DEVELOPMENT OF AN ADVANCED 16X16 WESTINGHOUSE TYPE PWR FUEL ASSEMBLY FOR SLOVENIA

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ABSTRACT

Industrias Nucleares do Brasil (INB), KOREA Nuclear Fuel Company, Ltd. (KNFC), and Westinghouse Electric Company (Westinghouse) have jointly designed an advanced 16x16 Westinghouse type PWR fuel assembly. This advanced 16x16 Westinghouse type PWR fuel assembly, which will be implemented in both Kori Unit 2 (in Korea) and Angra Unit 1 (in Brazil) in January and March 2005, respectively, is an integral part of the utilities' fuel management strategy. This same fuel design has also been developed for future use in Krsko Unit 1 (in Slovenia).

In this paper we will describe the front-end nuclear fuel management activities utilized by the joint development team and describe how these activities played an integral part in defining the direction of the advanced 16x16 Westinghouse type PWR fuel assembly design. Additionally, this paper will describe how this design projects improved margins under high duty plant operating conditions.

The primary reason for initiating this joint development program was to update the current 16x16 fuel assembly, which is also called 16STD. The current 16STD fuel assembly employs a fuel rod diameter and a fuel rod pitch (i.e. 0.374 inch (9.500 mm) OD fuel rods at a 0.485 inch (12.319 mm) pitch) that is not optimized for fuel cycle cost reduction with neutronically inefficient components (i.e. Inconel Mid grids), no Intermediate Flow Mixer (IFM) grids, and other mechanical features that represent older and less efficient designs. The advanced 16x16 fuel assembly is being designed for peak rod average burnups of up to 75 MWd/kgU and will use an optimized fuel rod diameter (i.e. 0.360 inch (9.144 mm) OD ZIRLO™ fuel rods), neutronic efficient components (i.e. ZIRLO™ Mid grids), ZIRLO™ Intermediate Flow Mixer (IFM) grids to improve Departure from Nucleate Boiling (DNB) margin, and other mechanical features that improve design margins.

Nuclear design activities in the areas of fuel cycle cost and fuel management were performed in parallel to the fuel assembly design efforts. As the change in reactivity due to the change in the fuel rod diameter influences directly the amount of uranium and related services, the evaluation was performed aiming at having a fuel rod diameter that achieves the cycle requirements with the optimized uranium cost. The optimum fuel rod diameter and supporting mechanical design features were based on these fuel cycle cost and fuel management evaluations.

In designing the advanced 16x16 fuel assembly for high duty conditions key design considerations for the various operational modes (i.e. power uprating, high burnup, long cycles, etc.) must be identified. These design considerations will include the traditional factors such as safety margin (DNB and LOCA), fuel rod design margin (e.g. corrosion, internal pressure, etc.), and mechanical design margins, among others. In addressing these design considerations, the fundamental goal is to provide additional design margin through materials, mechanical, and thermal performance enhancements, to promote flawless fuel performance.

In summary, this paper will show how the joint fuel assembly design and development activities were performed, coupled with extensive core design work and fuel management strategy evaluations, that should lead to significant fuel cycle economic benefits and a superior fuel assembly design.

1 INTRODUCTION

Industrias Nucleares do Brasil (INB), KOREA Nuclear Fuel Company, Limited (KNFC) and Westinghouse Electric Company LLC (Westinghouse) have continued to focus on developing products that will meet the challenge of increasing fuel duty requirements. These higher duty conditions include higher energy core designs through improved plant capacity factors, power uprate, extended fuel burnup, peaking factor increases, and more severe coolant chemistry (including high lithium concentration). INB, KNFC, and Westinghouse have jointly designed an advanced 16x16 Westinghouse type PWR fuel assembly. This advanced 16x16 Westinghouse type PWR fuel assembly, which will be implemented in both Kori Unit 2 (in Korea) and Angra Unit 1 (in Brazil) in January and March 2005, respectively, is an integral part of the utilities' fuel management strategy. This same fuel design has also been developed for future use in Krsko Unit 1 (in Slovenia).

This paper will focus on the front-end nuclear fuel management activities utilized by the joint development team and describe how these activities played an integral part in defining the direction of the advanced 16x16 Westinghouse type PWR fuel assembly design. Additionally, this paper will describe how this design projects improved margins under high duty plant operating conditions.

