3.7 SUPPLEMENTARY FUEL DESIGN AND EVALUATION

3.7.1 FUEL ROD DESIGN EVALUATION

3.7.1.1 Mechanical Design Evaluation

a. Clad Creepdown/Creep-Collapse

Historical Perspective

Clad creepdown is the phenomenon caused by inward stresses on the cladding (caused by the difference in external and internal pressure) in combination with effects from temperature and neutron fluence. If the clad slowly ingresses toward the pellet stack, it would reduce gap size and increase gap conductance. Densification of fuel pellets leads to the formation of axial gaps in the fuel stacks and a loss of support for the cladding in these locations. Creepdown and subsequent collapse into axial gaps induced by fuel densification is called creep-collapse.

The minimum time to collapse for CE Zircaloy-clad fuel was calculated by the CEPAN computer code (Reference 13). The experimental database used for modeling creep collapse consists of measurements made on fuel rods irradiated in a CE reactor. The analytical creep correlation used in the model was fit to this data. That correlation leads to the time to collapse predictions given by CEPAN.

Beginning with Unit 1 Cycle 6, improvements were made in the modeling technique. These improvements (Reference 26) revised the method for establishing uncertainties in cladding geometrical parameters (diameters, thicknesses, etc.) used in the collapse analysis, and provided new criterion for the occurrence of collapse.

Present Analysis

Analysis of the phenomena of interpellet gap formation and clad collapse in modern PWR fuel rods (i.e., nondensifying fuel in prepressurized tubes), demonstrates that the collapse time for modern fuel is significantly larger than its expected useful life. This conclusion is discussed in an EPRI-sponsored report (Reference 28) and is based upon both empirical data covering several vendors' fuel and an analytical evaluation of the propensity for clad collapse into a postulated gap of finite length. Based upon the conclusion and recommendation of this report, cycle-specific clad collapse analyses are not necessary for modern CE manufactured fuel. A cycle-specific calculation was not prepared beginning with Unit 1 Cycle 8, and Unit 2 Cycle 7.

Beginning with Unit 2 Cycle 19 and Unit 1 Cycle 21, the RODEX2 fuel rod analysis code is used to evaluate the cladding creepdown and creep collapse for AREVA/Framatome fuel. Creep collapse and the subsequent potential for fuel failure are avoided in the fuel system design by eliminating the formation of axial gaps in the fuel column. The licensing criterion for preventing cladding collapse is to maintain a radial gap large enough to prevent pellet hang up and, therefore, axial gap formation. The maximum cladding circumferential creep and ovalization, up to the time of maximum densification, are computed to demonstrate that a radial gap between pellet and cladding is maintained. The evaluation is performed using the approved RODEX2 code (References 33 and 34) and the COLAPX code on a cycle specific basis beginning with Unit 2 Cycle 19 and Unit 1 Cycle 21. The RODEX2 code is used to provide initial in-reactor fuel rod conditions to COLAPX. The COLAPX code calculates the cladding ovality changes (flattening) and creep deformation of the cladding as a function of time. M5® properties were incorporated, as appropriate, into these codes in Reference 36.

b. Fuel Rod Bowing

Fuel rod bowing is the phenomenon whereby a curvature of the rod is experienced, changing the thermal-hydraulic and neutronics characteristics of the region, and potentially affecting the mechanical performance of the fuel. It is primarily caused by a combination of rod axial growth and spacer grid restraint. Rod axial growth is largely the result of normal Zircaloy/ZIRLO growth, although some enhancement due to stresses caused by Pellet-clad Interaction (PCI) is possible. Fuel design changes to decrease the effects of PCI (chamfering, reduced length/diameter, etc.) tend to reduce PCI contributions to rod axial growth, and to bowing of the rod.

Fuel rod bowing leads to variations in the flow characteristics and neutronics of the affected region. Neutronic changes due to enhanced/decreased moderation (depending on the direction of bow) and, in the case of bowed BPRs, enhanced/decreased thermal neutron absorption, lead to changes in local LHRs. Flow changes due to opening/closing of channels can lead to changes in the margin to DNB. Both of these effects are analyzed in Reference 14, and are shown to be within existing margins.

Mechanical performance of the fuel itself can be affected by rod bowing. Rods bowed toward each other may come into contact. Restriction of flow in this region can enhance clad corrosion. Flow induced vibration of the rods may cause fretting wear. Present fuel designs are such that bowing to this extent is not experienced. Only a small reduction in channel size is seen, as compared to the channel closure necessary for mechanical degradation.

The effects of fuel rod bowing on DNBR are discussed in Section 3.5.3.2.b.8.

Starting with Unit 2 Cycle 19 and Unit 1 Cycle 21, the methodology described in Reference 35 was used to evaluate fuel rod bowing for the AREVA/ Framatome assemblies.

c. Shoulder Gap Closure

The fuel assembly shoulder gap is defined as the axial gap between the top of a fuel rod and the bottom surface of the upper end fitting. During irradiation, the gap becomes smaller due to differences in irradiation-induced growth and thermal expansion of fuel rods and guide tubes (fuel rod growth has an interactive component related to pellet-clad interaction). Complete closure of the gap would result in additional stresses on the fuel, enhancing rod bowing. Therefore, it is important to ensure that the BOL gap is large enough to preclude gap closure by the EOL of the fuel. The model for Zircaloy growth is presented in Reference 15. Reference 32 discusses the impact of ZIRLO clad. Shoulder gap is reviewed using SIGREEP (Reference 31).

AREVA/Framatome fresh fuel reloads use M5® clad fuel rods with Zircaloy-4 guide tubes. The growth of the fuel rods is assessed using M5® cladding growth correlations. The upper bound fuel rod growth is considered in conjunction with the lower bound assembly growth along with the manufacturing tolerances that would result in the minimum fabricated clearance.

3.7.1.2 Fuel Thermal Design Evaluation

a. Introduction

The Combustion Engineering fuel rod thermal Analysis code, FATES (Reference 17), is used in the fuel evaluation model to predict fuel rod temperature distributions, fuel-clad gap conductance, rod internal pressures, and fuel rod stored energy. The effects of fuel densification and the subsequent formation of axial gaps are taken into account to calculate augmentation factors used to modify linear heat generation rate values. The densification process itself is modeled. Fission gas production is predicted by FATES and, using the internally-modeled temperatures, fission gas release is predicted as well.

Reference 17 compares FATES results with experimental data from in-reactor and out-of-reactor tests to show the conservatism in the model as well as to show the validity of the modeling techniques used.

Beginning with Unit 1 Cycle 6, an improved version of FATES, entitled FATES3 (Reference 27) was used for fuel thermal design evaluation. While a great number of the models remained unchanged, revisions included the models for 1) fission gas release, 2) fuel swelling, 3) closed gap conductance, 4) fuel relocation, 5) cladding axial growth [a calculation previously performed via Reference 15], and 6) plenum gas temperature. Additionally, the code was modified to include an annular fuel pellet geometry. This modeling modification required changes to the models for fuel pellet temperature distribution, fuel pellet thermal expansion, and rod internal void volume calculations.

Beginning with Unit 1 Cycle 9, an improved model, FATES3B (Reference 29), is used for fuel thermal design evaluation. FATES3B incorporates changes to the fission gas release model, specifically related to burnup dependence, kinetics of grain growth, and fission gas release calculation.

Reference 32 documents a modification to FATES3B for implementation of ZIRLO clad material.

Beginning with Unit 2 Cycle 19 and Unit 1 Cycle 21, the approved fuel rod thermal analysis code, RODEX2 (References 33 and 34), is used to evaluate AREVA/Framatome fuel. The RODEX2 code incorporates models to describe the gas generation and release, swelling, densification, and cracking in the pellet, gap conductance, radial thermal conduction, free volume, gas pressure internal to the fuel rod, fuel and cladding temperatures and deformations, and cladding corrosion. The calculations are performed on a time incremental basis with conditions being updated at each calculated increment.

b. Fuel Densification and Swelling

1. Fuel Densification

The FATES model includes correlations to account for burnup-dependent fuel densification. This phenomenon is different from fuel densification caused by high temperatures and thermal gradients experienced by the fuel (Reference 18). The rate and extent of burnup-dependent densification varies with original fuel density and microstructure. Original Calvert Cliffs fuel was of a relatively unstable, densifying type. Subsequent design changes have resulted in a more stable, non-densifying fuel.

The primary concerns regarding fuel densification were:

a) Decrease in pellet diameter (increased gap size) which lowers gap conductivity and increases fuel temperatures and stored energy.
b) Decrease in pellet length, which increases the Linear Heat Generation Rate along the fuel rod.
c) Decrease in pellet length coupled with pellet cocking, which leads to axial gaps in the fuel pellet stack. Augmentation factors for LHGR were based on the formation of these axial gaps.

Burnup-dependent densification is a factor only at BOL of fuel. The terminal density is predicted to be achieved at a burnup of 4000 MWD/MTU. The terminal density is determined in one of two ways, depending on the type of fuel (densifying/non-densifying) (Reference 17).

The effects of densification on the Safety Analyses are presented in Reference 19. As the fuel will begin to swell after 4,000 MWD/MTU, some of the effects of densification (axial and radial shrinkage) will be reversed by the swelling process.

The RODEX2 fuel rod analysis code contains both time and burnup dependent fuel densification correlations which are applied in the densification model for Uranium and Gadolinia fuel. The densification of the fuel is a phenomenon that is only observed at BOL, this is reflected in both the burnup and time dependent densification correlations. The densification model calculates the change in volume per unit volume or dilatation of the fuel material along with radial displacement, axial fuel stack length change, and change in the void fraction.

2. Fuel Swelling

Fuel swelling refers to the change in pellet volume which occurs as a result of the buildup of porosity and accumulation of fission products with increasing burnup. During the first 4,000 MWD/MTU of exposure, the densification mechanism prevails, but after the point where the fuel reaches its terminal density, the fuel begins to expand. Fuel swelling is said to be unrestrained until the time of pellet-clad contact, after which it is said to be restrained. The FATES model (Reference 17) contains a correlation for the rates of diametral and axial swelling while swelling is unrestrained. A new, restrained swelling rate is assumed after contact.

The FATES3 model (Reference 27), used beginning with Unit 1 Cycle 6, incorporated a lower swelling rate than that incorporated into the original FATES model. This new rate is based on results of recently published data and post-irradiation measurements made on Calvert Cliffs Unit 1 fuel.

The RODEX2 fuel rod analysis code has models that account for the phenomenological swelling processes (solid swelling and gaseous swelling). The swelling of the fuel material contributes to the radial deformations, axial fuel column length changes, filling of dish volumes, and is related to the fabricated porosity and available crack volume; the models incorporated into RODEX2 take into account such design variables. The swelling models in RODEX2 also take into account restraint of the fuel (due to pellet-to-clad contact) as well as an incubation period in which nondensified porosity is utilized by swelling.

3. Fuel Pellet Relocation

During irradiation, the fuel pellet cracks radially (and reheals in a distorted shape) and the pellet pieces approach the clad, decreasing gap size and enhancing gap conductivity. This improved heat transfer due to relocation reduces centerline temperature and stored energy.

The FATES3 model incorporates a modeling change with regard to fuel relocation after the pellet-clad gap has closed.

Additionally, the FATES3 model explicitly treats the pellet-clad interface, allowing for calculation of pellet-clad interfacial pressure and gap conductance after contact occurs. The previous FATES model used preassigned maximum values for these parameters after pellet-clad contact occurred.

Beginning with Unit 2 Cycle 19 and Unit 1 Cycle 21, the RODEX2 fuel rod analysis code is used for fuel thermal design evaluations. The RODEX2 code contains models that account for fuel relocation prior to and after contact between pellet and cladding. The radial displacements caused by pellet cracking are factored into calculations of the effective width of the open gap, which in turn is used to establish the gap conductance.

c. Linear Heat Generation Rate Augmentation Factor

Historical Perspective

One former concern regarding fuel densification was the decrease in pellet length. This allegedly decreases the overall pellet stack length, increasing the LHR. Presumably the pellets will tend to settle at the bottom of the rod, but interference from clad creepdown and pellet cocking and lockup may lead to the formation of axial gaps in the fuel column. It was assumed that these gaps could cause local power peaking in that axial region in surrounding rods, because the loss of neutron absorption in the gap outweighs the loss of fission. If the clad collapses completely into the gap (less likely in pre-pressurized fuel), local peaking is enhanced further due to the replacement of the gap void with moderator.

