Hardware Concepts for a Large Low-Energetics LMFBR Core

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Master

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Prepared by

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EPRI PERSPECTIVE

PROJECT DESCRIPTION

Considerable work has been accomplished over the last three years to evaluate the feasibility of large low-energetics cores for liquid metal fast breeder reactors (LMFBRs). These cores obtain a low sodium-void coefficient (≈ -2.50) by the placement of blanket subassemblies at strategic locations within the core, in addition to the radial breeder blanket that surrounds the core. In a hypothetical core disruptive accident (HCDA), this type of core would exert little or no impact force on the reactor cover (low energetics).

This report under RP620-25 presents design concepts of hardware for such a core. This includes design of fuel, blanket, and reflector-shield subassemblies; control rods; support grids; and the core-blanket-reflector-shield overall assembly. While these designs have not been optimized as would be the case in final engineering for construction, they do show that practical hardware can be designed for large low-energetics cores. Related work has been accomplished by other groups at Argonne National Laboratory (ANL) and Science Applications, Inc. (SAI): Core Restraint and Seismic Analysis of a Large Heterogeneous Free-Flowing Core Design by J. T. Madell et al. of ANL is reported in EPRI Final Report NP-1615; and General Design of a 1000-MW(e) Heterogeneous Oxide LMFBR by W. P. Barthold and C. O. Tzanos et al. of SAI is reported in EPRI Final Report NP-1616. The work described in these two reports is analytic in nature and complimentary to these hardware concepts.

PROJECT OBJECTIVE

The objective of the work reported here is to show that practical hardware can be designed for large low-energetics LMFBR cores of a type that will be required for the Prototype Large Breeder Reactor power plant and subsequent commercial breeder

plants. It is realized that the designers who do the final engineering of the plant will be responsible for the core and blanket design that is finally fabricated and used. The hardware concepts presented here show the way and may be considered as "yardsticks to measure" good or better final designs.

PROJECT RESULTS

The engineers who produced these design concepts have an in-depth understanding of what it takes to make practical fast reactor core and component hardware. Many of the features and little details are based on the successful hardware they have designed and used in ANL's EBR-II program during the 16 successful operating years of that LMFBR pilot power plant. As in all early designs, these concepts for core hardware--for example, stiffness of subassemblies, hardness of load pads, attenuation of neutron currents above and below the axial blanket material, numbers of rows of removable radial reflector-shield subassemblies and many others--would need much detailed attention during final engineering. The hardware concepts presented here are a valuable first iteration of the ultimate core.

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ABSTRACT

A design study was made to identify a practical set of hardware configurations that would embody the requirements developed in the numerical study of a low-energetics core and blanket for a prototype large breeder reactor. Dimensioned drawings are presented for fuel, blanket, reflector/shield, and control rod subassemblies. A horizontal cross section drawing shows how these subassemblies are arranged in the total core/blanket assembly. A core support is illustrated showing a dual plenums arrangement.

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SUMMARY

Comprehensive design concepts have been worked out and illustrated in dimensioned drawings. The components include a fuel subassembly of mixed oxides, a blanket subassembly containing depleted urania as the fertile material, a stiff version of removable reflector/shield subassembly, a more flexible version of removable reflector/shield subassembly, a normal stroke (40" travel) control rod, and an abnormally long stroke (52" travel) control rod.. A horizontal cross sectional assembly drawing is also included to show the arrangement of these components into the total assembly making up a large LMFBR core-blanket-reflector. The removable reflector/shield subassemblies (titled Shield Assembly on the drawings) arrangement is shown two rings wide in the radial direction. If necessary, a third ring can be used, reducing the neutron fluence into an outboard stationary shield which cannot be removed and replaced by fuel/blanket handling equipment. As stated in the text the radial location of the core barrel is open to the designer's choice depending on other details of the structure within the Primary Sodium Tank or Reactor Vessel whichever the case may be.

A concept of a dual plenums support grid is illustrated. The dual plenums offer the possibility of varying the portions of the total coolant flow that cools the fuel and that cools the blankets. The concept is that fuel subassemblies (which decrease in % of total heat production as the cycle progresses from fresh fuel to spent fuel at the end of cycle) can be cooled from the upper higher-pressure plenum. The fertile material produces plutonium as power production continues from the beginning of the cycle until the blanket subassemblies are replaced. Hence, the % of total power in the blankets increases by the amount that the % power decreases in the fuel subassemblies. The blanket subassemblies can be cooled

from the lower plenum. As the cycle progresses, the flow from the upper plenum would be decreased and flow from the lower would increase. The means for adjusting the flow balance between the two plenums would be outside the reactor support grid assembly.

