

## DESIGN DEVELOPMENT OF THE HTGR CORE AND ITS SUPPORT STRUCTURE — SEISMIC CONSIDERATIONS

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### SUMMARY

This paper discusses the development of the core support structure design from that employed on Fort St. Vrain to recently announced contracts by Philadelphia Electric, Delmarva Power and Light and Southern California Edison for the large HTGR. Particular emphasis is given to the seismic considerations in design of the structure for the large HTGR.

The overall configuration of each reactor type is critically compared. Although similar components are employed, the basic difference in layout configuration results in significant conceptual differences in the structural and mechanical requirements of the core support components. The configuration and major components for the large reactor are described in some detail. The essential features and function of components are discussed.

The graphite components in the core support floor and permanent reflector are designed to form a tight array during reactor normal operating conditions. This composite structure resists compressive loading due to differential gas forces and concrete pressure vessel movement. This tight array concept has important advantageous effects on primary coolant flow distribution and seismic capability.

The paper discusses the inherent requirements and methodology in developing a standard plant design for high seismic sites. A design suitable for 0.15 g operating basis earthquake and 0.25 g safe shutdown earthquake has been developed which is applicable for over 80% of the expected sites in the U.S.A.

The HTGR core and support structure consists of many thousand graphite elements. It behaves as an inelastic body having random response when subjected to seismic excitation. The paper describes simplified analytical models which have been developed to investigate this phenomenon. An overview of a test program to substantiate and correlate with the analytical models is provided. The program addresses the inter-element collision forces and frequencies of elements within the core and the load/deflection at the boundary. Various one-, two-, and three-dimensional scale models have been tested. A summary of the objectives of the program is provided.

## 1. INTRODUCTION

The overall reactor configuration for recently announced large HTGR contracts of 3000 MW(t) by Philadelphia Electric (PE), and 2000 MW(t) by Delmarva Power & Light (DPL) and Southern California Edison (SCE) is significantly different from that employed on the 850 MW(t) Fort St. Vrain (FSV) nuclear generating station. A comparison of each reactor type is shown in Figures 1 and 2, respectively. The primary circuit is as follows:

Fort St. Vrain employs a single cavity prestressed concrete reactor vessel (PCRIV) with an intermediate internal concrete structure to support the core. A continuous welded steel barrel keyed to the PCRIV is provided to restrain the core laterally. The gas flow is upwards in the annulus between the core barrel and the PCRIV, down through the core, through vertical ducts in the concrete support floor, down through the steam generator, then pumped by gas circulators into the plenum below the concrete floor and hence to the annulus to complete the circuit.

By comparison, the large HTGR employs a multicavity PCRIV. The central cavity houses the reactor core; heat exchanger and circulator equipment are located in cavities in the PCRIV sidewall. Cross ducts are provided to connect the peripheral and central cavities. The core is supported directly from the bottom head of the PCRIV and laterally restrained directly from the central cavity sidewall. The gas flow is again downward through the core into a plenum created below the graphite core support floor; then through the lower cross duct into the steam generators. The circulator returns coolant through the upper cross duct to the plenum above the core. In addition to the obvious advantage of eliminating the intermediate concrete support floor, this basic difference in layout configuration results in conceptual differences in the structural and mechanical requirements of the core components.

## 2. COMPARISON OF CORE SUPPORT DESIGNS

A detailed description and dimensions of the core and support structure components for Fort St. Vrain are given by Nehrig, D. A., Neylan, A. J. and Winkler, E. O. [1] and will not be repeated here. The basic components are similar in the large HTGR. The core configuration is also similar and is shown for the large reactor in some detail in Figure 3. The major structural differences between the large HTGRs and Fort St. Vrain are discussed below with particular reference to seismic considerations. A comparison of significant core statistics is given in Table 1.

The individual fuel elements in each reactor type are similar, being hexagonal in cross section with dimensions of 14.17 in. across flats by 31.22 in. high. There are significant detail differences between the elements for each reactor type, the discussion of which is beyond the scope of this paper. From the viewpoint of seismic design the most important change is that the element in the large HTGR has a smaller number of larger diameter fuel and coolant holes (see Table 1 for details). The resulting ligaments affect both the structural capacity of the block and the effective damping due to energy loss during inter-element collisions.

The total number of fuel elements is 3,944 and 2,744 for the 3000 and 2000 MW(t) reactors, respectively. In the larger reactors the elements are stacked eight high versus six high on Fort St. Vrain, resulting in an overall core height of 20.8 ft compared to

15.6 ft. The number of fuel columns is increased to 493 and 343 in the 3000 and 2000 MW(t) compared to 247 in FSV. This results in an active core diameter of 27.8 ft and 23.2 ft, respectively.

