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ILLINOIS POWER COMPANY

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L05-82(01-15)-L
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January 15, 1982

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Mr. Richard E. Cunningham
Director, Division of Fuel Cycle
and Material Safety
Office of Nuclear Material Safety & Safeguards
U. S. Nuclear Regulatory Commission
Washington, D. C. 20555

Dear Mr. Cunningham:

Reference: Illinois Power Co. Letter 7/15/81, U-0260, L. J. Koch, IP to R. E. Cunningham, NRC, Subject: SNM License Application

Clinton Power Station Unit 1
Docket No. 50-461

This is in response to the verbal request of Mr. Barry Serini, NRC for some additional supporting information relative to the referenced SNM license application for the Clinton Power Station Unit 1. The information requested and furnished herewith is supplemental to that in Section 2.2, Nuclear Criticality Safety, of the referenced application.

Included in this submittal are:

1. CPS-FSAR Subsections 9.1.1 through 9.1.2.3.2.8 and all figures referenced therein (current through Amendment 11).

2. CPS-FSAR Subsections 4.2.2 through 4.2.2.3.6 and all Tables and figures referenced therein (current through Amendment 11).

3. Drawings and an explanation of the drawings which show dimensions and elevations of the new fuel vault and the upper containment fuel storage pool.

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Mr. Richard E. Cunningham
Page #2

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In addition to one signed original, seven copies of this submittal are provided. Please let us hear soon if you have any questions on this material.

Sincerely,

G. E. Wuller

G. E. Wuller
Supervisor - Licensing
Nuclear Station Engineering

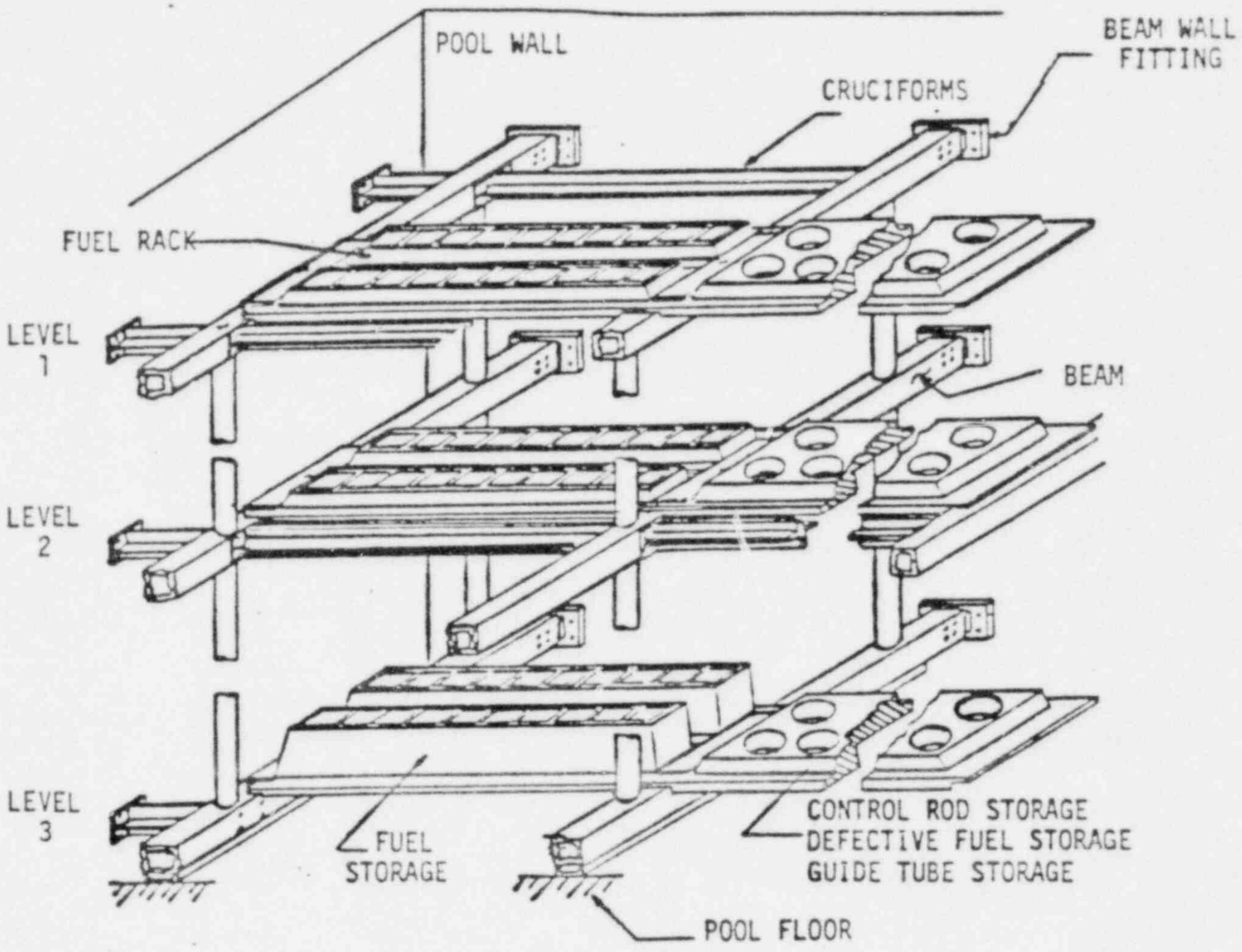
GEW/em/wp

cc: J. H. Williams, NRC Clinton Project Manager (w/o att.)
H. H. Livermore, NRC Resident Inspector (w/o att.)
B. Serini, NRC Mail Stop 396SS

Description of Drawings

Drawings 794E971 Sheets 1 and 2 show the layout of upper containment fuel storage rack and the miscellaneous braces and brackets. Figure 1 of GE document 22A3823, Sheet No. 4, Rev. 4, illustrates a three dimensional perspective of these racks. These racks will be in the lower portion of the upper pool. Drawings A27-1003-02A and A27-1003A-03A show the bottom elevation and width of this part of the storage pool. Drawings A27-1004-02A and A27-1004-03A are from a higher elevation and show the length and width of the upper portion of this containment pool. Also top wall and bottom elevations can be noted from these figures.

Drawing 794E969 illustrates the layout of the new fuel vault storage racks. The dimensions and elevations of top wall and bottom for the new fuel and spent fuel pools can be extracted from drawings S28-1001-04A, S28-1001-07A and S28-1001-08A.



NOTE:

This sketch illustrates concept only. Arrangements will vary - refer to applicable installation kit drawing.

EQUIPMENT STORAGE RACK

FIG. 1

CHAPTER 9 - AUXILIARY SYSTEMS

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CHAPTER 9 - AUXILIARY SYSTEMS

9.1 FUEL STORAGE AND HANDLING

9.1.1 New Fuel Storage

9.1.1.1 Design Bases

9.1.1.1.1 Storage Design Bases

a. New fuel storage racks are provided for approximately 38% of the full core fuel load in each unit.

b. New fuel storage racks are designed and arranged so that the fuel assemblies can be handled efficiently during refueling operations.

9.1.1.1.2 Safety Design Bases - Structural

a. The new fuel storage racks, fully loaded with fuel assemblies, are designed to withstand all credible static and dynamic loadings, to prevent damage to the structure of the racks, and therefore the contained fuel, and to minimize distortion of the racks arrangement. (See Table 3.9-2[h].)

b. The modules are designed to protect the fuel assemblies from excessive physical damage under normal or abnormal conditions caused by impacting from either fuel assemblies, bundles or other equipment.

c. The racks are constructed in accordance with the Quality Assurance Requirements of 10 CFR 50, Appendix B.

d. The new fuel storage racks are categorized as Safety Class 2 and Seismic Category I.

e. The new fuel storage facility is designed in accordance with General Design Criteria 2, 3, 4, 5, 61, 62, and 63. The new fuel storage facility is also designed in accordance with Regulatory Guides 1.13, 1.29, 1.102, 1.115, and 1.117. Its design precludes any deleterious effects on new fuel rack integrity due to phenomena such as earthquakes, tornadoes, hurricanes, flood, and turbine missiles. The new fuel storage vault is a seismic Category I structure.

9.1.1.1.3 Safety Design Bases - Nuclear

The new fuel storage rachs are designed and maintained with sufficient spacing between the new fuel assemblies to assure that the array, when racks are fully loaded, shall be subcritical, by at least 5% K_{eff} including allowance for calculational biases and uncertainties. In the calculations performed to assure that K_{eff} ≤ 0.95, the standard lattice methods (Reference 1) used at General Electric are employed. Under conditions where diffusion theory is valid, it is used in calculations. Monte Carlo techniques are employed to "bench mark" the diffusion theory results to assure accuracy.

It is assumed that the storage array is infinite in all directions. Since no credit is taken for leakage, the values reported as effective neutron multiplication factors are in reality infinite neutron multiplication factors.

The biases between the calculated results and experimental results as well as the uncertainty involved in the calculations are taken into account as part of the calculational procedure to assure that the specified K_{eff} limits are met.

9.1.1.2 Facilities Description

The location of the new fuel storage facility within the station complex is shown in Figure 1.2-6. Each new storage rack (Figure 9.1-1) holds up to 10 channeled or unchanneled assemblies in a row.