No attempt was made to present detailed design criteria for core and blanket hardware but brief mention is made of some of the more important considerations in the design of a low-energetics reactor core. Mention is made of further refinements that can be accomplished by incorporating some additional EBR-II type features concerning orificing for different heat production in individual sub-assemblies.

These hardware concepts can be a starting point when final engineering begins on the prototype large breeder reactor (PLBR). The concept and details will be carefully engineered during the final work to be smoothly integrated with the other parts of the reactor, the fuel handling system and the entire power plant.

1. INTRODUCTION

The effort on reactor core design is intended to develop, within the bounds of the contractual limitations, design concepts for a 1000-MW(e) LMFBR against which other designs can be compared.

This section deals primarily with some aspects of the design of components associated with the core. Although design of the core barrel, the support grid, and the instrument tree is not included in the scope of this contract, some features of these components are shown and discussed. In some cases, the designs are generic because the requirements are preliminary.

In the following sections, these subjects are discussed:

- General considerations in reactor core design
- Reactor support grid and zone discriminator
- Fuel assembly
- Blanket assembly
- Shield assembly (Reflector assembly)
- Control-rod assembly.

2. GENERAL CONSIDERATIONS IN REACTOR CORE DESIGN

Figures 1 and 2 show the overall reactor core configuration. The reactor assembly is heterogeneous and is made up of 16 rows. The inner 14 rows are made up of several radial core and blanket zones, and these are surrounded by a radial shield-assembly zone. This configuration, including the location of the control-rod assemblies, conforms to the design described in Sec. 3 entitled CORE DESIGN. It can be contained by a core barrel with an ID of about 16 ft. However, more shielding than that provided by the two rows of removable shield assemblies may be required. This could be provided by a cylindrical shield 12 in. to 24 in. wide around the shield assemblies in the 16th row. Such a nonremovable shield section could be located inside or just outside the core barrel. If inside, it would reduce the fluence to which the core barrel is exposed but would increase the core barrel ID to 18-20 ft.

Conceptual design of the core barrel is not part of this contract, so no attempt is made to show any of its significant details. Nevertheless, it seems prudent to point out that the size and type of construction of the core barrel, and the size of the area of removable core assemblies have significant impact on the design of other parts of the reactor system. Examples are:

- Size of the rotating shield plugs
- Size and design of the instrument tree
- Fuel-handling features, such as the in-vessel handling machine (IVHM) and location of the fuel-assembly transfer point for tilted entrance and exit ramps (if applicable)
- Diameters of the primary-sodium pool and the primary tank
- Construction of reactor internals such as the reactor support grid; this complex component, shown in Fig. 2, should be fabricated as a separate unit, and the core barrel design should allow for it.

Previous studies [see A. Amorosi et al., An Overview of Pool-type LMFBR: General Characteristics, ANL-76-61 (May 1976), Chapters V and VI], describe various fuel-handling methods and primary-system configurations and options. If a straight push-pull IVHM is used with a double or triple rotating shield plug and a tilted entrance and exit ramp, a reactor area with a diameter of about 16 ft requires a large rotating shield plug with a diameter of 30 ft. A "Split Instrument Tree and Control-Drive Area" scheme could reduce the diameter of the large rotating shield plug to about 20 ft.

Similarly, an overall length of 15 or 16 ft for fuel assemblies is acceptable, but a shorter length would be much more desirable, because these dimensions determine the height of the reactor and the height of the sodium pool and affect many fuel-handling components.

3. REACTOR SUPPORT GRID AND ZONE DISCRIMINATOR

Conceptual design of the reactor support grid is not part of this contract. However, because some of the support-grid features are very closely tied to the reactor core design, a generic concept is shown in Fig. 2. No analyses and calculations have been made of the flow conditions, pressure drop, height of the inlet plenum, thickness of the three perforated grid plates, location and spacing of tie rods, and other design considerations.

Basically, the support grid consists of three perforated plates that hold the fuel, blanket, shield, and control-rod assemblies in their respective locations, support their combined weight, provide hydraulic holddown for them, and form high-pressure and low-pressure coolant inlet plena.