As in Fort St. Vrain, the columns are grouped to form fuel regions containing seven columns each. The center column of each region provides channels for insertion of the two control rods and a third channel for insertion of reserve shutdown material. The elements within the center column of each region are displaced downward approximately 7.5 in. relative to the surrounding column, thereby eliminating the possibility of a horizontal shear plane existing at element interfaces across the complete core.

The means of aligning fuel elements is similar in each reactor design. Alignment of the coolant channels and the control rod channels within the columns is maintained by three graphite dowels on the top face of each element which fit into mating holes in the bottom of each element above. The bottom element or block in each column is doweled to the core support block. All dowels are solely shear connectors. The dowels restrict horizontal motion between elements but neither vertical nor rocking motions. Alignment and lateral end restraint of all columns at the top of the core are provided by the top keyed metal plenum element. Each fuel region is keyed together at the topmost layer with six rectangular keys. This provides a stable array with controlled clearances to mate with each orifice valve. Maintaining alignment is essential during a seismic disturbance to allow insertion of control rods.

The gaps between columns are slightly greater in the large reactor due to differences in the lateral restraint discussed below. This larger gap plus the increased number of columns results in a larger cumulative clearance which is a significant consideration in the seismic design.

The graphite core support floor is conceptually different between the two reactor types. The Fort St. Vrain floor is formed by graphite support blocks 37 in. across flats by 23 in. thick. The hexagonal flat of each support block contains large vertical keys and keyways in an alternating pattern such that all of the blocks are keyed to each other. A uniform ditch and alignment is maintained by the tolerances between the keys and their respective keyways. During reactor normal operating condition the hexagonal faces of each block are separated by approximately 1/4 in. due to the growth of the core barrel side restraint structure. Additional graphite tiles are provided at the upper surface of the floor to restrict gas flow through this face to face clearance between blocks.

In the large reactor the core support floor is formed by star shaped graphite blocks. Each block is the same size as a fuel region. The permanent side reflector is also supported on correspondingly shaped graphite support blocks surrounding the star shaped blocks under the core. The floor is designed to form a tight array during reactor normal operating conditions.

The star shaped configuration avoids overlap of a fuel column in one region to the support block of an adjacent region as in Fort St. Vrain. This eliminates the need for surface rebates on the blocks and avoids the possibility of interference due to adverse tolerances which could impose excessive loads on the fuel element dowels in the tight array concept.

Eliminating gaps between blocks improves the design from the following viewpoints during the higher seismic disturbances in the large reactor.

1. The strength of a keyed block subjected to interelement collisions is limited by the key strength. The design of the FSV block keys was at an optimum, i.e., it was not possible to obtain more strength by increasing key sizes, as this would result in a reduced ligament between the adjacent key and keyway on a single block.
2. Eliminating the gaps reduces the possible accumulated gap across the core diameter and hence reduces the resulting impact forces between blocks.

The tight array concept also has advantageous effects on the primary coolant flow distribution. The face to face contact is a better seal than the additional tile used on Fort St. Vrain. This reduction in core by-pass flow through the type graphite floor improves plant performance and reduces peak fuel temperatures. The reduction in peak temperatures is achieved in that the core outlet temperature is closer to the mean value for a given thermal performance, i.e., higher fuel temperatures are not required to compensate for the "cold" by-pass.

As in Fort St. Vrain, the graphite floor supports the weight of the core and reflector and also the total pressure differential across the core. Each core support block is supported by three graphite posts. The ends of each post are spherical and located in spherical seats which allows unrestrained horizontal movement of the block relative to the PCRV bottom head. Overall horizontal restraint is provided by an extension of the lateral restraint structure. The total vertical load is approximately 2,800,000 lbs, resulting in about 12,000 lbs per support post. Each post is approximately twice as long as a Fort St. Vrain post, having an l/d ratio of approximately 12. This increase in length has little effect on the load carrying capability of the post as the critical load is dependent on the local Hertzian stresses developed in the post seats. Development tests have indicated that a factor of safety of approximately 12 exists under static loading. This factor of safety is directly related to the radius of curvature selected for the post and seat, respectively.

The most significant difference in the core support structures between Fort St. Vrain and the large reactor is in the design of the lateral restraint structure. In each case a permanent side reflector is provided to reflect core neutrons, moderate escaping neutrons and absorb thermal neutrons with boron at the outer periphery to prevent excessive heat generation in the PCRV. On Fort St. Vrain the permanent side reflector consists of large irregularly shaped graphite blocks adjacent to the hexagonal reflector elements and smaller custom fitted rectangular spacer blocks adjacent to the core barrel. The boron is provided by inserting boron carbide compacts into an array of holes at the periphery of the permanent reflector block. Coolant gas by-pass between the reflector and the core barrel is minimized by custom fitting the rectangular blocks.