Fuel spacing (7 inches nominal center-to-center within a rack, 12.25 inches nominal center-to-center between adjacent racks) within the rack and from rack-to-rack limits the effective multiplication factor of the array (K_{eff}) to not more than 0.95. The fuel assemblies are loaded into the rack through the top. Each hole for a fuel assembly has adequate clearance for inserting or withdrawing the assembly channeled or unchanneled. Sufficient guidance is provided to preclude damage to the fuel assemblies. The upper tie plate of the fuel element rests against the rack to provide lateral support. The design of the racks prevents accidental insertion of the fuel assembly in a position not intended for the fuel. This is achieved by abutting the sides of each casting to the adjacently installed casting. In this way, the only spaces in the assembly are those into which it is intended to insert fuel. The weight of the fuel assembly is supported by the lower tie plate which is seated in a chamfered hole in the base casting.

The floor of the new fuel storage vault(s) is sloped to a drain located at the low point. This drain removes any water that may be accidentally and unknowingly introduced into the vault. The drain is part of the floor drain liquid radwaste processing and disposal system.

The new fuel storage vaults are provided with removable steel plate covers to prevent moisture and debris from entering the vault.

Curbs around the perimeter of the vault prevent the entry of liquids.

The radiation monitoring equipment for the new fuel storage area is designed in Subsections 7.7.1.9 and 12.3.4.

9.1.1.3 Safety Evaluation

9.1.1.3.1 Criticality Control

The calculations of K_{eff} are based upon the geometrical arrangements of the fuel array and subcriticality does not depend upon the presence of neutron absorbing materials. The arrangement of fuel assemblies in the fuel storage racks results in K_{eff} below 0.95 in a dry condition or completely flooded with water which has a density of 1 g/cc. To meet the requirements of General Design Criterion 62, geometrically-safe configurations of fuel stored in the new fuel array are employed to assure that K_{eff} will not exceed 0.95 if fuel is stored in the dry condition or if the abnormal condition of flooding (water with a density of 1 g/cc) occurs. In the dry condition, K_{eff} is maintained ≤ 0.95 due to under moderation. In the flooded condition, the geometry of the fuel storage array assures the K_{eff} will remain ≤ 0.95 due to over-moderation. The condition of optimum moderation is precluded, since the steel plate covers provided over the vault prevent the entry of mist.

No limitation is placed on the size of the new fuel storage array from a criticality standpoint since all calculations are performed on an infinite basis. The new fuel storage area therefore accommodates fuel from a multi-unit facility with no safety implications. All handling conditions remain the same and there is no compromise of any safety considerations.

9.1.1.3.2 New Fuel Rack Design

The new fuel rack design is illustrated in Figure 9.1-1.

a. The new fuel storage vault contains 24 sets of castings which may contain up to 10 fuel assemblies; therefore a maximum of 240 fuel assemblies may be stored in the new fuel vault.

b. The storage racks provide an individual storage compartment for each fuel assembly and are secured to the vault wall through associated hardware. The fuel assemblies are stored in a vertical position, with the lower tie plate engaging in a captive hole in the lower fuel rack support casting.

c. The weight of the fuel assembly is held by the lower support casting.

d. The new fuel storage racks are made from aluminum. Materials used for construction are specified in accordance with the latest issue of applicable ASTM specifications. The material choice is based on a consideration of the susceptibility of various metal combinations to electrochemical reaction. When considering the susceptibility of metals to galvanic corrosion, aluminum and stainless steel are relatively close together insofar as their coupled potential is concerned. The use of stainless steel fasteners in aluminum to avoid detrimental galvanic corrosion is a recommended practice and has been used successfully for many years by the aluminum industry.

e. The nominal center-to-center spacing for the fuel assembly between rows is 12.25 inches. The nominal center-to-center spacing for the fuel within the rows is 7.00 inches. Fuel assembly placement between rows is not possible.

f. Lead-in and lead-out guides at the top of the racks provide guidance of the fuel assembly during insertion or withdrawal.

g. The rack is designed to withstand the impact force generated by the vertical free fall of a fuel assembly from the height of 6 feet while maintaining the safety design basis. Fuel will not be elevated to a height of more than 6 feet above the new fuel storage racks due to upward travel limits on the handling equipment hoists.

h. The storage rack is designed to withstand the pull-up force of 4000 pounds and a horizontal force of 1000 pounds. The racks are designed with lead outs to prevent sticking. However, in the event of a stuck fuel assembly, the fuel handling platform auxiliary hoist which is used to remove the fuel, is limited to a maximum lifting force of 1000 pounds.

i. The fully loaded storage rack is designed to withstand acceleration levels associated with the design basis earthquake.

j. The fuel storage rack is designed to handle non-irradiated, mildly radioactive fuel assemblies. The expected radiation levels are well below the design levels.

k. The fuel storage rack is designed using non-combustible materials. Plant procedures and inspections assure that combustible materials are restricted from this area. Fire prevention by elimination of combustible materials and fluids is regarded as the prudent approach rather than fire accomodation and the need for fire suppressant materials which could inhibit or negate criticality control assurances. Therefore, fire accommodations is not considered a problem.

1. The fuel storage racks are provided protection from adverse environmental effects by proper design of the new fuel storage facility.

9.1.1.3.3 Protective Features of New Fuel Storage Vault

The new fuel storage vault is provided with removable aluminum checkerplate covers. To prevent moisture and debris from entering the vault, the covers will normally be in place over the vault, except when new fuel is to be inserted or removed from the rack.

The new fuel storage vault is provided with embedded angle frame perimeter. This frame extends above floor level and prevents liquids from entering the vault.

9.1.2 Spent Fuel Storage

There will be two types of spent fuel storage racks in use at CPS. High-density racks utilizing a neutron poison are installed in the fuel building spent fuel storage facility. Cast aluminum racks are in the upper containment fuel storage area.

9.1.2.1 Design Bases

9.1.2.1.1 Safety Design Bases

9.1.2.1.1.1 Safety Design Bases - Structural

a. The spent fuel storage racks are designed to withstand all credible static and dynamic loadings to prevent damage to the structure of the racks and the stored spent fuel and to minimize distortion of the rack arrangement.

b. The spent fuel storage racks are designed to protect the fuel assemblies from excessive physical damage which could cause the release of radioactive materials in excess of 10 CFR 20 and 10 CFR 100 limits.

c. The spent fuel storage racks are categorized as Seismic Category I.

d. The spent fuel storage racks are constructed in accordance with the quality assurance requirements of 10 CFR 50, Appendix B.

e. The spent fuel storage facility is also designed in accordance with General Design Criteria 2, 3, 4, 5, 61, 62, and 63. The spent fuel storage facility is also designed in accordance with Regulatory Guides 1.13, 1.29, 1.102, 1.115, and 1.117. Its design precludes any deleterious effects on spent fuel rack integrity due to phenomena such as earthquakes, tornadoes, hurricanes, floods, and turbine missiles.

9.1.2.1.1.2 Safety Design Bases - Nuclear

The fuel array in the fully loaded spent fuel racks is designed so that $K_{eff} \leq 0.95$.

9.1.2.1.2 Power Generation Design Bases

Storage space for spent fuel is provided in the fuel building spent fuel storage pool and in the upper containment fuel storage pool. The fuel building spent fuel storage pool contains sufficient storage space for approximately 400% of one full core fuel load. The upper containment fuel storage pool, which will be used only during refueling operations (racks will contain no fuel during plant operation), contains sufficient storage space for approximately 25% of one full core fuel load.

9.1.2.2 Facilities Description

The spent fuel storage racks provide a place in the respective fuel pools for storing spent fuel assemblies. Use of proper geometry, and in the case of the fuel building spent fuel storage pool, a neutron poison, precludes the possibility of criticality in the storage racks under normal and abnormal conditions. The location of the spent fuel storage facilities within the station complex is shown in Figure 1.2-5.

9.1.2.2.1 Fuel Building Spent Fuel Storage Pool

9.1.2.2.1.1 Spent Fuel Storage Array

The spent fuel storage array is composed of 22 individual free-standing racks (shown in Figure 9.1-2a). The racks are positioned within the pool to provide rack-to-rack and rack-to-wall spacing sufficient to preclude impact/collision during a seismic event.

9.1.2.2.1.2 Rack Construction

Each rack is composed of square storage cells which are corner-connected in a checker-board fashion. Spent fuel assemblies are placed either in the storage cell themselves or in the spaces formed by the outside surfaces of four adjacent cells. The support feet of the racks contain remotely adjustable jack-screws to achieve required levelness.

9.1.2.2.1.3 Storage Cell Construction

The storage cell walls are composed of three layers. The inner and outer layers are stainless steel. The middle layer is BORAL, a neutron poison material which is a physical mixture of boron carbide and particulate aluminum. The BORAL is employed to prevent criticality. In all structural integrity and stress calculations, only the layers of stainless steel were considered.

9.1.2.2.1.4 Spacing

Fuel assemblies are stored at a nominal 6.4375-inch, center-to-center spacing in a rectangular-pitch array.

9.1.2.2.1.5 Capacity

The spent fuel pool contains 22 racks to store a maximum of 2,512 fuel assemblies plus 10 failed fuel canisters.

9.1.2.2.1.6 Fuel Containment

The fuel assemblies are stored in a vertical position. The rack arrangement is designed to prevent accidental insertion of fuel bundles between adjacent racks.

9.1.2.2.2 Upper Containment Fuel Storage Pool

9.1.2.2.2.1 Rack Construction

The racks are pinned to the rack support structure. All racks are built with a common mounting dimension to facilitate rack re-arrangement or replacement and are secured to the pool wall with associated hardware.

9.1.2.2.2.2 Spacing

The rack holddown bolt spacing is maintained large enough to prevent criticality from the geometry considerations alone. The racks are designed to maintain a nominal fuel storage cell spacing of 7 inches (center-to-center) within a rack and 12.25 inches (center-to-center) from rack to rack.

