MASTER

U. S. Atomic Energy Commission
Docket 50-3
Exhibit K-5A1

BAW-136

CONSOLIDATED EDISON THORIUM REACTOR
REACTOR VESSEL INTERNAL
COMPONENTS DESIGN

July 1960

541-001

THE BABCOCK & WILCOX COMPANY

ATOMIC ENERGY DIVISION

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REACTOR VESSEL INTERNAL
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PREPARED FOR
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CROSS REFERENCE INDEX

This Cross Reference Index has been prepared to key the supplementary material to the information which is contained in the Hazards Summary Report dated January, 1960, Exhibit K-5 (Rev-1) filed with Amendment No. 10 to Consolidated Edison's Application for Licenses.

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I. INTRODUCTION

The design functions and fabrication details for internal components of the Consolidated Edison Thorium Reactor (CETR) are presented and pertinent analytical stress studies are summarized. Functions of the internal components include proper orientation and support for the fuel elements, proper distribution of primary coolant within the reactor vessel, and the establishment of guide channels for the control rods.

The general arrangement of the reactor vessel and its internals is shown in Figure 1. The carbon steel pressure vessel, which contains the entire reactor core assembly, is a cylindrical shell with an inside diameter of 9 feet 9 inches and a minimum wall thickness of $6 \frac{15}{16}$ inches. The inside surface of the pressure vessel wall is clad with a Type 304 stainless steel. Three alternate layers of steel and water between the fuel elements and the pressure vessel serve as thermal shields and reduce the effects of neutron bombardment and gamma radiation on the pressure vessel wall.

The internal components of the reactor are divided into major assemblies according to functional criteria. These assemblies, listed in sequence of installation in the reactor, are:

1. Control rod nozzle seal assembly
2. Lower grid plate and plenum chamber assembly
3. Core shroud assembly
4. Holddown columns
5. Upper grid plate and plenum chamber assembly.

All of these assemblies may be removed after reactor operation; however, only the upper grid plate and plenum chamber assembly must be removed from the vessel for refueling operations.

Most of the internal components are fabricated from Type 304 stainless steel to minimize corrosion from long term exposure to hot water. Inconel X material is used for special bolting and springs where

greater material strength is required. All bolts, dowels, and orifice plugs are tack welded to insure lasting functional integrity of the assemblies.

The primary coolant makes a single pass through the reactor core between the inlet and outlet nozzles, entering the reactor vessel through the four inlet nozzles at the bottom. The bulk of this water (~ 87%) is directed through the fuel elements and holddown columns after it has been distributed by the lower plenum chamber. This water is discharged directly into the transition cylinder and thence to the outlet nozzles through eight 18 1/2 inch diameter holes. Flow in the holddown columns is controlled by an orifice in the upper end of the assembly.

The remainder of the coolant (~ 13%) is diverted into three basic flow paths:

1. One path is through the control rod nozzle seals atop the control rod nozzles of the reactor vessel. The flow is controlled by four orifices in each seal assembly. This water enters the control rod guide tube and is discharged into the core area, i. e., the channels between the fuel elements.
2. Water in the lower plenum chamber which has not been directed into either the fuel elements or holddown columns flows directly from the lower plenum chamber through 52 orifices in the cover plate of the lower grid plate into the core area.
3. The third flow path is through the openings between the pads securing the conic section of the core support ring to the reactor vessel wall. After this water is past the core support ring, it separates into two channels:
 - a. One portion is through the annuli formed by the reactor vessel wall, fixed thermal shields, and core shroud. Flow is directed to the outlet nozzles through 99 orifices in the thermal shield support weldment.
 - b. The other portion is through 20 orifices in the lower end of the core shroud into the baffle section. Flow is directed to the outlet nozzles through the orifice ring between the upper grid plate assembly and core shroud.

The water from the core area is directed into the three following passages:

1. Part of it enters the control rod guide tubes in the transition cylinder. This flow is controlled by orifices in the upper end of the guide tube. This water is eventually discharged through the flow holes in the upper plenum chamber.
2. Another portion flows directly across the cover plate of the upper grid plate through 16 orifice plugs.
3. The remainder is controlled bypass leakage through the orifice ring between the upper grid plate assembly and the core shroud into the outlet nozzles.

