10 CFR 50.90

APS

A subsidiary of Pinnacle West Capital Corporation

Palo Verde Nuclear
Generating Station

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102-05867-DCM/RJR
July 02, 2008

ATTN: Document Control Desk
U.S. Nuclear Regulatory Commission
Washington, DC 20555-0001

Dear Sirs:

Subject: Palo Verde Nuclear Generating Station (PVNGS)
Units 1, 2, and 3
Docket Nos. STN 50-528, 50-529, and 50-530
Request for Amendment to Technical Specification 4.2.2, Control Element Assemblies

Pursuant to 10 CFR 50.90, Arizona Public Service Company (APS) hereby requests to amend Operating Licenses NPF-41, NPF-51, and NPF-74 for Palo Verde Nuclear Generating Station (PVNGS) Units 1, 2, and 3, respectively.

The proposed change will revise Technical Specification (TS) 4.2.2, Control Element Assemblies, to support replacement of the full strength (FS) control element assemblies (CEAs) with a new design beginning with the Unit 3 fourteenth refueling outage (U3R14) in the spring of 2009. Additionally, APS will be updating the TS by removing the registered trademark "Inconel" while retaining the generic terminology "Alloy 625" and deleting the references to part length CEAs in TS 4.2.2. APS has determined that no significant hazards have been introduced by these changes.

Approval of the proposed amendment is requested by April 4, 2009, to support restart following U3R14. Upon approval, APS will implement this amendment within 60 days.

In accordance with the PVNGS Quality Assurance Program, the Plant Review Board and the Offsite Safety Review Committee have reviewed and concurred with this proposed amendment. By copy of this letter, this submittal is being forwarded to the Arizona Radiation Regulatory Agency (ARRA) pursuant to 10 CFR 50.91(b)(1).

A001
NRR

No commitments are being made to the NRC by this letter. If there are any questions or if additional information is needed, please contact Russell A. Stroud, Licensing Section Leader, at (623) 393-5111.

I declare under penalty of perjury that the foregoing is true and correct.

Executed on 7/2/08
(Date)

Sincerely,

D.C. Mims

DCM/TNW/RJR/gat

Enclosure: Evaluation of the Proposed Change

cc:	E. E. Collins Jr.	NRC Region IV Regional Administrator
	M. T. Markley	NRC NRR Project Manager
	R. I. Treadway	NRC Senior Resident Inspector for PVNGS
	A. V. Godwin	Arizona Radiation Regulatory Agency
	T. Morales	Arizona Radiation Regulatory Agency

ENCLOSURE

Evaluation of the Proposed Change

Subject: **Request for Amendment to Technical Specification 4.2.2, Control Element Assemblies**

ATTACHMENTS:

1. Technical Specification Page Markup
2. Retyped Technical Specification Page

1. SUMMARY DESCRIPTION

This evaluation supports a request to amend Operating License(s) NPF-41, NPF-51, and NPF 74, for Palo Verde Nuclear Generating Station (PVNGS) Units 1, 2, and 3, respectively.

The proposed change will revise the plant Technical Specification (TS) 4.2.2, Control Element Assemblies, to support replacement of the full-strength control element assemblies (CEAs) that will have reached the end of their useful life with a new design. Additionally, Arizona Public Service Company (APS) will be removing the registered trademark "Inconel" while retaining the generic terminology "Alloy 625" and deleting the references to part-length CEAs in this TS section.

Replacement of the full-strength CEAs is planned to take place according to the following schedule:

Unit 1 – Refueling Outage 19, spring 2016
Unit 2 – Refueling Outage 15, fall 2009
Unit 3 – Refueling Outage 14, spring 2009

2. DETAILED DESCRIPTION

TS 4.2.2, "Control Element Assemblies," provides a summary description of the full-strength CEAs currently used at PVNGS. This section of the TS is being revised to include a description of the replacement full-strength CEA design while maintaining the description of the current full-strength CEA design to accommodate a staggered installation of the replacement full-strength CEAs. This change will also allow use of either design in the future. Upon approval of this request, the PVNGS Updated Final Safety Analysis Report (UFSAR) will be revised to indicate that only one design at a time will be used in each of the three units.

In addition to the change described above, two other changes are being made in TS 4.2.2. First, references to Inconel will be removed. Inconel is a registered trademark of Special Metals Corporation. Alloy 625 is generic terminology for the Unified Numbering System (UNS) material N06625 and will remain. Changes to delete "Inconel" are considered editorial. Secondly, part-length CEAs were replaced in accordance with License Amendment 152, dated March 23, 2004 (Agency Document Access and Management System [ADAMS] Accession No. ML040860573) and the reference to them is no longer applicable. This proposed amendment deletes the references to part-length CEAs in TS 4.2.2. References to part-length CEAs in other TS sections will be deleted by a separate amendment request.

Technical Specification Section 4.2.2 (Design Features – Reactor Core – Control Element Assemblies) currently states:

> *The reactor core shall contain 76 full-strength and either 13 part-length or 13 part-strength control element assemblies (CEAs).*
>
> *The control section for the full-strength CEAs shall be boron carbide with Inconel Alloy 625 cladding.*
>
> *For units that have part-length CEAs, the control section shall be Inconel Alloy 625 in the lower half, followed by perforated stainless steel tubing over the next 40%, and boron carbide pellets with Inconel Alloy 625 clad over the last 10% of the control section.*
>
> *For units that have part-strength CEAs, the control section shall be solid Inconel Alloy 625 slugs with Inconel Alloy 625 cladding.*

This part of Technical Specification 4.2.2 will be changed to state:

> *The reactor core shall contain 76 full-strength and 13 part-strength control element assemblies (CEAs).*
>
> *The control section for full-strength CEAs shall be either boron carbide with Alloy 625 cladding, or a combination of silver-indium-cadmium and boron carbide, with Alloy 625 cladding.*
>
> *The control section for the part-strength CEAs shall be solid Alloy 625 slugs with Alloy 625 cladding.*

During 2001, it was discovered that the cladding of several full-strength CEA neutron absorber elements (fingers) in all three Palo Verde units exhibited cracks in the tip sections. The failure mode was determined to be Irradiation Assisted Stress Corrosion Cracking (IASCC). The failures occurred when the irradiation induced swelling of the boron carbide (B_4C) pellets inside of the fingers generated sufficient strain in the Alloy 625 cladding to initiate IASCC. Irradiation Assisted Stress Corrosion Cracking can occur when the cladding material is sensitized by fast neutron flux in combination with the presence of strain while exposed to an aggressive environment. The calculated fluence of the failed fingers exceeded the sensitization threshold for IASCC and a small amount of strain was detected in some of the fingers removed from Unit 2. The threshold for IASCC in Alloy 625 is generally accepted to be 2.0×10^{21} neutrons per square centimeter (n/cm^2) for neutrons with energy greater than 1.0 MeV.

In order to prevent future occurrences of IASCC in the CEA tips, APS is requesting this amendment to allow replacement of the Palo Verde full-strength CEAs with a different design. Additionally, APS has placed limits on the service life of the compression sleeve type full-strength CEAs (8 effective full power years [EFPY]) or about 5 cycles, in contrast to the original expected lifetime of about 10-11 EFPY. The replacement schedule detailed in Section 1 of this enclosure will ensure that the service life of the compression sleeve type CEAs is not exceeded.

The fingers of the current full-strength CEA consist of an Alloy 625 tube loaded with a stack of cylindrical absorber pellets. The absorber material consists of 73% theoretical density (TD) B_4C pellets, with the exception of the lower portion of the fingers, which contain reduced diameter B_4C pellets wrapped in a compression sleeve of type 347 stainless steel. The purpose of the compression sleeve is to prevent infiltration of B_4C fines (free B_4C powder) into the pellet/clad gap preserving room for pellet swelling and to compress allowing the pellet to swell while limiting cladding strain. This is shown in Figure 1.