9.1.2.2.2.3 Capacity

Each standard spent fuel rack (shown in Figure 9.1-2b) stores 10 fuel assemblies. A minimum of 16 fuel storage racks will be utilized, which will facilitate storage of 160 fuel assemblies (approximately 25% one full core fuel load). Additional fuel storage racks may be utilized if determined to be beneficial for refueling expendiency. Additional storage racks are available for storage of control rods, control rod guide tubes, defective fuel storage canisters, and fuel channels. These special castings prevent fuel from exceeding K_{eff} of 0.95 in the event that fuel is inserted in these positions.

9.1.2.2.2.4 Fuel Containment

The storage racks provide an individual storage location for each fuel assembly. Each fuel assembly is stored in a vertical position with the lower tie plate engaged on a captive slot in the lower fuel rack support casting. The weight of the fuel assembly is held by the lower rack support casting.

The rack arrangement is designed to prevent accidental insertion of fuel bundles between adjacent racks. The storage rack structure is so designed that the upper tie plate casting cannot be lowered below the top of the upper rack. This prevents any tendency of the fuel bundle jamming on insertion or removal from the rack. Lead-in and lead-out guides at the top of the racks provide guidance of the fuel assembly during insertion or withdrawal.

9.1.2.3. Safety Evaluation

9.1.2.3.1 Criticality Control

The design of the spent fuel storage racks provides for a subcritical multiplication factor K_{eff} of ≤ 0.95 for normal and abnormal storage conditions. Normal conditions exist when the fuel storage racks are covered with approximately 25 feet of water above the stored fuel and contain any possible number of fuel bundles. An abnormal condition may result from the accidental drop of a fuel assembly onto a loaded fuel rack or the placement of a fuel assembly adjacent to, or lying horizontally across the top of a loaded rack.

9.1.2.3.1.1 Design Analyses for Spent Fuel Pool

To ensure that the design criteria are met, the following conditions were analyzed for the spent fuel pool storage racks:

a. Normal positioning in the spent fuel storage array.

b. Eccentric positioning in the spent fuel storage array (Figure 9.1-3a).

c. Storage cell wall thickness variation.

d. Storage cell inside diameter variation.

e. Fuel enrichment variation.

f. Poison concentration variation.

g. A fuel assembly positioned adjacent to a loaded fuel rack.

h. A fuel assembly lying horizontally across the top of loaded fuel racks.

i. Rack loaded with 10% compacted fuel to represent a dropped fuel assembly.

j. Pool water temperatures varied from 68° to 260° F.

9.1.2.3.1.2 Design Analyses for Upper Containment Fuel Pool

To ensure that the design criteria are met, the following spent fuel storage conditions were analyzed for the upper containment fuel pool:

a. Normal positioning in the spent fuel storage array.

b. Eccentric positioning in the spent fuel storage array (Figure 9.1-3a).

c. Fuel stored in control rod racks (Figure 9.1-3b).

d. Pool water temperature increases to 212° F.

e. Two bundles placed side by side while separated from the storage racks area by 12.25 inches of water (Figure 9.1-3c).

f. Three-bundle tee array separated from the storage rack area by 12 inches of water (Figure 9.1-3c).

g. Three-bundle linear array separated from the storage rack area by 12 inches of water (Figure 9.1-3c).

h. Normal storage array of ruptured fuel.

i. Abnormal condition of pool being drained and ruptured fuel containers being flooded.

j. Moving fuel bundle in aisle between storage racks.

k. Grapple drop displacing two fuel bundles (Figure 9.1-3c).

l. Four-bundle square array separated from the storage rack area by 12 inches of water (Figure 9.1-3c).

m. Moving fuel bundle between work platform and storage area.

The spent fuel storage racks in the upper containment fuel pool maintain K_{eff} ≤0.95 under these conditions.

9.1.2.3.1.3 Analytical Methods

Standard lattice methods and Monte Carlo techniques were employed in the calculations performed to assure that the design criteria are met. For the fuel building spent fuel storage facility, it was assumed that the storage array is infinite in all directions. Since no credit was taken for leakage, the reported effective neutron multiplication factors are in reality infinite multiplication factors. The biases between the calculated results and the experimental results, as well as the uncertainty invovled in the calculations, were taken into account as part of the calcuational procedure to assure that the specified K_{eff} limits were met. The models employed have been verified via a series of benchmarking analyses of critical experiments conducted with typical LWR fuel lattices, with and without various poison absorbers.

9.1.2.3.1.4 Use of Poison in the Fuel Building Spent Fuel Storage Pool Racks

A neutron absorbing poison material, BORAL, aids in maintaining a subcritical configuration. See Subsection 9.1.2.2.1.3 for further description.

9.1.2.3.2 Control of Other Hazards

9.1.2.3.2.1 Radiation

The fuel storage racks are composed of all metal components and as such will not be adversely affected by exposure to radiation from the stored fuel. Adequate water shielding had been provided for both storing and transporting fuel in the spent fuel pool. Liquid level sensors are installed to detect and alarm on a low pool water level, and adequate makeup water is available to assure that the water level is maintained above the stored fuel for shielding and heat removal.

9.1.2.3.2.2 Corrosion

The racks in the spent fuel pool are made of stainless steel to minimize corrosion. The racks in the upper containment fuel pool are made from aluminum. Materials used for construction are specified in accordance with the latest issue of applicable ASTM specifications. The material choice is based on a consideration of the susceptibility of various metal combinations to electrochemical reaction. When considering the susceptibility of metals to galvanic corrosion, aluminum and stainless steel are relatively close together insofar as their coupled potential is concerned. The use of stainless steel fasteners in aluminum to avoid deterimental galvanic corrosion is recommended practice and has been used successfully for many years by the aluminum industry.

9.1.2.3.2.3 Earthquakes

There are no connections of the fuel building spent fuel storage racks in the spent fuel storage pool walls or floor; therefore the potential for movement exists. The fuel racks have been analyzed using a nonlinear time-history method which accounts for the hydrodynamic possibilities of sliding and tipping. The analyses conclude that the maximum relative sliding and/or tipping displacement along the floor is well within the clearance between fuel racks and the pool walls and appurtenances and that the racks will not tip over. The analyses also show that the resulting stresses are within the allowable limits given in ASME Section III, Subsection NF.

The storage racks in the containment upper fuel pool are designed to withstand a single horizontal force of 1000 pounds and horizontal combined loads of up to 222,000 pounds well in excess of expected loads.

9.1.2.3.2.4 Impact Forces

The storage racks in both pools are designed to withstand the impact force generated by the vertical free fall of a fuel assembly from the height of 6 feet while maintaining the safety design basis.

9.1.2.3.2.5 Pull-Up Forces

The storage racks in the containment upper fuel pool are designed to withstand a pull-up force of 4000 pounds. There are no readily available forces in excess of 1000 pounds. The racks are designed with lead outs to prevent sticking.

The storage racks in the fuel building spent fuel storage pool are designed to withstand a pull-up force of 1200 pounds. There are no readily available forces in excess of 1000 pounds. The racks are designed to permit smooth withdrawal.

9.1.2.3.2.6 Tornadoes

The capability of the fuel storage facilities to prevent missiles generated by high winds from contacting the fuel is discussed in Subsection 3.5.2.

9.1.2.3.2.7 Fire

Since the fuel racks are made of noncombustible material and are stored under water, there is no potential fire hazard.

9.1.2.3.2.8 Pipe Breaks

The large water volume in the fuel storage pools protects the racks from potential pipe breaks and associated jet impingement loads.

From the foregoing analyses, it is concluded that the spent fuel storage arrangement meets its safety design bases.