Present Analysis

The local power peaking is dependent on the number of gaps as well as the size of gaps, both of which are modeled in FATES. A peaking factor was determined, called the augmentation factor, which is defined as the ratio of peak augmented power to peak unaugmented power. The peak augmented power was determined statistically so that there is a 95% certainty that no more than one rod will be at a higher power.

Analysis of the phenomenon of interpellet gap formation in modern PWR fuel (Reference 28) demonstrates that the increased power peaking associated with the small interpellet gaps found in modern, i.e., pre-pressurized and non-densifying, fuel is insignificant compared to the uncertainties in the safety analyses and Technical Specifications. Consequently, augmentation factors used for interpellet gap formation were eliminated from the analysis beginning with Unit 1 Cycle 8 and Unit 2 Cycle 7.

The RODEX2 fuel rod analyses, performed for AREVA/Framatome fuel, use a conservative engineering heat flux augmentation factor to perform the fuel thermal design evaluations (Reference 35). The factor is based on a 95/95 statement including pellet and pellet lot variations in enrichment, as-sintered pellet density, and pellet diameter. The factor includes conservative allowances for in-reactor densification.

d. Fission Gas Release

1. Fission Gas Generation

Products that remain within the fuel matrix after fissioning of U-235 include primarily unstable isotopes with mass numbers ranging from 72 to 160. Each of these will experience an average of three stages of radioactive decay before being converted into a stable nucleus. This results in over 200 isotopes of 30 or more different elements present as fission products within the fuel pellets. Xenon and krypton, two of the stable gaseous elements liberated from the fuel matrix, are assumed to comprise the fission gas. FATES models the amount of fission gas generated in the fuel. The fuel rod is divided into axial nodes, and the gas generated in that node is calculated as a function of local burnup.

The RODEX2 fuel rod analysis code is used for fuel thermal design evaluations of AREVA/Framatome fuel. The RODEX2 code uses a bounding, power dependent fission gas generation rate per unit of energy produced that is applied to each axial region of the fuel column.

2. Fission Gas Release

While gas generation is strictly a function of burnup, the release of the fission gas from the fuel matrix is dependent on temperature and on temperature gradient. At low temperatures, recoil and knockout are the primary release mechanisms, as the relatively low energy of the gas precludes diffusion-type movement in the matrix. Recoil release is the direct release from the matrix to the free space directly as an energetic fission fragment, and knockout release is release resulting from the impact of another energetic fission fragment. At higher temperatures, the diffusion of gases within the grains is significant, and by diffusing to grain boundaries, gases can escape to cracks or to porosity already present in the fuel matrix. At high temperatures, gas bubbles are driven along the thermal gradient and released to the free space.

Grain growth also plays an important part in fission gas release, and is itself strongly temperature dependent. At fairly high temperatures the pores initially present in the fuel begin migrating along the thermal gradient toward the center of the pellet. These pores leave a trail of small gas bubbles which form the boundary of a columnar grain extending radially from the pellet center. As the pores move inward they collect fission gas from the fuel matrix and grain boundaries, and eventually deposit it in the center of the pellet, forming, with other pores, the central void. Migration of these pores leave behind a crystal structure which is more dense than the original microstructure. The growth rate and extent of growth of columnar grains plays an important part in the fission gas release mechanism.

FATES modeled fission gas release in the following manner. The columnar grain growth boundary temperature T_g was determined by the equation:

$\int_{400°C}^{T_g} k_{95} dT$ = 42W / cm (Reference 17)

where: k_{95} is the thermal conductivity of 95% td UO_2

The FATES model combined the work of Notley and MacEwan with that of Lewis.

The original Lewis model is of the form:

$$\%Release = \frac{a\int_{T_s}^{1000} k_{dt} + b\int_{1000}^{1300} k_{dt} + c\int_{1300}^{1000} k_{dt} + d\int_{1000}^{T_c} k_{dt}}{\int_{T_s}^{T_c} k_{dt}}$$

where k is a function of temperature.

Notley and MacEwan showed the effect of columnar grain growth on release. The temperature bands in the Lewis model were retained in the FATES model, but the limits of the bands were changed to incorporate the temperature bands defined for the growth of columnar grains. A burnup-dependent correction factor was applied to the first three integrals of the FATES model to account for the gas diffusion mechanism which prevails in regions operating below the columnar grain growth boundary temperature.

The release function was calculated for each axial node. To obtain the accumulated fission gas release, the axial fractional releases were summed. No allowances were made in FATES for re-absorption of fission gas or any re-entry into the fuel matrix once the gas has been released.

A comparison of FATES predictions with experimental data is presented in Reference 17. Overall results are shown to be conservative.

Beginning with Unit 1 Cycle 6, the FATES 3 (Reference 27) model for fission gas release was used. The burnup and fuel microstructural (grain size) effects on fission gas release were more implicitly modeled in FATES 3. A restriction was placed on the effective grain size of the fuel for FATES 3 analyses. This restriction was burnup-dependent, and had no effect on the model at low burnups. At higher burnups, the restriction acted by incorporating a smaller grain size into the gas release model yielding higher predicted releases, which was conservative.

Beginning with Unit 1 Cycle 9, the FATES3B (Reference 29) model for fission gas release is used. The imposed grain size restriction is removed based on recent high burnup, high temperature fission gas release data. The new model increases the burnup dependence of fission gas release, i.e., it predicts higher releases at high burnup while not significantly affecting lower burnup release predictions. The grain growth model is modified in FATES3B, as is the calculated gas release following grain growth.

The RODEX2 fuel rod analysis code, used for AREVA/Framatome fuel, contains a physically based fission gas release model. The model is based on several physical mechanisms, described in References 33 and 34, that are active in producing the release of the fission gas in the fuel. The importance of each mechanism is dependent upon the operational history of the fuel, the fuel design and the structure of the fuel material. The release model involves a two-stage release process of gas being released from the grains and accumulating in the grain boundary region and then this gas being released to the free volumes in the fuel rod as the gas concentration in the boundary increases. The phenomena incorporated into the gas release evaluation model are:

1. Release to the open porosity by a direct recoil mechanism
2. Release to the grain boundary by grain boundary sweeping due to grain growth
3. Release to the free volume due to columnar grain formation
4. Diffusion to the grain boundary controlled by a re-solution barrier
5. Release from the grain boundaries to the interconnected free gas volume when the boundary concentration barrier is exceeded

3.7.1.3 License Conditions with RODEX2 Methodology

Use of the RODEX2 methodology is restricted by the following NRC imposed license conditions from Reference 37. These license conditions are required to compensate for the RODEX2 methodology which does not explicitly model degraded fuel thermal conductivity nor adequately account for modeling uncertainties.

a) A reduction of the rod internal pressure limit is required to compensate for the RODEX2 methodology. Cycles which rely on the RODEX2 methodology must ensure that predicted maximum rod internal pressure in fuel remains below the steady-state system pressure.

b) A reduction of the LHGR fuel centerline melt safety limit is required to compensate for the RODEX2 methodology. The linear heat generation rate fuel centerline melting safety limit shall remain below 21.0 kW/ft.

3.7.2 DESIGN EVALUATION OF OTHER FUEL ASSEMBLY COMPONENTS

3.7.2.1 Burnable Poison Rod Design Evaluation

a. Introduction

Fixed BPRs (neutron absorbing) are included in selected fuel assemblies to reduce the BOL MTC. They replace fuel rods at selected locations. The poison rods are mechanically similar to fuel rods, but contain a column of burnable poison pellets instead of fuel pellets. The poison pellets consist of alumina with uniformly dispersed boron carbide particles.

b. BPR Hydriding and Bowing

At the end of Unit 1 Cycle 1, it was noticed that a BPR end cap had become detached from its rod in one assembly. A subsequent detailed inspection revealed extensive hydriding of several BPRs, with subsequent failure of some cladding. A significant amount of rod bowing/Zircaloy growth was also seen. Analysis of rods examined showed that they were acceptable for reinsertion for Cycle 2 use as scheduled.

1. Hydriding

Hydride-induced failure occurs primarily due to initial moisture in the pellets. At high temperatures, the water dissociates and hydrogen gas accumulates in the gap. This hydrogen interacts with the Zircaloy-clad, forming hydride blisters, embrittling the clad and allowing subsequent perforation of the clad walls. An analysis of the neutronic and thermal hydraulic effects of hydride blisters, perforation of the clad, and loss of some exposed poison material by erosion, as well as a discussion of the possibility of fuel rod fretting caused by material dispersed in the coolant, is given in Reference 3.

2. Bowing

Bowing in BPRs is largely a result of grid restraint, rod axial growth, and pellets becoming cocked and lodged against the clad wall resulting in localized stresses. The rod axial growth is, in part, the irradiation-induced growth of Zircaloy, but is enhanced by outward pressure on the clad inner surface by poison pellet swelling. Clad creepdown, caused by the inward pressure on the clad due to coolant pressure, limits pellet movement resulting in pellet cocking and lockup. These stresses, together with those resulting from spacer grid restraint, when coupled with axial elongation of the rod itself, result in rod bow.

c. Burnable Poison Rod Improvements

Improved designs were used in manufacturing BPRs subsequent to Unit 1 Cycle 1. Pellet moisture content was maintained at a lower level during manufacturing to prevent hydriding and pellet/clad design was modified (chamfered pellet, smaller pellet, thicker clad wall, larger gap) to decrease PCI which can induce bowing and rod elongation.

3.7.2.2 CEA Guide Tube Evaluation

The CEA guide tubes form part of the structural frame of the fuel assembly and provide channels which guide the CEAs over their entire length of travel. The center guide tube houses the incore instrumentation assemblies and irradiation samples/surveillance capsules in selected assemblies. One of the corner guide tubes housed the neutron source assemblies in each of two peripheral assemblies.

The neutron sources were removed beginning with Unit 1 Cycle 9 and Unit 2 Cycle 8. For Unit 1 Cycle 11 and Cycle 12, GTFSs were inserted into the guide tubes of selected peripheral assemblies.

The guide tubes are constructed of Zircaloy-4 and are integrated into the assembly as described in Section 3.3.2.3. The Zircaloy-4 is softer than the Inconel 625 cladding on the CEA, which can result in significant wear of the guide tube as a result of CEA vibration caused by turbulent coolant flow. As a result, SS sleeves have been installed in fuel assembly guide tubes that show wear or which house CEAs. In Unit 1 Cycle 8 and Unit 2 Cycle 7, a short-sleeve design was implemented which is considered the permanent fix to CEA guide tube wear (Reference 30). All new fuel assemblies will contain the short-sleeve.

The sleeves are constructed of Type 304 SS and extend 15.375" into the guide tubes. They are chrome-plated on the wear surface to provide resistance to wear without promoting wear on the CEA cladding (Reference 5). The sleeving program was initiated with Unit 1 Cycle 3, Unit 2 Cycle 2 and has been maintained since.

Several additional measures have been taken to mitigate guide tube wear. As described in Section 3.3.2.6, PLCEAs were replaced with CEA plugs which retain the dynamic operating characteristics of the region (flow rate, pressure drops), but prevent vibration wear. The fingers of the plugs extend only 5" into the top of the fuel assembly and are positioned by a leaf spring to prevent vibration. The CEA plugs were installed beginning in Unit 1 Cycle 3, Unit 2 Cycle 2 and removed at the end of Unit 1 Cycle 7, Unit 2 Cycle 6.

In Unit 2 Cycle 2, Unit 1 Cycle 4, and Unit 1 Cycle 5, some assemblies were fabricated with small flow hole guide tubes to reduce flow induced CEA vibration (Reference 6). This design has since been discontinued.

AREVA/Framatome fuel was added to the core starting in Unit 2 Cycle 19 and Unit 1 Cycle 21. The guide tubes are similar to the Westinghouse design described here. The guide tubes are constructed of Zircaloy-4 with 22” wear sleeves constructed of Type 304 stainless steel.