In the large reactor, irregularly shaped large permanent reflector blocks also surround the hexagonal core reflector pattern. Thirty-six columns are provided, each covering approximately a 10° arc. Outboard of the permanent reflectors are located boronated graphite blocks in metal boxes. Eliminating the large number of holes for individual encapsulated compacts inserted in holes which were used in Fort St. Vrain improves the

structural capacity of the block itself, particularly under seismic impact loading. The design encasing large slabs of boronated graphite has also been found more economical. Out-board of the boronated graphite boxes are located 2 in. thick segmented shield plates. Approximately 3% of the primary coolant flow is allowed to by-pass the core by flowing between the permanent reflector and the shield plates.

Each shield plate and box is approximately the same size as the reflector block being about 3 ft wide by 5 ft-6 in. high, forming a 36 sided polygon. Each plate and box is supported by posts welded to the PCRV cavity liner. The boxes are supported at their corners and the plates at their center points thereby avoiding direct "windows" to the PCRV. The support posts also function as the central fixture for the thermal insulation protecting the cavity liner. Each support point allows relative vertical and horizontal movement between the core reflector components and the PCRV. The support points also incorporate spring devices to attenuate seismic input to the core and reduce the resulting impact between individual core and reflector components and also between these components and the boundary.

Using segmented sections minimizes the cavity space that would be required due to the diametral thermal expansion of a continuous barrel. The absence of this continuous barrel results in the core array no longer being "pulled apart" during normal reactor operating as in Fort St. Vrain. Rather it is "squeezed together" due to the inward PCRV movements. It is estimated that the maximum radial inward movement is about 3/4 in. due to concrete creep under the applied PCRV prestress for forty years. Clearances between core components tend to reduce during reactor operating conditions in the large HTGR for this reason.

Unlike Fort St. Vrain, the graphite components in the permanent side reflector are designed to form a tight array during normal operating conditions. The core support floor and permanent side reflector effectively go "solid" to form a composite structure able to resist compressive vertical and radial inward loads. The side reflector resists the radial inward force due to the pressure differential between the main coolant flowing through the core and the by-pass coolant flowing between the permanent reflector and the PCRV sidewall. The pressure drop across the core is approximately 9.5 psi, while the by-pass is essentially at the inlet plenum pressure. The differential pressure gradient is approximately linear over the height of the core. The permanent side reflector operates at high temperature due to the heat transferred from the core and nuclear heating generating in the components themselves. The by-pass flow serves to alleviate the severe temperatures experienced, particularly in the metal components and also at the face of the thermal insulation of the PCRV sidewall. This by-pass flow is controlled by a seal provided between the periphery of the core support floor and the PCRV liner.

### 3. SEISMIC DESIGN CONSIDERATIONS

For the large HTGR, the core and its support structure are designed to meet the licensing requirements for seismic conditions specified by the United States Atomic Energy Commission (USAEC). The following briefly summarizes the general seismic terminology and criteria used in siting a nuclear power plant. The definitions and requirements are extracted from USAEC, 10 CFR 100, Appendix A, "Seismic Siting Criteria," November 1971. Reference to that document should be made for a more complete statement of the requirements.

Seismic Siting Criteria

- SSE . . . . . Safe Shutdown Earthquake
  - Components important to safety are designed to remain functional
- 50% SSE . . . . . Safety Related Structures
  - Designed well within elastic limits
- OBE . . . . . Operating Basis Earthquake
  - Components necessary for power generation are to remain operable
- OBE . . . . . Is Specified by Owner
  - If an actual earthquake  $\bar{}$  OBE occurs then shutdown and inspection is required. If an OBE is not specified and an actual earthquake  $>$  0.05g occurs shutdown and inspection is required. Site seismic instrumentation is required at all sites.

In developing the large HTGR, GGA has standardized the design for a site g level of 0.15 for the operating basis earthquake (OBE) and 0.25 for the safe shutdown earthquake (SSE), which is suitable for over 80% of the expected sites in the US. An optional design for 0.25g OBE and 0.50g SSE is provided for major parts of Southern California and Japan. This compares to a level of 0.05g and 0.10g for the Fort St. Vrain site. Two-thirds of the above g levels are used as vertical ground seismic inputs concurrently applied with the corresponding horizontal input.

Unfortunately, the designation of a "g" level does not adequately define the structural design requirements for a given site. The ground motion at that site and the response of structures to that motion also requires definition. For structural design purposes, it is common to provide a family of response spectra normalized to specific g levels for various damping coefficients for the designated nuclear power plant site. The designer normally uses these spectra to determine a response magnification in terms of "g" level based on the natural period of the structure under consideration. This effective g is then used as an equivalent static load in the design structural analysis. The response spectra analysis is limited in that it gives only the peak "g" without relationship to time and also assumes that the natural period of the structure is readily determinable.

This procedure is unacceptable in the case of the core, because it is an inelastic body having random response. Only acceleration versus time-history methods may be used. The time-history approach is able to handle more complex problems and provide a direct relationship between the dynamic model of the structure under consideration and the acceleration level of the input motion with respect to time.

