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THERMAL-HYDRAULIC EFFECTS OF TRANSITION TO IMPROVED SYSTEM 80™ FUEL

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ABSTRACT

ABB CE's improved System 80™ PWR fuel design includes GUARDIAN™ debris-resistant features and laser-welded Zircaloy grids. The GUARDIAN™ features include an Inconel grid with debris-filtering features located just above the Lower End Fitting, and a solid fuel rod bottom end cap that extends above the filtering features. Tests and analyses were done to establish the impact of these design improvements on fuel assembly hydraulic performance. Further analysis was done to determine the mixed core thermal-hydraulic performance as the transition is made over two fuel cycles to a full core of the improved System 80™ fuel.

Results confirm that the Thermal-Hydraulic (T-H) effects of the reduction in hydraulic resistance between the improved and resident fuel due to the laser-welded Zircaloy grids offsets the effects of the increased resistance GUARDIAN™ grid. Therefore, the mechanically improved System 80™ fuel can be implemented with no net impact on Departure from Nucleate Boiling (DNB) margin in transition cores.

INTRODUCTION

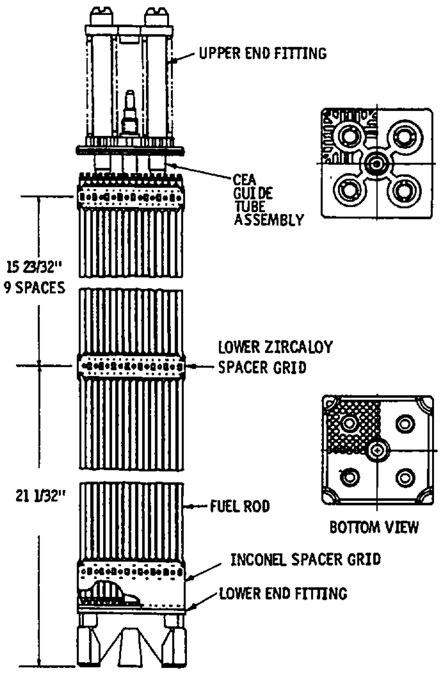
ABB Combustion Engineering's System 80™ fuel has been used in the Palo Verde reactors since the early 1980s. Fuel design improvements were recently implemented to make this design even more robust. ABB Combustion Engineering Nuclear Fuel's (CENF's) GUARDIAN™ grid has been adopted to reduce the potential for debris-induced fuel rod clad fretting. In addition, the designs of all the spacer grids were optimized for state-of-the-art laser beam welding, which has replaced Tungsten Inert Gas (TIG) welding at ABB CENF.

These mechanical design improvements impact the hydraulic characteristics of the fuel design, and thus can potentially affect the core thermal-hydraulic (T-H) performance. One of the design objectives in the development of the improved System 80™ fuel was to minimize the impact on transition core T-H performance. The methods used to quantify the changes in the fuel hydraulic characteristics, and the impact of those changes on core T-H performance are discussed in this paper.

SYSTEM 80™ FUEL DESIGN

The System 80™ fuel design, shown in Figure 1, is a 16x16 array of 9.70 mm (0.382 in) O.D. fuel rods. Five Control Element Assembly (CEA) guide tubes of 24.89 mm (0.98 in) O.D. displace a total of 20 fuel rods in each assembly to provide structural support for the assembly and lead-in for reactor control rods. The guide tubes are mechanically attached to the assembly Lower End Fitting and Upper End Fitting. Fuel rods are supported by 10 wavy-strip Zircaloy spacer grids at a spacing of 399.3 mm (15.72 in) and an Inconel-625 grid at the bottom of the fuel assembly. The Inconel grid is welded to the Lower End Fitting.