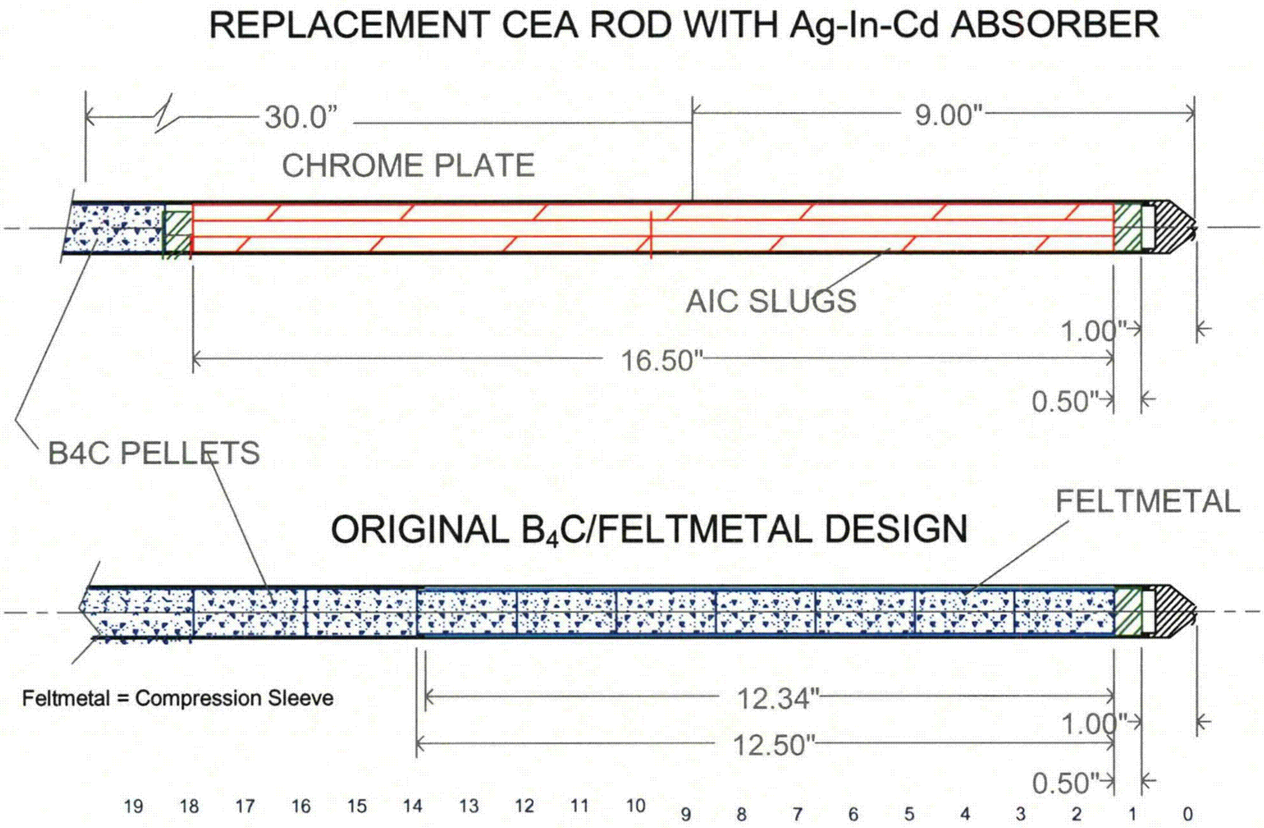

Figure 1
Comparison of Ag-In-Cd and Compression Sleeve CEA
Tip Designs

3. TECHNICAL EVALUATION

The CEAs are described in the PVNGS UFSAR Sections 4.2 and 4.3. Each reactor at Palo Verde contains 89 CEAs. The purpose of the CEAs is to provide reactivity control during operation and shutdown of the reactor. The CEAs consist of either four or twelve fingers arranged to engage the peripheral guide tubes of fuel assemblies.

There are two types of CEAs, part-strength CEAs and full-strength CEAs. Seventy-six CEAs are full-strength CEAs and contain B_4C neutron absorber pellets, which span the range of the entire height of the fuel core when the CEA is fully inserted. Forty-eight of the 76 full-strength CEAs are 12-finger and the remaining 28 are 4-finger. The CEA fingers are connected by a spider structure which couples to the control element drive mechanism (CEDM) extension shaft. The neutron absorber elements of a 4-finger CEA engage the four outer guide tubes in a single fuel assembly, while the 12-finger CEAs engage the four outer guide tubes in one fuel assembly and the two nearest outer guide tubes in four adjacent fuel assemblies. The regulating banks of full-strength CEAs consist of both 4-finger and 12-finger CEAs, while the shutdown banks consist entirely of 12-finger CEAs.

The remaining 13 CEAs are 4-finger part-strength CEAs. Each of these contain alloy 625 neutron absorber slugs, which span the range of the entire height of the fuel core when the CEA is fully inserted. The part-strength CEAs provide control of axial power distribution, particularly in the event of axial xenon oscillations. The part-strength CEAs are not credited for shutdown margin (SDM) and their drop times and reactivity worth is not considered for accident mitigation in the safety analyses.

In the outlet plenum region, all full-strength CEAs/part-strength CEAs are enclosed in CEA shrouds which provide guidance and protect the full-strength CEAs/part-strength CEA and extension shaft from coolant cross flow. Within the core, each finger travels in a Zircaloy guide tube. The guide tubes are part of the fuel assembly structure and ensure proper orientation of the fingers with respect to the fuel rods.

The lower ends of the four outer fuel assembly guide tubes are tapered gradually to form a region of reduced diameter which, in conjunction with the finger on the CEA, constitutes an effective hydraulic buffer for reducing the deceleration loads at the end of a trip stroke. This purely hydraulic damping action is augmented by a spring and plunger arrangement on the CEA spider. When fully inserted, full-strength CEAs and part-strength CEAs rest on the upper guide structure support plate.

The full-strength CEAs are categorized by their intended function, i.e., shutdown or regulating. During reactor startup and operation, the shutdown full-strength CEAs are fully withdrawn before the regulating full-strength CEAs can be withdrawn for controlling the approach to criticality. Only the regulating full-strength CEAs are then used in a predetermined sequence for reactivity control.

The CEAs are designed with a maximum drop time of 4.0 seconds, where the drop time is defined as the interval between the time power is removed from the CEDM holding coils and the time at which the CEAs reach 90% of their fully inserted positions. For those safety analyses that model CEA insertion following a reactor trip, the 4.0-second CEA drop time is subdivided into two intervals: the holding coil delay time and the CEA insertion time. During the holding coil delay time, which is defined as the time interval between opening of the reactor trip breakers and the time at which the magnetic flux of the CEDM holding coils has decayed enough to allow for CEA motion, the CEAs are assumed to remain in their withdrawn positions. Following expiration of the holding coil delay time, the CEAs are assumed to drop 90% into the core during the remaining CEA insertion time.

A series of tests prior to plant operation are performed to assure that each full-strength CEA will function as expected. Such testing includes a drop test to confirm that each full-strength CEA safely reaches 90% insertion within four seconds. Another test involves measurement of the worth of each full-strength CEA during startup testing of each reload cycle in order to verify the expected design values.

Description of the Replacement Silver-Indium-Cadmium (Ag-In-Cd) CEA Design

Westinghouse has developed a new design for Combustion Engineering (CE) System 80 full-strength CEAs that increases the useful life by reducing cladding strain. The new design maintains essentially the same external dimensions as the original design, but with changes to the internal components of the CEA finger. Figure 1 is a comparison of the current compression sleeve full-strength CEA tip design and the new Ag-In-Cd full-strength CEA tip design. The new Ag-In-Cd design full-strength CEA replaces the 12-1/2 inch column of reduced diameter B_4C pellets (including the compression sleeve) and the bottom 4-1/2 inches of full diameter B_4C pellets in the current design with 16-1/2 inches of hollow Ag-In-Cd absorber slugs and a 1/2 inch stainless steel spacer. The remainder of the CEA finger internals remains the same as the current design.

Westinghouse has shown by analysis that expansion and swelling of the Ag-In-Cd absorber slug is compensated for by a change in the slug inner diameter once the pellet/clad gap is closed. The stresses calculated for the Alloy 625 cladding as a result of absorber thermal expansion and radiation induced swelling remain well below the yield and allowable stresses at conservative absorber swelling rate and conservative creep.

The replacement Ag-In-Cd full-strength CEAs have a lifetime of approximately 11 EFPY as opposed to a lifetime of 8 EFPY for current compression sleeve full-strength CEAs. To assure that the Alloy 625 cladding is capable of supporting the increased lifetime without violating established wall thinning criteria, the Ag-In-Cd full-strength CEAs will have chrome plating, as shown in Figure 2, applied to the outside diameter in the area expected to contact the fuel assembly upper guide posts when the reactor is operating in an essentially unrodded condition, or during normal maneuvering within the Power Dependent Insertion Limit (PDIL). Westinghouse has determined that application of chrome plating to the Alloy 625 cladding will allow the Ag-In-Cd full-strength CEAs to remain parked in one position for the entire design life without violating wall-thinning criteria.

Additionally, the upper edges of the spider bosses have been chamfered, as shown in Figure 3, to prevent damage to the self-latching mechanisms that can occur if the CEA hangs up when lifting through the upper guide structure cut outs. This change is for ease of maintenance and has no impact on operation of the CEAs.

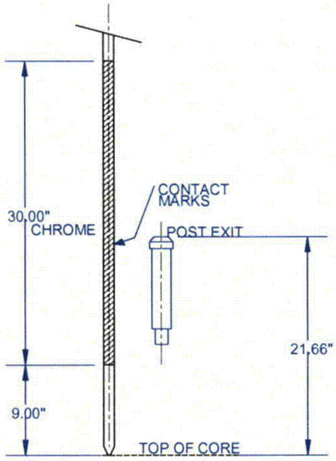

Figure 2
Chrome Plated Zone to
Primary Contact Region with Post Exit

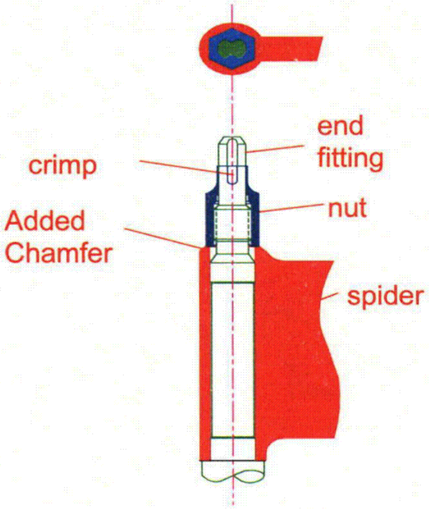

Figure 3
Spider with Chamfered Boss

The outer geometries of the current compression sleeve full-strength CEAs and replacement Ag-In-Cd full-strength CEAs are essentially identical, the only differences being the chrome plating on the lower portion of the Ag-In-Cd CEA cladding, and the chamfers on the spider bosses of the Ag-In-Cd full-strength CEA. The principal design differences between the compression sleeve full-strength CEAs and the Ag-In-Cd full-strength CEAs are associated with the neutron absorber materials used for the lower end of each finger. As previously discussed, the neutron absorber stack of the current design is comprised of B_4C pellets and a compression sleeve. The neutron absorber in the replacement design is made up of B_4C pellets with Ag-In-Cd slugs in the tip section. A comparison of the significant design differences is summarized in the following table:

