Nuclear Fuel Basics

LWVNM Nuclear Waste Storage Study October 2017

US Nuclear Fuel Production (Source: Nuclear Energy Institute, www.nei.org)

- Mining/Milling – 16% of world supply in US (AZ, CO, NM, TX, UT, WY)
- Conversion of Yellowcake to UF6 (IL)
- Enrichment – increase the U235 isotope concentration from <1% to 3-5% to sustain nuclear fission chain reaction (Urenco/NM)
- Fuel Fabrication in US by AREVA, Global Nuclear Fuel (WA, NC, SC, UT)

US Nuclear Reactor Design (Operating 2017 - 34 Boiling Water Reactors, 65 Pressurized Water Reactors, Source: www.nrc.gov)

- BWR Fuel assembly is 8 fuel rods x 8 fuel rods, 5.5" x 5.5", 14' length, with 370 - 800 fuel assemblies/reactor, each with 8-12 year lifetime (GE BWR 6 – 1200 MWe power, 748 fuel assemblies, 177 control blades)
- PWR 150-200 Fuel assemblies/reactor

Reactor Illustrations (Source: General Description of a Boiling Water Reactor, General Electric Nuclear Energy Division, May 1978)

Figure 3-2 Fuel Rod – fuel pellets for nuclear fission reaction, Tie Rod – support during handling, Water Rod – coolant and moderator, Control Blade - absorbs neutrons to control the nuclear reaction

Figure 3-3 Fuel Pellet – UO2, 0.4" diameter

Figure 3-4 Fuel Rod End – designed to seat in fuel assembly upper and lower tie plates

Figure 3-5, 3-6 Fuel Assembly Upper & Lower Tie Plates – permits handling and water (coolant/moderator) flow through fuel assembly

Figure 3-7 Typical Fuel Rod Spacers – Inconel springs maintain fuel rod spacing to preserve fuel cladding

Figure 3-8 Completed Fuel Bundle

Figure 3-8 Fuel Assembly – fuel channel & fuel rod (0.5" d, 0.03" wall thickness) are Zr alloys to maximize fission reaction, fuel pellets stacked ~150" with upper springs to permit axial pellet expansion from nuclear fission reaction

Figure 3-14 Control Rod contains Boron Carbide (B4C) neutron absorber to control the nuclear reaction. The BWR control rod is inserted from the bottom of the reactor, either by 6" notches or scram to insert quickly and completely. Control rod length 177", includes 16 - 0.6" diameter tubes/wing, 15 year lifetime

Figure 7-1, 7-2 Reactor Building - refueling platform and upper pool location permit fuel transfer above reactor so that fuel removal can be performed safely under water

Page 9-6 Note that Spent Fuel reprocessing in US was anticipated during 1978 BWR-6 design

Fuel Bundle

Each fuel bundle contains 64 rods which are spaced and supported in a square (8 by 8) array by a lower and upper tie plate. The lower tie plate has a nosepiece which fits into the fuel support piece and distributes coolant flow to the fuel rods. The upper tie plate has a handle for transferring the fuel bundle. Both tie plates, shown in Figures 3-5 and 3-6, are fabricated from Type-304 stainless steel and are designed to satisfy flow considerations as well as mechanical strength considerations. Mechanically, these parts have been designed to stay within the yield strength of the material during normal handling operations.

Three types of rods are used in a fuel bundle: tie rods, water rods, and standard fuel rods. The third and sixth fuel rods along each outer edge of a bundle are tie rods. The eight tie rods in each bundle have threaded end plugs which screw into the lower tie plate casting and extend through the upper tie plate casting. A stainless steel hexagonal nut and locking tab, shown in Figure 3-5, is installed on the upper end plug to hold the assembly 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. Two rods