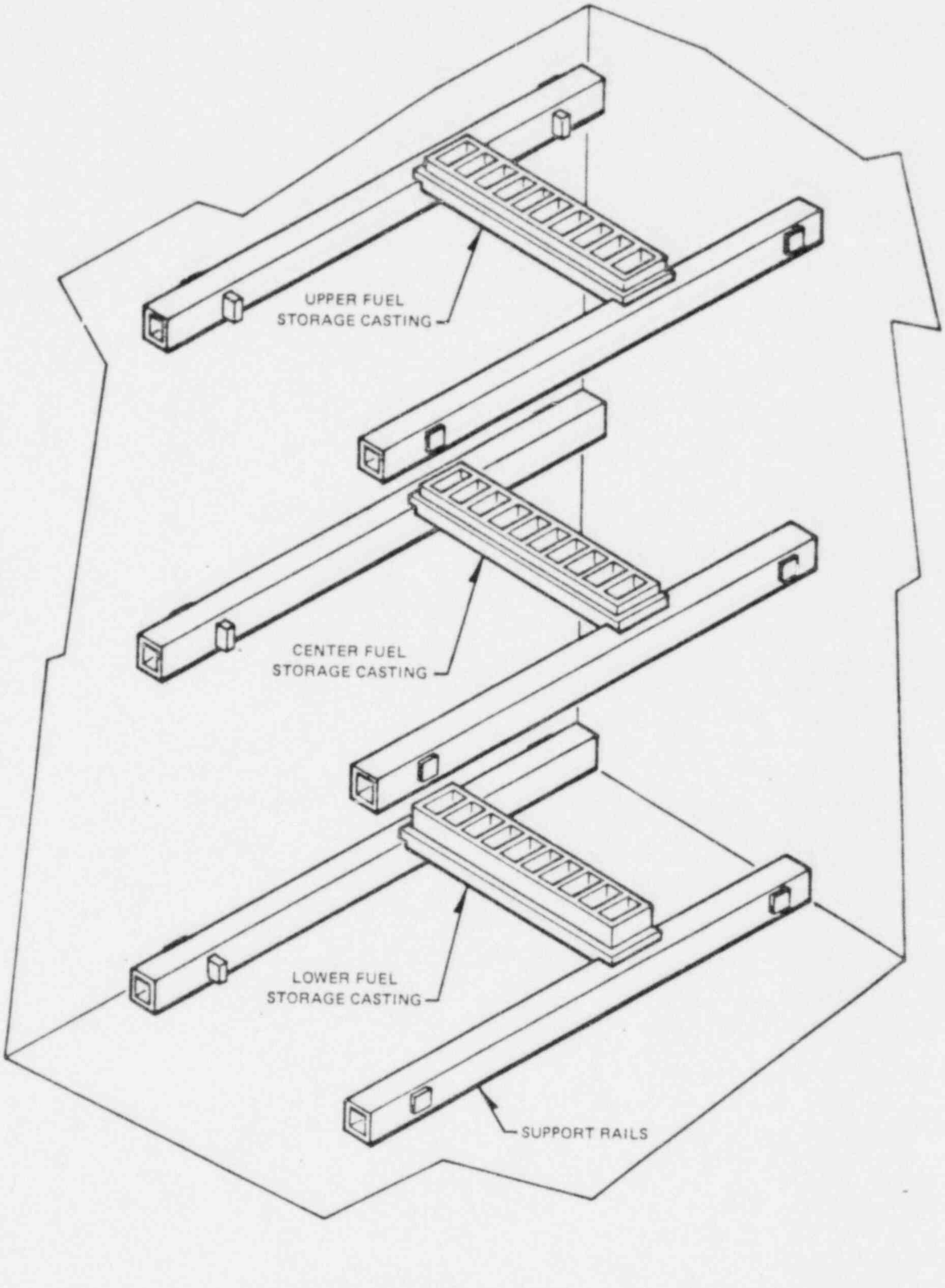

Figure 9.1-1. New Fuel Storage Vault

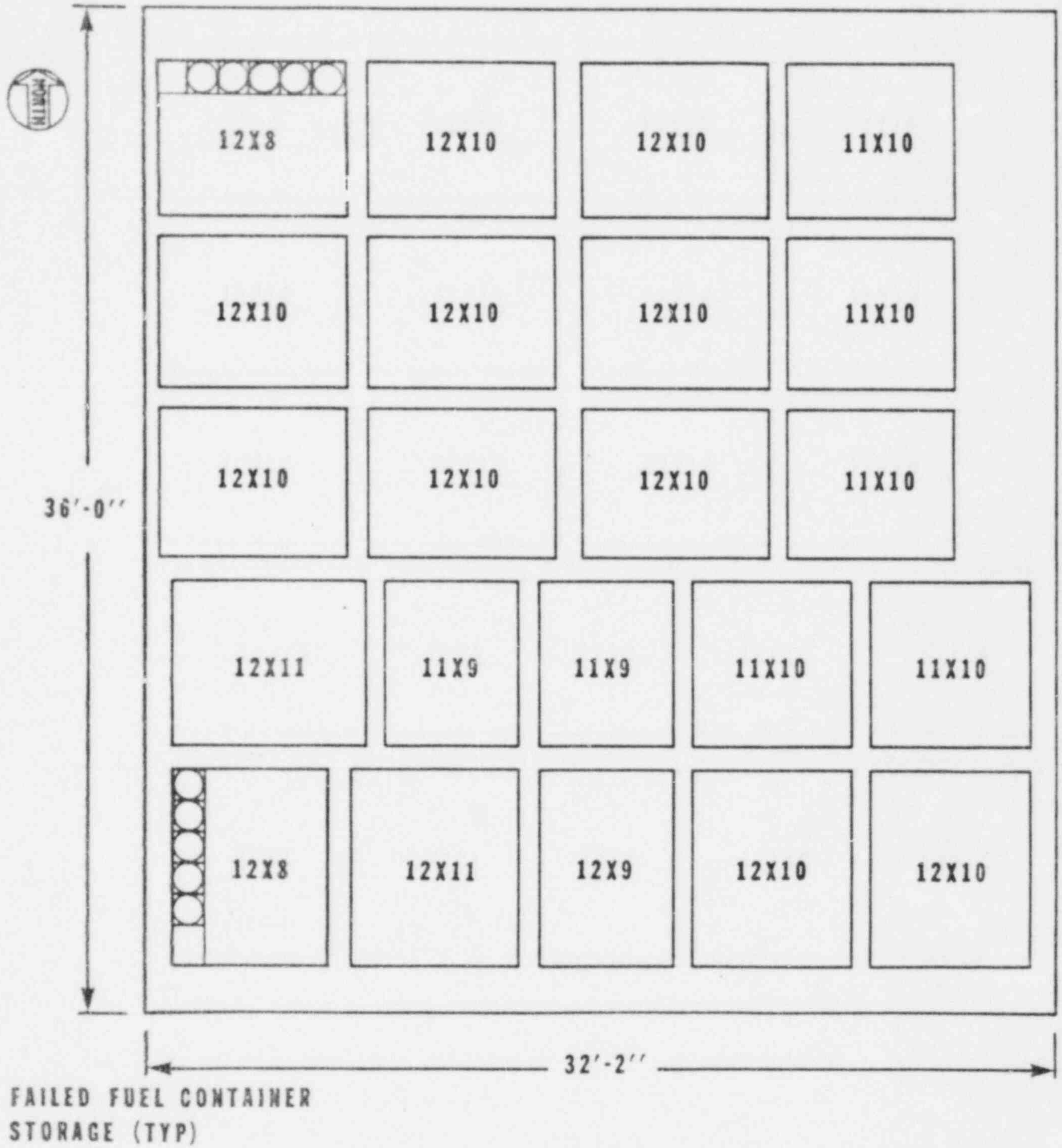

FIGURE 9.1-2a FUEL STORAGE RACK ARRANGEMENT

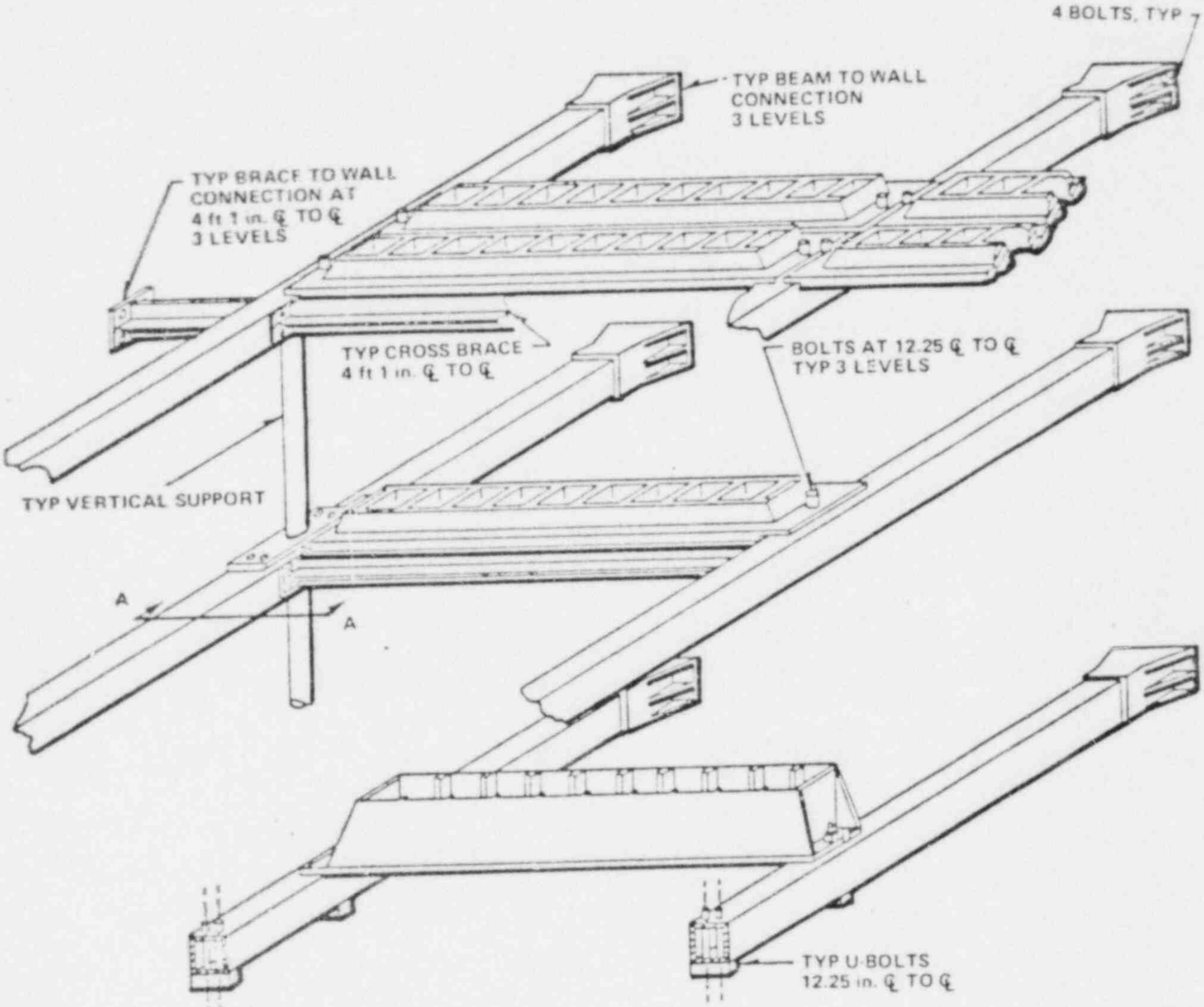

Figure 9.1-2b. Upper Containment Fuel Storage Rack

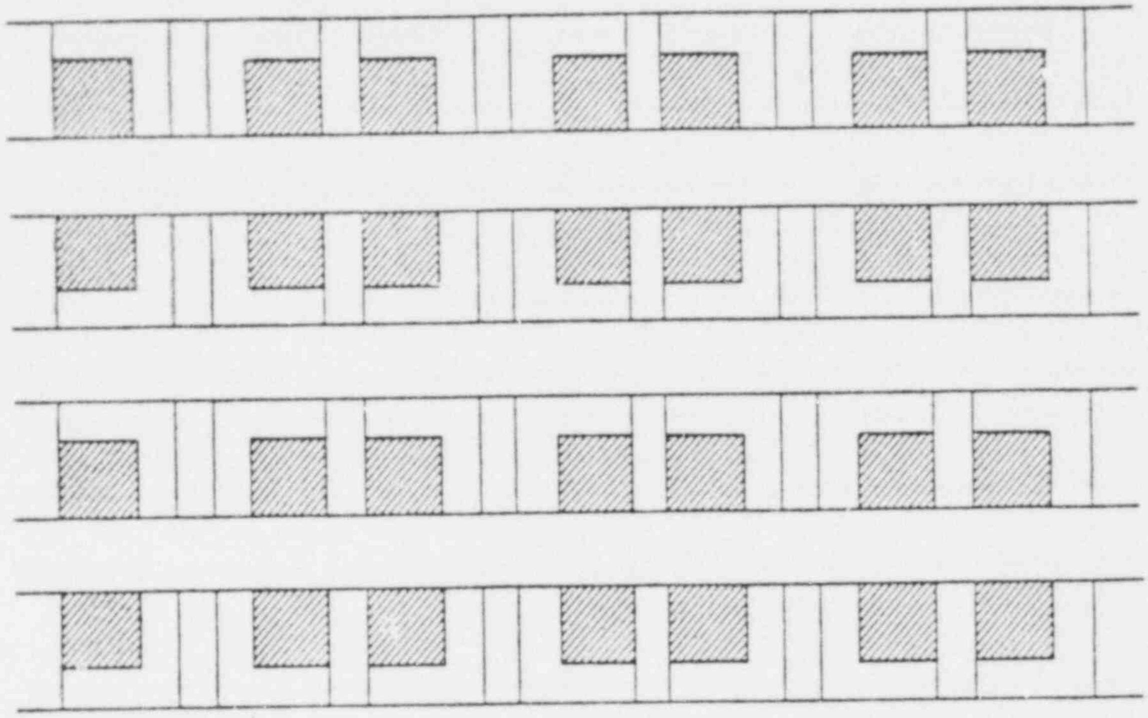

Figure 9.1-3a. Eccentric Fuel Positioning

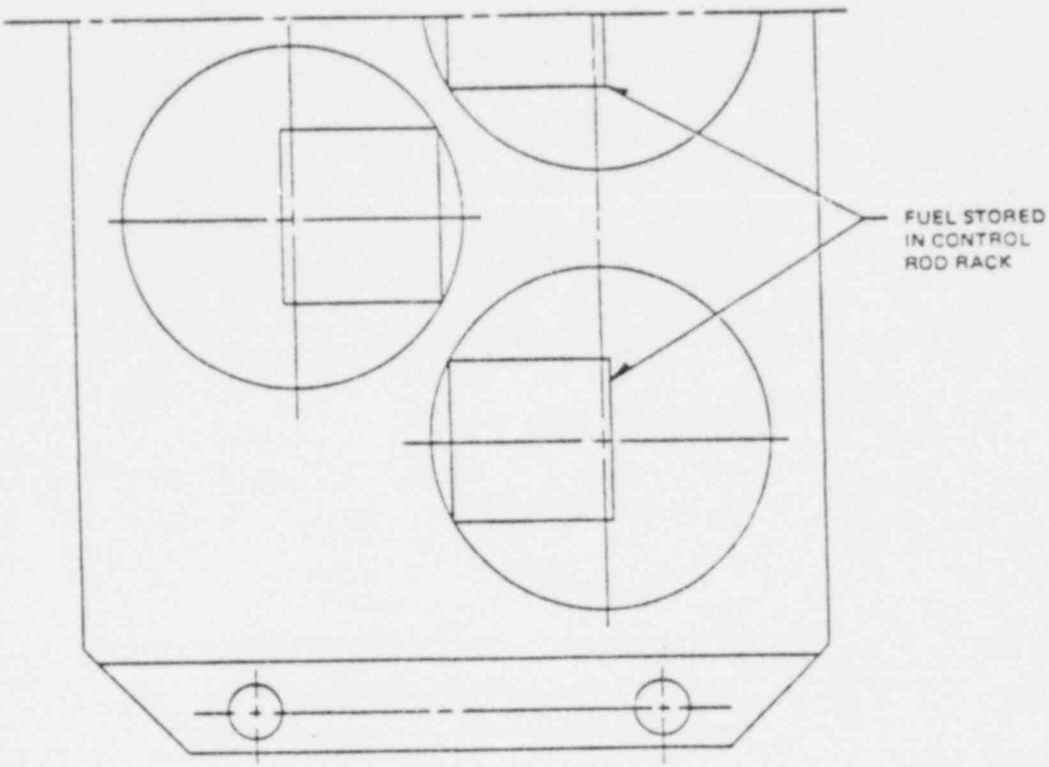

Figure 9.1-3b. Fuel Stored in Control Rod Racks

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4.2.1.2.2.4 Material Selection

The selection of materials for use in the control rod design is based upon their in-reactor properties. The irradiated properties of Type-304 austenitic stainless steel which comprises the major portion of the assembly, B_4C powder, Inconel X-750, and Stellite are well known and are taken into account in establishing the design of the control rod components. The basic cruciform control rod design and materials have been operating successfully in all General Electric reactors.

4.2.1.2.2.5 Radiation Effects

The radiation effects on B_4C powder include the release of gaseous products and swelling. The B_4C cladding is designed to sustain the resulting internal pressure buildup due to gaseous products, and the lifetime of the control rod has been established to minimize the effects of swelling. The corrosion rate and the physical properties, e.g., density, modulus of elasticity, dimensional aspects, etc., of austenitic stainless steel, and Inconel X-750 are essentially unaffected by the irradiation experienced in the BWR reactor core. The effects upon the mechanical properties, i.e., yield strength, ultimate tensile strength, percent elongation, and ductility on the 304 stainless steel cladding also are well known and are considered in mechanical design.

4.2.1.2.2.6 Positioning Requirements

Rod positioning increments (not lengths) are selected to provide adequate power shaping capability. The combination of rod speed and notch length must also meet the limiting reactivity addition rate criteria.

4.2.1.2.2.7 Burnable Poison Rods

The design basis of the initial core supplementary fuel/reactivity control rods ($UGdO_2$) is the same as UO_2 fuel rods. Additional information on urania-gadolinia physical and irradiation characteristics and material properties is provided in Reference 31.

4.2.2 General Design Description

4.2.2.1 Core Cell

A core cell consists of a control rod and the four fuel assemblies which immediately surround it. Figure 4.3-2 provides core cell dimensions. Each core cell is associated with a four-lobed fuel support piece. Around the outer edge of the core, certain fuel assemblies are not immediately adjacent to a control rod and are supported by individual peripheral fuel support pieces.