Compression Sleeve CEAs vs. Ag-In-Cd CEAs Design Criteria

Design Criteria	Compression Sleeve	Ag-In-Cd	Comment
Clad Material	Inconel 625	Alloy 625	There is no change in actual clad material; the change eliminates the trade name Inconel from the Technical Specifications.
Clad Outer Diameter	0.816 ± 0.002 in.	0.816 ± 0.002 in. 0.8164 +0.0036/-0.002 in. in the area of chrome plating.	The Ag-In-Cd full-strength CEA cladding is chrome plated over a 30 inch length beginning approximately 9 inches from the bottom of the finger. This plating is 0.0002" to 0.0010" thick.
B_4C Pellet Diameter (Full Diameter)	0.737 ± 0.001 in.	0.737 ± 0.001 in.	There is no change to the full diameter pellets.
B_4C Pellet Diameter (Reduced Diameter)	0.664 ± 0.001 in.	N/A	Not used in Ag-In-Cd full-strength CEAs.
Compression Sleeve Thickness	0.032 ± 0.002 in.	N/A	Not used in Ag-In-Cd full-strength CEAs.
Compression Sleeve Length	12.344 ± 0.031 in.	N/A	Not used in Ag-In-Cd full-strength CEAs

Design Criteria	Compression Sleeve	Ag-In-Cd	Comment
Ag-In-Cd Slug Outside Diameter	N/A	0.734 ± 0.003 in.	Not used in Compression Sleeve full-strength CEAs.
Ag-In-Cd Slug Inside Diameter	N/A	0.250 ± 0.016 in.	B_4C pellets do not have central holes on either design.
Ag-In-Cd Slug Length	N/A	8.250 ± 0.062 in.	2 slugs per finger
Total Neutron Absorber Length	12.5 in. Reduced Diameter B_4C 135.5 ± 0.5 in. Full Diameter B_4C	16.5 in. Ag-In-Cd 131 +.5/-.125 in. Full Diameter B_4C	The Ag-In-Cd full-strength CEA contains a 0.5 in spacer between the Ag-In-Cd stack and the B4C stack.
Total Length of the Control Rod Top Assembly	73.625 in.	73.625 in.	No change for either 4 or 12-finger CEAs.
Total Finger Length (including top assembly)	244.625 in.	244.625 in.	No change for either 4 or 12-finger CEAs.
Spider Bosses		Top edge chamfered	For ease of maintenance
Total CEA Length	252.969 in.	252.969 in.	No change for either 4 or 12-finger CEAs.
Total 12-Finger CEA Weight	212.3 lbs	234.56 lbs	
Total 4-Finger CEA Weight	81.1 lbs	88.53 lbs	

Compliance to Functional Requirements

The following discussion evaluates compliance of the functional requirements of CE compression sleeve full-strength CEA design to the Westinghouse Ag-In-Cd full-strength CEA design.

Functional Requirement 1 – Absorber Location/Free Movement

In conjunction with the fuel assemblies and reactor internals, support and locate the neutron absorbing material so that all clusters move as required for both insertion and withdrawal.

The envelope dimensions of the replacement full-strength CEAs are essentially identical (the only difference is the thickness of the chrome plating) to current full-strength CEAs at Palo Verde and also a number of operating Korean plants. Therefore, the correct interfaces with the internals and fuel assemblies are preserved. Additionally, the interface with the extension shaft gripper is identical to current CEAs in configuration and material composition. The top and bottom elevations of the absorber stack within the finger remain unchanged. Substitution of Ag-In-Cd tips is viewed as a positive step relative to this requirement to support the absorber and providing for free movement, in that cladding integrity is enhanced based on the results of analysis and the experience of other plants with similar designs.

Functional Requirement 2 – Contain Products of Irradiation

Contain the nuclear poison material and activation products produced by irradiation of the poison material without CEA cladding failures.

The absorber stack positioning within the finger remains unchanged, as does the plenum volume above the absorber stack. The product of irradiation is primarily helium, a fraction of which is released from the B_4C. The design criterion is that the internal pressure must not exceed system operating pressure at end-of-life (EOL). The replacement full-strength CEAs, if operated in the same fashion as current full-strength CEAs, will generate substantially less helium because the B_4C in the tip zone closest to the core (the only location that sees any appreciable exposure) has been replaced with Ag-In-Cd which has no irradiation byproduct release. Given that the available volume is essentially the same as before (except for a slight loss of the open porosity in the bottom B_4C which has been eliminated) and given that the material that produced the helium in the tip region has been removed, it is concluded that the new design is fully capable of accommodating any helium release over the design life of 11 EFPY. Westinghouse has determined the internal pressure generated as a result of helium release to be 410 psia at hot conditions, far less than system pressure. More importantly, it is shown that clad stresses remain well below allowable values under the combined effect of absorber swelling and internal pressure throughout design life.

Functional Requirement 3 – Locate the Absorber

Support and locate the poison material such that its location with respect to the CEA extension shaft (the position of which is integrated as CEA position) is maintained.

The envelope dimensions of the replacement CEAs are identical (except for the chrome plating) to the current CEAs at Palo Verde and also a number of operating System 80 Korean plants; therefore, the interfaces with the internals and fuel assemblies are maintained. Additionally, the interface with the extension shaft gripper is identical to the current CEAs in configuration and material composition. The top and bottom elevation of the absorber stack within the finger remains unchanged from the current all-B_4C design.

Functional Requirement 4 – Limit Stresses to Preserve Function

Limit the magnitude of stresses and the range of stresses for cyclic conditions to values which will not result in damage to any piece of the control element assembly to an extent which would preclude satisfaction of functional requirements.

Discussions related to individual component designs contained in the Compliance to Design Criteria section below show that this functional requirement is met.

Functional Requirement 5 – Provide Sufficient Rod Worth

Provide sufficient negative reactivity insertion and insertion rate (through scram capability) for adequate control and shutdown of the reactor for specified conditions.

From a mechanical perspective, the weight of the replacement 12-finger and 4-finger full-strength CEAs with Ag-In-Cd tips has increased somewhat (~1.874 lb/per finger) over the current design, while the same physical envelope and absorber positioning is retained. These factors result in slightly faster insertion of the absorber column during a SCRAM. The time reduction to 90% insertion ranges anywhere from 48 to 163 milliseconds depending on the CEA configuration and thermal hydraulic conditions.

The second element affecting rod worth is the change in absorber material in the tip region from B_4C to Ag-In-Cd. This change results in a small decrease in total rod worth (less than 1%). Results of rerunning events which exhibit sensitivity to time dependent rod worth (sheared shaft/seized rotor, loss of flow from specified acceptable fuel design limits (SAFDL) and total loss of reactor coolant flow) demonstrate that all acceptance criteria continue to be met. Rod worth changes from cycle to cycle are considered in the core design and compared with a Physics Assessment Checklist (PAC) limit. The rod worth of the new CEA design will continue to satisfy the existing PAC limit.

Compliance to Design Criteria

The following discussion evaluates compliance of the replacement Ag-In-Cd full-strength CEA design to the design criteria applied by CE to the compression sleeve full-strength CEAs.

The symbols taken from the UFSAR Section 4.2.1.1.1, Fuel Assembly Structural Integrity Criteria, used in defining the allowable stress levels are as follows:

P_m = Calculated general primary membrane stress$^{(a)}$

P_b = Calculated primary bending stress

S_m = Design stress intensity value as defined by Section III, ASME Boiler and Pressure Vessel Code$^{(b)}$

S_u = Minimum unirradiated ultimate tensile strength

F_s = Shape factor corresponding to the particular cross-section being analyzed$^{(c)}$

S'_m = Design stress intensity value for faulted conditions

The definition of S'_m as the lesser value of 2.4 S_m and 0.7 S_u is contained in the ASME Boiler and Pressure Vessel Code, Section III.

Notes: a. P_m and P_b are defined by Section III, ASME Boiler and Pressure Vessel Code.

b. With the exception of zirconium base alloys, the design stress intensity values, Sm, of materials not tabulated by the Code are determined in the same manner as those in the Code. The design stress intensity of zirconium base alloys shall not exceed two-thirds of the unirradiated minimum yield strength at temperature. Basing the design stress intensity on the unirradiated yield strength is conservative because the yield strength of Zircaloy or ZIRLO^{TM} increases with irradiation. The use of the two-thirds factor ensures 50% margin to component yielding in response to primary stresses. This 50% margin, together with its application to the minimum unirradiated properties and the general conservatism applied in the establishment of design conditions, is sufficient to ensure an adequate design.

c. The shape factor, F_s, is defined as the ratio of the "plastic" moment (all fibers just at the yield stress) to the initial yield amount (extreme fiber at the yield stress and all other fibers stressed in proportion to their distance from the neutral axis). The capability of cross- sections loaded in bending to sustain moments considerably in excess of that required to yield the outermost fibers is discussed in Timoshenko (Reference 1)

Spider Structure

The spider shall provide a structurally sound support for the control rods. The webs shall be resistant to vertical and lateral bending and shear loads produced by the appropriate combination of the Control Element Drive Mechanism (CEDM) stepping action, seismic, and Loss of Coolant Accident (LOCA) events, and SCRAM loads. The stress limits shall be as follows:

Design Conditions I and II

$$P_m \leq S_m$$
$$P_m + P_s \leq F_s S_m$$

Design Condition III

$$P_m \leq 1.5\ S_m$$
$$P_m + P_b \leq 1.5\ F_s S_m$$

Design Condition IV

Loads produced by faulted conditions consisting of a break in the primary system, plus the appropriate normal operating loads above, shall not cause stresses in excess of the following limits:

$$P_m \leq S'_m$$
$$P_m + P_b \leq F_s S'_m$$

Where S'_m = the smaller value of 2.4 S_m or 0.7 S_u.

After the replacement full-strength CEAs are installed in the Palo Verde units, the population of CEAs will consist of 4-finger and 12-finger full-strength CEAs with Ag-In-Cd in the tips plus a subset of 4-finger part-strength CEAs that have Alloy 625 material (inside the standard cladding) over the entire absorber length. The structural assessment addressing the Ag-In-Cd design draws upon the result of earlier analysis and makes a determination as to whether the earlier result is applicable and bounding for the new replacement design. The new design is bounded in many cases by prior analyses. However, because the weight increase of the proposed design for each full-strength Ag-In-Cd CEA finger is1.874 lbs, the 12-finger spider stress intensity for stepping and SCRAM during Conditions I and II was required to be recalculated. As shown below, in both instances, the value was below the criteria by a wide margin.