3.7.3 DEMONSTRATION PROGRAMS

3.7.3.1 Introduction

In an effort to provide data on fuel design and performance, several experimental programs have been established. These programs include the SCOUT and PROTOTYPE assemblies, a prototype CEA design, surveillance capsules, a joint CE/EPRI fuel performance evaluation program, a separate CE program involving the irradiation of test fuel rods, and the ANF demonstration assemblies.

3.7.3.2 CE/EPRI Fuel Performance Evaluation

Three Batch B fuel assemblies in the initial core of Unit 1 were modified to provide fuel performance data in a variety of areas. A major modification was the reconstitutability feature to facilitate pin removal for inspection.

One assembly was intended for one cycle of irradiation, while the other two were intended for two and three cycles of irradiation, respectively. Each assembly contained fueled and non-fueled test rods. The non-fueled rods were included to obtain information concerning Zircaloy-clad creep. Steel mandrels took the place of fuel pellets to act as support for the clad, prohibiting complete collapse. The fueled rods were of varying enrichment, pellet geometry, fill pressure, and pellet microstructure. Pellet density was varied using different pore-formers to determine the effect of pellet microstructure on the densification characteristics of the fuel. Fill pressures were varied from 150 psig to 450 psig to learn the effects of fuel pressure on clad creepdown. Higher enriched fuel rods were included to gain information concerning clad creepdown at higher clad temperatures and the performance of fuel rods operating at higher LHR.

At the end of Unit 1 Cycle 1, all three assemblies were inspected and BT01 and BT02 were disassembled. Pins from each were examined for growth, visual appearances, etc. (Reference 20). BT01 was discharged as planned and BT02 was reassembled and reinserted along with BT03 for Cycle 2. At the EOC 2, BT02 and BT03 were inspected and disassembled and pins from each inspected (Reference 20). BT02 was discharged as planned and BT03 was reassembled and reinserted for Cycle 3. After Cycle 3, BT03 was inspected and disassembled and pins were removed for inspection (Reference 21). Six pins from BT03 were sent for examination in a hot cell and were replaced with six two-cycle rods from BT02. BT03 was then reinserted for Cycle 4. At the EOC 4, BT03 was inspected, disassembled and pins were removed for inspection (Reference 22). BT03 was not returned to the core for Cycle 5, but 13 pins (5 of which were 3-cycle rods and 8 were 4-cycle rods) along with one 2-cycle non-fueled rod from BT02 were inserted into a bundle from another test program (Section 3.7.3.3) for a fifth cycle. Results from analysis concerning densification and swelling, as well as fission gas release, performed on the pins sent to the hot cell, are documented (References 23, 24, and 25).

3.7.3.3 CE Irradiation of Test Fuel Rods

Three Unit 1 Batch D assemblies (D042, D047, D048) used initially in Unit 1 Cycle 2 contained graphite coated rods. Other than graphite coating on the cladding inner surface, there was no difference between the design of the test fuel and that of standard Batch D fuel. Fuel assembly D042 contained only graphite rods, while the other two assemblies each had one-fourth of their rods graphite coated. All three assemblies were irradiated for three cycles, and D047 was reinserted into Unit 1 Cycle 5 for a fourth cycle. It served as a carrier for the 14 test pins from BT03/BT02 (Section 3.7.3.2). D047 was removed at the EOC 5, and D042 was reinserted into Cycle 6 for its fourth cycle of irradiation. D042 was removed at the EOC 6 after its fourth cycle of irradiation.

3.7.3.4 SCOUT Program

One Unit 1 Batch F Assembly (F048) was designated as SCOUT. It was designed as a high burnup demonstration assembly. It contained 15 rods of various non-standard designs (Reference 8), and 5 well-characterized standard design rods for comparison. It was discharged at the EOC 8 after five cycles of irradiation.

3.7.3.5 PROTOTYPE Program

Four Unit 1 Batch G assemblies (G003, G004, G006, G008) were designated as PROTOTYPE assemblies and were initially inserted in Cycle 5. They were designed to obtain data concerning fuel performance on significant numbers of rods of standard and non-standard design in conjunction with the extended burnup program. There are several factors to consider in looking at the ability of fuel to withstand prolonged exposure, such as fission gas release and clad stresses. These factors were the bases of the experimental fuel designs used in PROTOTYPE (Reference 10) as well as in SCOUT. Before returning the PROTOTYPE assemblies to the core for their third cycle of irradiation in Cycle 7, two segmented test rods were removed from one of the assemblies and replaced with two SS rods.

The PROTOTYPE assemblies remained in the core for Cycle 9, their fifth cycle of irradiation. The PROTOTYPE assemblies were removed at the EOC 9.

3.7.3.6 Materials Surveillance Specimens

Three surveillance capsules were inserted in the Unit 1 Cycle 5 core in order to obtain data on the material properties of irradiated Inconel 625. These specimens resided in the center guide tubes of assemblies in high flux areas. One capsule was removed at the EOC 5, another at the EOC 6, and the last one at the EOC 7.

In the initial Unit 1 core, each of the three test assemblies (Section 3.7.3.2) contained a surveillance capsule in the center guide tube. These capsules contained Zircaloy and Zr-Mo-Si alloy specimens. One capsule was removed after one cycle, and another after two cycles. The third and final capsule was removed at the EOC 6.

3.7.3.7 Prototype CEA

A prototype CEA was installed in Unit 2 at the BOC 3. The changes from standard design included a change in cladding material (from Inconel to SS), reconstitutable fingers, and a change in material for the tips of the poison rods from Ag/In/Cd to B_4C. The size of the B_4C pellets used in the tips was decreased from the pellet size used for the remainder of the rod length. A metal liner was added to prevent any B_4C fragments from collecting in the high flux tip.

3.7.3.8 ANF Demonstration Assemblies

Four new demonstration assemblies, designated as Batch 1MX, were loaded into Unit 1 Cycle 10. These assemblies were manufactured by ANF and contain gadolinium as the burnable poison material. Each assembly consists of 164, 4.08 wt% U-235 enriched fuel pins and 12 fuel-bearing gadolinium poison pins. The poison pins contain natural uranium and 10 wt% Gd_2O_3. The mechanical configuration of the MX assemblies is essentially the same as the other Batch 1M assemblies. The purpose of installing the ANF assemblies in the Unit 1 core for Cycle 10 is to qualify an alternate source of supply for 24-month fuel assemblies. The ANF assemblies were reinserted into Unit 1 Cycle 11 for their second cycle of irradiation.

3.7.3.9 Erbium Demonstration Assemblies

For Unit 2 Cycle 9, four demonstration assemblies containing Erbium as a burnable absorber were introduced. Each assembly consists of 80 standard pins at 4.3 wt% U-235, 52 standard pins at 3.4 wt% U-235, and 44 Erbium bearing pins. The fuel stack in each erbium bearing fuel pin consists of a central 115.7" region containing 3.4 wt% of U-235, 0.9 wt% Er_2O_3, UO_2/Er_2O_3 pellets and two 10.5" cutback regions, one at each end of the stack containing standard 3.4 wt% U-235 pellets. The major incentives of erbium as a burnable absorber is an increase in core thermal margin and lower local peaking through the decrease in nonfuel bearing discrete burnable absorbers. The erbium assemblies were reinserted into Unit 2 Cycle 10 for their second cycle of irradiation.

3.7.3.10 Test Capsule Assemblies

The Test Capsule Assembly Program is being conducted to evaluate the effects of irradiation at reactor temperatures on materials being considered for advanced spacer grid spring designs.

In Unit 1 Cycle 12, three test capsules were placed in the outer guide tubes of three separate once-burned fuel assemblies.

Four test capsules were placed in the outer guide tubes of four separate fresh fuel assemblies in Unit 1 Cycle 13. Two of these capsules were from Unit 1 Cycle 12 and two are new capsules.

Two test capsules were placed in the outer guide tubes of two separate fuel assemblies in Unit 1 Cycle 14. Both of these capsules were from Unit 1 Cycle 13. Test capsules TCA-3 and TCA-5 were discharged at the end of Unit 1 Cycle 14.

3.7.3.11 Lead Fuel Assemblies for Unit 2 Cycle 11

Four Lead Fuel Assemblies were loaded in Unit 2 Cycle 11. The Lead Fuel Assemblies, designated Batch 2NT, have larger pellet diameter, larger pellet length, slightly reduced clad thickness, greater stack height density and shorter rod length. Zircaloy-2P is used for 216 fuel rods. The remaining rods are standard Zircaloy-4 clad. The Batch 2NT LFAs were re-inserted for a second cycle of operation in Unit 2 Cycle 12 and were discharged to the spent fuel pool after completion of that cycle.

3.7.3.12 Batch 1RT Lead Fuel Assemblies

Four Lead Fuel Assemblies (LFAs) designated as Batch 1RT were loaded into Unit 1 Cycle 13. These assemblies all have a larger pellet diameter, larger pellet length, slightly reduced clad thickness, greater stack height density and shorter rod length.

Five cladding variants were used in 176 rods in two of the Batch 1RT Lead Fuel Assemblies (12 rods of Zircaloy-2P, 20 rods of Zircaloy-4F, 60 rods of Zirconium Alloy E, 24 rods of Zirconium Alloy C, and 60 rods of Anikuloy™).

Two of the Batch 1RT LFAs utilize an advanced assembly design. From the bottom to the top of the assembly, the advanced assembly design contains the laser welded straight strip GUARDIAN™ grid, two laser welded straight strip intermediate spacer grids, four laser welded straight strip mixing grids, and a laser welded straight strip end grid. The advanced assembly design also contains an advanced spring design and a locking guide tube to upper flow plate design.

In Unit 1 Cycle 14, the Batch 1RT LFAs were carried over for their second cycle of irradiation. The LFA set was split up and asymmetrically loaded into the Unit 1 Cycle 14 core. The asymmetric loading (2 LFAs on the core periphery, and 2 LFAs in the core interior) was performed to gather data about Batch 1RT LFA performance on the core periphery.

In Unit 1 Cycle 15, Batch 1RT LFAs (1RT1 and 1RT3) were located on the core periphery for a second cycle in a row to gather data about Turbo test grids performance. Batch 1RT LFAs (1RT2 and 1RT4) were discharged to the spent fuel pool following Unit 1 Cycle 14.

In Unit 2 Cycle 14, the reconstituted LFA 1RT4 was located on the core periphery to gather data about Turbo test grids and advanced cladding material performance. The original LFA 1RT4 was reconstituted with fuel rods from LFA 1RT2, after Unit 1 Cycle 14. The original LFA 1RT4 assembly was reconstituted because the corrosion performance of Anikuloy, Zircaloy-2P, and Zirconium Alloy C claddings were not better than the standard OPTIN cladding. During the reconstitution, 1RT4 fuel rods with Anikuloy, Zircaloy-1P, and Zirconium Alloy C claddings were replaced with LFA 1RT2 fuel rods with OPTIN and Zirconium Alloy E claddings. The reconstituted LFA 1RT4 contains fuel rods with OPTIN, Zirconium Alloy E, and Zircaloy-4F claddings.

3.7.3.13 Framatome and Westinghouse Lead Fuel Assemblies for Unit 2 Cycle 15

Eight LFAs were loaded into Unit 2 Cycle 15. Four assemblies were manufactured by Westinghouse, and they were designated as 2TW, and four assemblies were manufactured by FANP, and they were designated as 2TF. The purpose of the LFAs is to test fuel cladding variants, and in the case of FANP, to evaluate an alternate fuel supplier.

In the Westinghouse LFAs, the standard ZIRLO cladding is present along with three test claddings. In the FANP LFAs, their standard M5® cladding is present. The test claddings (e.g., low tin ZIRLO and M5®) in the LFA do not meet the NRC definition of Zircaloy-4 or ZIRLO. An explicit submittal for each set of LFAs was made. The NRC reviewed each LFA submittal and approved the use of the LFAs for peak rod burnups up to 60,000 MWD/MTU. Neither LFAs contain any burnable absorbers.

The Westinghouse LFAs utilize the standard Turbo grid cage design, with one minor design change where the back-up arch on the perimeter Turbo grid strip is slightly longer. This change further improves the grid to rod fretting performance and does not impact the flow, structural, or mechanical characteristics of the grid.