II. FUNCTIONAL REQUIREMENTS AND STRUCTURAL DESIGN

A. CONTROL ROD NOZZLE SEALS

The 21 control rod nozzle seals are designed to control primary coolant flow into each of the control rod guide tubes of the lower grid plate and plenum chamber assembly. The seal assembly basically consists of two concentric cylinders with four piston rings for sealing between the cylinders. The cylinders are flanged to establish seal faces on both ends. The inner and outer cylinders are spring loaded longitudinally by 12 Inconel "X" springs and face sealing is established between the top of the control rod nozzle of the reactor vessel and the bottom of the control rod guide tube. Four orifice plugs screwed into the outer cylinder of each seal control the coolant flow entering the control rod guide tube.

The cylinders are machined from A182-55T F304 forgings. The piston rings are fabricated from Haynes No. 25 stellite alloy to prevent galling or seizing during seal operation. A nominal radial clearance of 0.032 in. is provided between the cylinders and the piston rings.

A prototype seal was fabricated and tested prior to final design approval. The seal was tested using a specially designed fixture to simulate the spring loading placed on the seal when the reactor internals are installed in the vessel. The orifice plugs were replaced with blind plugs to determine actual leakage of the face sealing and the effectiveness of the piston rings. Room temperature water at a pressure corresponding to the design pressure drop (25 ± 5 psig) was introduced into the fixture. Leakage under these conditions was 0.5 gpm as compared with a design allowable leakage of 15 gpm.

The principal analytical considerations in the seal design are: to determine the hydraulic forces resulting from the pressure drop across the assembly; and to confirm, with a tolerance analysis, that the maximum spring stress is acceptable and the minimum spring force

is adequate for face sealing. The analysis indicated the assembly is functionally adequate and the spring design is conservative. The maximum stress of 50,000 psi is below the level at which relaxation is likely to occur in Inconel "X".

B. LOWER GRID PLATE AND PLENUM CHAMBER ASSEMBLY

The major design functions of the lower grid plate and plenum chamber assembly are:

1. To provide adequate support for the weight and spring forces developed by the fuel elements and holddown columns.
2. To orient the fuel elements and holddown columns in the reactor core.
3. To orient and guide the control rods.
4. To establish proper flow distribution of primary coolant in the reactor vessel.
5. To establish proper indexing of the core shroud.

The lower grid plate and plenum chamber assembly is shown in Figure 2 and consists of three subassemblies bolted and doweled together. These subassemblies are the lower grid plate, the control rod guide tubes, and the lower plenum chamber. Type 304 stainless steel is used throughout these units except for bolting and doweling. The lower plenum chamber and control rod guide tubes are bolted to the grid plate by specially designed Inconel "X" bolts threaded into tapped holes with Inconel "X" inserts. All doweling is Inconel "X" material.

The lower grid plate is a welded subassembly consisting of a top or cover plate, an outer cylinder, 120 fuel element guide tubes, 28 holddown column guide tubes, a honeycomb weldment of support ribbing, and an index ring.

The honeycomb weldment consists of ribbing 1 1/4 in. thick by 15 in. deep and provides the major support for the reactor core. Machined cruciform slots in the 1 in. thick cover plate establish the pitch spacing of the control rods and provide face or side guidance during movement of the rods in the core. The control rod has a nominal side clearance of 0.131 in. in the cruciform slot. The guide tubes for the fuel elements and the holddown columns extend through

the cover plate for the full depth of the ribbing. Rigidity for the lower ends of these tubes is developed by a series of pads welded onto the lower surface of the honeycomb weldment. The tubes in turn are welded to these pads. These tubes establish and maintain the verticality of the fuel elements and holddown columns by a conical seat which extends $3/4$ in. above the cover plate, and a closely machined diameter in the lower 4 in. of the tube. These two surfaces mate with similar surfaces on the two core components. The nominal diametral clearance between the diameter of the guide tubes and the lower end of the fuel element and holddown column is 0.005 in.

Coolant flow for the fuel elements in the core periphery is controlled by 52 orifice plugs screwed into the cover plate. The indexing ring of the lower grid plate and plenum chamber assembly engages four index keys bolted on the core support ring of the reactor vessel, and orients the entire grid plate assembly relative to the control rod nozzles of the vessel. The clearance between each key slot on the ring and the key on the vessel is 0.015 in. Three of the keys are 5.985 in. wide and one is 6.985 in. wide to assure proper indexing during each installation. Rotational orientation of each fuel element is established by pins screwed into the cover plate and bearing against two sides of the lower transition section of the fuel element.

The lower plenum chamber is a conical shaped baffle fabricated from 1 in. plate with 76 $10\ 5/16$ in. diameter holes to provide correct flow distribution to the core section. Directly in line with the four inlet nozzles of the reactor vessel, the plenum chamber is blind; i. e., it has no flow holes in this area. This section is shown in Figure 3 and acts as a baffle to prevent the inlet water from impinging against the control rod guide tubes.