The top guide is an "egg-crate" structure of stainless steel bars which form a 4-bundle cell. The four fuel assemblies are lowered into this cell and, when seated, springs mounted at the tops of the channels force the channels into the corners of the cell such that the sides of the channel contact the grid beams (see Figure 4.2-3).

4.2.2.2 Fuel Assembly

A fuel assembly consists of a fuel bundle and the channel which surrounds it (see Figure 4.2-4). The fuel assemblies are arranged in the reactor core to approximate a right circular cylinder inside the core shroud. Each fuel assembly is supported by a fuel support piece and the top guide.

The general configuration of the fuel assembly and the detailed configurations of the assembly components are the results of the evolutionary change in customer, performance, manufacturing, and serviceability requirements and the experience obtained since the initial design conception. A summary of fuel assembly mechanical data is presented in Table 4.2-4.

4.2.2.2.1 Fuel Assembly Orientation

Proper orientation of fuel assemblies in the reactor core is readily verified by visual observation and is assured by verification procedures during core loading. Five separate visual indications of proper fuel assembly orientation exist:

(1) The channel fastener assemblies, including the spring and guard used to maintain clearances between channels, are located at one corner of each fuel assembly adjacent to the center of the control rod.

(2) The identification boss on the fuel assembly handle points toward the adjacent control rod.

(3) The channel spacing buttons are adjacent to the control rod passage area.

(4) The assembly identification numbers, which are located on the fuel assembly handles, are all readable from the direction of the center of the cell.

(5) There is cell-to-cell replication.

Experience has demonstrated that these design features are clearly visible so that any misoriented fuel assembly would be readily distinguished during core loading verification.

4.2.2.3 Fuel Bundle

A fuel bundle contains 62 fuel rods and 2 water rods which are spaced and supported in a square (8x8) array by 7 spacers and the lower and upper tie plates. The lower tie plate has a nosepiece which has the function of supporting the fuel assembly in the reactor. The upper tie plate has a handle for transferring the fuel bundle from one location to another. The identifying assembly number is engraved on the top of the handle and a boss projects from one side of the handle to aid in assuring proper fuel assembly orientation. Both upper and lower tie plates are fabricated from Type-304 stainless steel castings. Finger springs, of the same design previously used with 7x7 and 8x8 initial core and reload fuel, are also employed with the BWR 6 fuel design. The finger springs are located between the lower tie plate and the channel for the purpose of controlling the bypass flow through that flowpath (see subsection 4.2.2.3.6). Zircaloy-4 fuel rod spacers equipped with Inconel X-750 springs maintain fuel rod-to-fuel rod spacing.