Where acceleration versus time-history methods are used for design purposes, it is required that the traces developed encompass the prescribed response spectra for all damping values to meet USAEC requirements.

The seismic analytical procedure at GGA is to create a dynamic multi-degree-of-freedom model of the major structural component on the site. This idealized model includes the PCRV, major NSS components and the containment structure (Jeng, D. C. [2]). The time-history of actual earthquakes or random motions enveloping the specified response spectra are used in conjunction with this dynamic model to calculate floor response spectra or time-history response at key locations for the NSS components. Here again the basic change in overall configuration from Fort St. Vrain is advantageous to the large plant. The PCRV and internal support structures have much lower centers of gravity and are considerably less flexible. The resulting amplification factors for components in and on the PCRV are consequently much lower. In the case of the core, acceleration and displacement at the PCRV sidewall resulting from the ground input are provided to the core support structure designer.

The response of the core to the horizontal seismic input becomes a problem of many individual elements which are free to translate in a horizontal plane within limits of the movement determined by the top keyed plenum layer and the core support floor, the design of the lateral restraint structure, the flexibility of the doweled columns and the proximity of adjacent columns. Some of the major parameters affecting the response of the core are the clearance between elements, the size of the array, the phenomena of collision and rebound between elements, the extent of "lumping" and the spring rate of the attachment fixture between the lateral restraint and the PCRV. The equations of motion for the complete system are too complex to handle so that analytical models of one and two-dimensional sections through the core have been developed. These models have been and are being substantiated by an ongoing test program utilizing one, two and three-dimensional vibration test models.

Before going on to describe these models and the experimental program, let us first consider the design acceptance criteria and the information required to be determined.

To meet the requirements during the OBE, (or 50% SSE), the design shall preclude damage to fuel elements which would either release fuel particles to the primary circuit or prevent subsequent full load reactor operation. Local chipping of corners or edges of elements which are inconsequential to refueling operations are permitted. Any temporary seismic motion shall not cause damage to other internal components, e.g., the PCRV sidewall thermal barrier. Stresses in the steel lateral restraint structure components are limited in accordance with Section NG (draft) of Section III of ASME Boiler and Pressure Vessel Code.

During the SSE the design shall prevent permanent disarray of or damage to the core or support components that would prevent insertion of the control rods or reserve shutdown material to reduce system reactivity to a subcritical level. It should be recognized here that due to the high heat capacity of the graphite in the HTGR system a normal reactor scram is designed to take 150 seconds to complete. As the typical earthquake duration is less than 60 seconds the problem relates to safe shutdown after the excitation ceases. The main concerns are: 1) breakage of dowel pins or sockets allowing lateral displacement of fuel elements and hence relative misalignment of control rod channels, 2) fracture of fuel elements precluding the insertion of control rods or reserve shutdown material and, 3) damage to the core support structures resulting in permanent disarray or collapse of the core.

The particular information required from the analytical and supporting test program is:

Firstly, for the graphite core and support structure:

1. Interelement collision forces and collision frequencies.
2. Shear forces on the dowels.
3. Deflections and disarrays which could cause disengagement of dowels and affect control rod insertion.

Secondly, for the side support system:

1. Load and deflection at each lateral support point.
2. Frequency of load repetition.

In order to relate the response and acceptability of the core and support structure elements to the above design criteria, the impact fatigue life for the components must be determined and compared to the imposed loading.

#### 4. ANALYTICAL APPROACH

Exact modeling of the complete three-dimensional core array is not possible. Major problems arise from the tremendously large number of core elements to be considered, the number of degrees of freedom, the varying boundary conditions and the complexity of the damping/impact characteristics of interacting elements. The analytical approach adopted has been to use simplified models of planar and columnar sections through the core array. It may prove possible in the future that these simplified analytical techniques may be combined, but this is not considered worthwhile until further test results and correlations are available. The following codes have been and are being developed:

1. PIC (Ingber, J. F. [3]). This analytical technique analyzes a horizontal array of fuel and reflector elements idealized as circular pucks. The boundary pucks are attached to the PCRV by a spring to simulate the sidewall attachment. Each puck is also "attached" to the PCRV by a spring and damper to simulate the column interaction of elements above and below the plane under consideration (Figure 4). PIC analyzes the collisions by solving the equations of momentum and conservation of energy. The code calculates the relative velocity between impacting elements from which the impact forces may be calculated. The distribution and frequency of impacts is also calculated. Sinusoidal, random and specific earthquake motions may be imposed at the model boundary. The model is limited to array sizes of 91 elements. The model was initially used to investigate system characteristics such as the affect of interelement clearances, the affect of boundary stiffness, the affect of a range of material properties affecting interelement collision dynamics, e.g., coefficient of restitution, the effect of damping, column stiffness and array size. Good correlation with a 2D planar array shake test has been obtained.
2. COSAM (Gorholt, W. [4]). This code analyzes a horizontal row of fuel and reflector elements across the core. Collision dynamics are described by a mass spring relationship. Each element is provided with a zero tension impact spring which compresses when the element collides with the adjacent one. The outer elements