The control rod guide tubes, in conjunction with the side guidance provided by the grid plate, provide tip guidance for the control rods and protect them from the buffeting forces of the inlet coolant flow. The control rod guide tube (see Fig. 4) is a welded assembly consisting of a cruciform transition casting to enclose the control rod in the grid plate area, and a cylindrical tube for the lower section. The control rod has a 0.125 in. nominal radial clearance in the cylindrical section and a $5/16$ in. radial clearance in the transition section. It does not

provide any guidance. The transition section is bolted to the underside of the cover plate of the grid plate and establishes a cruciform channel for the rod. The cylindrical section is bolted to a 1/4 in. thick diaphragm plate. The diaphragm plate is bolted to a machined counter-bore on the base of the lower plenum chamber, and restrains the lower ends of the guide tubes from any radial movement. The diaphragm is designed to accommodate any vertical thermal expansion of the guide tubes relative to the lower plenum chamber during start up.

The philosophy of stress analysis and pertinent results used in the design of the lower grid plate and plenum chamber assembly is summarized in the Appendices. All stresses are well below the material yield strength except near notches or other areas where relatively high stresses will be removed by localized yielding after the first core loading and reactor operation. Subsequently, all stresses will be below the yield strength.

Drive line tests were conducted in a specially designed test stand at the General Electric facilities in San Jose, California to confirm the adequacy of control rod clearances and alignment of the control rod drive mechanisms. (Details of this test program are presented in BAW-137, CETR Control Rod Drive Line Testing.) The maximum misalignment of the lower grid plate and plenum chamber assembly relative to the control rod nozzles of the vessel, based on design tolerance and differential thermal expansion stackups, is 0.120 in. on one ordinate and 0.107 in. on the other.

During the trial fit-up of reactor internals at the Babcock and Wilcox plant in Barberton, Ohio, the centerline of each control rod guide tube in the lower grid plate and plenum chamber assembly was checked relative to the lower counterbore of the reactor vessel control rod nozzles. This lower counterbore orients each control rod drive mechanism and the final alignment established that all counterbores of the nozzles of the vessel and control rod guide tubes were within 0.002 in. of true alignment.

C. CORE SHROUD

The design functions of the core shroud assembly are:

1. To provide shielding for the reactor vessel wall in conjunction with the two fixed thermal shields.

2. To establish proper flow of the primary coolant to the core by restricting leakage in the annulus between the innermost fixed thermal shield and the core shroud.
3. To insure proper coolant flow in the core by restricting cross flow to the periphery of the core.

The core shroud assembly, shown in Figure 5, is a bolted assembly consisting of the thermal shield seal and the core shroud. The seal assembly has a cylindrical housing with a piston and a chrome plated piston ring. The piston ring seals against a seal ledge in the reactor vessel which supports the two fixed thermal shields. The piston is spring loaded by 40 Inconel "X" springs to insure positive seating of the piston against the seal ledge. During installation or removal of the core shroud, the piston is retained by four Inconel "X" dowels on the periphery of the thermal shield. The seal is designed to utilize the pressure drop present in the reactor vessel plus the spring loads to provide sealing during operation.

The thermal shield seal was tested at the vendor's plant in a specially designed test stand to determine its leakage and functional characteristics. The test stand simulated the flow and pressure drop within the reactor vessel at the thermal shield area. No attempt was made to simulate the primary coolant temperature. The test was conducted with filtered room temperature water and a seal chamber pressure of 50 psig. Under these conditions the maximum allowable leakage for a satisfactory seal was 250 gpm. For the functional test, the piston ring and piston assembly were cocked 1/4 in. with respect to the seal housing, checked for hang up, then returned to full seating position.

The following results were obtained from the leakage tests.

1. Leakage through the piston ring was approximately 30 gpm.
2. Leakage past the seal lip was negligible.

This latter result was attributed to the extremely close tolerance machining performed by the vendor on the seal ledge of the test stand which mated with the seal lip of the thermal shield seal assembly. To determine the allowable flatness tolerance for the machining of the seal ledge in the reactor vessel, shims in increments of 0.001 in.

were placed between the seal lip of the piston and the seal ledge of the test stand, and the increase in leakage was noted. These tests established that machining of the vessel seal ledge within a flatness of 0.005 in. would maintain sealing within the specified leakage rate. Final inspection records of the vessel indicate this surface was machined to a flatness of 0.002 in.