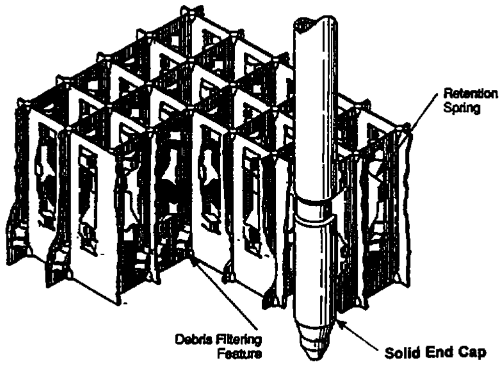
Figure 1: System 80™ Fuel Assembly



GUARDIAN™ GRID

In the improved System 80™ fuel, ABB CENF's Inconel GUARDIAN™ grid replaces the Inconel grid located at the bottom of the standard fuel assembly adjacent to the Lower End Fitting. The GUARDIAN™ grid, as shown in Figure 2, incorporates special features to filter and trap debris. ABB CENF has pioneered the use of a debris-filtering grid at the bottom of the fuel because of the effectiveness of this device in both filtering debris and trapping the debris in a benign location. The GUARDIAN™ grid is used in conjunction with a solid fuel rod end cap to prevent both trapped debris and grid-to-cladding support features from causing fuel failure due to fretting wear. Tests have shown that the GUARDIAN™ grid is effective in filtering over 90% of debris and capturing the debris in a benign location. The spectrum of metal debris used in these tests ranged from 1 mm (0.04 in) wide x 13 mm (0.5 in) long to 50 mm (2 in) long metal shavings. This spectrum spans the range of debris that has typically been found to reach the fuel in reactor.

Figure 2: GUARDIAN™ Grid



All Lower Grid Rod Support Features Are In Contact with Solid End Cap

In addition to having special features to filter debris, the straight strip GUARDIAN™ grid is located closer to the Lower End Fitting flow plate than the previous Inconel grid. This reduces the length of the solid end cap needed to extend above the filtering features of the GUARDIAN™ grid. Both the additional flow blockage area presented by the filtering features and location of the grid closer to the Lower End Fitting act to increase the hydraulic resistance of the GUARDIAN™ grid relative to the previous Inconel grid.

LASER WELDED ZIRCALOY GRIDS

ABB CENF's wavy strip Zircaloy grid design has been optimized for laser welding. Weld nuggets at strip intersections produced by laser welding are smaller but deeper and more uniform than nuggets produced by the previous Tungsten Inert Gas (TIG) methods. Minor changes were also made to the grid perimeter strip. The overall impact of the changes in the Zircaloy grid is to reduce flow blockage area, thereby reducing the grid's hydraulic resistance with no loss of strength.

HYDRAULIC IMPACT

ABB CENF has developed a variety of tools to assess the hydraulic impact of fuel design changes ranging from analytic techniques to full scale testing at PWR operating conditions. The impact of small design changes is quantified using analytic methods in conjunction with full scale cold water pressure drop testing.

The analytic methods calculate form and friction components of pressure drop based on the geometric characteristics of the fuel assembly component. These methods are benchmarked against cold water pressure drop test data, then applied to determine component loss coefficients at reactor conditions. Results agree with available pressure drop data at PWR operating conditions within measurement uncertainties.

Cold water pressure drop tests were run with the GUARDIAN™ grid and data from the tests were used to benchmark an analytic model for use in determining the hydraulic loss coefficient at reactor operating conditions. Since only minor design changes were made to optimize the Zircaloy grids for laser welding, analytic methods were sufficient to determine the impact of the design changes and no testing was required. Changes in loss coefficients associated with the GUARDIAN™ and laser-welded grids are summarized in Table 1. Loss coefficients are referenced to the bare rod flow area.

Table 1
Change in Hydraulic Loss Coefficients Associated with GUARDIAN™ and Laser-Welded Grids

Component	**Kimproved - Koriginal**
Lower End Fitting + Inconel Grid	**+0.21**
Individual Zircaloy Grid	**-0.06**

where,

$$K = \frac{\Delta P}{\left(\frac{\rho V^2}{2g}\right)}$$

THERMAL-HYDRAULIC IMPACT

The Thermal-Hydraulic (T-H) impact of the difference in hydraulic performance between standard fuel (Inconel bottom grid and TIG-welded Zircaloy grids) and improved fuel (GUARDIAN™ bottom grid and laser-welded Zircaloy grids) was determined for mixed cores using CENF's TORC computer code (Reference 1). TORC determines flow redistribution in an open PWR core, subject to user-specified boundary conditions at the core inlet and exit.

Scale model flow tests run by Combustion Engineering for the System 80™ reactor provide an inlet flow distribution and exit pressure distribution boundary conditions for non-mixed cores. However, with a mixed core of standard and improved fuel, flow redistribution upstream of the core inlet occurs because of the increased hydraulic resistance of the GUARDIAN™ grid in the improved fuel. Therefore, flow redistribution both upstream of, and within, the core was evaluated in the analyses.