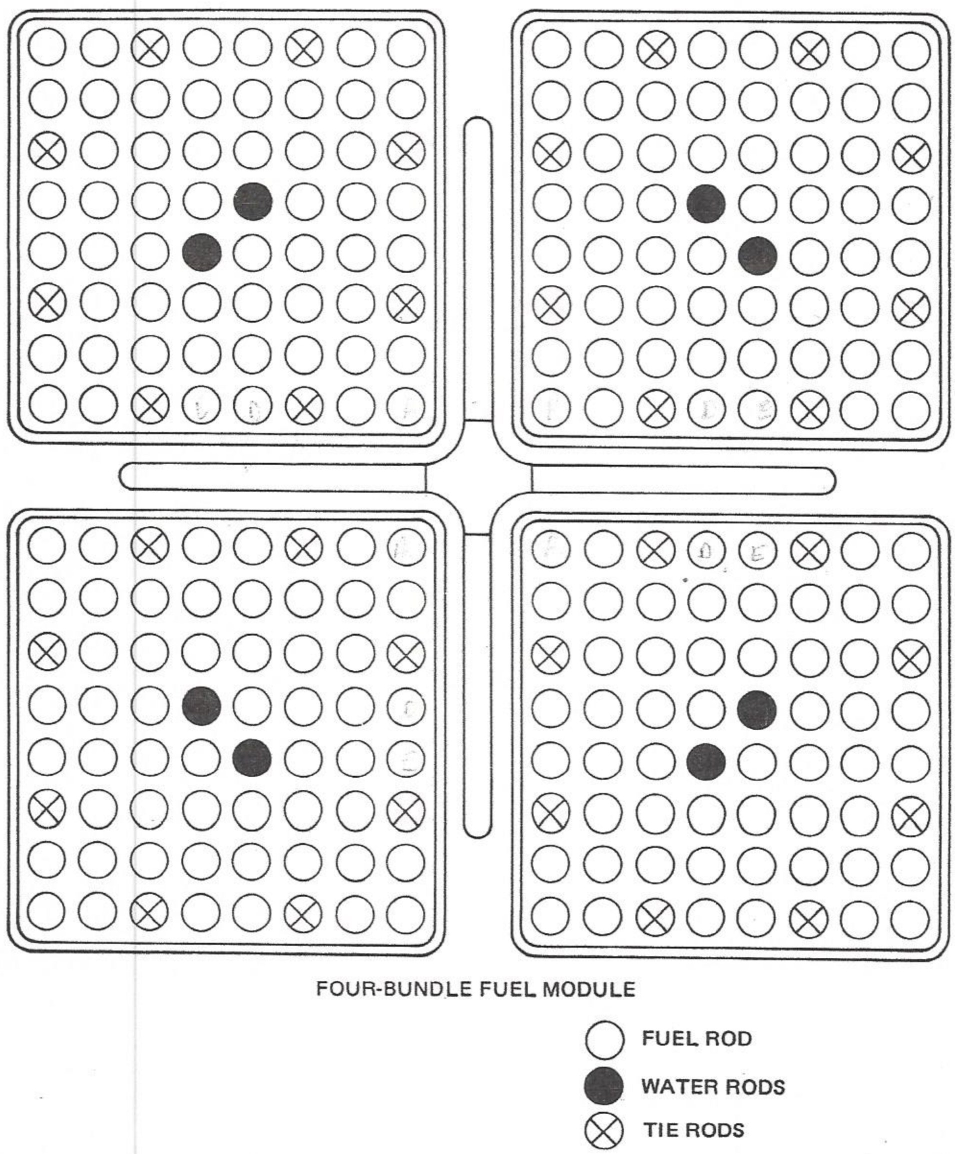

Figure 3-2. Core Lattice

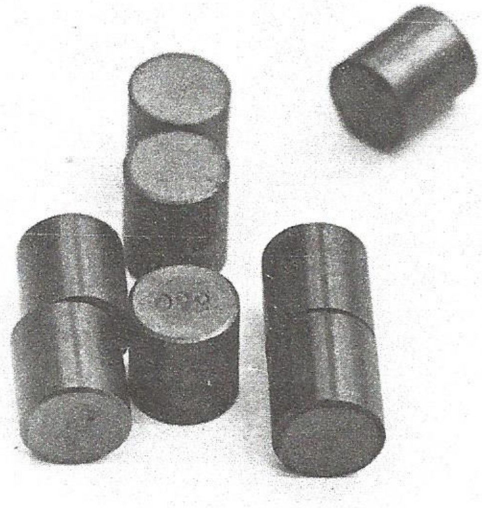

Figure 3-3. Typical BWR Fuel Pellets

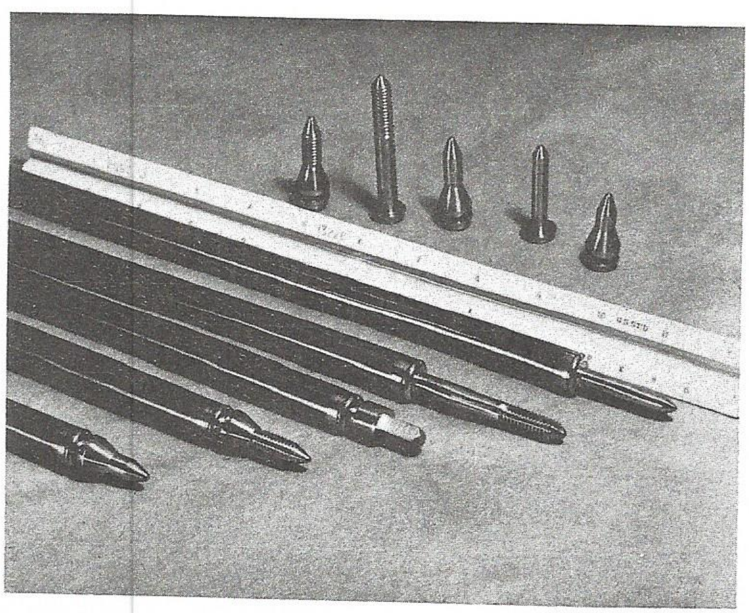

Figure 3-4. Typical End Plugs and Welded Tube Ends

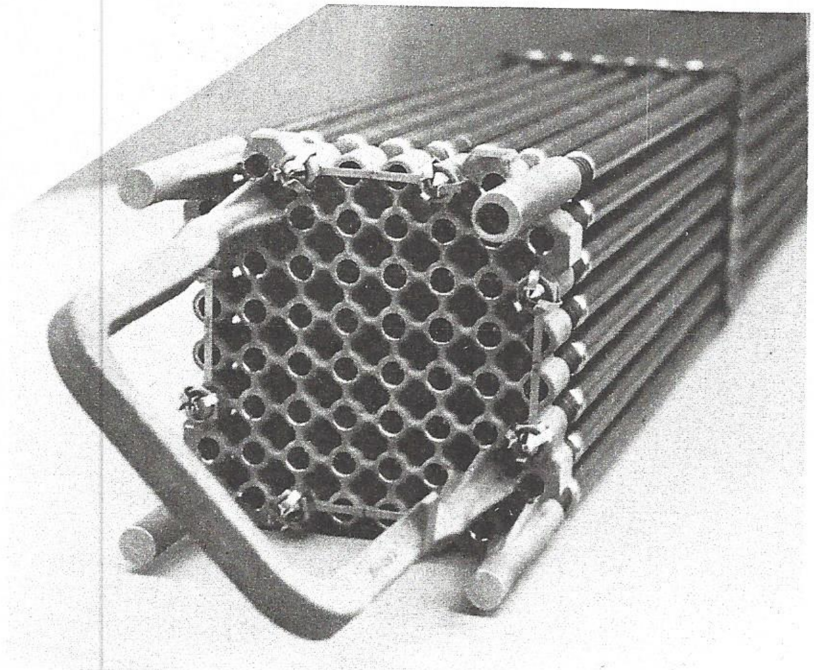

Figure 3-5. Upper Tie Plate

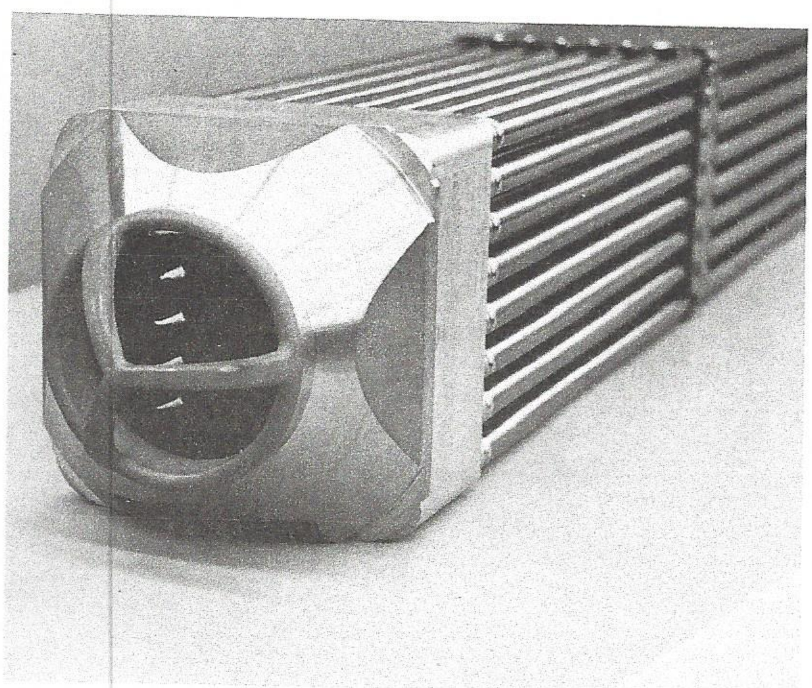

Figure 3-6. Lower Tie Plate