As shown in Fig. 1, the core contains various distinct zones, and safeguards must be provided to prevent inserting an assembly into the wrong zone. One way of doing this is to make different size holes in the grid plates and different size locking bars for each of the different types of assemblies, which would then have different dimensions for their bottom adapter. However, "freezing" the zones in this way at the time of grid fabrication would remove the possible advantage of being able to change the zone boundaries at a later date or during the life of the reactor. The proposed generic concept of the reactor support grid provides the flexibility for changing the zone boundaries by use of replaceable zone-discriminator sleeves. These sleeves are designed so that only the assemblies intended for the zone can be inserted into them.

In this concept, the holes for the fuel, blanket, shield, and control-rod subassemblies in each grid plate are of the same size, but the holes in the bottom grid plate are 5/8 in. smaller than in the middle plate and the holes in the middle plate are 1/4 in. smaller than in the top plate. The actual size of these holes will depend on the final height of the reactor-support-grid plena, flow requirements, and acceptable pressure drops. (See Fig. 2.) The fuel-assembly holes in the three grid plates have matching locations. A replaceable discriminator sleeve

is inserted into each set of the three matching holes in the plates. The top flange of the sleeve rests on the upper surface of the top grid plate, and the bottom of the sleeve is bayonet-locked against a locking bar on the bottom grid plate. After the discriminator sleeve has been locked, it cannot move up or down with respect to the reactor support grid. Because of their hexagonal ducts, the fuel or other assemblies can not rotate once inserted into the reactor matrix. Therefore the bottom adapter of the fuel or other assembly in the sleeve prevents the sleeve from rotating and loosening during reactor operation. Each discriminator sleeve can be inserted into the reactor support grid in only one orientation. Insertion 180° from the desired orientation is prevented by having a different cross section at each end of the locking bar. All discriminator sleeves have the same inside and outside diameters. Only the flow holes and the discriminator keys (described below) vary from zone to zone. The coolant inlet holes in the sleeves are at different elevations, depending on whether the assembly it contains requires flow from the high-pressure plenum or the low-pressure plenum.

In each sleeve, two internal keys protruding from the sleeve wall match with grooves on the bottom adapter of each fuel or other assembly. (See Fig. 3.) The wider key, designated as the "orientation key," faces in the same direction in all sleeves. It allows insertion of an assembly in only one orientation (vs. 60° insertion options). The narrower key, designated as the "discriminator key," is about 4 in. below the orientation key, and, depending on the zone, is at a different increment angle from the orientation key. (Figure 3 shows arbitrarily a 24° increment.) The bottom adapter of each type of assembly must have grooves that match the keys in order to be acceptable in a specific zone of the reactor support grid.

This concept provides a number of advantages. It provides up to 15 easily discernible zones. (The larger the number of zones, the smaller the increment angles between key orientations.) In cases of a loading error (i.e., an attempt to load an assembly into a wrong zone), the IVHM would stop at least 4 in. above its normal bottoming elevation. Because the orientation key and the discriminator key are different in size and elevation, wrong orientation of a subassembly can be distinguished from wrong destination. Each discriminator sleeve can be replaced individually with a special tool. This provides the option of changing the size, shape, or number of zones while retaining the intended safeguards against loading errors. (No "special" bottom adapters would have to be attached to fuel assemblies

to circumvent the original zone pattern.) The discriminator sleeves protect the reactor support grid from damage. They also make it easier and less expensive to fabricate the grid, because all holes in each plate are of the same size. Similarly, the outside dimensions of all assembly bottom adapters are identical except for the location of the discriminator groove.

Further refinements can be accomplished by incorporating some EBR-II features into this scheme. For example, each row, or even each assembly location, could be individually orificed while retaining identical bottom adapters. Thus a specific type of fuel assembly (there may be fuel assemblies with different enrichments) could fit into a number of reactor locations. The bottom adapter would have several rows of coolant inlet holes and would be identical in every respect. The corresponding discriminator sleeves however would slightly differ from each other, according to the location which they serve. In a location requiring maximum coolant flow, all holes in the fuel-assembly bottom adapter would pass the coolant. In a location requiring less flow, one or more rows of bottom adapter holes would be blocked off by the inside diameter of the discriminator sleeve, thus effectively throttling the coolant flow through the fuel assembly. Such a scheme could further reduce the differences in coolant outlet temperatures of fuel assemblies situated in different locations yet retain identical bottom adapters.

