is 19 feet and each ring is 5-1/2 inches in thickness. The rings are not welded to each other and the bottom ring simple rests on the bottom of the outer tank while being centered between cleats located there.

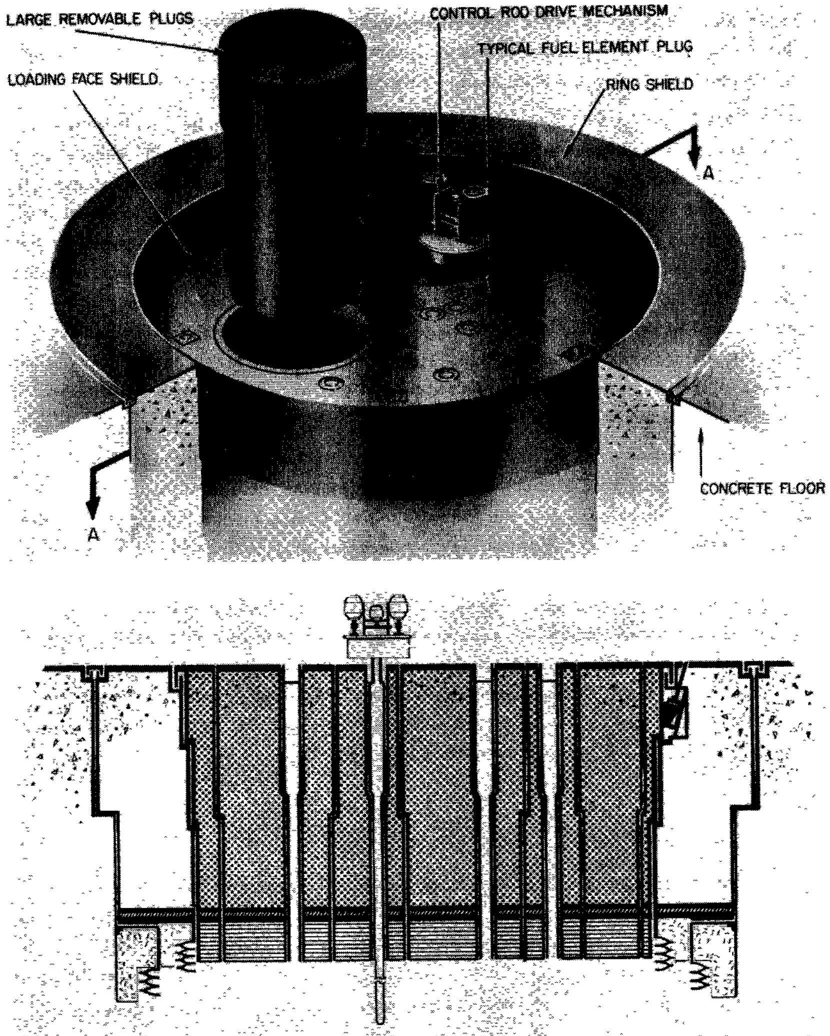
Since the core tank and the outer tank are of different types of material with different thermal coefficients of expansion, radial motion between the two bottom surfaces will result with changes in temperature. While the expected loading is nominal, approximately 15 psi if distributed uniformly, it is important that these surfaces not adhere as a result of diffusion or other process during operation. Otherwise, this could result in large thermal stresses and possible distortion of the bottom of the core tank. Experiments have been conducted by E. C. Phillips using sliding surfaces at 750° F in a helium atmosphere and with a load of 100 psi. Dissimilar types of steel were tested and the frictional force measured after different treatments involving time and temperature. Galling was observed to take place when two surfaces of type 304 stainless steel were repeatedly cycled. More satisfactory results including low starting frictional forces were obtained when the two sliding surfaces were different in hardness. As a result of these tests, a "slider" plate has been added between the bottom of the core tank and the bottom of the outer tank. This plate is 1/2 inch thick and is fabricated from type 4130 steel. Its presence should permit the necessary relative motion between the two tanks without destructive effects.

IX. Top Shield

The core tank is closed at its top by a shield approximately 11-1/2 feet in diameter, 6 feet thick, and weighing 75 tons. (See Fig. 11.) It is fabricated from type 405 stainless steel used as a form and from concrete made with magnetite iron ore aggregate. This ore has a density of approximately 4.6 and will be mixed together with some steel shot in proportions leading to final concrete density of about 3.8.