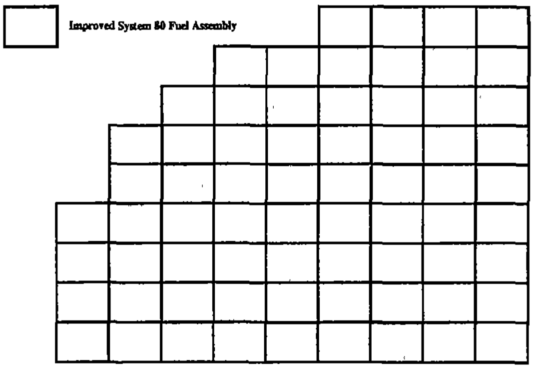
Upstream flow redistribution was determined from an isothermal TORC analysis to establish the impact of the GUARDIAN™ grid on the mixed core inlet flow distribution. In-core flow redistribution was evaluated in TORC analyses run with the modified inlet flow distribution and the different TIG and laser-welded Zircaloy spacer grid loss coefficients.

Fuel in current System 80™ fuel management strategies typically is in the core for 3 cycles. Therefore, two transition cores were analyzed, corresponding to approximately 1/3 and 2/3 of the core loaded with the improved fuel. Typical transition core loading patterns were used, as shown in Figure 3.

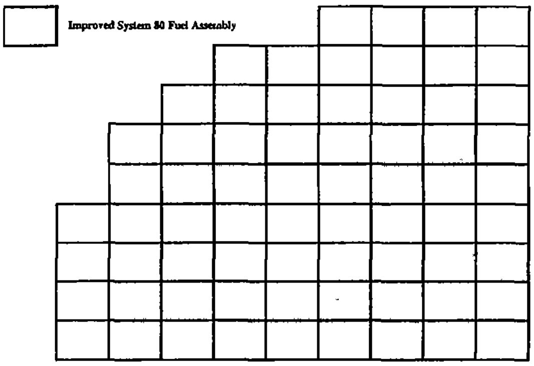
The effect of the GUARDIAN™ grids on the inlet flow distribution for the transition cores is shown in Figure 4. Flow shifts from the improved fuel assemblies, which are more resistive at the inlet, to the fuel without the GUARDIAN™ grid. This results in reductions in the hot assembly inlet flow of 5.4 % and 1.2%, for the first and second transition cores, respectively. However, the laser-welded Zircaloy grids in the improved fuel are less resistive than the TIG-welded grids, as indicated in Table 1. Therefore, as the coolant passes through the core, it redistributes into the improved fuel assemblies with the lower resistance laser-welded Zircaloy grids.

Figure 3: Typical Transition Core Fuel Loading Patterns

Core Loading Pattern for First Transition Core

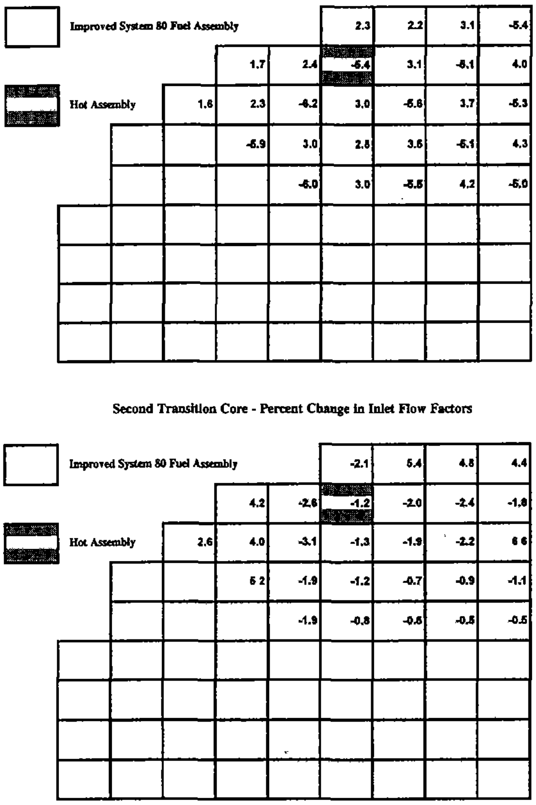


Core Loading Pattern for Second Transition Core



The overall effects of the flow redistribution on hot channel Minimum DNBR are summarized in Table 2. TORC analyses were run at nominal operating conditions and a constant hot pin radial peaking factor with the bottom-peaked, chopped cosine, and top-peaked axial power distributions shown in Figure 5. Core average heat flux in these analyses was increased to achieve a hot channel Minimum DNBR near the DNBR limit. The results in Table 2 indicate that the beneficial effects of the less resistive laser-welded Zircaloy grid offset the adverse effect of higher resistance GUARDIAN™ grid at the core inlet. Therefore, there is essentially no net impact on the DNB margin for the transition cores.