are connected to the boundary with springs and dampers to simulate the reflector to PCRV attachment. The number and mass of elements in the row may be varied. As in PIC, each element is also attached to the PCRV by a spring and damper to simulate column interaction (Figure 5). This model, which is much less time consuming to use, is employed to investigate the affect of array sizes on core lumping and the resulting impact loads between elements and on the support. Similar input capability and parametric studies are conducted as with PIC. Comparison of core response using the PIC and COSAM codes indicates good agreement in cases other than lumped core resonance. Because of the ease and versatility in its use the COSAM code is extensively used as a preliminary design tool.

3. COSAM 2 (Deardorff, A. F. [5]). This code is a two-dimensional version of COSAM. The model handles hexagonal elements compared to the circular elements in PIC. Only impacts normal to the hexagonal faces of the element are permitted. The collision dynamics are described by a mass spring relationship as in COSAM. The model is capable of handling array sizes up to the full 550 fuel columns in a 3000 MW(t) reactor system. Input facilities and parametric studies are conducted as in PIC. This program, although demonstrated to be feasible, is time consuming. It is undergoing refinement, particularly to investigate the effect of reducing the calculation time steps pending receipt of test data.
4. SECA (Gorholt, W. [4]). This code analyzes a column of fuel elements using the same simplifying techniques as in COSAM: Each fuel element has two vertical and four horizontal zero-tension impact springs attached to it, in addition to a rigid shear connector (Figure 6). The column is allowed to "break" and permit elements to "rock" on each other within the spring characteristics. The code provides vertical and shear forces, deflections and velocities at each element location and column end reactions. No test data for correlation with this model have been obtained although it is anticipated that the predictions are very conservative. Subsequent extension of this code to handle a complete vertical section across the core appears feasible although it is probably prohibitive in computer time.
5. Support Programs. In order to effectively utilize the programs described above it has been necessary to develop subroutine programs that describe the collision characteristics utilized in the impacts between elements. Due to the complexity of the collision process, the analytical model does not accurately represent the elastic-plastic events actually taking place in the collision. However, a reasonable force displacement relationship has been derived which correlates well with data from impact tests. This relationship is incorporated into the COSAM codes.

## 5. EXPERIMENTAL PROGRAM

Concurrent with the above analytical development work an experimental program has been implemented as follows:

1. 2D Puck Test. Vibration tests were made on a model where a planar array of fuel elements was simulated by circular "pucks". A two-dimensional array of 3-1/2 in. diameter, 1 in. high pucks resting on a base and within a rigid hexagon shaped

boundary was used. These tests are representative of arrays with only negligible three-dimensional effects, and were used to substantiate the PIC model. Good correlation was obtained.

2. Column Test. A series of scaled-column vibration tests has been completed in which sinusoidal excitations were imposed on the ends of single columns of 14 fuel and reflector elements.

The data obtained has been used to study the effects of the column on a planar array, as part of the effort to assess how the three-dimensional core can be described by a two-dimensional model of a horizontal array.

3. Pendulum Test. Impact tests between single elements using a twin pendulum apparatus were made. The elements were simultaneously released from various displaced positions and allowed to impact on each other. Data was obtained relating relative velocity, impact force, collision duration and coefficient of restitution. The tests were conducted to compare the behavior of scaled and full size elements, and to provide data to describe the collision phenomenon in the analytical codes.
4. Partial Array Test. A model of a partial core array is currently being tested in a joint GGA-CEA program at Saclay, France. The model comprises 61 columns each 10 elements high. Each element is approximately one quarter the HTGR element scale. The clearances and end fixity are representative of the HTGR configuration. Two phases of the experiment are being undertaken to compare the effect of hard versus soft side support spring stiffness (e.g., to examine possible resonance and degree of lumping).

This model provides the first check of the simplified computer codes against a three-dimensional model (e.g., interelement collision force and frequency; support structure loadings). This program is described more fully in a later paper in this conference (Berriaud, C., et al. [6]).

5. 2D Hexagonal Array Test. This test is similar to (1) above, except that hexagonal elements 1/5 HTGR scale are used. The model is used to correlate with COSAM codes and demonstrate the behavior of an array of hexagonal elements.
6. Instrumentation Development. An extensive instrumentation development program has been undertaken in conjunction with the dynamic model testing. Accelerometers, interelement relative displacement gages, strain gages, interelement contact gages and boundary deflection instruments have been successfully developed. Performance and durability have been extensively demonstrated in conjunction with the pendulum and hexagonal array tests. The instruments themselves are an essential but partial section of an elaborate overall data acquisition and software handling program in the 3D test model.
7. 1/5 Scale Test. The model for this test is fully representative of a complete 3000 MW(t) HTGR core. The model includes the core support floor blocks, upper plenum elements, permanent reflector and spring lateral restraint structure. The model is excited in a single horizontal direction by any arbitrary or random

time-history function. Testing will be completed by mid 1973. The 1/5 scale test is designed to provide the following information.