There is a total of 81 small plugs extending through the top shield. In addition. there are three larger plugs, two about 40 inches in diameter and one 20 inches in diameter. These three are located so that there can be access for removal of any graphite assembly within the core tank by rotating the top shield to a proper position and removing one of these three plugs. The top shield is normally sealed at floor level by means of Cerrobend alloy contained in a trough extending around the outer edge of the shield. Before rotating, it is necessary to melt the Cerrobend with electrical heaters permanently installed in the trough. The shield may then be raised about 1/2 inch by means of the handling bridge hoist and the shield rotated. Three built-in rollers serve to center the shield at this time.

Between the hot sodium pool and the underside of the shield, a helium atmosphere at 3 psig is maintained. To prevent excessive heating of the shield, insulation in the form of a series of horizontal thin stainless steel plates is suspended from the shield. There are thirteen such plates, 1/32 inch in thickness and successively spaced at 3/4 inch intervals. While it serves as a thermal radiation shield, this plate assembly is not gas tight and will permit sodium condensation on the seal plate at the bottom of the shield. The seal plate is type 405 stainless steel, 1 inch thick. On its upper surface, it is in thermal contact with a 1-1/4 inch thick lead layer in which tubing is imbedded for the circulation of tetralin. Immediately above the lead layer a 1 inch plate of low carbon steel provides an additional thermal shield for the nuclear radiation. The dense concrete extends from this surface to the top of the shield but incorporates no other tubing for cooling. Normally, the bottom of the shield operates at a slightly higher temperature than the circulating tetralin and may reach about 140° F. If, after a long period of operation, sufficient sodium condenses on the underside of the shield to thermally short out some of the stainless steel plates serving as thermal radiation shielding, it is possible to increase the temperature to the



SECTION A-A

Fig. 11. Top Shield

melting point of sodium by reducing the flow of tetralin. At this time, the stresses in the casings for the plugs are at a maximum since the lower seal plate expands radially. As designed this condition is tolerable, but has been made so by the choice of a low coefficient of expansion stainless steel, and by the use of relieving sleeves which are installed at the lower ends of the casings to prevent seizure of the casings by the concrete in this region.

All of the plugs within the rotatable shield which have been mentioned are stepped to prevent radiation streaming. The step also serves as a means of mechanical support. Sodium vapor is free to diffuse up the annulus between each plug and its casing but should condense in the low temperature region near the bottom of the shield. In all cases the final gas seal on the plugs is made by two "O" rings compressed between the plug and the casing near the top of the shield. As an extra precaution, a third gasket, depressed by a retaining ring is incorporated at the top lip of each plug, where it is available for maintenance without the necessity of lifting the plug. This retaining ring arrangement is used on all of the plugs in the rotatable shield and performs the additional function of positively locking the plugs in place.

Experiments are in progress but have not been completed which will measure the extent of sodium vapor diffusion and condensation on the shield structure. If over long periods there is considerable sodium condensing in the annuli around the internal plugs, it may be necessary to depend upon the application of mechanical force to shear the plugs free. Melting of the sodium will probably only be possible near the bottom surface of the shield. Other experimental work is in progress on the use of the Cerrobend sealing arrangement and on the method of preparing dense concrete with satisfactory properties. Because of the complicated structure within the shield, the concrete will be prepacked and grouted. The same procedure is necessary in the individual shield plugs because of the small dimensions involved.

X. Other SRE Components

The components which have been described in the preceding sections comprise the reactor portion of the SRE. The overall installation includes many other components. In the heat removal system there are pumps, pipes, valves, heat exchangers, cold traps, tanks, and instrumentation. Facilities provided for the radioactive elements include the hot cell, handling coffin, cleaning cells, storage cells, and shipping casks. Other features integrated into the SRE and necessary for its operation include systems to provide control, emergency power, tetralin cooling, helium gas, nitrogen gas, sodium service, and radioactive liquid and gaseous waste disposal. Although these portions of the SRE installation external to the reactor have also presented design and development problems, no description of this work is included.