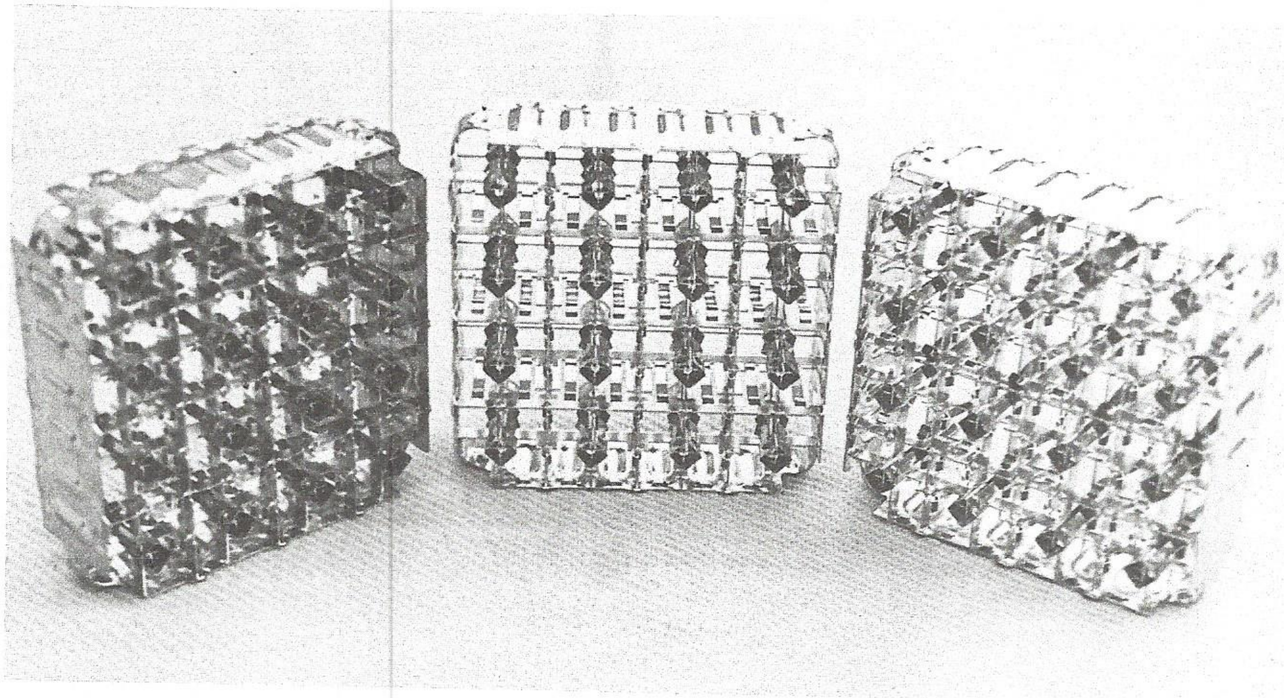

Figure 3-7. Typical Fuel Rod Spacers

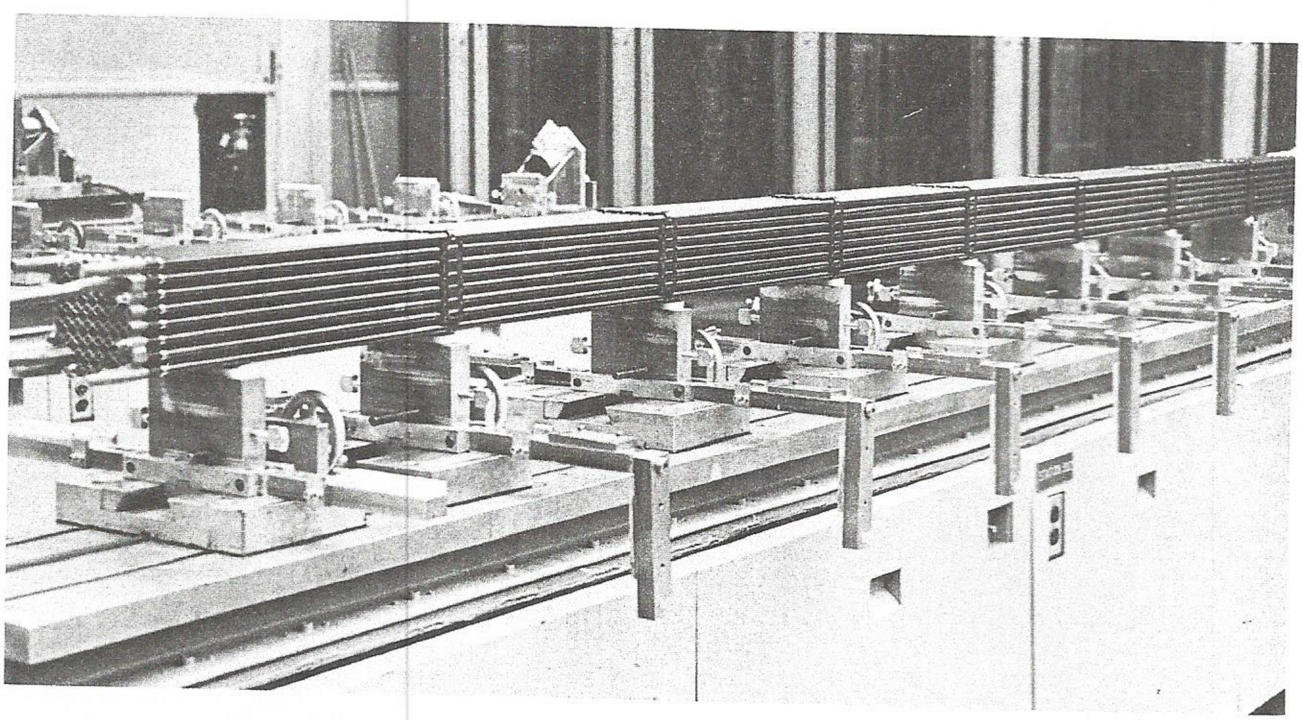

Figure 3-8. Completed Fuel Bundle

grid and a hole in the lower core support plate (see Figure 3-11). The compression of a spring at the top of the housing exerts a column-type loading on the source. Though anchored firmly in place, the sources can easily be removed, but they need not be disturbed during refueling.

The active portion of each source consists of a beryllium sleeve enclosing two antimony-gamma sources. The resulting neutron emission strength is sufficient to provide indication on the source range neutron detectors for all reactivity conditions equivalent to the condition of all rods inserted prior to initial operation.

The active source material is entirely enclosed in a stainless steel cladding with an outside diameter of approximately 0.7 inch. The source is cooled by natural circulation of the core leakage flow in the annulus between the beryllium sleeve and the antimony-gamma sources.

The current neutron source mechanical design and the design analysis methods have been verified in the various General Electric operating BWRs.