- a. Assessment of the response of the full array core and core support system.
  - b. Comparison of a partial (Saclay) and full array core model response under design seismic conditions.
  - c. Core support floor and side reflector loadings.
  - d. Comparison of effect of changes in boundary stiffness.
  - e. Comparison and correlation with the computer codes developed/modified following the Saclay tests (e.g., interelement collision force and frequency).
8. Impact Tests. Impact tests have been performed between fuel elements of the Fort St. Vrain (FSV) design. In one test high energy impacts were simulated by dropping full size FSV blocks on a massive steel block. Drops were made repeatedly on the same side and after each drop, the blocks were examined to look for any cracks or other damage which might have been initiated by the drop.

In a second test an apparatus was constructed which caused two FSV fuel blocks suspended on pendulums to collide. Blocks were tested at various collision energies up to 10,000 impacts.

Similar tests will be undertaken on the large HTGR elements including the effect of flat face and angular impacts. The fatigue strength of various dowel designs will be included.

Data from these tests is used to establish the statistical probability of element survival when subjected to multiple impacts.

## 6. CONCLUSION

The adoption of the revised reactor configuration employing a multicavity PCRV has resulted in considerable improvement in the design of the core support structures in the larger reactor. This change has significant beneficial effects from the viewpoint of the higher seismic design requirements in the large HTGR.

An extensive analytical and testing program has been implemented to examine the behavior of the HTGR core subjected to earthquake. This program is unique in that it investigates an inelastic and unkeyed multibody structure having random response to seismic excitation. Although not yet complete, the preliminary results of the aseismic program described in this paper have reinforced the conviction that the design of the core and support structures in the large HTGR is conservative and highly amenable to location in regions of high seismicity.

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Table I. Comparison of HTGR Core Statistics

	FSV	DEL and SCE	PE
Reactor Output MW(t)	850	2000	3000
Core Dimensions, Height/Feet	19.5	23.2	27.8
Number of Fuel Regions, Diameter Full/Partial	15.6 37	20.8 37/18	20.8 61/24
Number of Fuel Elements	1482	2744	3944
Number of Fuel Columns	247	343	493
Number of Elements in Column	6	8	8
Core Pressure Drop, psi	8.4	9.7	10.0
Average Power Density, KW(t)/Liter	6.3	8.1	8.4
Fuel Element Ac Hex. Flat in.	14.0	14.17	14.17
Overall Length in.	31.0	31.22	31.22
Fuel Holes/Std. Element	210	132	132
Fuel Hole Diameter in.	0.491	0.619	0.619
Coolant Channel/Std. Element	108	72	72
Coolant Channel Dia. in.	0.625	0.826	0.826
Permanent Reflector Thk. in.			
Top/Bottom/Side (mean)	39.6/46.8/46.8	46.8/46.8/42	46.8/46.8/42
Total Weight, Reactor Graphite, 10 <sup>6</sup> lb	1.44	1.69	2.19