The core shroud, shown in Figure 6, is a cylinder with a series of horizontal baffles with vertical plates riveted to the baffles. These baffles and plates form 20 compartments arranged to conform to the outline of the reactor core with a nominal clearance of 5/16 in. Coolant flow into each compartment is controlled by plug type orifices screwed into the periphery of the core shroud at the lower end. The pressure drop through the baffles is established by this orificing so the net force produces compression of the baffles instead of tension in the rivets.

The core shroud is indexed by four pins which engage lugs bolted to the lower grid plate. These pins are shown in Figure 7. Three of the pins are 1.750 in. in diameter and the fourth has a diameter of 2.000 in. This variance in diameter assures correct orientation of the core shroud with respect to the core during installation in the reactor vessel. The nominal diametrical clearance for all of the pins with the engaging slot is 0.015 in.

Pertinent stress analysis results for the over-all core shroud design are listed in the Appendices.

D. HOLDDOWN COLUMNS

Twenty-eight holddown columns are located in the periphery of the core proper. They provide, in conjunction with the springs of the upper grid plate and plenum chamber assembly, the necessary holddown force to overcome the hydraulic force of primary coolant flow on the lower grid plate. The holddown column assembly, shown in Figures 8 and 9, consists of a tube welded to an upper and lower transition with a spring located in the upper end. Four plates bolted to spacers form the sides. Except for the spring, which is fabricated from Inconel "X" material, all material used in this assembly is Type 304 stainless steel.

The spring force is transmitted by the tube directly to the lower grid plate. Primary coolant flows through the tube controlled by an

orifice in the upper transition. The holddown column is indexed by a pin, which is an integral part of the lower transition, and engages a hole in the cover plate of the lower grid plate. The radial clearance between the pin and the hole is 0.015 in. The guide tube for the holddown column in the lower grid plate has a smaller inside diameter than the fuel element to prevent accidental overloading of the core.

The analytical stress work on the holddown columns is summarized in the Appendices.

E. UPPER GRID PLATE AND PLENUM CHAMBER ASSEMBLY

The major functions of the upper grid plate and plenum chamber assembly are:

1. To position properly the upper ends of the fuel elements and holddown columns.
2. To provide guidance for the control rods.
3. To provide the necessary force to the holddown columns to balance the hydraulic force acting on the lower grid plate and plenum chamber assembly.
4. To establish proper flow distribution of the primary water from the reactor core to the outlet nozzles.

This assembly, shown in Figures 10 and 11, consists of an index ring, upper plenum chamber, transition cylinder, holddown springs, orifice ring, control rod guide tube, and upper grid plate. With the exception of the orifice ring and the holddown springs, the subassemblies are bolted and doweled together. The orifice ring is attached to the transition cylinder by four slots at 90 degree intervals which engage four dowels on the periphery of the transition cylinder. Each holddown spring assembly is retained by a special nut and washer combination which is locked by a counterbored slot in a ring welded on the outside diameter of the transition cylinder. The entire assembly is fabricated of Type 304 stainless steel except for Inconel "X" dowels, springs, and bolts which secure the control rod guide tubes to the grid plate.

The index ring has four adjustable lugs which engage with index keys located on the counterbored diameter of the reactor vessel flange. Three of the keys are 5.000 in. wide and one key is 5.750 in. wide. The nominal clearance between the lugs and the keys is 0.015 in. After proper alignment of the entire upper grid plate and plenum chamber assembly with the control rod nozzles of the vessel during trial fit-up,

these lugs were bolted and doweled in position. The reactor vessel head closure force is transmitted to the upper grid plate and plenum chamber assembly by 12 stellite pads bolted and doweled to the upper face of the index ring. The index ring is bolted and doweled to the upper plenum chamber.

The upper plenum chamber is a conical shaped baffle with four 12 in. diameter flow holes. Four pads are welded to the outside diameter of the plenum chamber at 90 degree intervals and center the entire upper grid plate assembly prior to engagement with the fuel elements, holddown columns, and control rods during installation. These pads are machined to provide a 1/4 in. clearance with the vessel wall in the flange area when the index keys on the vessel and lugs on the index ring are in engagement.

A slotted ring is welded on the outside diameter of the transition cylinder and provides a shelf through which the 54 holddown springs exert their force on the orifice ring. This force is transmitted to the core shroud, and eventually to the lower grid plate. The ring is slotted to facilitate remote removal and replacement of the holddown springs if this becomes necessary. Figure 12 shows the available maximum and design spring forces (holddown springs plus the holddown column spring forces) corresponding to the hydraulic forces generated by various pump and loop combinations.