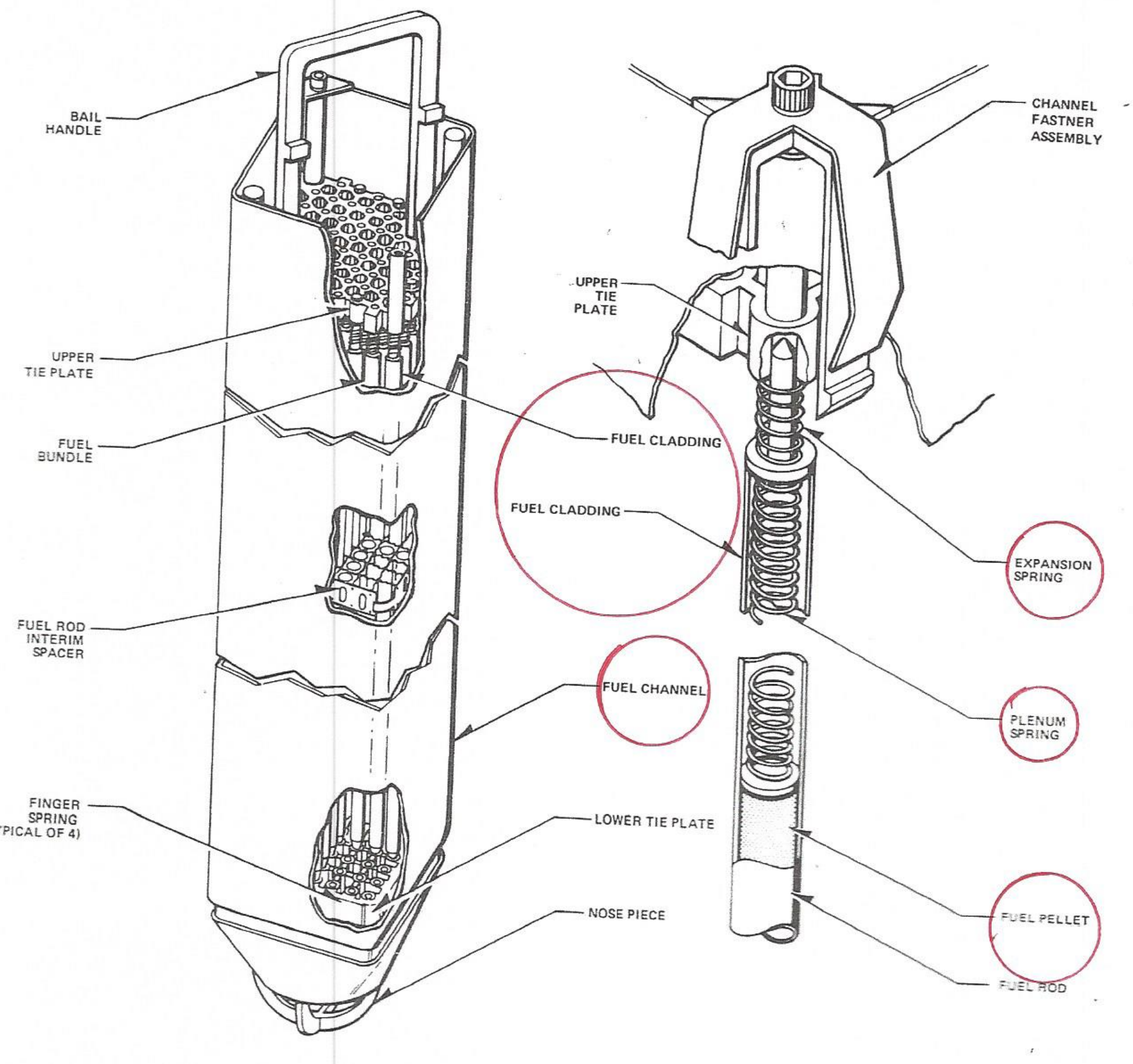

Figure 3-9. Fuel Assembly

dynamic forces resulting from a scram. They are connected to bottom-mounted, hydraulically actuated drive mechanisms which allow either axial positioning for reactivity regulation or rapid scram insertion. The design of the rod-to-drive connection permits each blade to be attached or detached from its drive during refueling without disturbing the remainder of the control system. The bottom-mounted drives permit the entire control system to be left intact and operable for tests with the reactor vessel open.

Description of Rods

The cruciform control rods contain 84 stainless steel tubes (21 tubes in each wing of the cruciform) filled with boron carbide powder compacted to approximately 65% of theoretical density. The tubes are seal welded with end plugs on either end. Stainless steel balls are used to separate the tubes into individual 18-inch longitudinal compartments. The stainless steel balls are held in position by a slight crimp in the tube. The individual tubes, 3/16 inch in diameter, act as pressure vessels to contain the helium gas released by the boron-neutron capture reaction.

The tubes are held in cruciform array by a stainless steel sheath extending the full length of the tubes. A top casting and handle, shown in Figure 3-14, aligns the tubes and provides structural rigidity at the top of the control rod. Rollers, housed by the top casting, provide guidance for control rod insertion and withdrawal. A bottom casting is also used to provide structural rigidity and contains positioning rollers and a parachute shaped velocity limiter. The castings are welded into a single structure by means of a small cruciform post located in the center of the control rod. The control rods have an active length of 144 inches of boron carbide, a span of 9.75 inches, and an overall length of 173.75 inches. The control rods can be positioned at 6-inch steps and have a nominal withdrawal and insertion speed of 3 inches per second.

Control rods are cooled by the core leakage (bypass) flow. The core leakage flow is made up of recirculation flow that leaks through the several leakage flow paths:

- The area between fuel channel and fuel assembly nosepiece
- The area between fuel assembly nose piece and fuel support piece
- The area between fuel support piece and core plate
- The area between core plate and shroud
- Holes in the core plate for bypass flow control

Design Estimates of Rod Life

In addition to satisfying initial control effectiveness requirements, it is expected that the control rods will have an average lifetime of approximately 15 full-power years. Operating lifetime of the control rods is governed by the following two factors:

- Loss of control effectiveness because of depletion of boron (specifically the boron 10 isotope): design allowance on the control system is 10% loss