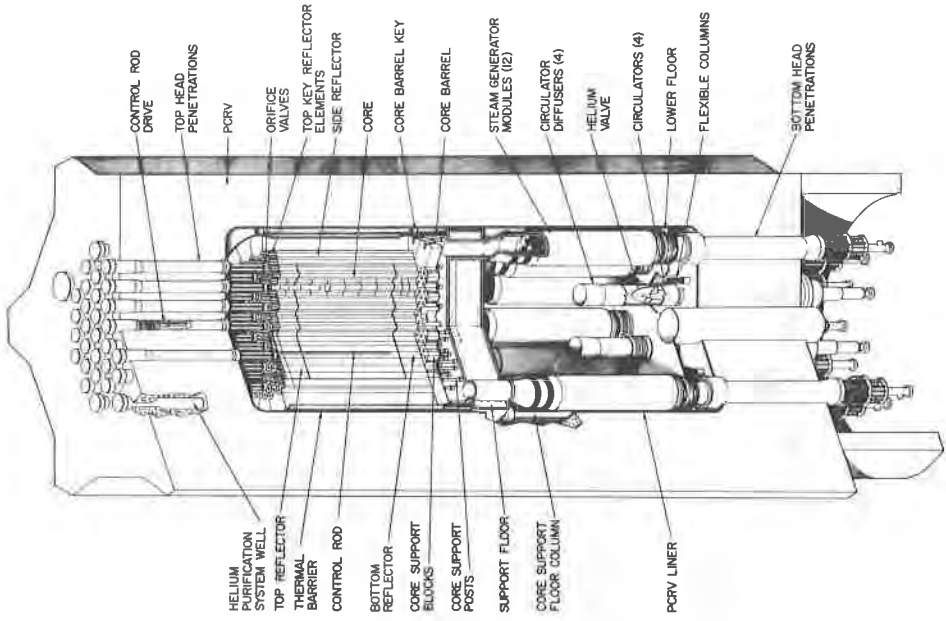


Figure 2. General Arrangement - FSV

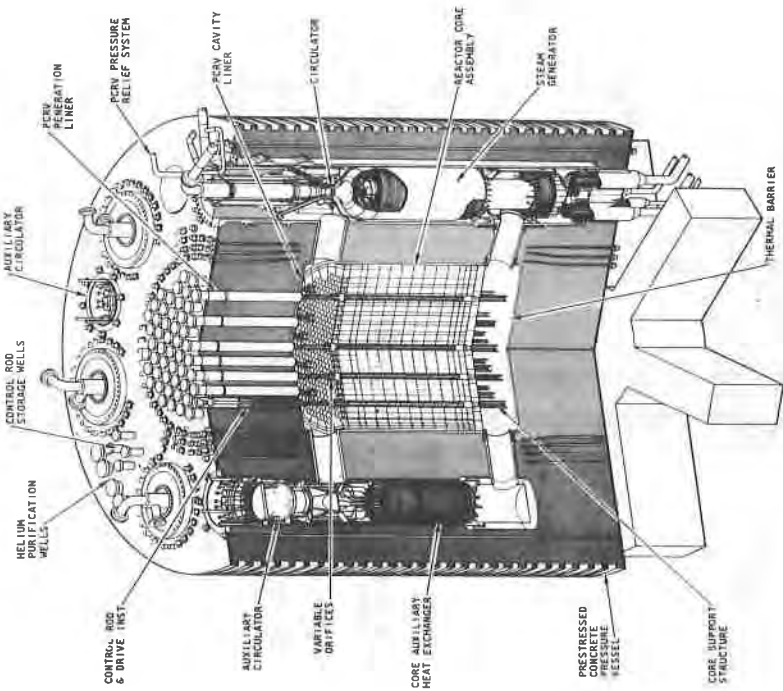


Figure 1. General Arrangement - Large HTGR

HTGR REACTOR CORE AND SUPPORT ARRANGEMENT

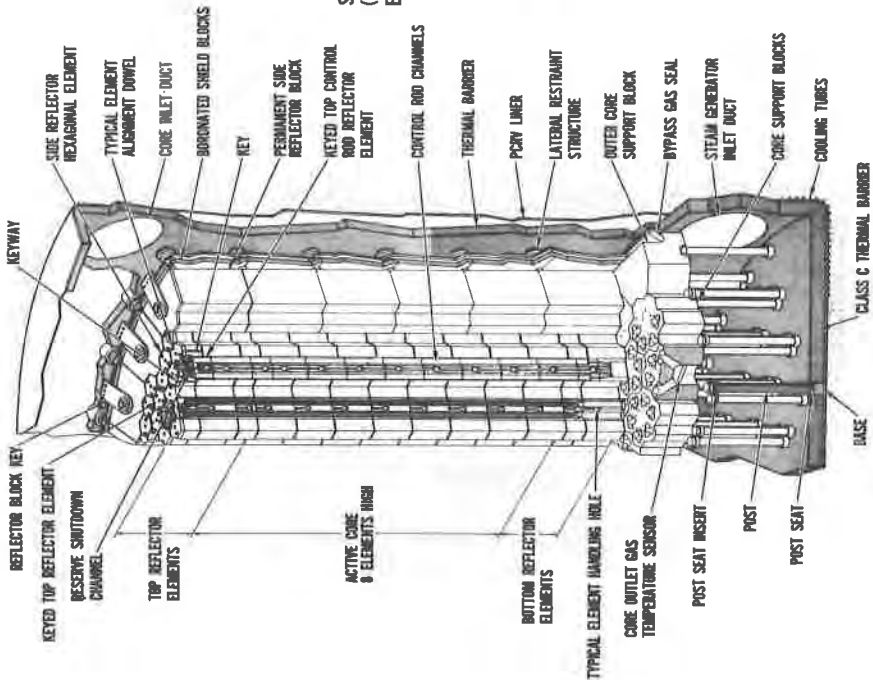


Figure 3. Core Support - Large HTGR