As shown in Figure 12, the following sequence of pump operation is dictated by the design.

<u>Primary System Temperature</u>	<u>Number of Pumps</u>
Ambient to 200 F	6
200 to 340 F	7
340 and above	8

The operating instructions for this plant will specifically direct the operator to follow the preceding sequence, which allows an 20% margin between the design holddown force and maximum holddown force of the springs.

Eight 18 1/2 in. diameter flow holes permit the flow of the primary water from the transition cylinder to the outlet nozzles of the reactor vessel. To keep the over-all pressure drop to a minimum,

four of the flow holes are directly in line with the outlet nozzles and the other four are equispaced about the remaining circumference of the transition cylinder.

The orifice ring has a nominal radial clearance of 0.090 in. with the transition cylinder and controls the leakage flow of water from the active core region. The slot and dowel retention of the orifice ring previously mentioned is also designed to accommodate the relative thermal expansions of the reactor vessel and internals.

The upper grid plate is similar in construction to the lower grid plate except the fuel element and holddown column guide tubes have been eliminated. The cover plate is 1 1/2 in. thick and has a large lead-in chamfer on each hole receiving core components, and also on the central portion of the control rod cruciform, to establish proper engagement with the upper grid plate and plenum chamber assembly during installation. These chamfers, shown in Figure 13, are designed to accommodate a maximum deviation from true verticality of 5/8 in. for the fuel elements and holddown columns, and 1 1/8 in. for the control rods.

The philosophy of stress analysis and pertinent results used in the design of the upper grid plate and plenum chamber assembly are summarized in the Appendices. All stresses are well below the material yield strength except near notches or other areas where relatively high stresses will be removed by localized yielding after the first core loading and reactor operation. Subsequently all stresses will be below the yield strength.

The control rod guide tubes are similar to those described for the lower grid plate and plenum chamber assembly, and the over-all attachment is the same. The control rod has a nominal radial clearance of 0.131 in. in the cruciform slot of the grid plate and 0.125 in. in the cylindrical portion of the control rod guide tube. The same philosophy of guidance employed in the lower grid plate and plenum chamber assembly has been followed; i. e., side guidance in the grid plate and end guidance in the guide tube. Loadings on these guide tubes and the diaphragm plate are less than on the guide tubes in the lower plenum chamber, and therefore all stress levels are lower. Refer to the Appendices for results of the stress analysis.

III. APPENDICES

APPENDIX A

LOWER GRID PLATE AND PLENUM CHAMBER STRESS ANALYSIS

1. DIAPHRAGM PLATE (Lower)

a. Analysis

The diaphragm plate was analyzed to determine the effects of pressure drop and grid plate deflection. The deflection of the grid plate, due mainly to thermal gradients, must be absorbed by the diaphragm plate. The stresses in the diaphragm plate due to this deflection were analyzed in both the hot and the cold conditions.

b. Results

The maximum bending stress in the plate at cold conditions is about 15,000 psi. The stress level approaches 30,000 psi in the hot condition. For this application, these stresses are acceptable. Other stresses are not significant due to negligible pressure drop.

c. Discussion

The plate is made of a ductile, strain hardening material (SS 304 yield strength 20,000 to 30,000 psi at 500 F), and it may yield plastically on the first load cycle. Since the material will work harden during the first cycle and deflect elastically from then on, it is acceptable because this plate is not a load-carrying member.

2. LOWER PLENUM CHAMBER

a. Analysis

The lower plenum chamber was analyzed to determine the effects of hydraulic loads from the impingement of primary cooling water entering the vessel. The effects of the edge slope (due to thermal gradient) of the lower grid plate were also analyzed. Maximum coolant flow and maximum edge slope were used in the analysis.

b. Results

Bending stresses in the conic section and supporting rings are all below 10,000 psi. Loading of the bolts results in a maximum stress below 50,000 psi.

c. Discussion

The stress of 50,000 psi in these bolts is acceptable since this is approximately 40% of the yield strength for this material (Inconel X) and because the bolt is in turn threaded into an Inconel X "Helicoil" insert. Tests have been performed by the insert manufacturer to show that the female joint is stronger than the bolt. The bending stresses in the conic section and supporting rings are well below the material yield strength of 18,000 psi and are therefore acceptable.

3. CONTROL ROD GUIDE TUBES

a. Analysis

The control guide tubes and their attaching bolts were analyzed to determine stresses in them due to pressure drops across the guide tubes from coolant crossflow and grid plate deflections.

b. Results

The maximum bending stress in the guide tube due to hydraulic loading and grid plate deflection is below 12,000 psi.