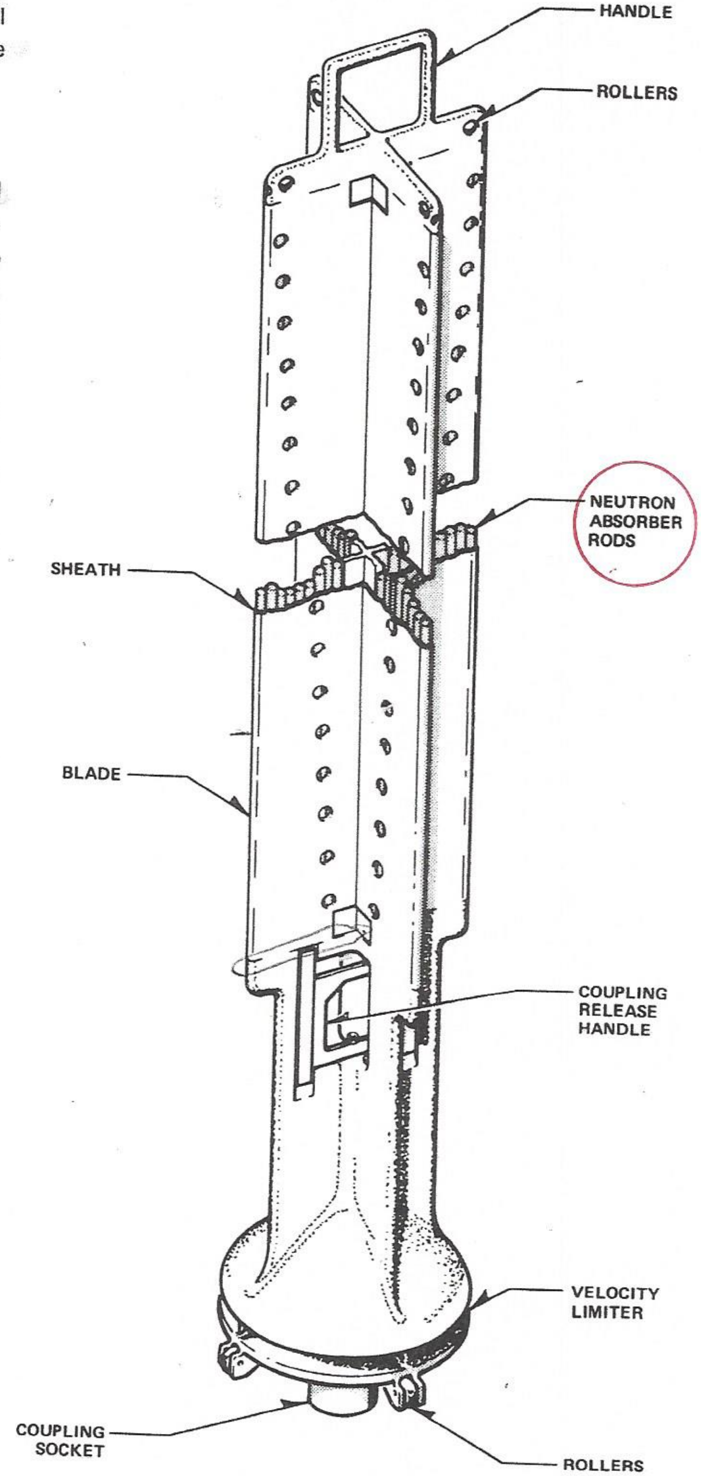

Figure 3-14. Control Rod

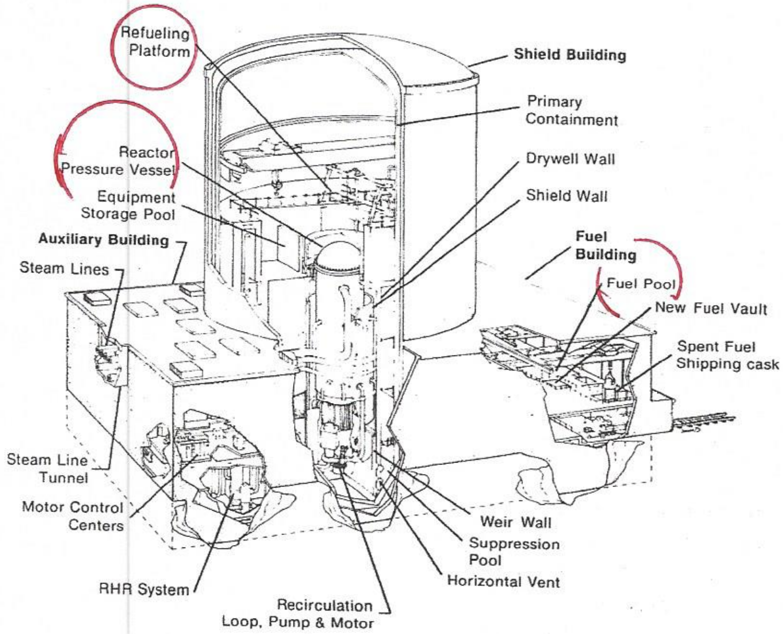

Figure 7-1. Mark III Reactor Building, Fuel Building, and Auxiliary Building

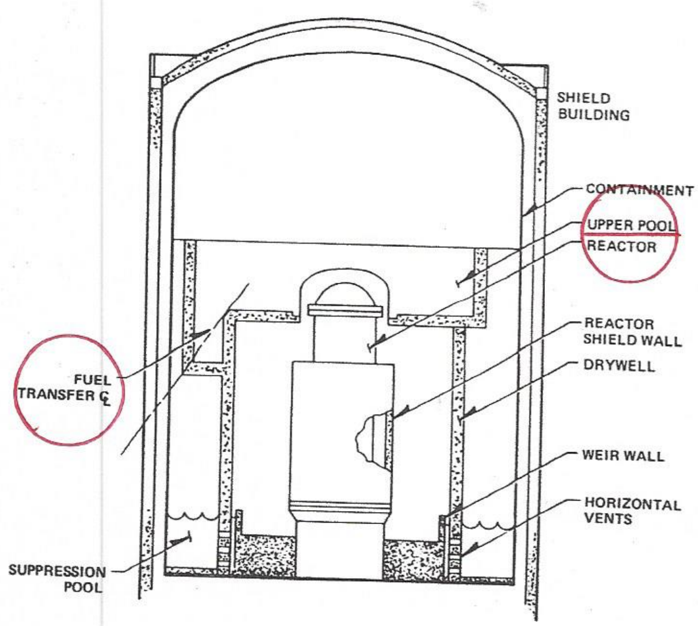

Figure 7-2. Mark III Reactor Building (Containment and Shield Building)

Inspection of the new fuel is normally deferred until all the reusable metal containers are emptied and the area around the new fuel vault is cleaned. The individual fuel bundles are then removed from the vault, inserted in the new fuel inspection stand, dimensionally and visually inspected, and returned to the storage vault to await affixing of channels.

New Fuel Inspection Stand

The new fuel inspection stand located in the refueling building is a frame structure which holds two fuel bundles in the vertical position adjacent to each other. The lower socket receptacle for the fuel bundle permits the rotation of the bundle. The upper receptacle is a retaining clamp to support the fuel bundle in the vertical position. A motor-operated lift raises and lowers a U-shaped working platform for inspection of each fuel bundle over its entire 12-foot length.

Channeling New Fuel

Two fuel preparation machines are located in the fuel pool: one used for dechanneling spent fuel, and the other for channeling new fuel. New fuel bundles without channels are unloaded from the new fuel vault and transported to the fuel racks in the fuel pool. A spent fuel bundle is transported to the fuel preparation machine, using the fuel handling platform in the fuel building. The channel is unbolted from the bundle, and the channel handling tool is fastened to the top of the channel. The fuel preparation machine carriage is lowered, removing the fuel from the channel. The channel is then positioned over a new fuel bundle located in the second fuel preparation machine, and the process reversed. The channeled new fuel is stored in the pool storage racks ready for transfer and insertion into the reactor.