	Calculated Stress Intensity (thousand pounds per square inch) (ksi)		Allowable Stress Intensity
	Stepping	SCRAM	
Condition I & Condition II	3.7	0.2	S_m = 10.8 ksi
	5.5	0.3	F_s*S_m = 16.2 ksi

Since the weight of the new 4-finger replacement Ag-In-Cd full-strength CEA is less than the original 4-finger part-length or part-strength designs, the CEDM stepping loads acting on the spider for the replacement 4-finger Ag-In-Cd CEAs are bounded by the previous 4-finger part-length and part-strength analyses.

Gripper Coupling / Extension Shaft Connection

The gripper coupling must provide a connection point with the extension shaft coupling mechanism which permits remote coupling and uncoupling without jamming.

All System 80 CEAs use a heat treatable Type 403 stainless steel gripper coupling which is permanently threaded and pinned to the spider hub. The top end of the gripper coupling includes a series of internal grooves and ridges that are engaged by the extension shaft gripper. No changes have been made to the coupling configuration or elevation, assuring proper gripper actuation once installed in the plant.

Furthermore, development testing of the extension shaft and gripper coupling was performed that included 30,000 feet of travel with a weight heavier than the new 12-finger CEA. Post test examination revealed only nominal wear. This amount of travel is equivalent to driving the CEA from fully withdrawn to fully inserted and back to the fully withdrawn position more than once every week during 20 EFPY of operation, far more than will be required in actual plant operation.

Threaded Joints

To ensure tightness, threaded connections (including the gripper coupling/spider connections) shall be designed to be preloaded to a value greater than the operating cyclic loads produced by the connection. The gross primary axial stresses produced by the preload must not be greater than S_M for the materials involved, except shear stress shall be limited to less than 0.6 S_M and bearing stresses shall be limited to less than the yield stress at temperature. Positive locking devices shall be provided on threaded joints to limit loss of preload. Permanent locking devices shall be trapped in place by a weld to insure their continued function. The locking device designed for use during reconstitution must be capable of remote removal. Mechanical loads transmitted through the joint must not be carried by the locking devices.

Materials of construction and key dimensions of all threaded connections remain as previously specified and used in Palo Verde and other System 80 units. Each connection is discussed in the following paragraphs:

Spider to Control Rod Connection - The principal load acting on this connection is the inertial load from CEDM stepping action. Part-strength CEA rods and earlier part-length rods were substantially heavier than the new Ag-In-Cd rod and are therefore bounding. Since the same preload is applied to all rods by a specified assembly torque, the preload and joint stresses are identical. Margin between preload and operating load is improved with the new design or the current part-strength rods.

Control Rod Top Assembly to Finger Threaded Connection - This connection is located between the active finger and the upper stainless steel extension rod that spans the tube sheet in the reactor internals outlet plenum. An identical connection is used in part-strength CEAs which again bound the replacement Ag-In-Cd design in terms of inertial loading. Margin at this connection between preload and operating load is therefore improved relative to the current part-strength CEA.

4-Finger CEA Gripper Coupling to Spider Connection - The 4-finger part-strength or part-length designs bound the new Ag-In-Cd design because they are heavier.

12-Finger CEA Gripper Coupling to Spider Connection - This connection will see a slightly higher inertial loading than any current or previous 12-finger spider because they never carried any fingers other than the original lighter weight all-B_4C design. With the assembly torque specified in past practice, the minimum preload is 6533 lb compared to the new stepping load of 6629 lb. Since tensile, compressive, and shear stresses in this connection due to preload are all below 3 ksi, the preload can easily be increased. The assembly torque for Ag-In-Cd CEAs will therefore be increased to 280 ± 5 ft-lb, which assures that the minimum preload (7,333 lb) exceeds the applied operating load (6,629 lb) and also continues to satisfy stress limits in all parts of the connection by a wide margin.

With respect to locking devices, all permanent rod and spider threaded connections are locked with solid dowel pins trapped in place by welds. The control rods are attached to the spider with a crimp nut whose crimp zone is positioned at the top of the nut outside of the load path within the joint. Thus, the locking criteria are satisfied.

Fatigue Damage

The CEA shall be designed such that the fatigue damage produced by cyclic loads does not result in a fatigue usage factor greater than 0.8 for the lifetime of the CEA.

For evaluation of fatigue damage, the cyclic loads shown in the table below must be included.

	CEA Spider	Control Rod Components	Clad and Clad Welds	Other Structural Welds
CEDM Stepping Loads	X	X	X	X
Coolant Pressure Cycles			X	X
SCRAM Hydraulic Loads			X	
SCRAM Mechanical Loads	X	X	X	X

Seismic loads and other abnormal loads are not considered in the fatigue evaluation.

The existing analysis of record was reviewed, and it was determined that for the current CEA designs, the fatigue damage factors, considering CEDM stepping (at ~27.4g's), SCRAM, and pressure cycling, were ~0.0 compared to a limit of 0.8 (Sect. 6.3.3, Reference. 2). Doubling the number of cycles to account for a 20 EFPY operating life of the Ag-In-Cd tipped CEAs still results in damage factors of ~0.0.

Pellet / Clad Interaction

It shall be a design objective to limit the 10 year (Note: 11 EFPY in the case of replacement CEAs that are the subject of this analysis) *burnup of the worst burned B_4C pellet to a value which will not cause excessive strain, where excessive strain is defined as the least of the following:*

a. *1.0% permanent circumferential strain of the mean clad diameter.*
b. *Strain in excess of the irradiated value of uniform elongation of the clad.*
c. *That value of strain which would produce scram times in excess of allowable values.*

Note: Recently, criteria for acceptable strain have been updated based on an enhanced knowledge of IASCC, as well as, an assessment of the field operating experience with earlier CEAs at Palo Verde and elsewhere. The new criteria in Westinghouse calculation CN-NF-PPT-06-142 are more restrictive on strain and are listed below:

> *Cladding that receives an exposure less than* $2x10^{21}$ n/cm^2 $(E > 1\ MeV)$ *is said to be below the threshold for IASCC and can accommodate strain in excess of 1%; thus 1% is chosen as the limit; the value of Boron-10 (B-10) depletion associated with 1% clad strain in this design is 7.3%. Cladding operating above the threshold for IASCC is incapable of accommodating plastic strain; therefore, strain is constrained to the elastic range.*

For the B_4C region, compliance with the updated criteria is demonstrated by Westinghouse through analysis. The maximum B-10 burnup for several different CEA finger configurations was computed for an arbitrary period of time. Next, the fluence and depletion results were increased to account for 2% power uncertainty (3990 x 1.02 = 4070 MWt) and then the operating time factored up to reach the appropriate limit. For the B_4C section of the finger it was shown that 7.3% B-10 burnup would be reached in 26.1 EFPY, which exceeds the 11 EFPY design life. Therefore, it can be concluded that B_4C pellet clad interaction (PCI) will not occur during the design life and the criterion is satisfied.

For the Ag-In-Cd region, PCI in the traditional sense has not been a concern, recognizing that the annular Ag-In-Cd is deformable when confronted by the Alloy 625 cladding particularly at operating temperature. Additionally, the Ag-In-Cd slugs shrink away from the cladding upon cool down in a way that will not suddenly stress the cladding. The objective for this portion of the finger cladding is to limit strain to the proportional limit, i.e., zero permanent strain. The capacity of the Ag-In-Cd design configuration with a central hole to accommodate irradiation induced swelling by material creeping into the hole, instead of displacing the cladding outward with unrelenting force, is demonstrated by analysis. Even though it is shown that hole fill well beyond 20% could be achieved without affecting the cladding stress and strain, 20% is taken as the limit, and it is shown that 20.3 EFPY is achieved at that limiting value. Thus, the potential for cladding failure due to irradiation induced swelling of the absorber material is controlled throughout the design life.

Clad Collapse

The clad must be free standing against the entire range of differential pressure encountered. The ratio of the critical pressure to produce elastic buckling of tubing with *maximum ovality divided by the maximum system pressure shall be greater than 1.3 at beginning-of-life (BOL). During the lifetime, ovality must be limited to a value which will not cause interference between the CEA cladding and the guide tube inside diameter in the buffer region.*

The criterion is satisfied by analysis. The ratio (margin) is 1.50 where the maximum pressure is taken as the high pressure trip point setting (excluding uncertainties) of 2400 psig. The clad material specified for the replacement full-strength CEAs is unchanged from the earlier CEAs for Palo Verde and for other 16x16 CEA designs used over the history of the 16x16 fleet. It is seam welded Alloy 625 (Inconel 625) with a minimum specified yield strength of 65 ksi at 650° Fahrenheit (F). As previously mentioned, chrome plating will be applied to a portion of the tubing. Tubing mechanical properties are not impacted by chrome plating since the chrome plating process takes place at low temperature and no subsequent bake-out or other process step at high temperature is allowed.

A separate determination of collapse resistance was made that applied lessons learned from an unexpected collapse of some test tubes of a material and size unrelated to the actual CEA material. A group of 40 CEA tubes was measured to allow statistical treatment of tubing dimensions important to collapse including ovality. The calculated collapse at 650°F with upper 95/95 ovality and lower 95/95 wall thickness, and taking no credit for internal support, is 3407 psig or a factor of 1.36 higher than the reactor vessel design pressure. Again applying the 2400 psig high pressure trip setting, the ratio becomes 1.42. This assessment of as-built tubing is a further demonstration that the cladding satisfies the design criterion for collapse resistance.

With respect to ovality causing interference in the dashpot region, it is shown in the Dimensional Stability section that the minimum hot diametrical gap is approximately 0.010 inches. Ovality is included in that assessment since the outside diameter was taken at its maximum specified value to minimize the gap, and ovality can only be present when the outside diameter is less than its maximum. Thus, the gap will remain in the dashpot region unless the tube creeps into an oval shape that consumes the gap. However, Alloy 625 exhibits excellent creep resistance in a pressurized water reactor (PWR) environment as supported by data for solution treated Alloy 625 that shows no appreciable creep below 1100°F.