The FANP LFAs for the Calvert Cliffs Unit 2 reactor will be the CE 14x14 design. The bundle uses nine Zircaloy-4 grid spacers of the high thermal performance design. The lower tie plate is the FUELGUARD™ design, and the upper tie plate is the standard, reconstitutable FANP design for CE 14x14 fuel. The high thermal performance spacer was generically reviewed and accepted by the NRC and has been used for reload designs for CE, Westinghouse, and Kraft-werke Union reactors since 1991. The FUELGUARD™ lower tie plate has also been used in reload designs for CE, Westinghouse, and boiling water reactor designs. The reconstitutable upper tie plate design has been in use for reloads for CE plants since the early 1980s. Except for the changes to the fuel rod described in the following paragraphs, the LFA fuel bundle design has been used in reloads for other CE 14x14 plants. An illustration of this design is shown in Figure 3.7-1.

Each fuel bundle contains four corner guide tubes, one center guide tube/instrument tube, and 176 fuel rods. The corner guide tubes in the LFAs have the same nominal inside diameter/outside diameter (ID/OD) and dashpot design as used for the standard CE 14x14 reload fuel supplied by FANP. The elevations of the features (e.g., weep holes, upper sleeve attachment, etc.), except for the total length, are the same as has been used on other CE 14x14 reload designs. Similarly, the center guide tube has the same nominal ID/OD as has been used on other CE 14x14 designs and as the co-resident fuel. The height and elevations are established to be compatible with the Calvert Cliffs core plate separation distance, the co-resident fuel and the FANP manufacturing processes.

The fuel rod design for Calvert Cliffs uses a 136.7 inch fuel column of uranium dioxide pellets. The rod consists of cladding, an upper end cap, a lower end cap, fuel pellets, and a plenum spring. The differences between the Calvert Cliffs lead assemblies and the standard FANP reload design for CE designed 14x14 plants are changes to the fuel rod design.

Specifically, the rod changes are:

* the cladding material used for the fuel rod is M5® instead of Zircaloy-4;
* the cladding inner diameter is increased by 0.003 inches to 0.387 inches;
* the pellet diameter is increased by 0.0035 inches to 0.3805 inches;
* the pellet density is 96% TD instead of 95.35% TD;
* the initial rod internal pressure will be increased from 315 psig to 375 psig; and
* the cladding length is increased by about 0.2 inches.

The increased cladding length provides more plenum volume, but requires the plenum spring to be modified to accommodate the longer plenum. The cladding OD is unchanged and is the same as the standard CE 14x14 reload fuel supplied by FANP and the same as the co-resident fuel. The lengths of the end caps will be the same as used for the standard CE 14x14 reload design.

All eight LFAs resided in symmetric core locations for both Unit 2 Cycle 15 and Unit 2 Cycle 16. For Unit 2 Cycle 17, only two Westinghouse LFAs (2TW02 and 2TW03) were inserted along the core periphery to gather additional data on grid-to-rod fretting resistance. The remaining LFAs (four FANP and two Westinghouse were discharged to the spent fuel pool).

For Unit 1 Cycle 19, two Westinghouse LFAs and two FANP LFAs were loaded in symmetric locations to evaluate the cladding at high pin burnups (up to 70 GWD/MTU).

3.7.3.14 Framatome Lead Test Assemblies for Unit 2 Cycle 24

Two Lead Test Assemblies (LTAs) were loaded into Unit 2 Cycle 24. One assembly, BE601, is an Accident Tolerant Fuel (ATF) demonstration assembly while the other LTA, designed as AE135, is an irradiated assembly armored with 8 Chromium coated inert rods in locations along it periphery where it would reside with half a peripheral face against the core shroud.

BE601, the ATF LTA, consists of 164 fuel rods with chromium coating and chromia doped pellets and 12 chromium coated fuel rods with UO_2-GD_2O_3 pellets. The rods for the CE14x14 HTP™ LTA are built to the same requirements as the standard rods they replace, except for the doped pellets and coating. The difference in the LTAs is a slight change in pellet density. The external physical dimensions of the coated rods are identical to the standard fuel rods. The rod cladding material is M5®, with an added thin chromium layer. The gridcage for the LTA is the same as a standard reload batch namely the CE14x14 HTP™ design with FUELGUARD™ lower tie plate.

AE135 is an irradiated assembly slated for insertion into Unit 2 Cycle 24 in a core peripheral location where half of the assembly face would reside against the core shroud. To mitigate potential grid to rod fretting (GTRF) concerns, the 7 rods adjacent to thee core shroud plus one additional face adjacent rod (a total of 8) were removed and replaced with inert rods bearing the same chromium coating as discussed BE601. This was to demonstrate that the chromium coating, being materially harder than the standard M5® cladding, would be less susceptible to GTRF wear than uncoated cladding.

3.7.4 CHRONOLOGY OF FUEL EXPERIENCE

The following summaries provide a brief synopsis of major fuel performance-related changes and experiments associated with each cycle.

3.7.4.1 Unit 1

a. Cycle 1

Three assemblies of Batch B fuel designated as experimental assemblies were inserted for the purpose of providing fuel design and performance data, and were the only assemblies inserted in Cycle 1 which were designed to be reconstitutable. One was scheduled to be irradiated for one cycle (BT01), one for two cycles (BT02), and one for three cycles (BT03). Experimental designs for fuel pellets, BPRs, and plenum springs were incorporated, as well as test samples of zirconium alloys and non-fueled rods to test cladding design/materials. The test assemblies are described in Section 3.7.3.2; Reference 1 gives a detailed survey of the fabrication and characterization of the test assemblies.

b. Cycle 2

The design of Batch D fuel was modified from the original design used in Batches A, B, and C. Some design changes were made to allow for the reconstitution of all assemblies in order to permit replacement of failed rods or to provide for removal of rods for post irradiation examination. Design changes were also made to improve fuel performance. These changes included:

1. Changes in pellet shape [chamfering and reduced length/diameter (L/D) ratio];
2. Increased pellet density;
3. Increased clad thickness;
4. Decrease in helium fill gas pressure; and,
5. Decrease in pellet-clad gap size.

The density was increased to increase the stability of the fuel to densification, thereby improving gap conductance. The gap conductance was also enhanced by the reduction in gap size. The increased clad thickness and changes in pellet shape were made in order to reduce the susceptibility of fuel to failure by PCI/Corrosion cracking. The fill pressure could be reduced due to improved collapse resistance caused by thicker clad and a more stable fuel pellet design. The design changes are listed in Tables 3.3-1 and 3.3-2. The fuel assembly modifications were made, as stated above, to allow reconstitution, as well as to accommodate flow forces. Changes made to permit reconstitution were to the upper-end-fitting-to-guide-tube joint, anti-rotation device, and fuel rod upper and lower end caps. In addition, an Inconel bottom spacer grid replaced the mechanical retention grid.

Three test assemblies of a new design were incorporated into Unit 1 Cycle 2. The design of these three Batch D assemblies (D042, D047, D048), as well as an analysis of their impact on operations under normal and transient conditions, is contained in Reference 2. In addition to these three test assemblies, the two-and three-cycle Batch B test assemblies remained in the core for Cycle 2.

A detailed inspection program was undertaken to determine the extent and effect of bowing and hydriding of BPRs, which were present in Batch B fuel and 28 Batch C assemblies. This inspection was the result of: 1) the finding of a BPR end cap which had become detached from its BPR, and 2) the finding of several BPRs whose cladding had failed due to hydriding (Reference 3).

c. Cycle 3

The design of Batch E fuel was identical to standard Batch D design used in Cycle 2 with the exception of a 40 psi fill gas pressure reduction, and a pellet dish depth reduction of .002", increasing stack density to 10.046 g/cc. The increased density served to enhance fuel stability. The reduction in fill gas pressure reduced fuel temperature by accelerating clad creepdown and improving heat transfer. The resulting reduced fuel internal gas pressures remained conservative relative to predicted time for clad collapse.

Only one assembly containing BPRs (Batch B test assembly) remained in the core for Cycle 3. All three Batch D test assemblies remained in the core for their second cycle of irradiation.

A problem with CEA guide tube wear was noted prior to Cycle 3. This wear was the product of CEA vibration in the guide tubes (Reference 4). For Cycle 3 it was determined that no assemblies which had been under a CEA in a previous cycle would be inserted in a CEA location for Cycle 3 with the exception of BT03 in the core center location. In addition, all assemblies which were to be placed in CEA locations would have sleeved guide tubes (Reference 4). The core reload pattern was modified in order to ensure that CEAs were in previously unworn guide tubes. This resulted in eight Batch C assemblies being discharged and replaced with eight Batch A assemblies.

All part length control rods were replaced (for preservation of pressure drops, flow rates, etc.) with CEA plugs (Reference 5).

d. Cycle 4

There were no design changes to the fuel pellets used in Batch F fuel. Batch F fuel assemblies were modified from previous design in that the holddown plate in the upper end fitting was thickened slightly, and the cross bracing that connects the lower end fitting posts was thickened and raised slightly from the lowermost surface of the fuel assembly.

As part of the continuing effort to mitigate guide tube wear, all previously burned fuel assemblies scheduled to be placed in CEA locations were sleeved (Reference 4). The only exception to this was test bundle BT03, which was in the center of the core for Cycles 3 and 4. This location is typically a low-wear location, and the degree of wear found during inspection after Cycle 3 was acceptable for placement under the center CEA for Cycle 4. Of the 72 new Batch F assemblies, 24 were placed under CEAs and were sleeved. Of the 48 F assemblies not under CEAs, 16 assemblies (unsleeved) had modified guide tubes (Reference 7) and 32 assemblies (unsleeved) had standard guide tubes.

At the EOC 3, test bundle BT03 was discharged, disassembled, and inspected. Six pins were removed to go to hot cell for examination and pins from the BT02 two-cycle assembly were inserted in their place. BT03 was then placed back in the center of the core. The three D test assemblies were retained in the core for a third cycle.

In addition to these, a new test fuel assembly was introduced into the Cycle 4 core. The Batch F SCOUT bundle was designed as a high burnup demonstration to provide information for the extended cycle/high burnup program (Reference 8).

e. Cycle 5

Batch G assemblies introduced into the Unit 1 core were composed of higher enriched fuel (40 assemblies at 3.65 wt% and 52 assemblies at 3.03 wt%) for extended cycle length/extended burnup. The 52 assemblies of lower enriched fuel contained 8 BPRs per assembly. These poison rods were of an improved design to eliminate the hydriding induced failure found in the earlier design, as well as to mitigate poison rod growth and bowing. The BPR changes included reduced pellet moisture limit and improved manufacturing to lessen moisture ingress. To reduce the likelihood of PCI which leads to axial growth/rod wall perforation, several other BPR design modifications were made, including: 1) increased pellet/clad gap, 2) chamfered pellets, 3) increased rod pressurization, and 4) reduced plenum spring preload.

Besides the addition of BPRs and the higher enrichment, no design changes were initiated with standard Batch G fuel.

As in previous cycles, assemblies placed in CEA locations had modified guide tubes to mitigate wear (with the exception of test bundle D047 in the core center location). Thirty-two of those assemblies were of the modified design while the rest were sleeved. Sixteen of the modified assemblies were Batch F assemblies placed in single CEA locations. The remaining 16 were Batch G assemblies placed in dual CEA locations.

In an effort to expand the database on material properties of irradiated Inconel 625 CEA cladding, three empty CEA tubes were placed in the center guide tubes of assemblies placed in high flux areas (Reference 9). Test bundle D047, placed in the center of the core, was left in the core for its fourth cycle of irradiation. It served as a carrier for 14 test pins; 13 pins from test bundle BT03, of which 8 were 4-cycle rods and 5 were 3-cycle rods, and 1 2-cycle non-fueled rod taken from BT02.