4. FUEL ASSEMBLY

Each fuel assembly (see Fig. 3) consists of array of 271 fuel pins that are contained in a hexagonal duct with top and bottom adapters.

4.1 FUEL PIN

Each fuel pin contains pellet stacks of fuel and blanket material. The fuel (core) stack is 40 in. high. The upper and lower blankets above and below this stack are each 15-in.-high stacks of blanket pellets. A 30-in.-long gas plenum is near the upper end of the fuel pin. A 15-in.-long shield plug forms an upper closure on the fuel-pin tube. A collapsible perforated cylinder that fits into the gas plenum acts as a spacing (holddown) device for the pellet stacks. During their reactor lifetime, the fuel pellets will expand axially more than the fuel-pin tube. Thus, the collapsible cylinder will be compressed, but will retain its capability to resist fuel ratcheting.

The lower end of the fuel-pin tube (0.280 in. O.D. with 0.014-in. wall thickness) also contains a 15-in.-long shield plug, and ends in an EBR-II type of adapter tip. (The length of the upper and lower shield plugs is assumed somewhat arbitrarily. Other PLBR reports mention 21-26 in. Future shielding calculations may determine different lengths.) The adapter tip can be easily slipped on or off a T-bar grid welded to the bottom adapter of the fuel assembly. After assembly of the 271 fuel pins on the T-bar grid, the adapter tips form a pattern that acts as a strainer for foreign particles above a certain size. A 0.047-in.-dia. helically wound spacer wire with a 12-in. pitch is welded at each end to the fuel pin.

4.2 HEXAGONAL DUCT

The 271 fuel pins are contained in a hexagonal duct that is 5.682 in. across the outside of the flats and has a 0.100-in. wall thickness. This wall thickness is dictated mostly by the pressure differential across the wall and the resulting tendency of the wall to bulge. [Various schemes are available to reduce the duct-wall thickness by increasing the external pressure (and thereby reducing or eliminating the ΔP across the wall), but these schemes create problems in other areas that are beyond the scope of this contract.]

The fuel assembly uses two sets of load pads, called ACLP's and TLP's as shown in Figs. 2 and 3. The six ACLP's (above-core load pads) are on the outside of the hexagonal duct and 6 in. above the top of the core. They consist of an extruded duct-wall disk 1.5 in. in diameter and 0.103 in. high. The flat-to-flat space allotted for a hexagonal duct when cold is 5.907 in. With the flat-to-flat duct dimension 5.682 in., the nominal gap between adjacent duct flats is 0.225 in. when cold. The ACLP reduces this gap nominally to 0.019 in. The six TLP's (top load pads) can be part of the upper adapter, in which case they would be solid metal, or they could be located on the upper end of the hexagonal duct and therefore be flexible. In either case they extend outwardly only 0.033 in. and leave a nominal cold gap of 0.159 in.

An alternate TLP scheme is shown in Fig. 3. This scheme uses a 0.066-in.-high load pad near each corner of the top adapter. The eventual contact would thus be made near the edge rather than at the center of the hexagonal-duct flats. Such a geometry may make removal of swollen fuel assemblies easier because the duct may swell more across the centers of the flats than across the edges of the flats.

4.3 TOP ADAPTER

The top adapter is the part of the fuel assembly that is gripped by the various fuel-handling mechanisms. Its specific design depends on the type of the IVHM gripper component and on the fuel-assembly identification scheme to be employed. In this conceptual design, the upper adapter is assumed to be similar to the FFTF and CRBR designs.

4.4 BOTTOM ADAPTER

The bottom adapter supports the T-bar grid that anchors the 271 fuel pins, provides hydraulic holddown of the fuel assembly during coolant flow, and in conjunction with the discriminator sleeve provides the means for positioning the fuel assembly in the proper zone of the reactor support grid. It also provides for introduction and orificing of the coolant. (See Fig. 3.)