Figure 4: Impact of Mixed Core Hydraulic Characteristics on Inlet Flow Distribution



First Transition Core - Percent Change in Inlet Flow Factors

☐ Improved System 80 Fuel Assembly

▨ Hot Assembly

					2.3	2.2	3.1	-5.4
			1.7	2.4	▨ -5.4	3.1	-6.1	4.0
		1.6	2.3	-6.2	3.0	-6.6	3.7	-6.3
			-6.9	3.0	2.8	3.6	-6.1	4.3
				-6.0	3.0	-5.5	4.2	-6.0

Second Transition Core - Percent Change in Inlet Flow Factors

☐ Improved System 80 Fuel Assembly

▨ Hot Assembly

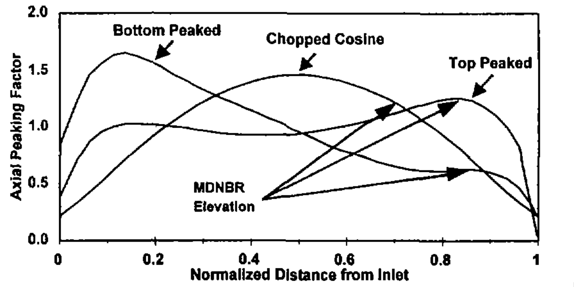
					-2.1	5.4	4.8	4.4
			4.2	-2.6	▨ -1.2	-2.0	-2.4	-1.8
		2.6	4.0	-3.1	-1.3	-1.9	-2.2	6 6
			5 2	-1.9	-1.2	-0.7	-0.9	-1.1
				-1.9	-0.8	-0.6	-0.5	-0.5

Table 2
Impact of Transition to Improved System 80™ Fuel on Thermal Margin

Axial Power Distribution	Hot Channel Minimum DNBR		
	1/3 Core Improved Fuel	2/3 Core Improved Fuel	Full Core Improved Fuel
Bottom Peaked	1.35	1.34	1.34
Chopped Cosine	1.34	1.33	1.32
Top Peaked	1.33	1.32	1.31

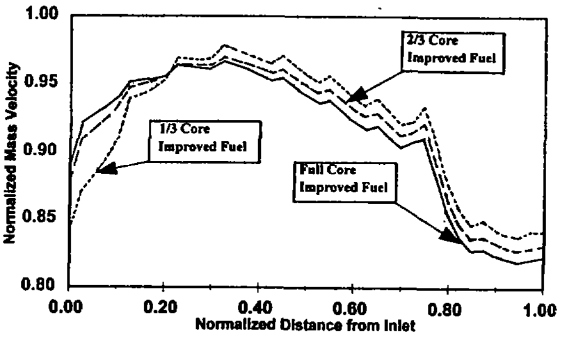
As can be seen from Figure 5, Minimum DNBR occurs relatively high in the core, even with a bottom-peaked axial power distribution. This allows flow to redistribute to the improved fuel which has lower flow at the inlet, but less resistive laser-welded Zircaloy grids.

Figure 5
Axial Power Distributions



Flow redistribution in the hot subchannel shown in Figure 6 for the chopped cosine analyses.

Figure 6
Hot Subchannel Mass Velocity



CONCLUSIONS

The hydraulic and T-H effects of mechanical improvements to the System 80™ fuel design have been evaluated by testing and analysis. Results indicate that the adverse effects of increased hydraulic resistance at the core inlet due to the GUARDIAN™ grid are offset by the flow redistribution that occurs due to the lower resistance of the laser-welded Zircaloy grids relative to TIG-welded grids. As a result, implementation of the mechanically improved System 80™ fuel has no net impact on the margin to DNB for transition cores.

REFERENCES

1. "TORC CODE; A Computer Code for Determining the Thermal Margin of a Reactor Core", *Combustion Engineering Report* CENPD-161-NP-A, April, 1986.

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