The Batch F SCOUT assembly remained in the core for its second cycle of irradiation. Introduced into the core for the first time in Cycle 5 were four lead assemblies called PROTOTYPE. They contained rods similar in design to SCOUT but greater in number in order to provide a sound statistical database for proper evaluation of fuel performance (Reference 10).

f. Cycle 6

Batch H assemblies introduced into Unit 1 core were composed of higher enriched fuel (40 assemblies at 4.00 wt% and 32 assemblies at 3.55 wt%) for extended cycle length/extended burnup. The 32 low enriched Batch H assemblies contained 8 BPRs per assembly. These BPRs were of similar design to those utilized in the low enriched Unit 1 Batch G fuel.

An additional design change introduced with Batch H fuel was a decrease in the overall length of the fuel rods of .200". This decrease yields additional shoulder gap clearance allowing for increased rod growth expected as the fuel is taken to higher burnups.

As in previous cycles, assemblies placed in CEA locations had modified guide tubes or were sleeved to mitigate wear. Four assemblies in CEA locations for Cycle 6 had modified guide tubes, while the remainder were sleeved.

Test assembly 1D042, which had been irradiated in Cycles 2, 3, and 4, was returned to the core for a fourth and final cycle of irradiation in Cycle 6. The Batch F SCOUT assembly remained in the core for its third cycle of irradiation. The four Batch G PROTOTYPE assemblies remained in the core for their second cycle of irradiation.

g. Cycle 7

Sixty-four new Batch J fuel assemblies were introduced into the Unit 1 core for Cycle 7. Of those, 48 were high enriched (4.05 wt%) and 16 were low enriched (3.40 wt%). None of the Batch J fuel contained BPRs. The mechanical design of Unit 1 Batch J fuel was identical to that of the Batch H fuel introduced in Cycle 6.

The SCOUT assembly remained in the core for its fourth cycle of irradiation during Cycle 7. At the EOC 6, two fuel rods were removed and replaced with SS rods.

The four PROTOTYPE assemblies remained in the core for their third cycle of irradiation during Cycle 7. At the EOC 6, two fuel rods were removed from one PROTOTYPE assembly, and replaced with SS rods.

Several Batch 1G and 1F fuel assemblies (remaining in the core for a third cycle of irradiation) were modified to allow for fuel rod growth. The modification involved the installation of a spacer shim which effectively raised the flow plate by .285". Modified upper end fitting corner posts were then installed to ensure compatibility between the upper end fitting and guide tubes. This modification is required when spacer shims are added.

Three inconel test specimens were placed in the core for irradiation during Unit 1 Cycle 5. Two of these remained in the core during Cycle 6. One specimen was then removed, leaving one specimen in the core for a third and final cycle of irradiation during Cycle 7.

h. Cycle 8

Seventy-two new Batch K fuel assemblies were introduced into the Unit 1 core for Cycle 8. Of those, 48 were high enriched (4.05 wt%) and 24 were low enriched (3.40 wt%). None of the Batch K fuel contained BPRs.

The mechanical design of the Batch K reload fuel was identical to that of Batch J, with the exception of the design features noted below:

1. The height of the lower end fitting is shorter. This reduction is achieved by shortening the legs of the lower end fitting assembly.
2. The overall lengths of the guide tubes are increased to compensate for the shorter lower end fitting described in 1. This increase is achieved by increasing the length of the buffer region, i.e., tapered region. The combination of this shorter lower end fitting and the longer guide tubes maintains the same overall assembly length as that of the Batch J fuel.
3. The elevations of the Inconel grid and the uppermost Zircaloy grid are changed to maintain their same relative elevations with respect to fuel rods as those of the reference cycle fuel design.

The changes described above were analyzed and found to have no significant adverse effect on the performance of the Batch K fuel relative to that of the Batch J fuel. These changes will result in improved fuel performance by increasing the shoulder gap from 1.400" to 1.775".

The SCOUT demonstration assembly remained in the core for its fifth cycle of irradiation in Cycle 8. The four PROTOTYPE assemblies remained in the Unit 1 core for their fourth cycle of irradiation.

As described in Section 3.3.2.4, nine CEAs were replaced and the configuration of two CEA banks were changed for Cycle 8 to increase net available scram worth.

CEA plugs were removed for Cycle 8 to facilitate the installation of the Reactor Vessel Level Monitoring System and to expedite refueling operation.

The phenomena of interpellet gap formation and clad collapse in modern PWR fuel rods was reassessed. It was concluded that the minimum time to clad collapse is significantly greater than its expected life and the augmentation factor associated with interpellet gaps is insignificant compared with the uncertainties in the safety analysis. Therefore, the cycle-specific clad collapse analysis is not necessary and the augmentation factor associated with interpellet gaps is removed from the Technical Specifications.

i. Cycle 9

Fifty-two new Batch L fuel assemblies were introduced into the Unit 1 Cycle 9 core. Of those, 40 were high enriched (4.05 wt%) and 12 were low enriched (3.40 wt%). None of the Batch L fuel contained BPRs. The mechanical design of Batch L fuel is identical to that of the Batch K fuel introduced in Cycle 8.

The four Batch G PROTOTYPE assemblies remained in the core for their fifth cycle of irradiation. One SS rod (inserted at EOC 6) was replaced with a test fuel rod from the SCOUT assembly (which was discharged at EOC 8).

One Batch H assembly was kept in the core for a fourth cycle of irradiation to obtain high burnup data. It resides in the center core location.

Six fuel rods (three failed, one damaged and two for future inspection) were replaced by SS rods prior to Cycle 9.

Sixty-eight CEAs (all CEAs not replaced at EOC 7) were replaced with new CEAs. These CEAs are similar in design to original CEAs with the following notable exceptions:

1. Ag-In-Cd slug in the tip of the center finger
2. Reconstitutable corner fingers.

j. Cycle 10

Ninety-six new Batch M assemblies were introduced into the Unit 1 core for Cycle 10, the first Unit 1 24-month fuel cycle. It is also the first Unit 1 cycle to use low-leakage fuel loading pattern. Ninety-two of the assemblies were supplied by CE with 4.08 wt% U-235 enrichment. Of these, 16 assemblies had no BPRs and 76 assemblies had 12 B_4C BPRs. The remaining four assemblies (Batch MX) are the ANF demonstration assemblies which have 3.85 wt% U-235 average assembly enrichment and contain 12 gadolinium, fuel bearing (natural uranium) BPRs.

The mechanical design of the CE supplied Batch M reload fuel is identical to that of the Batch L fuel except some Batch M assemblies contain BPRs. The design of these poison rods is the same as that of the poison rods in Batch 2K assemblies from Unit 2 Cycle 8. The only changes in BPR design concern the use of higher poison loadings and hollow spacers rather than solid spacers.

Four damaged fuel rods were replaced with SS dummy rods in three Batch L assemblies prior to Cycle 10.

To support 24-month cycle operation, the very weak center CEA (all Al_2O_3 fingers) installed as part of the CEA bank configuration prior to Cycle 8 were replaced with a weak CEA (center finger B_4C, other four Al_2O_3).

k. Cycle 11

Eighty-four new Batch N fuel assemblies were introduced into the Unit 1 Cycle 11 core. This includes 12 assemblies with no BPRs, 20 assemblies with 4 BPRs, and 52 assemblies with 8 BPRs. All Batch N assemblies were enriched with 4.20 wt% U-235. Guide Tube Flux Suppressors were placed in selected fuel assemblies near the periphery of the core to reduce the fluence at the critical vessel weld. The Batch N fuel employs the GUARDIAN™ debris-resistant fuel design. The GUARDIAN™ design includes a new grid and fuel pin design. The four Batch MX ANF fuel assemblies were returned to the Unit 1 Cycle 11 core for their second cycle of irradiation.

Changes incorporated by the GUARDIAN™ fuel design include the following: the length of the Zircaloy lower end cap was increased to provide a solid Zircaloy region in the area where debris is to be trapped. The overall length of the fuel and BPRs was increased, while the length of the plenum regions was reduced. This was done to compensate for the increase in the length of the lower end cap. The guide tube length was increased to maintain the same shoulder gap. The position of the active fuel region and burnable poison region was raised due to the increase in height of the lower end cap. The height of the lower end fitting was decreased to keep the overall length of the bundle unchanged. This was accomplished by decreasing the compression region for the hold-down spring without a change in dimension of the spring.

The Zircaloy spacer grids were redesigned by increasing the size of the outer pin cell through enlargement of the outside envelope of the spacer grid assembly. This allows fuel rods located along the periphery of the fuel bundle to receive more coolant flow when in contact with adjacent bundles.

Fourteen fuel rods were replaced with SS dummy rods during reconstitution, for a total of 16 SS rods reinserted into Unit 1 Cycle 11.

The weak center CEA (center finger B_4C, others Al_2O_3) was replaced with a similar CEA utilizing a SS slug in the bottom of each weak finger. This replaced the Zircaloy slug which was subject to hydriding.

l. Cycle 12

Eighty-eight new Batch P fuel assemblies with 4.3 wt% U-235 were introduced into the Unit 1 Cycle 12 core. This includes 16 assemblies with no burnable absorbers, 12 assemblies with 20 erbium pins, 8 assemblies with 44 erbium pins, and 52 assemblies with 60 erbium pins. Guide tube flux suppressors remained in select peripheral assemblies to reduce the fluence to the critical vessel weld. The four Batch MX ANF fuel assemblies were returned to the Unit 1 Cycle 12 core for their third cycle or irradiation.

The Batch 1P GUARDIAN™ fuel assembly employs a design change which involves the replacement of the top TIG-welded Zircaloy grid with a laser weld Zircaloy grid. This design change introduces a backup arch in each grid cell in addition to the existing design with backup arches placed only in peripheral cell locations.

Three test capsule assemblies were placed in the outer guide tubes of select once-burned assemblies for Cycle 12. The capsules contain test specimens of an advanced spacer grid spring design.

m. Cycle 13

There was a design change to the perimeter spring design in the GUARDIAN™ grid to reduce protrusion of the spring beyond the outer edge of the grid.

Four test capsule assemblies were placed in the outer guide tubes of four separate fresh fuel assemblies for Cycle 13. Two of the capsules are from Cycle 12, and two are new. The capsules contain test specimens of advanced spacer grid spring designs.

Batch 1R erbium rods have cutback regions of 10.5” at the top and 12.0” at the bottom.

n. Cycle 14

The Batch 1S erbium rods have cutback regions of 10.5” at the top and 12.0” at the bottom.

Two test capsules were placed in the outer guide tubes of two separate fuel assemblies in Unit 1 Cycle 14. Both of these capsules were from Unit 1

Cycle 13. The capsules contain test specimens of advanced spacer grid spring designs.

o. Cycle 15

The Batch 1T fresh fuel assemblies represent the first full batch implementation of the VAP fuel assembly design. The VAP feature has been tested at Calvert Cliffs in lead fuel assembly batches 1RT and 2NT. Value Added Pellets' diameter is 0.0045" larger than a standard pellet. The VAP clad wall thickness is 0.026" vs 0.028" for standard fuel. The Batch 1T erbium rods have cutback regions of 10.5" at the top of the fuel column and 14.0" at the bottom of the fuel column.

Unit 1 Cycle 15 is the first Calvert Cliffs reload designed with the ENDF/B-VI cross-section library in lieu of traditional ENDF/B-IV cross-sections.

Test capsules TCA-3 and TCA-5 were discharged to the spent fuel pool prior to the startup of Unit 1 Cycle 15.

Lead fuel assemblies 1RT1 and 1RT3 were returned to the core for a third cycle of irradiation. Lead fuel assemblies 1RT2 and 1RT4 were discharged to the spent fuel pool at the end of Unit 1 Cycle 14.

During the refueling outage, inspections were performed on the Batch 1R and 1RT fuel assemblies. Higher than expected grid-to-rod fretting was observed in certain fuel assemblies that had resided on the core periphery near the core shroud. Grid-to-rod fretting is an ongoing historical phenomena observed at Calvert Cliffs. To minimize grid to rod fretting during Unit 1 Cycle 15, several compensatory actions were implemented. First of all, the fuel management pattern was changed to rotate 1RT1 by 180° so that it would not have the same face against the core shroud for two consecutive cycles. Next, several fuel rods were rotated to present a fresh unworn surface to the rod support features. Finally, one heavily worn pin in 1R222 and two heavily worn pins in 1RT1 were replaced with stainless steel pins. These actions will minimize grid-to-rod fretting for Unit 1 Cycle 15. The grid-to-rod fretting wear that is expected to occur during Unit 1 Cycle 15 will occur in low power peripheral fuel rods that will not contribute significant activity to the coolant if they were to fail. The number of grid-to-rod fretting failures likely to be experienced in Cycle 15 will not result in the RCS coolant activity approaching the Technical Specification limit. The impact of the population of fuel rods exhibiting significant wear such that integrity under transient and accident conditions could be challenged is small enough that the coolant activity impact is bounded by previously analyzed levels.

p. Cycle 16

Due to the merger of Westinghouse and CE, the CE fuel fabrication facility at Hermatite was permanently shut down. Before it was closed, all of the Batch 1V erbium rods were built at Hermatite. The remaining non-erbium rods were built at the Westinghouse Columbia manufacturing facility.