The adapter dimensions are closely tied to the height of the support grid, the ID of the discriminator sleeve, and the final coolant-flow requirements. The bottom adapter is cylindrical over most of its 53-in. length. The hexagonal upper end converts into a spherical shape that sits on the conical chamfer of the discriminator sleeve. The T-bar grid is similar to the EBR-II design and is welded to the

hexagonal upper end of the adapter. The T-bar grid and fuel pin adapter tip scheme lends itself to remote assembly (and disassembly) of the 271 fuel pins with the remaining parts of the fuel assembly.

The coolant inlet holes are drilled into locations that match those of the holes in the discriminator sleeve [except for these holes that are blocked off on purpose (see Sec. 3, last paragraph).] The size and number of holes will be determined by future flow and pressure-drop calculations. On the lower third of the cylindrical portion of the adapter, two axially running grooves match the key orientation of the discriminator sleeve. If, during insertion, a fuel assembly is misoriented in multiples of 60° , its insertion into the support grid will be stopped when the assembly is about 8 in. above its normal bottoming elevation. If a fuel assembly is properly oriented but inserted into the wrong zone, it would be stopped about 4 in. above its normal bottoming elevation. These distances are large and distinct enough to give a clear indication of the type of fuel-handling error.

The discriminator sleeve is open at both ends. Its bottom end leads into the unpressurized space below the reactor support grid. The bottom adapter of the fuel assembly has a closed end that closely fits into the bottom diameter of the sleeve. The key grooves start above this elevation. During coolant flow, therefore, a pressure difference is established across the cylindrical section of the bottom adapter, creating a hydraulic holddown that counteracts the lifting forces created by the upward coolant flow.

5. BLANKET ASSEMBLY

The blanket assemblies (see Fig. 4) resemble the fuel assemblies in all aspects except for the locations of the coolant inlet holes and the discriminator key, the size of the T-bar grid, and the concept of the blanket pin.

Each of the 127 blanket pins contains a 70-in.-high stack of blanket-material pellets. The gas plenum and the upper and lower shield sections have the same lengths as in the fuel pin, but their diameter is different. The blanket-pin tube has a 0.447-in.-OD and a 0.013-in. wall thickness. The 0.030-in.-dia spacer wire of the blanket pin is helically wound on a 6-in. pitch. The size of the gas plenum as shown in Fig. 4 may be too large. Shortening the 30-in. dimension would allow an equivalent lengthening of the shield section.

6. SHIELD ASSEMBLY (REFLECTOR ASSEMBLY)

At present, there appears to be very little difference between the requirements for the reflector assemblies and the shield assemblies. However, this may change in the future, so it is prudent to consider two different concepts as generic designs. One is stiffer, or structurally stronger, than the other and thus might be used to provide more restraint in the outer rows of the reactor.

6.1 STIFF SHIELD ASSEMBLY

This concept (see Fig. 5) fulfills the requirements that the assembly be structurally very strong, so that several rows of such assemblies at the periphery of the reactor would act as restrainers against the bowing tendencies of the fuel and blanket assemblies. In other words, the stiff assemblies would carry out some of the functions of a core barrel.

In general, all dimensions of this type of assembly are identical to those of the fuel and blanket assemblies. However, the hexagonal part of the assembly between the top and bottom adapters is made of one solid piece of structural material that has only one axial cooling channel in the center. If required, a flow-orificing insert could throttle the flow to different magnitudes in the reflector and shield assemblies.

6.2 FLEXIBLE SHIELD ASSEMBLY

The flexible shield (see Fig. 6) assemblies differ from the stiff shield assemblies in that the hexagonal part between the top and bottom adapters is not made of one solid piece. Instead it is made of 11 individual plugs on top of each other, with each plug having a slightly convex bottom that makes it easy for the plug to "rock" on its base. The 11 plugs are in a hexagonal duct with the dimensions similar to those of the duct of the fuel assembly. Dimples in the duct wall keep the plugs centered. A crushable perforated cylinder acts as a holddown device. The coolant, orificed by an insert in the bottom adapter, can flow through the center of the plugs as well as at their periphery if desired.

The advantage of the segmented (individual plugs) design is that bowing of the heavy shield/reflector pieces is accommodated in a "forgiving manner". The disadvantage may be that the assembly is less stiff than desired for core restraint. It probably will be necessary to optimize stiffness of the hex duct, stiffness of the load pads and other related variables to develop the ultimate design for safe accommodation of all bowing and possible seismic forces.