Bolt stresses due to pressure drops are below 5000 psi and are below 50,000 psi due to the grid plate deflection.

c. Discussion

The 12,000 psi bending stress is well below the material yield strength of about 18,000 psi and therefore is acceptable. The bolts used in attaching the control rod guide tubes to the grid plate are made of Inconel X and threaded into Inconel X "Helicoil" inserts. The stress of 55,000 psi in the bolts is acceptable, since this is approximately 40% of the yield strength for this material. Other stresses are not significant.

4. LOWER GRID PLATE

a. Analysis

The lower grid plate was analyzed as a fabricated structure using beam analysis. Mechanical loading was based on the pressure drop of approximately 24 psig, a dead weight of 675 lb per element (including the fixed shims and flux depressor plates supported by the fuel elements), the hydraulic forces on the fuel elements, a spring load of 750 lb per element, and 5000 lb load per holddown column. The pressure drop loading on the grid plate and the hydraulic forces on the fuel elements act upwards while the weights and spring forces act downwards. These opposing forces are very nearly equal, and result in a low effective downward force during operation. (Additional holddown force from the thermal shield is transmitted directly through the grid plate without significant stress.)

Thermal stresses are produced by a thermal gradient of approximately 18°F from top to bottom of the cover plate (the bottom surface being hotter), and 59°F from top to bottom of the ribs (the top surface being hotter). Additional thermal stresses result from temperature differences through the thickness of the ribs and cover plate. Combined mechanical and thermal stresses and deflections are acceptable.

b. Results

The maximum mechanical stress during operation is about 1100 psi in bending (tension on top, compression on the bottom) at the center of the grid plate. The maximum mechanical shear stress is approximately 450 psi in the welds between the cover plate and ribs under the holddown columns. The deflection at the center is 0.003 in. upward due to these mechanical loads and the edge slope is 0.0001 in./in.

The maximum thermal shear stress is 650 psi in the weld between the cover and the ribs near the edge of the grid plate. The maximum tensile and compressive thermal stresses are less than 7500 psi tension in the upper surface of the cover plate and 5700 psi compression midway through the rib thickness near the weld joint to the cover plate. Thermal deflection due to the temperature gradients is 0.042 inches upward at the center of the structure. The edge slope

due to these gradients is 0.0017 in./in.

Maximum total shear stress is 2250 psi in the rib to cover welds under the holddown columns near the edge of the grid plate. Maximum total tensile stress is less than 7350 psi at the top surface of the cover plate at its center. Maximum total compressive stress is less than 5000 psi midway through the rib thickness near the weld joint to the cover. The combined deflection (mechanical and thermal) at the center is less than 0.045 in. upward. The combined slope at the edge of the grid plate is 0.0018 in./in.

c. Discussion

The total slope at the outer fuel element is 0.0013 in./in. which would result in about 1/8 in. of misalignment at the top end if that end were not restrained by the upper grid plate, and all joints in the fuel element and between the fuel element and grid plate were rigid. However, this is not the case, and the effects of this small slope will be negligible. All thermal slopes and deflections and the higher thermal stresses are conservative because the calculations of the thermal gradients do not include the cooling effect of the holes in the cover plate.

The maximum stresses are well below the material yield strength of 18,000 psi and are therefore acceptable. The 7350 psi tensile stress occurs at the ends of the control rod slots, where a larger radius has been employed to reduce the notch effect. Very local yielding at this point may occur at first loading due to the notch effect of the control rod slot; however, subsequent loadings will be elastic.

During assembly, the hydraulic forces do not subtract from the dead weight and spring loads, and the thermal loads do not exist. At that time the center deflection is 0.012 in. downward and the edge slope is 0.0004 in./in. This edge slope results in about 0.050 in. misalignment at the top end of the fuel element. This is insignificant in view of the large lead-in on the bottom of the upper grid plate. Maximum stresses at assembly are less than 5000 psi.

APPENDIX B

CORE SHROUD ASSEMBLY STRESS ANALYSIS

1. ANALYSIS

The core shroud assembly was analyzed to determine the bending stress at the pressure drop of 50 psi across the flange and the spring load of 12,000 lb from the thermal shield seal springs. The core shroud cylinder was also analyzed to determine the effect of the thermal gradient across the cylinder wall. Bolt loads were analyzed to determine the bolt stress. The core shroud was designed primarily on a deflection basis and was analyzed for both deflections and stresses due to pressure loading and differential thermal expansion.