PIC MODEL OF PARTIAL ARRAY

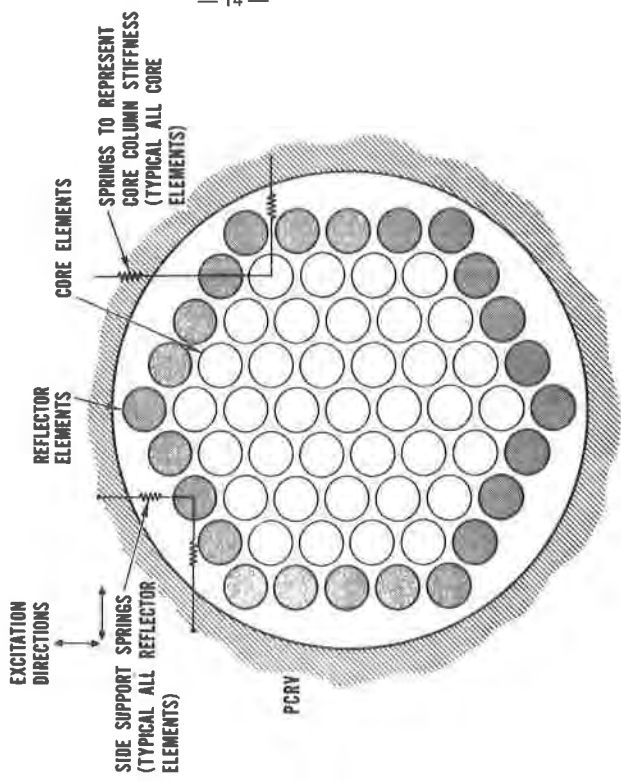
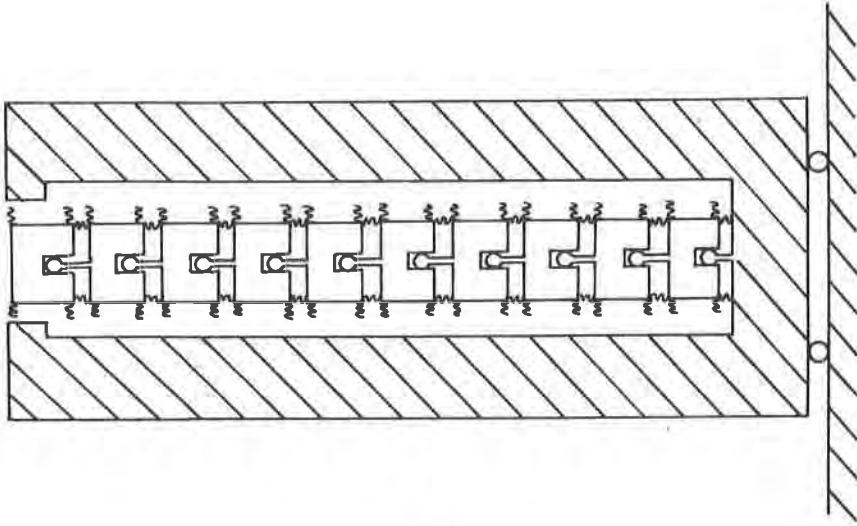


Figure 4. PIC



SECA MODEL OF CORE COLUMN

Figure 6. SECA

**COSAM 1 MODEL OF REACTOR CORE**

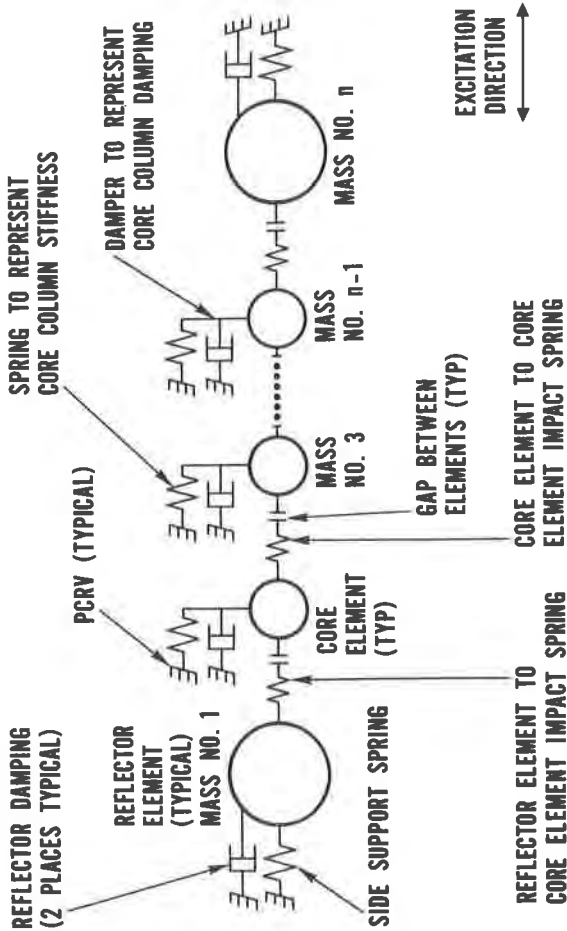


Figure 5. COSAM