<u>Control Rod Stress</u>

Stress produced in the clad, nose caps, connectors, and stainless sections by the appropriate combination of CEDM stepping motion, differential pressure, seismic and LOCA events, and scram loads, shall meet the same stress limits listed for the spider.

The results of prior control rod evaluations were reviewed, and it was concluded that the new design is bounded by or equivalent to earlier analyses of stepping, differential pressure, and SCRAM loads.

With respect to seismic and LOCA events, a new analysis was performed for the replacement Ag-In-Cd CEAs. Control rods are unique among reactor components because they experience rather strong inertial loads from drive mechanism stepping action. A common practice is to ignore seismic/LOCA loads since they are small compared to stepping. Nevertheless, the replacement Ag-In-Cd CEA fingers were evaluated by assuming they are inserted in the fuel, deforming the fingers to the deflected shape of the fuel assembly, and computing the stresses. The change to Ag-In-Cd in the tip region has no impact on the fuel assembly deflected shape or on the computed stresses in the finger. Thus, no new concerns are introduced by the change relative to control rod stresses. An evaluation of stress intensities and allowable limits shows all stress criteria are satisfied.

Spacers

All spacers shall be capable of withstanding the weights of the poison column multiplied by the maximum acceleration induced by CEDM stepping motion without exceeding the yield strength of the material at temperature.

The bottom absorber carries the inertial loading of the absorber stack plus the desired 5X plenum spring force and is reacted by the nose cap rim. The stack weight is derived by adding the difference for the new design to the weight of an existing stack; 4.904 + 1.845 = 6.749 lb. The spacer load passing through the spacer can be conservatively approximated as the CEDM stepping inertial load plus the desired 5X spring force as (27.4+5) x 6.75 = 219 lb. This causes a compressive stress in the 0.733 diameter spacer of 519 psi. The bottom side reacts against the narrow ledge whose nominal area is approximately 0.019 in^2, generating a stress of 11.5 ksi, which is below the minimum yield for 304 stainless steel of 20 ksi at elevated temperature.

Structural Welds

Control rod structural welds shall be designed to the same load conditions and primary stress limitations established in the discussion on control rod stress above; however, the combination of primary stresses and secondary stresses produced by the presence of weld discontinuity must not exceed 3.0 S_m. Evaluation of secondary stresses will not be required for Condition IV occurrences.

Structural welds are those welds in the clad to nose cap/end fitting and the welds in the upper stainless steel rod section. The weld requirements, geometries, and inspection requirements remain unchanged for all of these welds. The bottom of the absorber material is positioned slightly away from the nose cap weld zone so as to minimize the possibility of straining the weld zone. Additionally, the substitution of Ag-In-Cd in the tip region is shown by analysis to limit cladding strain adjacent to the absorber.

Maintaining the same design for the structural welds and substitution of annular Ag-In-Cd in the tip regions assures that margin in the weld areas is preserved or improved.

Clad Wear

A 5% maximum uniform wear depth of the cladding wall shall not impair CEA function.

The nominal wall thickness of the CEA cladding is 0.035 inches; therefore, 5% is 0.00175 inches. The System 80 reactor internals essentially isolate each individual control rod from high velocity core exit flow, done specifically to reduce the potential for wear of the fingers. Excellent wear performance was demonstrated by ultrasonic testing profilometry examination of about 40 original fingers discharged in 2001 after 11.53 EFPY. During their operating time, a multi-position maneuvering strategy was used by the plant. An estimate of the wear depths and volume loss was made and then extrapolated to 20 EFPY and concentrated in a narrow band approximating a 1-position (no maneuvering) strategy. Of the 40 fingers evaluated, some would not have passed the 5% wall thinning criterion at 20 EFPY. Thus, the chrome plating was added to the design as a prudent step consistent with a longer life for the replacement Ag-In-Cd design, a possible reduction in CEA maneuvering desired by the plant, and the inability to easily shuffle or inspect CEAs during normal refueling outages. The chrome extends well above the normal contact area when the CEA is full out, which provides for protection of the CEA when it is stepped into the core for maneuvering. With deeper insertion, the potential for CEA flow induced movements and the potential for wear are both reduced. Additionally, the operating time with CEAs partially inserted will typically be only a small portion of the total operating time.

Chrome plate is widely deployed in reactor applications. The tips of the CEA fingers (including the nose cap weld zone) were left unplated so as not to alter the wear couple where the Alloy 625 CEA tip contacts the Zircaloy guide tube.

Spider Spring

The spider mounted spring torsional shear stress must be limited to yield stress in shear. The spring must be prevented from reaching solid height in operation. The wet weight of the CEA plus extension shaft must be supported by the spring in a manner which provides flexibility in the axial direction during drive mechanism latch actuation. In addition, the spring shall be capable of absorbing the kinetic and potential energy associated with the heaviest CEA and shaft during normal operating conditions.

No changes are made to the spider spring, cavity, or plunger. Review of the current spring documentation confirmed that the most limiting spring compression occurs with 4-finger part-strength CEAs (because they have the highest drop weight per finger of any design and the least buffering action with only 4-fingers). Spring stresses are shown to meet allowable torsional shear stress.

Solid height cannot be reached by virtue of the design of the plunger and spring cavity. If the plunger were to be pressed flush with the bottom of the spider, the available cavity length remaining (5.701" minimum) exceeds the solid height of the spring (5.67" max).

The spring provides some flexibility during drive mechanism latch actuation. There is a wide operating load range approximating 1000 lb and extending up to 1400 lb; thus, the change in combined weight of the new 12-finger CEA and extension shaft assembly from ~344.2 lb to ~367.3 lb will not adversely interfere with the latch actuation since all or nearly all of the plunger travel remains to accommodate the latch actuation.

The SCRAM analysis demonstrates that spring compression is not fully consumed by any of the drops evaluated, including no-flow hot condition which results in the most spring compression.

Plunger

The plunger travel must be designed to prevent the spider spring from reaching solid height during operation. The plunger shall also be capable of transmitting the CEA to upper guide structure impact load resulting from zero-flow scram of the heaviest CEA-extension shaft combination without exceeding Condition I allowable stress intensities.

The spring is prevented from reaching solid height as per the previous discussion. The maximum load developed in the plunger occurs as the CEA abruptly decelerates to zero velocity following contact with the upper guide structure after a SCRAM. Plungers for 4-finger and 12-Finger CEAs are identical. The maximum spring load in a no-flow hot condition is 1091 lb. The load is transmitted through a nominal 1.483 inch plunger diameter which equates to a stress less than 1 ksi. The plunger/spring arrangement, in conjunction with the in-fuel dashpots, is effective in absorbing the last of the SCRAM energy before the spider can impact directly against the upper internals.

Plenum Springs

The poison rod springs shall provide a beginning of life (BOL) holddown force sufficient to prevent relative motion of the stack of filler materials with respect to the cladding for a nominal axial acceleration of 5 g's during shipping and handling. The maximum torsional shear stress in the spring shall be less than the yield stress in shear in BOL conditions.

The poison rod springs shall allow for differential growth and thermal expansion between clad and filler materials, while maintaining a minimum load on the stack equal to the stack weight. Springs shall not reach solid height during the useful life of the poison rods.

The plenum spring used in the new CEAs is identical to earlier springs and the nominal plenum length remains unchanged. Westinghouse has demonstrated by analysis that the 5 g criterion is satisfied. The analysis assumes four Ag-In-Cd components, each with a length tolerance of ±0.062 inches. If the number of pieces is reduced, the minimum spring force will increase further because the maximum plenum length will decrease.

Torsional shear stress in the spring remains as before at BOL ambient conditions. At BOL hot conditions thermal expansion will affect the spring compression. For the current compression sleeve full-strength CEA, the plenum size will increase because expansion of B_4C is less than Alloy 625, whereas for the part-strength CEA, the expansion will be much less since both clad and absorber are Alloy 625. The Ag-In-Cd full-strength CEA design is bracketed by the two current designs for which BOL stresses are as follows:

	BOL Ambient		BOL Hot	
Absorber Arrangement	Torsional Stress (ksi)	Allowable Stress (ksi)	Torsional Stress (ksi)	Allowable Stress (ksi)
Full-Strength All B4C Absorber	67.7	107	49.5	64.2
Part-Strength Alloy 625 Absorber	67.7	107	57.8	64.2
New Ag-In-Cd/B4C Absorber	67.7	107	>49.5 and <57.8	64.2

Poison Material Orientation

The position of the poison materials in the control elements and the element length must be such that the bottom of the poison (column) is within 2-1/2 inches of the bottom surface of the active fuel when the CEA and extension shaft are at the fully inserted equilibrium position. Similarly, when fully withdrawn, the poison must be capable of being placed at an elevation which is flush to above the top of the active fuel.

The distance from the bottom of the CEA absorber stack to the bottom of the UO_2 stack has been determined to be 1.981 inches at hot conditions. This value corresponds to a fuel rod design with a fuel assembly lower end fitting that is 4.312 inches high. The nominal CEA stroke provided by the CEDM is 150 inches, which is the same as the length of the active fuel column and therefore results in the same relationship to the top of the active fuel when the CEAs are fully withdrawn. Uranium Dioxide (UO_2) stack expansion is not included in this assessment. Satisfaction of this criterion is the same as the current CEA design as the placement and length of absorber remain unchanged.

Weights and CEDM

The maximum CEA weight shall be compatible with CEDM specification weight limitations.

The CEDM specifications specify 450 lb as the maximum dry weight for the combined extension shaft assembly (ESA) and CEA. The combined dry weight for the new 12-finger CEA and ESA is 367.3 lb. The new CEA design is also compatible with the new specification addressing replacement reactor vessel heads and CEDMs which continues to list the 450 lb value.

Bearing Surfaces

Stresses at bearing surfaces which are produced by mechanical loads and fastener preloads shall be limited to the yield stress of the materials involved.