7. CONTROL-ROD ASSEMBLY

There are 24 control-rod locations in the matrix shown in Fig. 1. At this time it is not certain that all control rods will be of the same type, so one should consider the control-rod assembly shown in Fig. 7 as a generic concept rather than a specific design. The concept as presented is a compromise between various control requirements, safety considerations, space restrictions, fuel-handling needs, etc. A limited discussion of some of these features and their impact on possible designs follows.

7.1 CONCEPT CONSIDERATIONS

In creating a useful control-rod assembly within the framework of this study, a number of requirements have to be considered, and their importance relative to each other has to be evaluated. In some cases, the effect of one requirement limits some other requirement, and one or both have to be modified. Several, mostly qualitative, requirements are listed here, and their impact is discussed after the listing.

A control-rod assembly should:

- Be either of a neutron-absorber type containing enriched B_4D or of a fuel type with a natural B_4C neutron-absorber follower
- Have a large cross-section to contain an optimum amount of B_4C and/or fuel
- Have a 40-in. vertical stroke (for a 40-in. core height) to get optimum scram results
- Have a hydraulic holddown during coolant flow
- Be compatible with the normal fuel-handling system
- Fit into the normal reactor matrix and reactor-support-grid design
- Have no movable latches, valves, or other devices that could fail mechanically.

Among the "nonnegotiable" of the above requirements is the need for a hydraulic holddown, because it is safety-related. The primary reason for its safety aspects is that the control-rod mechanisms are disconnected from the control rods during fuel handling. Thus, inadvertent operation of the primary pumps (although carefully guarded against during fuel handling) might raise the control rods by hydraulic pressure and therefore raise reactivity. A hydraulic holddown is a first-principle fail-safe device that will oppose such movement.

With the acceptance of a hydraulic holddown as an absolute necessity, basic design principles limit the vertical travel of a control rod to half the distance of about 80 in. between the bottom of the reactor support grid and the bottom of the core region. Thus a 40-in. vertical travel can be accommodated with an almost normal-length (193-in.) control rod. Although a longer vertical travel of 52-55 in. is not recommended because of other undesirable effects, it could be achieved by one of the following four modifications:

1. Making the control-rod pole piece 24-30 in. longer. This would lengthen the control rod by the same amount and would effect many fuel-handling components and ultimately the primary-tank depth.
2. Raising the core section 24-30 in., thus lengthening all fuel assemblies. Doing this would have the effects described under item 1 and would also make necessary a taller core barrel, etc.
3. Incorporating mechanical devices like telescoping tubes, snap-in seals, etc., all of which introduce questions of reliability that are not acceptable for control-rod operations.
4. Accepting a significant leakage flow through an otherwise closed bottom adapter of a control-rod guide thimble. This scheme has interesting aspects and is illustrated in Fig. 8 and described in Sec 7.2.3, below.

A neutron-absorber type of control rod is shown on the provided concepts. A fuel-type control rod with a neutron-absorber follower is also feasible. However, with the assumed height of the reactor support grid, and with the reactor core located 34.5 in. above the reactor support grid, only a relatively small cross-sectional area would be available for control-rod fuel pins. If the support-grid dimensions and/or the reactor dimensions increase significantly from these presented, the available space may be more favorable for a fuel-type control rod.

7.2 GENERIC DESIGN OF A CONTROL-ROD

Each control-rod assembly consists essentially of two parts. One is the control rod that moves up and down when it is connected to the operating control drive. The other is the control-rod guide thimble that is secured in the reactor support grid, but is removable by the use of special tools during the reactor shutdown.

7.2.1 CONTROL ROD

As shown in Fig. 7, the control rod consists of (a) a hexagonal duct that holds the B_4C pins, and (b) the cylindrical bottom adapter that acts as a guide, provides the coolant orificing, and accomplishes the hydraulic holddown.

The hexagonal duct of the control rod fits into the hexagonal duct of the control-rod guide thimble with about a 0.116-in. nominal clearance around its periphery. Its flat-to-flat outside dimension is 5.250 in. (vs.- the 5.682 in. of a standard fuel assembly). This size of duct accommodates 61 B_4C pins of 0.530-in. OD and wrapped with a 0.093-in.-dia helically wound spacer wire. Each pin contains a 40-in.-high stack of B_4C pellets, a 15-in.-long steel section, a 20-in.-long gas plenum, a collapsible perforated holddown cylinder, and upper and lower closures that resemble in type, but not in size, the closure of the fuel-pin concept.