4.2.2.3.1 Fuel Rods

Each fuel rod consists of high density (95 percent theoretical density) UO_2 fuel pellets stacked in a Zircaloy-2 cladding tube which is evacuated, backfilled with helium at 3 atmospheres pressure, and sealed by Zircaloy end plugs welded in each end. The 150-inch active fuel column includes a 6-inch zone of naturally enriched (0.711 wt% U-235) pellets at both the top and bottom. The fuel rod cladding thickness is adequate to be essentially free-standing under the 1000 psia BWR environment. Adequate free volume is provided within each fuel rod in the form of pellet-to-cladding gap and a plenum region at the top of the fuel rod to accommodate thermal and irradiation expansion of the UO_2 and the internal pressures resulting from the helium fill gas, impurities, and gaseous fission products liberated over the design life of the fuel. A plenum spring, or retainer, is provided in the plenum space to prevent movement of the fuel column inside the fuel rod during fuel shipping and handling (see Figure 4.2-4). A hydrogen getter is also provided in the plenum space as assurance against chemical attack from the inadvertent admission of moisture of hydrogenous impurities into a fuel rod during manufacture.

Two types of fuel rods are utilized in a fuel bundle: tie rods and standard rods (Figure 4.2-5). The eight tie rods in each bundle have lower end plugs which thread into the lower tie plate casting and threaded upper end plugs which extend through the upper tie plate casting. A stainless steel hexagonal nut and locking tab are installed on the upper end plug to hold the fuel bundle together. These tie rods support the weight of the assembly only during fuel handling operations when the assembly hangs by the handle; during operation, the fuel rods are supported by the lower tie plate. Fifty-four rods in the bundle are standard fuel rods. The end plugs of the standard rods have shanks which fit into bosses in the tie plates.

An Inconel X-750 expansion spring is located over the upper end plug shank of each rod in the assembly to keep the rods seated in the lower tie plate while allowing independent axial expansion by sliding within the holes of the upper tie plate. Additional information concerning the fuel rod expansion spring is provided in section 7 of Reference 4.

The fuel bundles incorporate the use of small amounts of gadolinium as a burnable poison in selected standard fuel rods.

The irradiation products of this process are other gadolinium isotopes having low cross sections. The control augmentation effect disappears on a predetermined schedule without changes in the chemical composition of the fuel or the physical makeup of the core. Some assemblies contain more gadolinia than others to improve transverse power flattening. Also, some assemblies contain axially distributed gadolinia to improve axial power flattening. Gd_2O_3 is uniformly distributed in the UO_2 pellet and forms a solid solution. The gadolinia-urania fuel rods are fabricated using characteristic extended end plugs. These extended end plugs permit a positive visual check on the location of each gadolinia-bearing rod after bundle assembly.

4.2.2.3.1.1 Fuel Pellets

T fuel pellets consist of high density ceramic uranium-dioxide manufactured by compacting and sintering uranium-dioxide powder into right cylindrical pellets with flat ends and chamfered edges. Some of the pellets contain small amounts of gadolinia as a burnable poison. The average pellet immersion density is approximately 95 percent of the theoretical density of UO_2. Ceramic uranium-dioxide is chemically inert to the cladding at operating temperatures and is resistant to attack by water. Several U-235 enrichments are used in the fuel assemblies to reduce the local power peaking factor. Fuel element design and manufacturing procedures have been developed to prevent errors in enrichment locations within a fuel assembly.

4.2.2.3.2 Water Rods

Two rods in each fuel bundle are hollow water tubes, one of which (the spacer-positioning water rod) positions the seven Zircaloy-4 fuel rod spacers axially in the fuel bundle. The water rods are made from Zircaloy-2 tubing of slightly larger diameter and thinner wall than the fuel rods. Several holes are punched around the circumference of each of the water rods near each end to allow coolant water to flow through the rod. Both water rods have square lower end plugs to prevent rotation. The spacer-positioning water rod is equipped with 14 tabs which are welded to its exterior. The spacer-positioning water rod and fuel spacers are assembled by sliding the water rod through the appropriate spacer cell with the welded tabs oriented in the direction of the corner of the spacer cell away from the spacer spring. The rod is then rotated so that the tabs are positioned above and below the spacer structure. The spacer-positioning rod is prevented from rotating and unlocking the spacers by engagement of its square lower end plug with the lower tie plate hole.

Differential thermal expansion between the fuel rods and the water rods can introduce axial loadings into the water rod through the frictional forces between the fuel rods and the spacers. The testing which was performed to address this condition, and to verify the water rod/spacer conceptual design, is discussed in section 2 of Reference 4 and in Reference 14.

4.2.2.3.3 Fuel Spacer

The primary function of the fuel spacer is to provide lateral support and spacing of the fuel rods, with consideration of thermal-hydraulic performance, fretting wear, strength, neutron economy, and producibility. The spacer represents an optimization of these considerations. Mechanical design of the BWR 6 spacer is similar, in concept, to that of the current 7x7 and 8x8 spacers.

The mechanical loadings on the spacer structure during normal operation and transients result from the rod-positioning spacer spring forces, from local loadings at the water rod-spacer positioning device, and a small pressure drop loading. During a seismic event, the spacer must transmit the lateral acceleration loadings from the fuel rods into the channel, while maintaining the spatial relationship between the rods.

As noted, the spacer represents an optimization of a number of considerations. Thermal-hydraulic development effort has gone into designing the particular configuration of the spacer parts. The resultant configurations give enhanced hydraulic performance. Extensive flow testing has been performed employing prototypical spacers to define single-phase and two-phase flow characteristics.

During the blowdown portion of the postulated loss-of-coolant accident (LOCA), the hydraulic (pressure differential) forces on the spacer are of about the same magnitude as those present during normal or transient operation of the fuel. There are no significant lateral hydraulic forces on the spacer, because the fuel channel maintains the normal flow path during the blowdown.

4.2.2.3.4 Fuel Channel

The fuel channel enclosing the fuel bundle is fabricated from Zircaloy-4 and performs three functions: (1) the channel provides a barrier to separate two parallel flow paths--one for flow inside the fuel bundle and the other for flow in the bypass region between channels; (2) the channel guides the control rod and provides a bearing surface for it, and (3) the channel provides rigidity for the fuel bundle. The channel is open at the bottom and makes a sliding seal fit on the lower tie plate surface. At the top of the channel, two diagonally opposite corners have welded tabs, one of which supports the weight of the channel from a raised post on the upper tie plate. One of these raised posts has a threaded hole, and the channel is attached using the threaded channel fastener assembly, which also includes the fuel assembly positioning spring. Channel-to-channel spacing is provided for by means of the fuel assembly positioning spring and the spacer buttons which are located on the upper portion of channel adjacent to the control rod passage area. Axial differential thermal expansion between the fuel bundle and its channel is accommodated at the lower tie plate.

In addition to meeting design limits, assurance is provided that the channels maintain their dimensional integrity, strength, and spatial position throughout their lifetime through specifications on the channel materials and manufacturing processes and by quality measurements and process qualifications to ensure compliance with these specifications.

Under situations of adverse tolerance stackup, differential thermal expansion between the stainless steel tie plates and the Zircaloy channel can result in an interference fit; however, the resultant stress and strain levels in the channel do not exceed design limits. The loads and resultant stress imposed on the fuel channel in the event of control rod interference are also within design limits.

4.2.2.3.5 Tie Plates

The upper and lower tie plates serve the functions of supporting the weight of the fuel and positioning the rod ends during all phases of operation and handling. The loading on the lower tie plate during operation and transients is comprised of the fuel weight, the weight of the channel, and the forces from the expansion springs at the top of the fuel rods. The loading on the upper tie plate during operation is due to the expansion spring force. The expansion springs permit differential expansion between the fuel rods without introducing high axial forces into the rods.

Most of the loading on the lower tie plate is due to the weight of the fuel rods and the channel, which are not cyclic loadings. During accidents, the tie plates are subjected to the normal operational loads plus the blowdown and seismic loadings. During handling, the tie plates are subjected to acceleration and impact loadings.

4.2.2.3.6 Finger Springs

Finger springs are employed to control the bypass flow through the channel-to-lower tie plate flow path. They have been used in the initial core and reload fuel of one BWR 3 and all BWR 4 and later plants. They have also been employed on some reload fuel in some additional BWR 2 and BWR 3 plants to control bypass flow through the lower tie plate to channel flow path.

Increases in channel wall permanent deflection at the lower tie plate resulting from creep deformation at operating conditions result in increased bypass flow through the channel to lower tie plate flow path. Changes in the flow through this path affect the total core bypass flow, which in turn, affects the active coolant flow, void coefficient, and operational transients.

Finger spring seals are employed to provide control over the flow through this path over a wide range of channel wall deflections by maintaining a nearly constant flow area as the channel wall deforms. The finger springs are located between the lower tie plate and the channel; a more detailed mechanical description is contained in section 9 of Reference 4.

4.2.2.4 Reactivity Control Assembly

4.2.2.4.1 Control Rods

The control rods perform the dual function of power shaping and reactivity control. A design drawing of the control blade is seen in Figure 4.2-6a and b. Power distribution in the core is controlled during operation of the reactor by manipulating selected patterns of control rods. Control rod displacement tends to counterbalance steam void effects at the top of the core and results in significant power flattening.

The control rod consists of a sheathed cruciform array of stainless steel tubes filled with boron-carbide powder. The control rods are 9.868 inches in total span and are separated uniformly throughout the core on a 12 inch pitch maximum. Each control rod is surrounded by four fuel assemblies.