The integration of the basic CE fuel designs into the Columbia fabrication process necessitated numerous internal rod design changes including TIG welding of end caps, elimination of the lower alumina spacer, redesign of the plenum spring, etc.

The merger of Westinghouse and CE resulted in the Westinghouse standard cladding material (ZIRLO) becoming available to Calvert Cliffs. Since ZIRLO has better water side corrosion properties than the CE standard OPTIN cladding material, Calvert Cliffs elected to phase in ZIRLO cladding. ZIRLO was only available in time to support manufacturing of the non-erbium pins. The erbium pins for Unit 1 Cycle 16 still use the OPTIN cladding material.

Unit 1 Cycle 16 is the first full batch implementation of the advanced grid design known as Turbo. This grid design was tested in the Batch 1RT LFAs. The Turbo grid features include mixing vanes (at five of the eight spacer grid locations) and a new rod retention device known as I-springs (at all eight spacer grid locations).

Batch 1V will be the second full batch of VAP fuel assemblies for Unit 1.

Some of the Batch 1V fuel assemblies will use a 60 erbium pin lattice pattern. This is the first use of the 60-pin pattern with VAPs. The 60 pin pattern was previously used at Calvert Cliffs in Batch 1P with standard fuel pellets.

q. Cycle 17

Eighty-eight fresh assemblies were installed for Unit 1 Cycle 17 (batch designation 1W).

Batch 1W is the third batch of VAP for Unit 1. Erbia remains the burnable absorber, the Erbia fuel pins have cutback regions of 10.5 inches at the top of the rod and 12.0 inches at the bottom.

Batch 1W is the second batch of the Turbo fuel assembly design for Unit 1. All but four assemblies utilized the same design and the same grid cage design as the U2C15 Westinghouse LFAs, see Section 3.7.3.13. The four different assemblies do not have the increased backup-arch length and have been given a unique sub-batch identifier. All of the fuel was manufactured by Westinghouse at their Columbia, SC facility. The cladding material for all fresh fuel is ZIRLO™.

As Unit 1 contains approximately 85% of the Turbo fuel assembly design, transient analyses were updated to utilize the ABB-TV CHF Correlation. Since the Turbo fuel has a non-mixing vane lower axial section and an upper section with mixing grids, both the ABB-NV and the ABB-TV CHF correlations are applied in the safety analysis.

r. Cycle 18

Ninety-seven fresh assemblies were installed for Unit 1 Cycle 18 (batch designation 1X). This reload incorporated the “T” pattern and contains no fresh fuel on the core periphery.

Beginning with Cycle 18, ZrB_2 (IFBA) has replaced erbia as the burnable absorber. Batch 1X fuel assemblies, with the exception of single 1X7 assembly, also contain axial blankets, which consist of a lower-enrichment at the top and bottom 6” of the fuel. The axial blankets in the fuel rods that contain IFBA consist of annular pellets to provide extra plenum volume to accommodate increased helium gas production associated with the ZrB_2.

Also beginning with Cycle 18 is the addition of radial enrichment zoning. Batch 1X assemblies, with the exception of single 1X7 assembly, contain fuel rods of two different enrichments, with lower enriched rods placed on the assembly corners and next to guide tube locations.

Cycle 18 also contains a single assembly, sub-batch 1X7, which is a single-enrichment assembly at 2.0 wt% U-235 and does not contain either IFBA rods or axial blankets. The assembly has been placed in the center of the core in lieu of a twice burned assembly. This is the first reload in which a low-enriched fresh assembly is used in this location.

During the refueling outage prior to the startup of Cycle 18, inspections were performed on several reinsert Batch 1W assemblies due to indications of pin failures during their first duty cycle. In three assemblies, a total of four fuel pins were replaced with other fuel pins (from the parent assemblies) and a total of four stainless rods were inserted.

s. Cycle 19

Ninety-six fresh assemblies were loaded for Unit 1 Cycle 19 with a batch designation of 1Z. Cycle 19 included the "T" pattern and contains no fresh fuel on the core periphery.

Batch 1Z consists of sub-batches with two-enrichment and three-enrichment radial zoning. Batch 1Z retains the use of IFBA as a burnable absorber and the use of axial blankets. Annular pellets are used in the blanket regions of rods that contain IFBA to provide extra plenum volume to accommodate increased helium gas production associated with the ZrB_2.

Two Westinghouse LFAs and two FANP LFAs were loaded in symmetric locations for a third cycle of irradiation of up to 70 GWD/MTU.

During the 2008 refueling outage prior to U1C19 startup, fuel inspections identified failed fuel pins in three once-burned (Batch 1X) assemblies slated for reinsertion into Cycle 19. Two of the failed assemblies were replaced with substitute assemblies and were not reinserted into the core. An inert stainless steel pin was inserted into the third failed assembly, allowing it to be used in Cycle 19.

t. Cycle 20

Ninety-two fresh assemblies were loaded for Unit 1 Cycle 20, eighty-eight with a batch designation of AA, and four with a batch designation of 2X7. Cycle 20 included the "T" pattern and contains no fresh fuel on the core periphery.

Batch AA consists of sub-batches with two-enrichment and three-enrichment radial zoning. Batch AA retains the use of IFBA as a burnable absorber and the use of axial blankets. Annular pellets are used in the blanket regions of rods and contain IFBA to provide extra plenum volume to accommodate increased helium gas production associated with the ZrB_2.

Batch 2X7 was originally purchased as spare fuel for Unit 2 Cycle 18. These assemblies were not used in U2C18 and are fresh for U1C20. Batch 2X7 consists of only one enrichment and does not contain any IFBA as a burnable absorber.

The rated thermal power was raised from 2700 MWt to 2737 MWt during this cycle and was based on flow measurement uncertainty capture.

u. Cycle 21

Ninety-six fresh AREVA Advanced CE HTP™ fuel assemblies were loaded for Unit 1 Cycle 21 with a batch designation of AB. The AREVA Advanced CE HTP™ fuel design employs the FUELGUARD™ lower tie plate, MONOBLOC™ guide tubes, and HTP™ spacer grids. Zr-4 was used for the guide tubes and spacer grids. M5® was used as the fuel cladding material. This is the first implementation of AREVA fuel in Calvert Cliffs Unit 1. Cycle 21 included the “T” pattern and contains no fresh fuel on the core periphery.

Batch AB consists of sub-batches with two-enrichment radial zoning. Batch AB uses Gd_2O_3 as a burnable absorber. Six inch low-enriched blankets are used on the top and bottom of non-gadolina-bearing fuel rods. Twelve inch low enriched axial blankets are used on the top and bottom of gadolina-bearing fuel rods.

Unit 1 Cycle 21 was designed using the AREVA physics code package (CASMO/PRISM).

v. Cycle 22

Ninety-six fresh AREVA Advanced CE HTP™ fuel assemblies were loaded for Unit 1 Cycle 22 with a batch designation of AC. The AREVA Advanced CE HTP™ fuel design employs the FUELGUARD™ lower tie plate, MONOBLOC™ guide tubes, and HTP™ spacer grids. Zr-4 was used for the guide tubes and spacer grids. M5® was used as the fuel cladding material. This is the second implementation of AREVA fuel in Calvert Cliffs Unit 1. Cycle 22 included the "T" pattern and contains no fresh fuel on the core periphery.

Batch AC consists of sub-batches with two-enrichment radial zoning. Batch AC uses Gd_2O_3 as a burnable absorber. Six inch low-enriched axial blankets are used on the top and bottom of non-gadolina-bearing fuel rods. Twelve inch low enriched axial blankets are used on the top and bottom of gadolina-bearing fuel rods.

Unit 1 Cycle 22 was designed using the AREVA physics code package (CASMO/PRISM). Unit 1 Cycle 22 is the second Calvert Cliffs reload to use the HTP critical heat flux correlation for AREVA fuel.

w. Cycle 23

Ninety-six fresh AREVA Advanced CE HTP™ fuel assemblies were loaded for Unit 1 Cycle 23 with a batch designation of AD. The AREVA Advanced CE HTP™ fuel design employs the FUELGUARD™ lower tie plate, MONOBLOC™ guide tubes, and HTP™ spacer grids. Zr-4 was used for the guide tubes and spacer grids. M5® was used as the fuel cladding material. This is the third implementation of AREVA fuel in Calvert Cliffs Unit 1. Cycle 23 included the "T" pattern and contains no fresh fuel on the core periphery.

Batch AD consists of sub-batches with two-enrichment radial zoning. Batch AD uses Gd_2O_3 as a burnable absorber. Six inch low-enriched axial blankets are used on the top and bottom of non-gadolina-bearing fuel rods. Twelve inch low enriched axial blankets are used on the top and bottom of gadolina-bearing fuel rods.

Unit 1 Cycle 23 was designed using the AREVA physics code package (CASMO/PRISM). Unit 1 Cycle 23 is the third Unit 1 reload to use the HTP critical heat flux correlation for AREVA fuel.

x. Cycle 24

Ninety-six fresh AREVA Advanced CE HTP™ fuel assemblies were loaded for Unit 1 Cycle 24 with a batch designation of AE. The AREVA Advanced CE HTP™ fuel design employs the FUELGUARD™ lower tie plate, MONOBLOC™ guide tubes, and HTP™ spacer grids. Zr-4 was used for the guide tubes and spacer grids. M5® was used as the fuel cladding material. This is the fourth implementation of AREVA/Framatome fuel in Calvert Cliffs Unit 1. Cycle 24 included the "T" pattern and contains no fresh fuel on the core periphery.

Batch AE consists of sub-batches with two-enrichment radial zoning. Batch AE uses Gd_2O_3 as a burnable absorber. Six inch, low-enriched, axial blankets are used on the top and bottom of non-gadolina-bearing fuel rods.

Twelve inch, low enriched, axial blankets are used on the top and bottom of gadolina-bearing fuel rods.

Unit 1 Cycle 24 was designed using the physics code package CASMO/PRISM. Unit 1 Cycle 24 is the fourth Unit 1 reload to use the HTP™ critical heat flux correlation.

y. Cycle 25

One-hundred-and-one fresh Framatome Advanced CE HTP™ fuel assemblies were loaded for Unit 1 Cycle 25 with a batch designation of AF. The Framatome Advanced CE HTP™ fuel design employs the FUELGUARD™ lower tie plate, MONOBLOC™ guide tubes, and HTP™ spacer grids. Zr-4 was used for the guide tubes and spacer grids M5® was used as the fuel cladding material. This is the fifth implementation of Framatome fuel in Calvert Cliffs Unit 1. Cycle 2S continued the practice of placing some fresh fuel in a "T" pattern.

Batch AF consists of sub-batches with two-enrichment radial zoning. Batch AF uses Gd_2O_3 as a burnable absorber. Six-inch, low-enriched, axial blankets are used on the top and bottom of non-gadolinia-bearing fuel rods. Twelve-inch, low enriched, axial blankets are used on the top and bottom of gadolinia-bearing fuel rods.

Four (4) fresh fuel assemblies and four (4) reconstituted assemblies are armored with 8 inert rods each for operation in Calvert Cliffs Unit 1 Cycle 25. Reconstituted fuel assemblies have been evaluated using the NRC-approved methodology specified in Reference 38. Fuel mechanical and thermal- mechanical design criteria and limits specified in References 36 and 39 will not be exceeded for implementing up to 8 armoring inert rods per fuel assembly in 8 assemblies for U1C25.