No changes have been made to the replacement Ag-In-Cd CEA that would affect the bearing stresses in any component other than the planned increase in assembly torque between the spider and the gripper coupling. Bearing and other stresses for threaded joints were recomputed and shown to be acceptable. A review of all other bearing stresses was not warranted since there are no changes.

B_4C Pellets

B_4C pellets shall have chamfered or rounded edges to minimize the likelihood of pellet/clad interaction.

B_4C pellets in both the compression sleeve and Ag-In-Cd design have a 0.007 to 0.040 inch edge radius.

Dimensional Compatibility

The CEA must be designed to be dimensionally compatible with interfacing hardware, including the fuel assemblies, upper guide structure, and CEA handling equipment.

Compatibility with all aspects of Palo Verde interfaces is assured with the replacement design by maintaining the envelope configuration the same as the current all-B_4C design, with the exception of two minor physical changes:

> The first is the addition of the chrome plating on a portion of the clad exterior. Its presence (extra resistance to flow exiting the guide tube as the CEA falls) has been conservatively accounted for in the SCRAM calculation which shows that the added weight more than compensates, resulting in slightly reduced insertion times.
>
> The second change is the addition of chamfers to the top of the CEA spider bosses to eliminate a potential ledge or step that can be present due to eccentricity that is typical between the cast boss diameter and the machined bore diameter as shown in Figure 3. The added chamfer removes a small amount of parasitic material and has no effect on the rod attachment design since the limiting contact bearing area as set by the bottom side of the crimp lock nut remains as in the current design. The added chamfer will have no impact on final CEA assembly or operation in the Palo Verde plant, but lessens the chance of catching an edge when the CEAs are pulled up through the Upper Guide Structure in preparation for refueling.

SCRAM CRITERIA

Both full and part-strength CEAs shall be capable of traveling from a fully withdrawn position to 90 percent insertion in accordance with time and displacement limits for all operating and accident conditions as described in the FSAR.

The SCRAM times were re-evaluated for the replacement Ag-In-Cd 4 and 12-finger CEAs. The added weight results in a small reduction in time to reach 90% insertion as shown in the following table:

CEA Type and Reactor Conditions	**Difference in Drop Time (Heavier AgInCd Design minus Current All-B_4C Design) (sec)**
12-Finger CEA Full Flow Hot Condition	- 0.120
12-Finger CEA No Flow Hot Condition	- 0.105
12-Finger CEA No Flow Cold Condition	- 0.163
4-Finger CEA Full Flow Hot Condition	- 0.052
4-Finger CEA No Flow Hot Condition	- 0.048
4-Finger CEA No Flow Cold Condition	- 0.063

Dimensional Stability

The rod tip design shall be such that the diametral clearance between the control element and the fuel assembly guide tube buffer zone is maintained. Accordingly, it shall be a requirement that the clad strain in the tip region be limited to zero.

The minimum ambient diametrical clearance in the dashpot region is (0.836 ± 0.002 Dashpot ID) – (0.816 ± 0.002 Clad) = 0.020 ± 0.004, or 0.016 inches minimum.

Consistent with the stated criterion, clad strain is limited in the Ag-In-Cd region to zero plastic strain due to the low creep strength of the Ag-In-Cd material and the central hole of the absorber slug. This limitation means the maximum clad strain is equivalent to the proportional limit of the material. The unirradiated minimum yield strength of the cladding is specified as 65 ksi at 650°F, but is expected to increase to approximately 100 ksi after irradiation. Thus the limit on strain is the proportional limit, or approximately 2/3 yield of 100 ksi, or 67 ksi, for which the diameter increase of the cladding is $\Delta D = \sigma \times D / E = 67{,}000 \times 0.816 / 27.8E{+}06 = 0.00197$ inches.

Differential expansion between Alloy 625 clad and Zircaloy guide tube material will further reduce the gap. At 600°F, the differential expansion is:

ΔD Alloy 625 = $\alpha D \Delta T$ = (7.4E-6) x 0.816 x (600-70) = 0.0032 in.
ΔD Zircaloy = $\alpha D \Delta T$ = (2.92E-6) x 0.836 x (600-70) = 0.0013 in.
ΔGap Thermal = 0.0013 – 0.0032 = -0.0019 in. or a reduction of 0.0019 in.

Lastly, the chrome plated zone on the finger will extend into the dashpot region by a few inches when the CEA is fully inserted. The plating thickness is limited to 0.001 inches maximum or 0.002 inches diametrically.

Therefore, the minimum hot gap is:

0.016 min. cold gap – (0.00197 strain component) – (0.0019 thermal component) – (0.002 max plating) = 0.01013, or ~ 0.010 inches.

Thus, the operation of the dashpot is maintained by virtue of maintaining a small clearance between the clad and the guide tube inside diameter.

Coolant Flow Access

The axial location of the CEA tip shall be such that the bleed hole in the fuel assembly guide tube buffer zone is not obstructed by the CEA tip when fully inserted into the fuel assembly.

The distance between the edge of the taper on the CEA tip to the bleed hole centerline for the original CEA/core design is 0.643 inches minimum. The only dimensions that would affect this relationship is the bleed hole elevation (since the CEA rests on the upper internals when fully inserted, not the fuel assembly). The same fuel assembly lower end fitting height is used in the current fuel design as the original design (4.312 inches); however, the bleed hole elevation within the guide tube is slightly higher. The bleed hole centerline can be derived for current fuel designs as 2.338 inches above the end of the guide tube compared to 1-13/16 for the original fuel design. So the 0.643 inch dimension of the original CEA/core design is reduced by 2.338 – 1.812 = 0.526 to 0.117 inches. This is further reduced by the small increase in weight of the 12-finger CEA (~24 lb) which depresses the spring an additional (24 lb) / (836 lb/inch) = 0.029 inches. The final distance is 0.117 – 0.029 = 0.088 inches, which satisfies the criterion.

Rod Void Volume

The void volume shall be sized so the available volume can accommodate the maximum predicted axial average B-10 burnup and the internal pressure associated therewith without exceeding allowable control rod stress discussed above. The plenum length must also be consistent with the plenum spring requirements discussed above.

The plenum volume for the Ag-In-Cd and compression sleeve CEAs remains unchanged. There is a small reduction in B_4C porosity volume because of the switch to Ag-In-Cd in the tip region. The available volume and helium generated for the Ag-In-Cd design results in an internal pressure of only 410 psia at a B-10 depletion of 7.8%, which is greater than the depletion of 7.3% corresponding to 26.1 EFPY. The internal pressure equates to a circumferential clad stress of 4.8 ksi, which is below allowable stress value.

Cooling of the Annulus

The temperature of the coolant in the control element guide tube annulus shall not cause bulk boiling of the coolant (concentric control element) during Conditions I, II, and III. This criterion is aimed at ensuring an unobstructed path for the coolant flow.

Heat deposition in the CEA finger, guide tube, and coolant is determined by analysis for an assembly with an assumed radial power density (RPD) of 1.0 with a 4-finger CEA inserted to the PDIL, which for Palo Verde is 28% insertion at full power for the lead bank. The allowed RPD is reached when the required flow to remain below saturated conditions equals the available flow. For the Ag-In-Cd design, the allowed RPD is 1.214. Key inputs for this thermal and hydraulic assessment are T_{IN} = 563°F, p = 2223.7 psia, and 454,000 gpm reactor coolant system (RCS) flow. The assembly design used in this analysis is the current design that contains one 0.093 inch dashpot bleed hole and one 0.093 inch cooling hole per rodded guide tube.

The limit on RPD is an input to the core design to assure that assembly power and CEA heating will satisfy the CEA thermal and hydraulic cooling criterion of no bulk boiling in the CEA annulus. RPDs in recent and current operating cycles at PVNGS are in the range of 0.94 to 1.15. Since these values are less than 1.214, the cooling criterion remains satisfied.

Absorber Temperature

The maximum centerline temperature of the poison materials shall not exceed 2000°F during Conditions I, II and III.

Note: *The above criterion was established for CEA designs containing all B_4C pellets. Similar criteria from Westinghouse desing documents for mixed absorber CEAs with both B_4C and Ag-In-Cd gives the following:*

The maximum centerline temperature of the poison materials shall not exceed the following during Conditions I, II and III:

B_4C - 2000°F
Ag-In-Cd - 1400°F

The 2000°F limit is a practical upper limit for the B_4C which is consistent with differential thermal expansion characteristics. The Ag-In-Cd limit is set slightly below its melting point of 1470°F.

Analyses show that absorber temperature limits would require an RPD of approximately 1.8 for the Ag-In-Cd or 2.8 for B_4C. The actual RPD is a function of core design; RPDs for recent PVNGS cycles are in the range of 0.94 to 1.15 under the lead bank of CEAs. Therefore, current operating conditions prevent the RPD from reaching a value that would cause the absorber temperature limits to be approached.