The main structural member of a control rod is made of Type-304 stainless steel and consists of a top handle, a bottom casting with a velocity limiter and control rod drive coupling, a vertical cruciform center post, and four U-shaped absorber tube sheaths. The top handle, bottom casting, and center post are welded into a single skeletal structure.

The U-shaped sheaths are resistance welded to the center post, handle, and castings to form a rigid housing to contain the boron-carbide-filled absorber rods. Rollers at the top and bottom of the control rod guide the control rod as it is inserted and withdrawn from the core. The control rods are cooled by the core bypass flow. The U-shaped sheaths are perforated to allow the coolant to circulate freely about the absorber tubes. Operating experience has shown that control rods constructed as described above are not susceptible to dimensional distortions.

The boron-carbide (B_4C) powder in the absorber tubes is compacted to about 70 percent of its theoretical density. The boron-carbide contains a minimum of 76.5 percent by weight natural boron. The boron-10 (B-10) minimum content of the boron is 18 percent by weight. Absorber tubes are made of Type-304 stainless steel. Each absorber tube is 0.220 inches in outside diameter and has a 0.027 inch wall thickness. Absorber tubes are sealed by a plug welded into each end. The boron-carbide is longitudinally separated into individual compartments by stainless steel balls at approximately 17 inch intervals. The steel balls are held in place by a slight crimp of the tube. Should boron-carbide tend to compact further in service, the

TABLE 4.2-4

FUEL DATA

Core

Number of Fuel Assemblies	624
Fuel Cell Spacing (Control Rod Pitch), in.	12.0
Total Number of Fueled Rods*	38688
Core Power Density (Rated Power) kW/l	52.4
Total Core Heat Transfer Area, ft^2	61151

Fuel Assembly Data

Nominal Active Fuel Length, in.**	150.0
Fuel Rod Pitch, in.	0.636
Fuel Rod Spacing, in.	0.153
Fuel Bundle Heat Transfer Area, ft^2	98
Fuel Channel Wall Thickness, in.	0.120
Channel Width (Inside), in.	5.215

Fuel Rod Data

Outside Diameter, in.	0.483
Cladding Inside Diameter, in.	0.419
Cladding Thickness, in.	0.032
Fission Gas Plenum Length, in.	9.48
Pellet Immersion Density, %TD	95
Pellet Outside Diameter, in.	0.410
Pellet Length, in.	0.410

Water Rod Data

Outside Diameter, in.	0.591
Inside Diameter, in.	0.531

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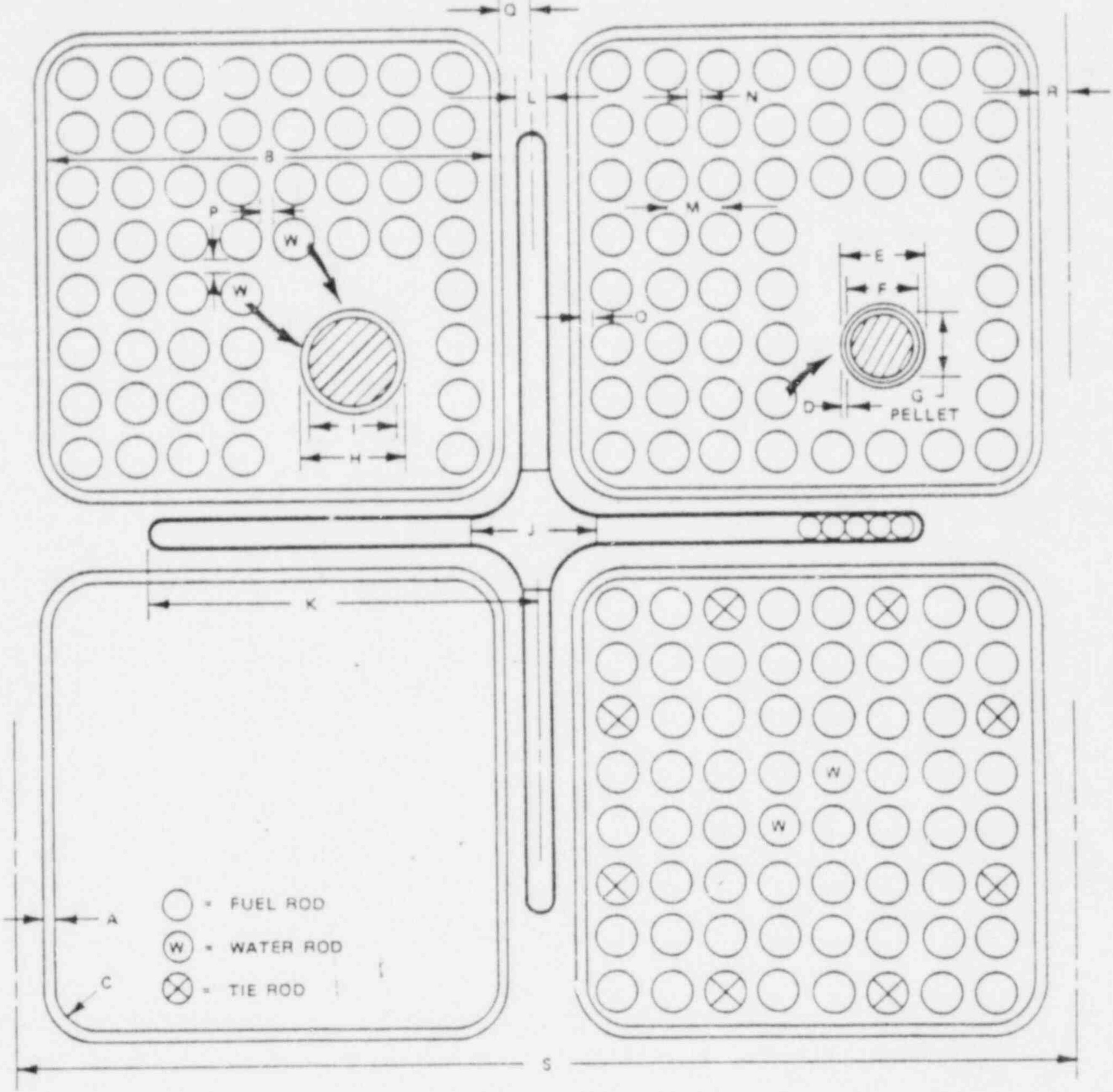
* Does not include two water rods in each assembly.

** Includes six inches of Natural U at the top and bottom of the fuel column.



	CHANNEL			FUEL ROD			PELLET	WATER ROD	
DIM. I.D.	A	B	C	D	E	F	G	H	I
DIM. INCHES	0.120	5.215	0.380	0.032	0.483	0.419	0.410	0.591	0.531

	CONTROL ROD			BUNDLE LATTICE				CELL		
DIM. I.D.	J	K	L	M	N	O	P	Q	R	S
DIM. INCHES	1.55	4.905	0.328	0.636	0.153	0.140	0.099	0.2725	0.2725	12.00

Figure 4.3-2. C Lattice 120-mil Channel

Figure 4.3-3. Rod Type Designations for Enrichment and Gadolinia Distributions in the High Enrichment Bundle (GE COMPANY PROPRIETARY)

Figure 4.3-4. Rod Type Designations for Enrichment and Gadolinia Distributions in the Medium Enrichment Bundle (GE COMPANY PROPRIETARY)

Figure 4.3-5. Axial Enrichment and Gadolinia Distribution, High Enrichment Bundle
(GE COMPANY PROPRIETARY)

Figure 4.3-6. Axial Enrichment and Gadolinia Distributions, Medium Enriched Bundle
(GE COMPANY PROPRIETARY)