Unit 1 Cycle 25 was designed using the Framatome physics code package (CASMO/PRISM). Unit 1 Cycle 25 is the fifth Unit 1reload to use the HTP critical heat flux correlation for Framatome fuel.

3.7.4.2 Unit 2

a. Cycle 1

Except for differences noted earlier in this chapter, the design of Unit 2 Cycle 1 fuel was identical to that of Unit 1 Cycle 1 fuel. BPRs incorporated into Cycle 1 fuel were of the improved design.

b. Cycle 2

Batch D fuel was identical in design to Batch E fuel from Unit 1. Design differences from original core load fuel were:

1. A 40 psi reduction in fill gas pressure,
2. A reduction in pellet dish depth of .002", increasing stack density to 10.046 g/cc.

To mitigate guide tube wear, all assemblies to be placed under CEAs were modified. Sixteen Batch D low enrichment assemblies had modified guide tubes. Of the 16, 4 were put in non-CEA locations, 4 were placed under single CEAs and the remaining 8 were placed as 4 pairs under dual CEAs (Reference 4). The remainder of the assemblies to be placed under CEA locations were sleeved (Reference 4).

All PLCEAs were replaced with CEA plugs (Reference 11).

c. Cycle 3

The mechanical design of new Batch E reload fuel was identical to that of Batch D fuel for the Unit 1 Cycle 2 reload. All assemblies placed under CEAs were sleeved to mitigate guide tube wear and, in addition, all Batch E fuel assemblies were sleeved prior to insertion. None of the modified assemblies in Batch D were used in CEA locations for Cycle 3.

A prototype CEA (Reference 12) was introduced as part of CEA Group 5. The design of the prototype involved a change in cladding material from Inconel to SS, as well as a change to reconstitutable poison rods. The poison rods themselves were modified to replace the Ag/In/Cd tips with B_4C for economic as well as material availability reasons.

d. Cycle 4

The mechanical design of Batch F reload fuel was identical to that of Batch G fuel used in Unit 1 Cycle 5 reload. The enrichment was increased from the previous cycle to accommodate the extended cycle/extended burnup program. The lower enriched Batch F assemblies each contained eight BPRs of the improved design. All assemblies placed in CEA locations contained sleeves to mitigate guide tube wear.

e. Cycle 5

The mechanical design of Batch G reload fuel was identical to that of the Batch H fuel used in Unit 1 Cycle 6. The overall rod length was reduced by .200" from that of Unit 2 Batch F fuel. This decrease yields additional shoulder gap clearance allowing for increased rod growth expected as the fuel is taken to higher burnups. Fuel enrichments were increased over Unit 2 Batch F enrichments to accommodate higher burnup/extended cycles. Batch G was comprised of 48 high-enriched (4.0 wt% U-235) and 28 low-enriched (3.55 wt% U-235) assemblies. The lower enriched assemblies each contained eight BPRs. All assemblies placed in CEA locations contained sleeves to mitigate guide tube wear problems.

f. Cycle 6

Seventy-two new Batch H assemblies were introduced into the Unit 2 core for Cycle 6. Of those, 48 were high-enriched (4.05 wt%) and 24 were low-enriched (3.40 wt%). None of the Batch H fuel contained BPRs. The mechanical design of Unit 2 Batch H fuel was identical to that of the Batch J fuel introduced in Unit 1 Cycle 7 with the following exception. A 0.2" spacer shim was installed between the upper end of the guide tube and the upper end fitting to provide more space for rod growth. The upper end fitting design was then modified to make it compatible.

Several of the high-enriched Batch 2F assemblies (remaining in the core for a third cycle of irradiation) required field installation of .285" spacer shims to allow for rod growth during Cycle 6. Four failed fuel pins from Batch 2G fuel assemblies (once burned) were identified and replaced with SS dummy pins prior to Cycle 6.

The prototype CEA-X remained in the core center location for its fourth cycle of irradiation in Cycle 6.

g. Cycle 7

Sixty new Batch J assemblies were introduced into the Unit 2 core for Cycle 7. Of those, 40 were high-enriched (4.05 wt%) and 20 were low-enriched (3.40 wt%). None of the Batch J fuel contained BPRs.

The mechanical design of Batch J reload fuel was identical to that of Batch K fuel used in Unit 1 Cycle 8.

The reassessment of the phenomena of interpellet gap formation and clad collapse in modern PWR fuels led to the conclusion that the minimum time to clad collapse is significantly greater than its expected life, and the augmentation factor associated with interpellet gaps is insignificant. Therefore, the cycle-specific clad collapse analysis and the augmentation factor associated with interpellet gaps were eliminated.

As described in Section 3.3.2.4, the composition of eight CEAs and the configuration of two CEA banks were changed. The prototype CEA-X was moved to another core location as part of the CEA bank reconfiguration and remained in the core for its fifth cycle of irradiation.

The eight CEA plugs were removed to facilitate the installation of the Reactor Vessel Level Monitoring System and to expedite refueling operation.

h. Cycle 8

Eighty-eight new Batch K assemblies were introduced into the Unit 2 core for Cycle 8, the first 24-month cycle. It is also the first cycle to use low-leakage fuel loading pattern. All 88 were enriched to 4.08 wt%. Of these, 16 assemblies had no BPRs, 28 assemblies had 12 BPRs and 44 assemblies had 8 BPRs.

The mechanical design of Batch K reload fuel is identical to that of Batch J fuel except some Batch K fuel assemblies contain BPRs. The design of these poison rods is essentially the same as that of the poison rods in Batch 2G assemblies from Cycle 5. The only changes in BPR design concern the use of higher poison loadings and hollow spacers rather than solid spacers.

Nine fuel rods were replaced with SS dummy rods prior to Cycle 8.

The prototype CEA-X was discharged at the EOC 8 after its sixth cycle of irradiation.

To support 24-month cycle operation, the very weak center CEA (five Al_2O_3 fingers), installed as part of the CEA bank reconfiguration prior to Cycle 7, was replaced with a weak CEA (center finger B_4C, other Al_2O_3).

i. Cycle 9

Ninety-Two new Batch L assemblies were introduced into the Unit 2 Core for Cycle 9: 16 unshimmed Batch L assemblies, 20 4-shimmed (B_4C) Batch LX assemblies, 24 8-shimmed (B_4C) Batch L/assemblies, 28 12-shimmed (B_4C) Batch L* assemblies all at 4.30 wt% U-235 enrichment, and 4 Batch LE Erbium demonstration assemblies.

The Erbium demonstration assemblies are included in Cycle 9 in order to determine their incore characteristics during a 24-month cycle. These assemblies contain Erbium as the burnable poison material. Each assembly consists of 80 standard pins at 4.30 wt% U-235, 52 standard pins at 3.40 wt% U-235, and 44 Erbium bearing pins at 3.40 wt% U-235. This configuration results in an assembly average U-235 enrichment of 3.81 wt%.

The mechanical design for the Batch L reload fuel is essentially identical to that of the Batch K fuel except as noted below.

The lower end fitting of the Batch L fuel is essentially the same as that of the previous design except for the configuration of the flow holes. In the Batch L design, a 3x3 array of small flow holes has replaced each of the large flow holes. Also, wherever possible, additional small holes were added to the Batch L design to minimize the increase in the pressure drop of the small hole lower end fitting design, relative to the previous design. This design change was made to improve the debris resistance of the Batch L reload fuel.

The fuel rod plenum spring in the Batch L fuel has been redesigned to minimize the amount of rod internal void volume that it occupies.

The overall length of the Batch L poison rods was increased such that the poison rod length is now the same as the fuel rod length.

The size and quantity of the crimp holes in the upper end of the guide tubes were modified for the Batch L fuel. This change allows the upper end fitting posts to be re-used if an assembly must be reconstituted.

Seven fuel rods were replaced with SS dummy rods prior to Cycle 9.

The weak center CEA (center finger B_4C, other Al_2O_3), installed prior to Cycle 8, was replaced with a similar CEA utilizing a SS slug in the bottom of each weak finger. The slug was used instead of Zircaloy, which in this application was found to be subject to hydriding.

j. Cycle 10

Eighty-eight new Batch 2M fuel assemblies were introduced into the Unit 2 core for Cycle 10. One-hundred twenty-four Batch 2K and 2L assemblies were retained from Cycle 9. One reinserted Batch 2H* assembly which had been discharged from Unit 2 Cycle 7 and four reinserted Batch 2J* assemblies which had been discharged at the end of Unit 2 Cycle 8 make up the remainder of the core. Four erbium demonstration assemblies (2LE) are carried over from Unit 2 Cycle 9 from a second cycle of irradiation.

The Batch 2M fuel employs the debris resistant GUARDIAN™ design as described in Section 3.7.4.1.k.

Eight fuel rods were replaced by SS replacement rods in Batch 2K during the refueling outage prior to Cycle 10.

The Batch 2M burnable absorber pins consist of a 115.7" central region containing the burnable material B_4C with two 10.5" cutback regions containing Al_2O_3, one at each end of the stack. This change is being made to enhance thermal margin by lowering the axial peak at BOC.

k. Cycle 11

The following changes were made to the Unit 1 Batch P fuel bundle assembly design to create the Unit 2 Batch N standard fuel bundle assembly design:

The TIG welded wavy strip GUARDIAN™ Inconel bottom spacer grid assembly has been replaced by a laser welded straight strip GUARDIAN™ spacer grid assembly. In conjunction with this change, the fuel rod lower end cap was redesigned for compatibility with the new spacer grid and to facilitate manufacturing. The new lower end cap has one long taper, rather than a taper, a flat and then another taper at the bottom of the cap.

The TIG welded wavy strip intermediate Zircaloy spacer grid assemblies have been replaced by laser welded wavy strip intermediate Zircaloy spacer grid assemblies.

Batch 2N erbium rods have a 12" cutback in neutron absorbing material.

l. Cycle 12

The following changes were made to the Unit 1 Cycle 13 (Batch 1R) fuel assembly design to create the Unit 2 Cycle 12 (Batch 2P) standard fuel bundle assembly design.

The perimeter strips have small guide holes to match pins on the grid assembly weld fixture. This is to ensure more consistent alignment of the grid strips within the fixture during welding.

Batch 2P erbium rods have cutbacks in the neutron absorbing material of 14.0" at the bottom and 10.5" at the top.

m. Cycle 13

Ninety-two fresh Batch 2R fuel assemblies were introduced into the Unit 2 Cycle 13 core. The Batch 2R erbium rods have a symmetric cutback region of 12.0" at the top and bottom of the fuel column.

n. Cycle 14

Ninety-two fresh Batch 2S VAP fuel assemblies were introduced into the Unit 2 Cycle 14 core. The Batch 2S VAP fuel assemblies represent the first full batch of VAP assemblies in Unit 2. Value Added Pellets' diameter are 0.0045" larger than a standard pellet. The VAP clad wall thickness is 0.026" vs 0.028" for standard fuel. The Batch 2S erbium rods have a symmetric cutback region of 12.0" at the top and bottom of the fuel column.

Unit 2 Cycle 14 was designed with the ENDF/B-VI cross-section library in lieu of the traditional ENDF/B-IV cross-sections.

Reconstituted LFA 1RT4 was inserted into the Unit 2 Cycle 14 core. The original LFA 1RT4 was reconstituted with fuel rods from LFA 1RT2, after Unit 1 Cycle 14. The original LFA 1RT4 assembly was reconstituted because the corrosion performance of Anikuloy, Zircaloy-2P, and Zirconium Alloy C claddings were not better than the standard OPTIN cladding. During the reconstitution, 1RT4 fuel rods with Anikuloy, Zircaloy-2P, and Zirconium Alloy C Claddings were replaced with LFA 1RT2 fuel rods with OPTIN or Zirconium Alloy E claddings. The reconstituted LFA 1RT4 contains fuel rods with OPTIN, Zirconium Alloy E, and Zircaloy-4F claddings.