The top of the hexagonal duct is capped with a top adapter similar to the fuel-assembly top adapter, described in Sec. 4.3, except for the following features: (1) Its outer dimensions are smaller to make it fit the control-rod duct size; (2) it has no top load pads (TLP's); and (3) if desired, orientation keys can be machined into the corners to minimize the limited rotation of the control rod within the control-rod guide thimble.

The bottom adapter is primarily a cylinder with a very short transition section connected to the hexagonal duct. The cylinder is closed at the bottom end and has two sliding seal rings attached to its outside, one near its bottom end, and the other about half way up. Between the two seal rings are a series of coolant inlet holes. These inlet holes and, if needed, an orifice insert throttle the coolant flow to the required magnitude. (If variable coolant flow as a function of control-rod elevation is desirable, as in the case of fuel-type control rods, this can be provided by making the coolant inlet pass between the discriminator sleeve and the bottom adapter less circuitous as the control rod is raised.) The sliding seal rings, in combination with the bottom adapter of the control-rod guide thimble, provide the hydraulic-holddown feature.

7.2.2 CONTROL-ROD GUIDE THIMBLE

As shown in Fig. 7, the control-rod guide thimble is the nonmovable part of the control-rod assembly and provides the channel in which the control rod moves up and down. It too consists of a hexagonal duct and a cylindrical bottom section.

The hexagonal duct has the same cross-sectional dimensions as the fuel assembly duct and has matching above-core load pads (ACLP's) and TLP's. In the conceptual illustration, the duct is shown to reach the same elevation as the upper surface of the fuel-assembly top adapters. However, depending on the fuel-handling cycles and the planned guide-thimble lifetime, it may be prudent to make the duct about 0.5 in. shorter to allow for radiation-induced elongation.

The bottom adapter replaces the discriminator sleeve (see Sec. 3) in the reactor support grid, but locks into a locking pin in an identical fashion. The approximately 31-in.-long section of the adapter that extends above the reactor support grid becomes hexagonal on the outside and connects to the hexagonal duct about 4 in. below the core region. The inside of the bottom adapter is a 4.000 in. -bore, carefully finished and chrome-plated. It provides the sliding surface of the two seal rings of the control-rod bottom adapter.

The thimble must be rotated 60° to insert it into or remove it from the reactor support grid. This cannot be done as long as the thimble is surrounded by regular-size fuel assemblies. Removing all six adjacent fuel assemblies to create the needed space is not advisable and will most probably be against fuel-handling rules. Therefore, six scalloped dummy assemblies are required, which are temporarily inserted into the adjacent locations (stepwise one for one exchange) and which then provide the space for guide-thimble rotation without creating more than one void fuel-assembly position in the reactor support grid at any one time.

7.2.3 CONTROL ROD WITH 52-in. OR LONGER STROKE

As stated in Sec. 7.1, control-rod travel of more than 40 in. creates problems in other areas, such as lengthening the reactor system, affecting the fuel-handling system, etc. One approach, however, does not cause these problems, although it compromises some other control-rod-assembly aspects, and careful analyses would be needed to evaluate the trade-offs. This concept, shown in Fig. 8, differs from the concept shown in Fig. 7 only by the design of the bottom adapter.

The control-rod bottom adapter in this concept has no seal rings and essentially consists of a cylinder that is closed at the bottom end and has flow inlet holes near the bottom. The guide-thimble bottom adapter has a seal ring at the top and is also closed near the bottom (just slightly above the bayonet lock). However, this closure has small weepholes of carefully considered size. A short section of reduced inner diameter near the bottom of the cylinder of the guide-thimble bottom adapter fits snugly around the end of the control-rod bottom adapter when it is in the down position. This arrangement provides hydraulic holddown when the control rod is in the down position. During reactor operation, however, when the control rod is more than about 1 in. from the down position, no hydraulic holddown exists, and some coolant flows through the weepholes into the bulk sodium. This arrangement allows a control-rod stroke of well over 40 in. Depending on the needed stroke length, a steel section of the required length could be added to the bottom of each B_4C pin. For the stroke length of 55 in., for example, this section would be 15 in. long.

Figure 2. Reactor Support Grid

Figure 6. Shield Assembly (flexible)

Figure 8. Control Rod (52' travel)