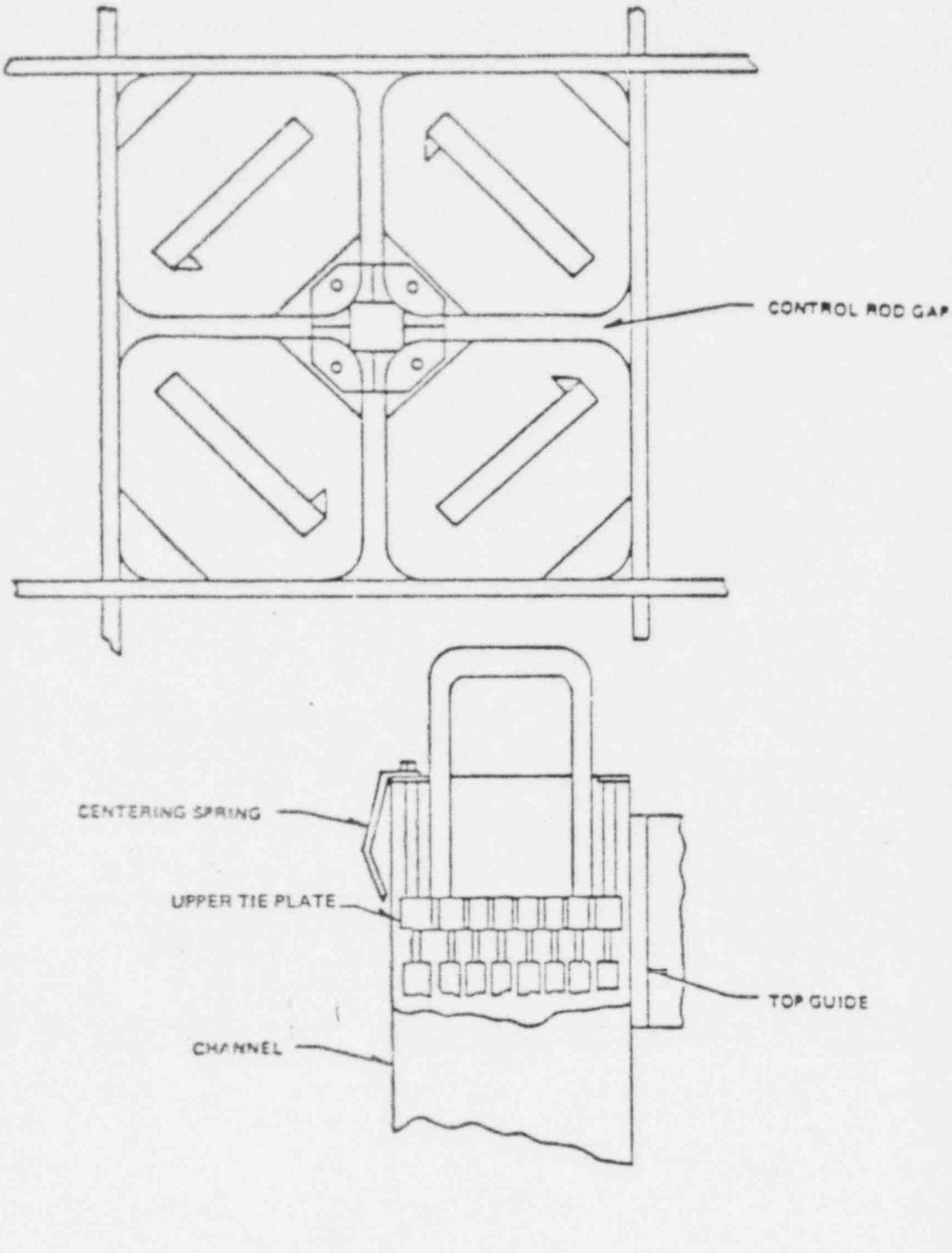


Figure 4.2-3. Schematic of Four-Bundle Cell Arrangement

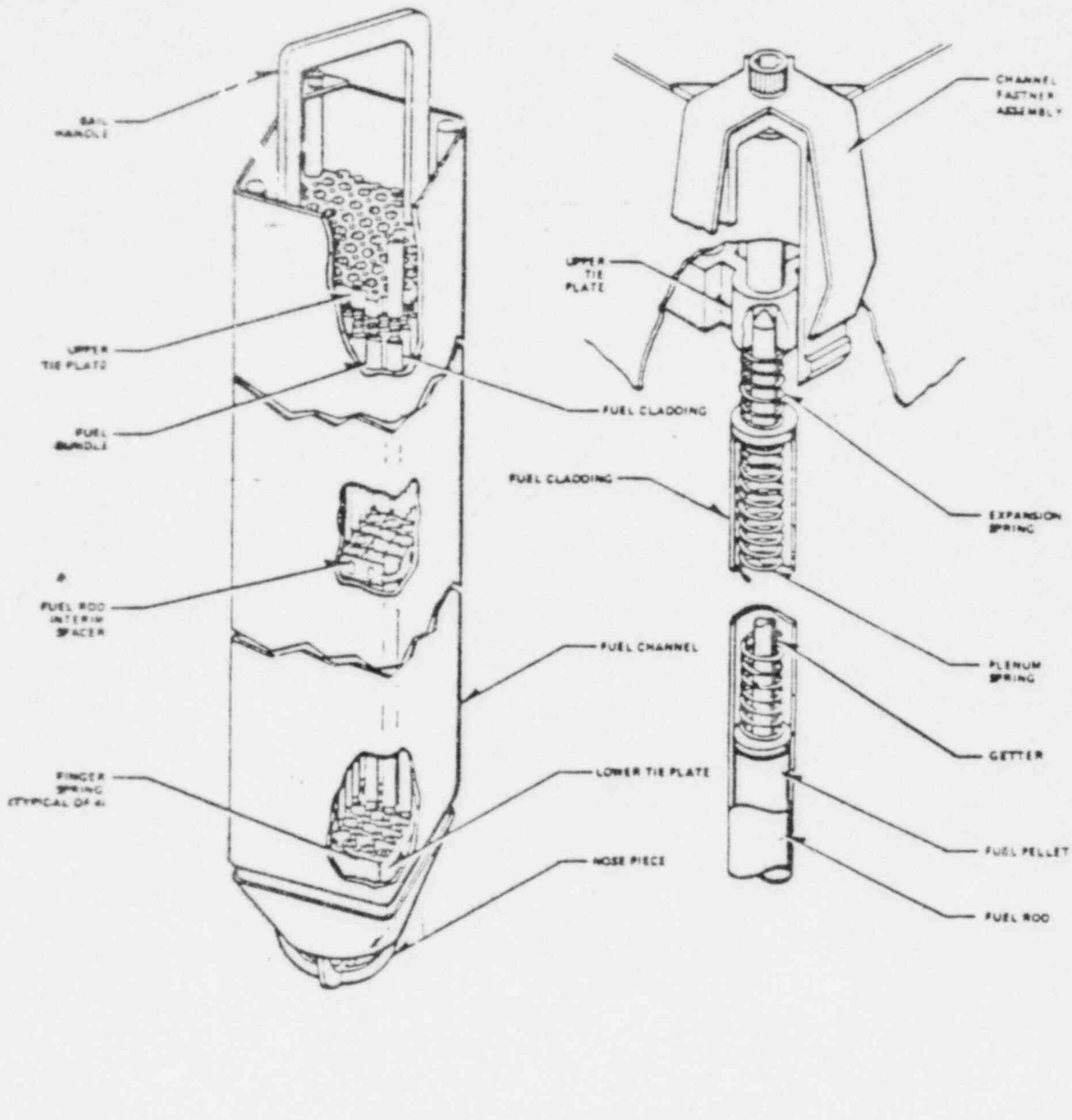


Figure 4.2-4. Fuel Assembly

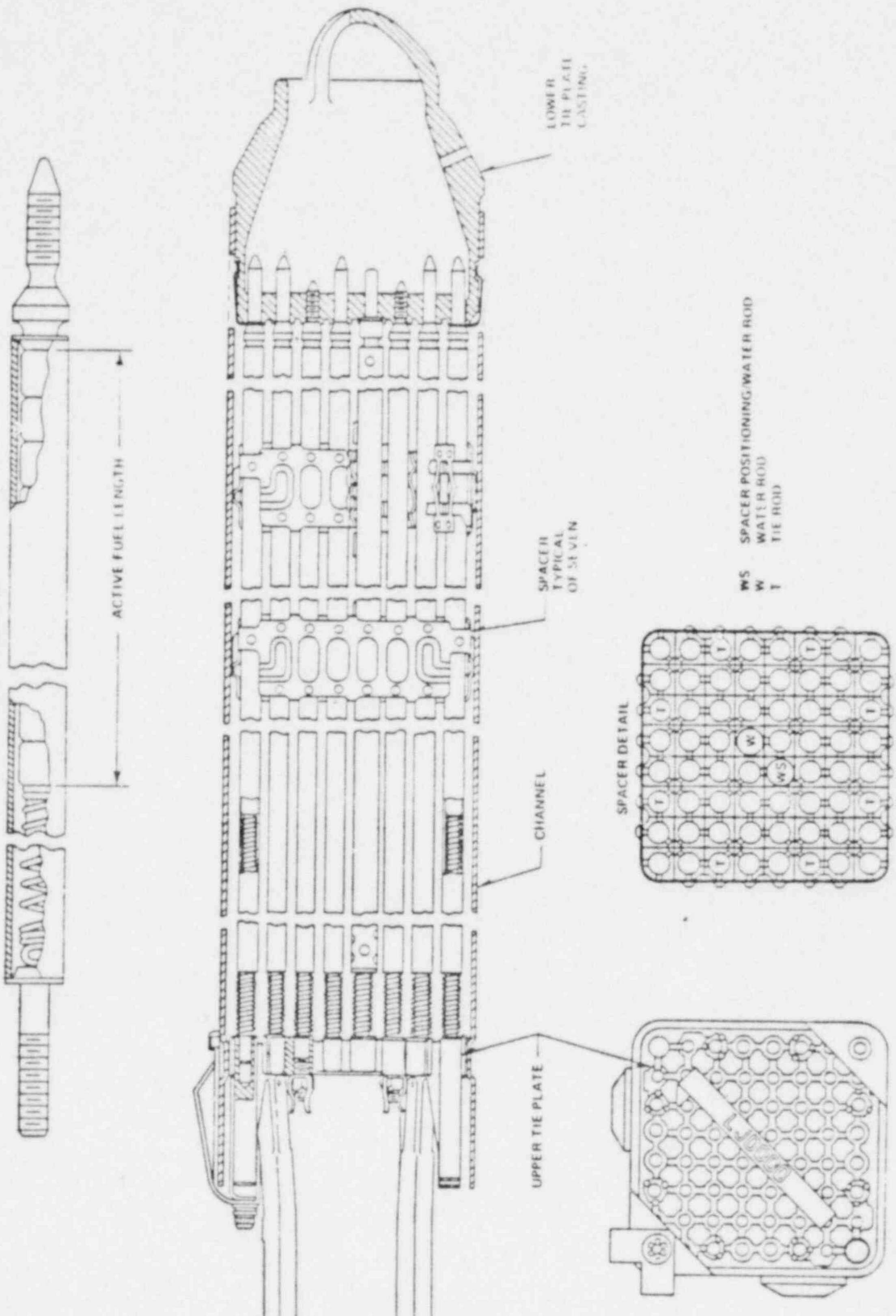


Figure 4.2-5. Fuel Assembly Cross Section