2. RESULTS

Calculated bending stresses are below 2000 psi. Thermal stresses in the core shroud cylinder are less than 16,000 psi. The stress level in the flange bolts is 8600 psi.

The maximum deflection in the 1/4 in. core shroud plates due to pressure loading is 0.030 in. (outward radially), and the maximum stress from this loading is less than 7500 psi. These stresses are below the material yield strength of 18,000 psi and therefore are acceptable. The 0.030 in. deflection is very conservative, but at face value will not cause excessive leakage around the core.

Differential expansion between the core shroud baffle support plate and the core shroud cylinder will cause some plastic deformation in some of the rivets joining the baffle support plate to the baffle. The rivets are capable of absorbing this deformation without failure.

3. DISCUSSION

An assumed pressure drop of 5 psi was used for calculating stresses and deflections in the 1/4 in. core shroud plates. Actual calculations of this pressure drop indicate that it is less than 1 psi. The 1/4 in. thick

core shroud baffle support plate operates about 100°F cooler than the core shroud resulting in about 0.045 in. relative motion at each end. This motion is absorbed by clearance between the rivet and the plate and baffle, by bending of the baffle; by local bearing and tensile deformation of the plate, baffle, and rivet; and by shear deformation of the rivet. The rivets are not loaded by the small outward pressure drop across the baffle support plates.

Except at the four corners of the widest baffle support plate, the flexibility of the baffle will allow most of the differential expansion to be absorbed in bending of the baffle. A large portion of the differential expansion may be absorbed in those four corners as plastic shear deformation of the rivets. The rivet selected for this application is of a fail safe design. In the improbable event of shear failure in the rivet body, a central pin will retain the rivet head to prevent its becoming dislodged. To prove the inherent safety in the design, a series of conservative cyclic shear tests were performed by the manufacturer. These tests indicate that the rivet body will absorb more than twice the maximum expected deformation without failure. When tests produced deformations which did produce failure, the heads were retained by the center pins.

APPENDIX C

HOLDDOWN COLUMN STRESS ANALYSIS

1. ANALYSIS

The holddown column springs were analyzed to insure the minimum force exerted by the spring would meet the holddown force requirements, and the stress at maximum spring force would not produce excessive relaxation. Factors affecting the above are manufacturing tolerances and operating conditions (temperature of vessel, internals, and primary coolant).

The units were also analyzed for column loading produced by maximum spring loads.

2. RESULTS

The spring design is adequate and the spring will deliver the 3500 lb required minimum force. The maximum stress of 60,000 psi at maximum working deflection is an acceptable value.

The holddown columns have a margin of safety of 15 against buckling at their maximum loading.

3. DISCUSSION

The 60,000 psi stress may produce a small degree of relaxation in the spring; however, there is a more than adequate margin in the total holddown force to absorb this small relaxation.

APPENDIX D

UPPER GRID PLATE AND PLENUM CHAMBER STRESS ANALYSIS

1. TRANSITION CYLINDER AND UPPER PLENUM CHAMBER

a. Analysis

The flanged joint between the upper grid plate and transition cylinder was analyzed to determine the effect of the upper grid plate edge slope on the joint.

Bending stresses in the spring support ring on the transition cylinder, due to holddown spring loading, were analyzed. The analysis disregarded the supporting effect of the gussets on the strength of the ring. The maximum holddown loading is 274,000 lb.

The maximum stress in the holddown springs was determined. This maximum stress is a result of:

1. spring preload
2. load due to differential thermal expansion between the reactor internals and vessel
3. effect of tolerance stack-up (including those of spring manufacturer).

The plenum chamber was analyzed to determine stresses resulting from the holddown forces.

The orifice seal ring was analyzed to determine the effect of pressure and holddown spring loading.

b. Results

Bending stresses in the flanges are below 5000 psi. Tensile stresses in the flange bolts are below 10,000 psi.

Bending stresses in the spring support ring of the transition cylinder are below 5000 psi.

The maximum stress in the holddown springs is 60,000 psi.

The maximum stress in the conical skirt of the plenum chamber is 4500 psi.

The maximum bending stress in the orifice seal ring is below 5000 psi.

c. Discussion

All stresses except those in the holddown springs are below the 18,000 psi yield strength of the 304 stainless steel and are acceptable. The maximum holddown spring stress of 60,000 psi may produce a small amount of relaxation in the Inconel "X" material; however, adequate margin is available in the total holddown load to absorb such relaxation.