Industry Experience

A search of the Institute of Nuclear Power Operations (INPO) website was performed to determine if there is any industry operating experience (OE) related to CEA failures caused by Ag-In-Cd material. While several OEs were retrieved, review revealed that the Ag-In-Cd material was not identified as a cause in any of the events. The following documents were reviewed:

- NRCB 96-01, "Control Rod Insertion Problems, " dated 03-08-1996
- OE12131, "CEA Failure to Insert During Planned Shutdown," dated 04/12/2001
- OE12371, "CEA Failure to Insert During Planned Shutdown," dated 06/14/2001
- OE12822, "Missing Boron Carbide from CEAs," dated 10/08/2001
- OE12887, "Palo Verde Unit 2 Shutdown to Replace Cracked CEAs," dated 11/01/2001
- OE15489, "Failed CEAs Replaced – Assessing Improved Design," dated 02/10/2003
- NRC:06:022, "Interim Report of an Evaluation of a Deviation Pursuant to 10 CFR 21.21(a)(2) (Control Rod Performance During LOCA)," dated 04/13/2006
- 50-213, LER 86-015-00, "Rod Cluster Control Assembly Cladding Wear and Cracking," dated 04/23/1986
- 50-482, LER 96-001-01, "Loss of Circulating Water due to Icing on Traveling Screens Causes Reactor Trip," dated 08/05/1997
- 50-305, LER 84-003-01, "Rod Cluster Control Assembly Cladding Wear," dated 10/31/1984
- 700-980327-1, "Potential Dilution of Boron Carbide in Hybrid Rodlets due to Primary Water Going Through Cracks in Silver/Indium/Cadmium of the Control Rods," dated 05/20/1999

- OE8978, "HPI Pump Increased Radiation Levels due to Silver in the RCS," dated 05/06/1998
- OE7631, "Control Rod Anomalies, " dated 01/11/1996
- OE4007, "CEA Problem at Maine Yankee," dated 06/18/1990
- OE22523, "Control Rod Performance During LOCA," dated 05/02/2006
- OE24493, "Control Rod Performance During LOCA," dated 03/30/2007
- SER 1-95, "Control Rod Not Fully Inserted After Scram," dated 01/05/1995
- SER 1-95 Supplement 1, "Control Rod Not Fully Inserted After Scram," dated 05/10/1996
- SER 1-95 Supplement 2, "Control Rod Not Fully Inserted After Scram," dated 02/13/1997

4. REGULATORY EVALUATION

4.1 Applicable Regulatory Requirements/Criteria

The proposed changes have been evaluated to determine whether applicable regulations and requirements continue to be met.

In accordance with 10 CFR 50 Appendix B, a Quality Assurance Program, as outlined in Chapter 17.2 of the Palo Verde UFSAR, is utilized by APS for designing, purchasing, fabricating, handling, shipping, storing, cleaning, erecting, installing, inspecting, testing, operating, maintaining, repairing, and modifying activities that affect the safety-related functions of structures, systems, and components. As stated in the PVNGS Equipment Qualification Program,

> "The design, specification, and procurement of new, replacement, or reworked equipment and parts shall consider the specific requirements necessary to maintain the continued qualification of installed equipment and environmental performance requirements of any "new" equipment."

Also, it states,

> "The qualification of new equipment and designs shall be verified prior to their installation in the plant."

In accordance with the Palo Verde Quality Assurance Program, the qualification requirements involving the replacement Ag-In-Cd CEAs such as suitability, functionality, environmental, seismic, human factors, defense-in-depth, and diversity analysis have been evaluated to ensure that the replacement CEAs meet or exceed the original CEA requirements.

10 CFR 50, Appendix A, General Design Criteria (GDC) for Nuclear Power Plants, as related to the design and operability requirements of the CEAs has been assessed to assure that the replacement Ag-In-Cd full-strength CEAs will satisfy regulatory design requirements. The criteria associated with the CEAs are listed below with the technical analysis summary.

Criterion 10 – Reactor design - The principal difference, which has some impact on reactor design, is the difference in weight with regard to the Ag-In-Cd full-strength CEAs. However, this difference has been analyzed with respect to the performance capability of the CEDMs and found to be within design capabilities and design analyses.

The second element affecting this criterion is the change in absorber material in the tip region from B_4C to Ag-In-Cd. This change results in a small decrease in total rod worth (less than 1%). Computer modeling of events which exhibit sensitivity to time dependent rod worth (sheared shaft/seized rotor, loss of flow from specified acceptable fuel design limits (SAFDL) and total loss of reactor coolant flow) demonstrate that all acceptance criteria continue to be met.

Criterion 12 - Suppression of reactor power oscillations - Axial power oscillations are controlled using the part-strength CEAs and/or full-strength CEAs. The Ag-In-Cd full-strength CEAs can be effectively used to control reactivity oscillations within the Power Dependent Insertion Limit (PDIL) as specified in the Core Operating Limits Report. The ability to reliably detect and suppress power oscillations is unaffected by the proposed changes.

Criterion 13 - Instrumentation and control - The existing systems and components used for monitoring and control of CEA positions are unaffected by the proposed changes and will be equally effective and relied upon for the control of the Ag-In-Cd full-strength CEAs.

Criterion 26 - Reactivity control system redundancy and capability - The operational reactivity control characteristic of the Ag-In-Cd full-strength CEAs is nearly identical to the existing compression sleeve full-strength CEAs. Redundancy and capability for the full-strength CEAs to control reactivity is not impacted and remains bounded by maintaining the operational restrictions required by the PDILs.

Criterion 27 - Combined reactivity control systems capability - The current design of the Reactor Control Systems include a more than adequate capability for reactivity control using only the full-strength CEAs. The design of the replacement Ag-In-Cd full-strength CEAs meet all the same performance requirements of the current design and will not introduce any new effect which could adversely impact the performance of the full-strength CEAs. Therefore, the reactivity control systems remain capable of reliably controlling reactivity changes to assure that under postulated accident conditions and with appropriate margin for stuck rods, the capability to cool the core is maintained.

Criterion 28 - Reactivity limits - The ability of the full-strength CEAs to control reactivity is not impacted and remains bounded by maintaining the operational restrictions required by the PDILs. The PDILs for regulating CEAs is assumed in the reload analysis and shown to be acceptable by the reload process. Operation within the PDILs assures that the assumptions regarding the initial conditions of postulated accidents remain valid. The impact of a slight reduction (less than 1%) in total rod worth due to lower rod worth at the tips (due to Ag-In-Cd) has been analyzed with the conclusion that all safety analyses will continue to meet the applicable success criteria. Therefore, this proposed change would not cause a change in the amount or rate of negative or positive reactivity inertion different than what is already assumed in accident analyses.

Criterion 29 - Protection against anticipated operational occurrences – the replacement Ag-In-Cd full-strength CEAs have been evaluated against design criteria applicable to the existing compression sleeve full-strength CEAs, and it was determined that they will function as required during anticipated operating occurrences (AOO). The slight increase in weight due to the change of absorber material in the tip section does not result in a total CEA plus extension shaft weight that is greater than the weight assumed in the design of the control element drive mechanisms (CEDM); therefore CEDM trip function is unaffected. The change does not alter the design of the CEDMs, reactor trip switchgear (RTSG), or CEDM control system; therefore, the function of these components during AOOs is not affected.

4.2 No Significant Hazards Consideration Determination

Arizona Public Service Company (APS) has evaluated whether or not a significant hazards consideration is involved with the proposed amendment(s) by focusing on the three standards set forth in 10 CFR 50.92, "Issuance of amendment," as discussed below:

1. Does the proposed amendment involve a significant increase in the probability or consequences of an accident previously evaluated?

   Replacement of full-strength compression sleeve control element assemblies with full-strength silver(Ag)-indium(In)-Cadmium(Cd) control element assemblies.

   Response: No.

   The proposed change involves a new design for the full-strength Control Element Assemblies (CEA) that replaces a portion of B_4C pellets (including the compression sleeve) in the tips of the CEA fingers with hollow silver-indium-cadmium slugs.

   The following events are related to inadvertent movement of the CEAs; however, they are not initiated by the CEAs.

- Uncontrolled Control Element Assembly Withdrawal from a Subcritical or Low (Hot Zero) Power Condition

- Uncontrolled Control Element Assembly Withdrawal at Power

- Single Full-Strength Control Element Assembly Drop

- Control Element Assembly Ejection

These previously analyzed accidents are initiated by the failure of plant structures, systems, or components (SSC) other than the CEA itself. The proposed change to the CEA design does not have a detrimental impact on the integrity of any plant SSC that initiates an analyzed event. Additionally, the CEAs mitigate other events. In these events, the chrome plating on the portion of the clad exterior and the added weight has been conservatively accounted for in the SCRAM calculation. The change does not adversely affect the protective and mitigative capabilities of the plant, nor does the change affect the initiation or probability of occurrence of any accident. The SSCs will continue to perform their intended safety functions.

The proposed change in CEA design has resulted in a slight (less than 1%) reduction of total reactivity.

Computer modeling events which exhibit sensitivity to time dependent rod worth (sheared shaft/seized rotor, loss of flow from SAFDL and total loss of reactor coolant flow) demonstrate that all acceptance criteria continued to be met.

Therefore this change will not significantly increase the probability or consequences of any accident previously evaluated.

<u>The removal of the registered trademark name "Inconel."</u>

Response: No.

This change is considered editorial. Inconel is a registered trademark of Special Metals Corporation, while Alloy 625 is a generic alloy designation from the Unified Numbering System. Retaining the already referenced term "Alloy 625" does not involve a significant increase in the probability or consequences of an accident previously evaluated, as the material properties and application of Alloy 625 have not changed.

<u>Deletion of the references to part-length control element assemblies</u>

Response: No.

This change is considered editorial. The removal of this information does not involve a significant increase in the probability or consequences of an accident previously evaluated as the part-length CEAs were replaced in accordance with License Amendment 152, dated March 23, 2004 (Agency Document Access and Management System [ADAMS] Accession No. ML040860573) and the information is no longer applicable.

2. Does the proposed amendment create the possibility of a new or different kind of accident from any accident previously evaluated?

<u>Replacement of full-strength compression sleeve control element assemblies with full-strength silver(Ag)-indium(In)-Cadmium(Cd) control element assemblies.</u>

Response: No.

There are three differences in the replacement CEAs as compared to the current CEAs.

First, there is a very slight change in the outside diameter of a portion of the cladding on the replacement CEAs due to chrome plating on the lower portion of cladding. Analysis demonstrates that this change will not cause interference between the CEA cladding and the guide tube inside diameter in the buffer region. Secondly, there is a slight increase in weight with the Ag-In-Cd CEAs. However, this difference has been analyzed with respect to the performance capability of the CEDMs and found to be within design capabilities and design analyses. Finally, the upper edges of the spider bosses have been chamfered to prevent damage to the self-latching mechanisms that can occur if the CEA hangs up when lifting through the upper guide structure cut outs. This change is for ease of maintenance and has no impact on operation of the CEAs.