Unit 2 Cycle 14 is the first Calvert Cliffs reload designed with ABB-NV critical heat flux correlation in lieu of the traditional CE-1 correlation.

o. Cycle 15

Ninety-two fresh Batch 2T VAP fuel assemblies were introduced into the Unit 2 Cycle 15 core. The Batch 2T VAP fuel assemblies represent the second full batch of VAP for Unit 2. The Batch 2T erbium rods had an asymmetric cutback region of 10.5 inches at the top of the rod and 14.0 inches at the bottom. Included in the 92 fresh assemblies are 8 LFAs: 4 from Westinghouse and 4 from FANP. These LFAs are further described in Section 3.7.3.13.

Due to the merger of Westinghouse and CE, the CE fuel fabrication facility at Hermatite was permanently shut down. All of the Batch 2T rods were built at the Westinghouse Columbia manufacturing facility.

The integration of the basic CE fuel designs into the Columbia fabrication process necessitated numerous internal rod design changes, including TIG welding of end caps, elimination of the lower alumina spacer, redesign of the plenum spring, etc.

The merger of Westinghouse and CE resulted in the Westinghouse standard cladding material (ZIRLO) becoming available to Calvert Cliffs. Since ZIRLO has better water side corrosion properties than the CE standard OPTIN cladding material, Calvert Cliffs elected to utilize the ZIRLO cladding.

Unit 2 Cycle 15 is the second full batch implementation of the advanced grid design known as Turbo at Calvert Cliffs. The first full batch of Turbo was implemented on Unit 1 Cycle 16. This grid design was tested in the Batch 1RT LFAs. The Turbo grid features include mixing vanes (at five of the eight spacer grid locations) and a new rod retention device known as I-springs (at all eight spacer grid locations).

Batch 2T will be the second full batch of VAP fuel assemblies for Unit 2.

p. Cycle 16

Ninety-two fresh assemblies were installed for Unit 2 Cycle 16 (batch designation 2V). This reload incorporated the “T” pattern and contains no fresh fuel on the core periphery.

Beginning with Cycle 16, ZrB_2 (Integral Fuel Burnable Absorber or IFBA) has replaced erbia as the burnable absorber. Batch 2V fuel assemblies also contain axial blankets, which consist of a lower-enrichment at the top and bottom 6” of the fuel. The axial blankets in fuel rods that contain IFBA consist of annular pellets to provide extra plenum volume to accommodate increased helium gas production associated with the ZrB_2.

Also beginning with Cycle 16 is the addition of radial enrichment zoning. Batch 2V assemblies contain fuel rods of two different enrichments, with lower enriched rods placed on the assembly corners and next to guide tube locations.

Sixty-four CEAs were replaced for Cycle 16. All Unit 2 CEAs now have a 12” Ag-In-Cd slug to increase life expectancy.

q. Cycle 17

Ninety-six fresh assemblies were installed for Unit 2 Cycle 17 (batch designation 2W). This reload continues use of the “T” pattern and contains no fresh fuel on the core periphery.

As with Batch 2V, Batch 2W fuel assemblies also contain axial blankets, which consist of a lower-enrichment at the top and bottom 6” of the fuel. The axial blankets in the fuel rods that contain IFBA consist of annular pellets to provide extra plenum volume to accommodate increased helium gas production associated with the ZrB_2.

Some subbatches (W1 and W2) use, like Batch 2V, two radial enrichment zones. But, beginning with Cycle 17, other subbatches (W3 through W6) use three radial enrichment zones.

Two Westinghouse LFAs (2TW02 and 2TW03) were reinserted into Unit 2 Cycle 17 for a third cycle of irradiation. The other two Batch 2TW and four Batch 2TF LFAs were discharged to the spent fuel pool.

r. Cycle 18

Ninety-six fresh assemblies were loaded for Unit 2 Cycle 18 with a batch designation of 2X. Cycle 18 included the “T” pattern and contains no fresh fuel on the core periphery.

Batch 2X consists of sub-batches with two-enrichment and three-enrichment radial zoning. Batch 2X retains the use of IFBA as a burnable absorber and the use of axial blankets. Annular pellets are used in the blanket regions of rods that contain IFBA to provide extra plenum volume to accommodate increased helium gas production associated with the ZrB_2.

During the 2009 refueling outage prior to U2C18 startup, fuel inspections indicated failed fuel pins in assembly 2V109, which was replaced with 2V103. Additionally, assembly 2V011 was flagged as suspect (but later cleared) and was replaced with 2V101. Lastly, assembly 2W508 was found with an elevated CEA, and was replaced with 1X411 (a once-burned assembly from Unit 1).

s. Cycle 19

Ninety-six fresh AREVA Advanced CE HTP™ fuel assemblies were loaded for Unit 2 Cycle 19 with a batch designation of 2Z. The AREVA Advanced CE HTP™ fuel design employs the FUELGUARD™ lower tie plate, MONOBLOC™ guide tubes, and HTP™ spacer grids. Zr-4 was used for the guide tubes and spacer grids. M5® was used as the fuel cladding material. This is the first implementation of AREVA fuel in Calvert Cliffs Unit 2. Cycle 19 included the “T” pattern and contains no fresh fuel on the core periphery.

Batch 2Z consists of sub-batches with two-enrichment radial zoning. Batch 2Z uses Gd_2O_3 as a burnable absorber. Six inch low-enriched axial blankets are used on the top and bottom of non-gadolina-bearing fuel rods. Twelve inch low enriched axial blankets are used on the top and bottom of gadolina-bearing fuel rods.

Unit 2 Cycle 19 was designed using the AREVA physics code package (CASMO/PRISM). Unit 2 Cycle 19 is the first Calvert Cliffs reload to use the HTP critical heat flux correlation for AREVA fuel.

t. Cycle 20

One-hundred fresh AREVA Advanced CE HTP™ fuel assemblies were loaded for Unit 2 Cycle 20 with a batch designation of BA. Four assemblies from batch 2Z were discharged to the pool for contingency planning for failed fuel assemblies. The AREVA Advanced CE HTP™ fuel design employs the FUELGUARD™ lower tie plate, MONOBLOC™ guide tubes, and HTP™ spacer grids. Zr-4 was used for the guide tubes and spacer grids. M5® was used as the fuel cladding material. This is the second implementation of AREVA fuel in Calvert Cliffs Unit 2. Cycle 20 included the “T” pattern and contains no fresh fuel on the core periphery.

Batch BA consists of sub-batches with two-enrichment radial zoning. Batch BA uses Gd_2O_3 as a burnable absorber. Six inch low-enriched axial blankets are used on the top and bottom of non-gadolina-bearing fuel rods. Twelve inch low-enriched axial blankets are used on the top and bottom of gadolina-bearing fuel rods.

Unit 2 Cycle 20 was designed using the AREVA physics code package (CASMO/PRISM). Unit 2 Cycle 20 is the second Calvert Cliffs reload to use the HTP critical heat flux correlation for AREVA fuel.

u. Cycle 21

Ninety-six fresh AREVA Advanced CE HTP™ fuel assemblies were loaded for Unit 2 Cycle 21 with a batch designation of BB. The AREVA Advanced CE HTP™ fuel design employs the FUELGUARD™ lower tie plate, MONOBLOC™ guide tubes, and HTP™ spacer grids. Zr-4 was used for the guide tubes and spacer grids. M5® was used as the fuel cladding material. This is the third implementation of AREVA fuel in Calvert Cliffs Unit 2. Cycle 21 included the “T” pattern and contains no fresh fuel on the core periphery.

Batch BB consists of sub-batches with two-enrichment radial zoning. Batch BB uses Gd_2O_3 as a burnable absorber. Six inch low-enriched axial blankets are used on the top and bottom of non-gadolina-bearing fuel rods. Twelve inch low enriched axial blankets are used on the top and bottom of gadolina-bearing fuel rods.

Unit 2 Cycle 21 was designed using the AREVA physics code package (CASMO/PRISM). Unit 2 Cycle 21 is the third reload to use the HTP critical heat flux correlation for AREVA fuel.

v. Cycle 22

Ninety-six fresh AREVA Advanced CE HTP™ fuel assemblies were loaded for Unit 2 Cycle 22 with a batch designation of BC. The AREVA Advanced CE HTP™ fuel design employs the FUELGUARD™ lower tie plate, MONOBLOC™ guide tubes, and HTP™ spacer grids. Zr-4 was used for the guide tubes and spacer grids. M5® was used as the fuel cladding material. This is the fourth implementation of AREVA fuel in Calvert Cliffs Unit 2. Cycle 22 included the “T” pattern and contains no fresh fuel on the core periphery.

Batch BC consists of sub-batches with two-enrichment radial zoning. Batch BC uses Gd_2O_3 as a burnable absorber. Six inch low-enriched axial blankets are used on the top and bottom of non-gadolina-bearing fuel rods. Twelve inch, low enriched, axial blankets are used on the top and bottom of gadolina-bearing fuel rods.

Unit 2 Cycle 22 was designed using the AREVA physics code package (CASMO/PRISM). Unit 2 Cycle 22 is the fourth Unit 2 reload to use the HTP critical heat flux correlation for AREVA fuel.

w. Cycle 23

Ninety-seven fresh Framatome Advanced CE HTP fuel assemblies were loaded for Unit 2 Cycle 23 with a batch designation of BD. The Framatome Advanced CE HTP fuel design employs the FUELGUARD lower tie plate, MONOBLOC guide tubes, and HTP spacer grids. Zr-4 was used for the guide tubes and spacer grids. M5 was used as the fuel cladding material. This is the fifth implementation of Framatome fuel in Calvert Cntfs Unit 2. Cycle 23 included the "T" pattern and contains no fresh fuel on the core periphery.

Batch BD consists of sub-batches with two-enrichment radial zoning. Batch BD uses Gd203 as a burnable absorber. Six inch, low-enriched, axial blankets are used on the top and bottom of non- gadolinia-bearing fuel rods. Twelve inch, low enriched, axial blankets are used on the top and bottom of gadolinia-bearing fuel rods.

Unit 2 Cycle 23 was designed using the Framatome physics code package (CASMO/PRISM). Unit 2 Cycle 23 is the fifth Unit 2 reload to use the HTP critical heat flux correlation for Framatome fuel.

x. Cycle 24

Ninety-six (96) fresh Framatome Advanced CE HTP Fuel assemblies, including one (1) Lead Test Assembly (LTA), were loaded for Unit 2 Cycle 24 with a batch designation of BE. The Framatome Advanced CE HTP™ fuel design employs the FUELGUARD™ lower tie plate, MONOBLOC™ guide tubes, HMP™ lower end grid, and HTP™ intermediate spacer grids. Zr-4 was used for the guide tubes and HTP™ spacer grids. M5® was used as the fuel cladding material. This is the sixth implementation of Framatome fuel in Calvert Cliffs Unit 2. Cycle 24 includes the “T” pattern and contains no fresh fuel on the core periphery.

Batch BE consists of sub-batches with two-enrichment radial zoning. Batch BE uses Gd_2O_3 as a burnable absorber. Six inch, low-enriched, axial blankets are used on the top and bottom of non-gadolinia-bearing fuel rods. Twelve-inch, low enriched, axial blankets are used on the top and bottom of gadolinia-bearing fuel rods. The CCL2-24 core contains one (1) enhanced accident tolerant (EATF) Lead Test Assembly. The LTA is the Advanced CE14X14 HTP™ Framatome fuel design with Chromia-doped (Cr_2O_3/UO_2) fuel pellets and Chromium-coated M5® clad features. Analyses and evaluation demonstrate compliance with applicable methodologies and criteria for the LTA fuel.

Fuel assembly reconstitution using up to eight (8) insert rods to support and armoring plan for seven (7) bundles for operation in Calvert Cliffs Unit 2 Cycle 24 has been evaluated using the NRC approved methodology specified in Reference 38. It has demonstrated that fuel mechanical and thermal mechanical design criteria and limits specified in References 36 and 39 will not be exceeded for implementing up to 8 armoring inert rods per bundle (in a total of 7 bundles). Similarly, one (1) bundle armored with eight (8) chromium coated inert rods has been evaluated using the same criteria demonstrating acceptable results. Evaluation also demonstrates compliance with applicable criteria for eight fresh fuel assemblies each armored with a single inert rod.

Unit 2 Cycle 24 was designed using the Framatome physics code package (CASMO/PRISM). Unit 2 Cycle 24 is the sixth Unit 2 reload to use HTP™ critical heat flux correlation for the Framatome fuel.

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