2. UPPER GRID PLATE

a. Analysis

The upper grid plate was analyzed as a fabricated structure using beam analysis. The total mechanical loading was based on the pressure drop of approximately 20 psi, a spring load of 750 lb per fuel element, and 5000 lb per holddown column.

Thermal stresses result from a thermal gradient of approximately 11°F across the grid plate ribs, and 11°F across the cover plate (from top to bottom surfaces; in each case the bottom is hotter than the top). Additional thermal stresses result from the cover plate being 29°F hotter than the ribs and from temperature differences through the thickness of the ribs and cover plate.

The combined mechanical and thermal stresses and the deflection are acceptable.

b. Results

The maximum mechanical stress is about 5000 psi in bending (tension on top, compression on bottom) at the center of the grid plate. The maximum mechanical shear stress is approximately 1500 psi in the welds between the ribs and the cover plate at the outer edge. The deflection at the center is 0.022 in. upward due to these mechanical loads and the edge slope is 0.0008 in./in.

The maximum thermal shear stress is 4000 psi in the weld between the cover and the ribs near the outside of the grid plate. The maximum tensile and compressive thermal stresses are less than 5500 psi compression about half-way through the cover plate, and

4000 psi tension on the surface of the ribs, near the joint to the cover plate. Thermal deflection due to temperature gradients is 0.022 in. downward at the center of the structure. The edge slope of the grid plate due to these gradients is 0.0009 in./in.

Maximum total shear stress is 6200 psi in the rib-to-cover weld near the edge of the grid plate. Maximum total compressive stress is less than 10,500 psi half-way through the cover plate at the center of the plate. Maximum total tensile stress is less than 5000 psi at the top of the rib at the center of the grid plates. The combined mechanical and thermal deflection at the center is nil. The combined slope at the edge of the grid plate is nil. Because of varying conditions in the reactor, mechanical and thermal deflections will not always completely cancel each other.

The notch effect at the ends of the control rod slots is probably less than an effective factor of 2 because the effects of thermal and mechanical loads are subtractive in this region.

c. Discussion

Mechanical and thermal deflections and slopes are subtractive, the mechanical deflection being upward, the thermal downward. Because of the ball-type joint of the fuel element in the upper grid plate, the total deflection and slopes have very little effect on fuel elements or control rod channels, even under conditions where mechanical and thermal effects do not completely cancel.

Stresses quoted in results are nominal stresses, excluding notch factors. Nominal mechanical stresses up to about 15,000 psi are acceptable in this material provided mechanical plus thermal stresses do not exceed the yield strength of the material (about 18,000 psi). Shear stresses are generally limited to 10,000 psi. The control rod slots would give a theoretical notch factor of about 5 in a plate without the holes for fuel elements. These holes reduce that factor appreciably. In addition, the calculations of thermal stresses are based on average temperatures through the cover plate. Actually the temperature at the ends of the slots will be lower than the average, and this will reduce the thermal stress considerably at that point. In addition, large radii are employed at the ends of the slots to reduce

the local peak stress. The overall result is slight local compressive yielding in this region the first time the reactor goes to full power, with no detrimental effects in the ductile 304 SS material.

FIGURES

FIG. 1: REACTOR VESSEL AND INTERNAL COMPONENTS

MECHANICAL ENGINEERING SECTION
THE BLACK & VEATCH CO.
REACTOR VESSEL &
INTERNAL COMPONENTS
NO. 7371 F-0
MODIFIED TO INDICATE
PRIMARY COOLANT FLOW

FIG. 2: LOWER GRID PLATE AND PLENUM CHAMBER ASSEMBLY

FIG. 3: LOWER PLENUM CHAMBER

FIG. 4: CONTROL ROD GUIDE TUBES

FIG. 5: CORE SHROUD ASSEMBLY

FIG. 6: CORE SHROUD IN PROCESS OF FABRICATION

FIG. 7: INDEX AND ORIFICE DETAILS OF CORE SHROUD ASSEMBLY

FIG. 8: HOLDDOWN COLUMN ASSEMBLY

FIG. 9: VIEW OF INTERNALS DURING FIT UP

FIG. 10: UPPER GRID PLATE AND PLENUM CHAMBER ASSEMBLY

FIG. 11: UPPER GRID PLATE AND PLENUM CHAMBER ASSEMBLY

FIG. 12: HYDRAULIC FORCES ON REACTOR INTERNALS VERSUS SPRING HOLDDOWN FORCES AND WEIGHT OF INTERNALS DURING STARTUP

FIG. 13: MACHINING DETAILS OF UPPER GRID PLATE