Therefore, the Ag-In-Cd CEAs are identical to the compression sleeve CEAs in terms of form, fit and function and the proposed change will not introduce any new failure mechanisms, malfunctions, or accident initiators not already considered in the design and licensing bases. The possibility of a new or different malfunction of safety-related equipment is not created. No new accident scenarios, transient precursors, or limiting single failures are introduced as a result of these changes. There will be no adverse effects or challenges imposed on any safety-related system as a result of these changes. Therefore, the possibility of a new or different accident from any accident previously evaluated is not created as a result of any dimensional change.

<u>The removal of the registered trademark name "Inconel."</u>

Response: No.

This change is considered editorial. Inconel is a registered trademark of Special Metals Corporation, while Alloy 625 is a generic alloy designation from the Unified Numbering System. Retaining the already referenced term "Alloy 625" does not create the possibility of a new or different kind of accident from any accident previously evaluated, as the material properties and application of Alloy 625 have not changed.

Deletion of the references to part-length control element assemblies

Response: No.

This change is considered editorial. The removal of this information does not create the possibility of a new or different kind of accident from any accident previously evaluated as the part-length CEAs were replaced in accordance with License Amendment 152, dated March 23, 2004 (Agency Document Access and Management System [ADAMS] Accession No. ML040860573) and the information is no longer applicable.

3. Does the proposed amendment involve a significant reduction in a margin of safety?

Replacement of full-strength compression sleeve control element assemblies with full-strength silver(Ag)-indium(In)-Cadmium(Cd) control element assemblies.

Response: No.

Reactor core safety limits are established in the PVNGS Technical Specifications to prevent overheating of the fuel and cladding that would result in the release of fission products to the reactor coolant during steady state operation, normal operational transients, and anticipated operational occurrences. The margin to these safety limits is not affected by the CEA design changes under consideration.

Overheating of the fuel is prevented by maintaining steady state, peak linear heat rate (LHR) below the level at which fuel centerline melting occurs. If the local LHR is high enough to cause the fuel centerline temperature to reach the melting point of the fuel, expansion of the pellet caused by centerline melting may cause the pellet to stress the cladding to the point of failure, allowing an uncontrolled release of activity to the reactor coolant.

Compliance with the DNBR and fuel centerline melt specified acceptable fuel design limits (SAFDLs) is assured through the CEA insertion limits and alignment technical specifications, and through the power distribution limit technical specifications.

There is no change to the operation of the full-strength CEAs due to the change from compression sleeve CEAs to Ag-In-Cd CEAs. Since the Ag-In-Cd CEAs may be used to control power distribution similar to the compression sleeve CEAs, power distributions will still be controlled and maintained within the limits necessary to assure SAFDLs are met.

The proposed change in CEA design has resulted in a slight (less than 1%) reduction in total reactivity.

Computer modeling results of events which exhibit sensitivity to time dependent rod worth (sheared shaft/seized rotor, loss of flow from SAFDL and total loss of reactor coolant flow) demonstrate that all acceptance criteria continued to be met.

Therefore, since SAFDLs continue to be met, the change from compression sleeve CEAs to Ag-In-Cd CEAs does not involve a significant reduction in a margin of safety.

The removal of the registered trademark name "Inconel."

Response: No.

The removal of the registered trademark name "Inconel." This change is considered editorial. Inconel is a registered trademark of Special Metals Corporation, while Alloy 625 is a generic alloy designation from the Unified Numbering System. Retaining the already referenced term "Alloy 625" does not involve a significant reduction in the margin of safety as the material properties and application of Alloy 625 have not changed

Deletion of the references to part-length control element assemblies

Response: No.

This change is considered editorial. The removal of this information does not involve a significant reduction in the margin of safety as the part-length CEAs were replaced in accordance with Amendment 152, dated March 23, 2004 (Agency Document Access and Management System [ADAMS] Accession No. ML040860573) and the information is no longer applicable.

Based on the above, Arizona Public Service Company concludes that the proposed amendment(s) does (do) not involve a significant hazards consideration under the standards set forth in 10 CFR 50.92(c), and, accordingly, a finding of "no significant hazards consideration" is justified.

4.3 Conclusions

Based on the considerations discussed above, (1) there is reasonable assurance that the health and safety of the public will not be endangered by operation in the proposed manner, (2) such activities will be conducted in compliance with the Commission's regulations, and (3) the issuance of the amendment will not be inimical to the common defense and security or to the health and safety of the public.

5. ENVIRONMENTAL CONSIDERATION

Arizona Public Service Company has evaluated the proposed changes and has determined that the changes do not involve (i) a significant hazards consideration, (ii) a significant change in the types or significant increase in the amount of effluent that may be released offsite, or (iii) a significant increase in the individual or cumulative occupational radiation exposure. Accordingly, the proposed change meets the eligibility criterion for categorical exclusion set forth in 10 CFR 51.22(c)(9). Therefore, pursuant to 10 CFR 51.22(b), an environmental assessment of the proposed change is not required.

6. REFERENCES

1. Timoshenko, S., Strength of Materials, Part II Chapter IX, D. VanNostrand Co., Inc., New York, 1956.
2. Westinghouse Memorandum LTR-WFE-02-189, Rev. 0, "Acceptability of Heavier Replacement System 80 CEAs with Ag-In-Cd," J. M. Burger, December 19, 2002.

7. ACRONYMS

Ag-In-Cd	Silver(Ag)-Indium(In)-Cadmium(Cd)
APS	Arizona Public Service Company
ADAMS	Agency Document Access and Management System
BOL	Beginning-Of-Life
CEA	Control Element Assembly
CE	Combustion Engineering
CEDM	Control Element Drive Mechanism
EFPY	Effective Full Power Years
EOL	End-Of-Life
IASCC	Irradiation Assisted Stress Corrosion Cracking
INPO	Institute of Nuclear Power Operations
LOCA	Loss of Coolant Accident
OE	Operating Experience
PAC	Physics Assessment Checklist
PCI	Pellet Clad Interaction
PDIL	Power Dependent Insertion Limit
PSI	Pounds/Square Inch

PVNGS	Palo Verde Nuclear Generating Station
PWR	Pressurized Water reactor
RPD	Radial Power Density
SAFDL	Specified Acceptable Fuel Design Limits
SDM	Shutdown Margin
TD	Theoretical Density
TS	Technical Specifications
UFSAR	Updated Final Safety Analysis Report
$U0_2$	Uranium Dioxide

ENCLOSURE, ATTACHMENT 1

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4.0 DESIGN FEATURES

4.1 Site Location

The Palo Verde Nuclear Generating Station is located in Maricopa County, Arizona, approximately 50 miles west of the Phoenix metropolitan area. The site is comprised of approximately 4,050 acres. Site elevations range from 890 feet above mean sea level at the southern boundary to 1,030 feet above mean sea level at the northern boundary. The minimum distance from a containment building to the exclusion area boundary is 871 meters.

4.2 Reactor Core

4.2.1 Fuel Assemblies

The reactor shall contain 241 fuel assemblies. Each assembly shall consist of a matrix of Zircaloy or ZIRLO fuel rods with an initial composition of natural or slightly enriched uranium dioxide (UO_2) as fuel material. Limited substitutions of zirconium alloy or stainless steel filler rods for fuel rods, in accordance with approved applications of fuel rod configurations, may be used. Fuel assemblies shall be limited to those fuel designs that have been analyzed with applicable NRC staff approved codes and methods and shown by tests or analyses to comply with all fuel safety design bases. A limited number of lead test assemblies that have not completed representative testing may be placed in nonlimiting core regions. Other cladding material may be used with an approved exemption.

4.2.2 Control Element Assemblies

The reactor core shall contain 76 full strength and ~~either 13 part length or~~ 13 part strength control element assemblies (CEAs).

The control section for the full strength CEAs shall be **either** boron carbide with ~~Inconel~~ Alloy 625 cladding**, or a combination of silver-indium-cadmium and boron carbide with Alloy 625 cladding.**

~~For units that have part length CEAs, the control section shall be Inconel Alloy 625 in the lower half, followed by perforated stainless steel tubing over the next 40%, and boron carbide pellets with Inconel Alloy 625 clad over the last 10% of the control section.~~

~~For units that have part strength CEAs, t~~The control section **for part strength CEAs** shall be solid ~~Inconel~~ Alloy 625 slugs with ~~Inconel~~ Alloy 625 cladding.

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ENCLOSURE, ATTACHMENT 2

Retyped Technical Specification Page

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4.0 DESIGN FEATURES

4.1 Site Location

The Palo Verde Nuclear Generating Station is located in Maricopa County, Arizona, approximately 50 miles west of the Phoenix metropolitan area. The site is comprised of approximately 4,050 acres. Site elevations range from 890 feet above mean sea level at the southern boundary to 1,030 feet above mean sea level at the northern boundary. The minimum distance from a containment building to the exclusion area boundary is 871 meters.

4.2 Reactor Core

4.2.1 Fuel Assemblies

The reactor shall contain 241 fuel assemblies. Each assembly shall consist of a matrix of Zircaloy or ZIRLO fuel rods with an initial composition of natural or slightly enriched uranium dioxide (UO_2) as fuel material. Limited substitutions of zirconium alloy or stainless steel filler rods for fuel rods, in accordance with approved applications of fuel rod configurations, may be used. Fuel assemblies shall be limited to those fuel designs that have been analyzed with applicable NRC staff approved codes and methods and shown by tests or analyses to comply with all fuel safety design bases. A limited number of lead test assemblies that have not completed representative testing may be placed in nonlimiting core regions. Other cladding material may be used with an approved exemption.

4.2.2 Control Element Assemblies

The reactor core shall contain 76 full strength and 13 part strength control element assemblies (CEAs).

The control section for the full strength CEAs shall be either boron carbide with Alloy 625 cladding, or a combination of silver-indium-cadmium and boron carbide with Alloy 625 cladding.

The control section for the part strength CEAs shall be solid Alloy 625 slugs with Alloy 625 cladding.

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