The preferred method is to channel a reload batch of fuel while the reactor is operating to ensure that the fuel is ready for use during the refueling operation. New fuel can then be transferred into the containment pool during reactor cooldown and refueling preparation tasks. Spent fuel can be transferred from the containment pool to the fuel building during vessel reassembly after refueling.

Dechanneling should immediately precede channeling, for maximum efficiency. Channel storage adaptors are used to permit irradiated channels to be stored in the fuel storage racks. These adaptors are inserted into the fuel racks as spacers and allow the top of the stored channels to project above the top of the racks for convenient handling. A channel transfer grapple is used for inserting or withdrawing channels from the fuel storage racks.

Unirradiated spare channels are normally stored in the vacant racks in the new fuel storage vault. These channels would be removed only as needed to complete the assemblies required for the next refueling outage.

A wall-mounted channel accumulation rack is provided between the two fuel preparation machines. The use of this rack permits some lag to occur between the dechanneling and channeling operations.

FUEL STORAGE AND SHIPMENT

Spent fuel removed from the reactor is stored in the fuel storage pool in the fuel building. Fuel storage rack capacity to hold a normal discharge batch of fuel bundles plus a full core is normally provided.

Spent fuel is stored for a time as determined by the schedule for shipment to the fuel reprocessing facility. For such shipments, fuel bundles are loaded into special design shipping casks which are generally made available by the fuel processor. The heavy casks, capable of holding many fuel bundles, arrive on special trucks or railroad cars which are brought into the car bay of the fuel building. The cask is lifted from the vehicle into the cask loading pool by the fuel building cask crane. This crane cannot traverse the spent fuel storage areas. Once fuel is loaded into the cask, it is sealed and lifted back onto the transport vehicle for its return trip to the reprocessing facility.