2 NUCLEAR INDUSTRY TRENDS

Fuel duty is a general term used to describe operating conditions that tend to damage the fuel over time. These operating conditions include heat flux, irradiation exposure, time at temperature, flow induced vibration, sub-cooled nucleate boiling, and coolant chemistry (Reference 1). With the desire to utilize the most economic core designs and to get maximum return from the reactor itself, reactor operators are increasing fuel duty through use of higher energy cores - primarily the result of significantly improved plant capacity factors, power upratings, longer cycle lengths, peaking factor increases, and/or reactor coolant system temperature increases. In the United States, fuel discharge burnup for Westinghouse fuel has increased 35% during the past decade to about 50 MWd/kgU batch average and up to the present licensing limit of 62 MWd/kgU maximum rod average burnup. In Slovenia, batch average burnup has increased to approximately 45 MWd/kgU for Krkso. Similar trends can also be observed in Korea (References 3, 4 and 6) and Brazil. Table 1 shows the current fuel management stragety for the Krsko, Angra-1 and Kori-2 sites. Additionally, Krsko has recently transitioned to 15-month cycles from 12-month cycles and, in the future, will transition to 18-month cycles.

Core reload design and economic analyses show that PWRs can derive significant benefits by increasing burnup of their fuel above the currently licensed values (Reference 2). To protect the reactor coolant system, new chemistry programs are being implemented that expose the fuel to new and possibly more severe coolant chemistry. These operating modes reduce design margin by operation closer to design limits or require new designs that provide additional margin. While today's fuel products can often be pushed into more extreme operational modes by trade offs with operational parameters such as peaking factors, fuel cycle economics are usually impacted. Advanced products under development will provide more design margin, which can be used to maximize fuel cycle economic benefits.

Table 1. Current 16STD Fuel Managament Strategies for Krsko, Angra-1 and Kori-2

Plant	Cycle Length	w/o U^{235}	Batch Avgerage Burn-Up (MWd/kgU)	Feed Region (Number of Fuel Assemblies)	Total Assemblies
Krsko (NEK)	15 Month	5.0	45	32 - 36	121
Angra-1 (INB)	Annual	3.4	32 – 33	40	121
Kori-2 (KNFC)	15 Month	3.8	34 – 35	36 - 40	121

3 ADVANCED PWR DESIGN FOR WESTINGHOUSE 16X16 TYPE PLANTS

The advanced fuel assembly design for the Krsko, Angra-1 and Kori-2 16x16 Westinghouse Type Plants in Slovenia, Brazil and Korea, respectively, had the following program objectives:

- Batch Average burnup greater than 55 MWd/kgU.
- More than 20% increase in DNB Margin over the existing 16x16 Westinghouse Fuel Assembly.
- Grid dynamic buckling strength and dynamic stiffness sufficient to meet LOCA/Seismic-related design criteria.
- Demonstration of compatibility between the advanced 16x16 fuel assembly and the existing Westinghouse 16x16 fuel assemblies in use in the Republic of Slovenia, Brazil and Korea.

The major focus for this joint development program was to update the current 16x16 fuel assembly, which is also called 16x16 Standard (16STD), being utilized at the Krsko, Angra-1 and Kori-2 sites. Basically, the 16STD design contains a non-optimized fuel rod diameter (i.e. 0.374 inch (9.500 mm) OD fuel rods) for the fuel rod pitch, non-neutronic efficient components (i.e. Inconel Mid grids), no Intermediate Flow Mixer (IFM) grids, non-optimized guide thimble tubes (i.e. swaged tube dashpot), and mechanical design features that have not been updated to allow for top-down fuel rod reconstitution (i.e. welded top nozzle to skeleton) for 16STD fuel currently used in Korea and Brazil.

The main reason for the design change from 16STD to the proposed next generation fuel assembly is to update the 16x16 design to current Westinghouse technology. As such, the advanced 16x16 fuel assembly, more commonly refered to as the 16x16 Next Generation Fuel (16NGF) assembly, will be designed for peak rod average burnups of up to 75 MWd/kgU and will use an optimized fuel rod diameter (i.e. 0.360 inch (9.144 mm) OD ZIRLO™ fuel rods), neutronic efficient components (i.e. ZIRLO™ Mid grids), ZIRLO™ Intermediate Flow Mixer (IFM) grids to improve Departure from Nuclear Boiling (DNB) margin, optimized ZIRLO™ guide thimble tubes (i.e. tube-in-tube dashpot) from an Incomplete Rod Insertion (IRI) standpoint, debris filter bottom nozzle and Protective Grid (P-Grid) to enhance debris filtering and capturing efficiency, and updated mechanical design features that allow for top-down fuel rod reconstitution (i.e. removable top nozzle).

The 16NGF assembly is a modification of the 16STD design. The principal changes were made to the fuel rod diameter, middle structural grids, intermediate flow mixing grids and the guide thimble/instrumentation tubes. The features of the 16NGF assembly designs include:

- Fuel Rod Diameter Optimization
- Annular Axial Blankets
- ZIRLO™ Enhanced Structural Middle Grids
- ZIRLO™ Enhanced Intermediate Flow Mixing (IFM) grids
- Removable Top Nozzle
- Debris Filter Bottom Nozzle
- Reduced Rod Bow Inconel Top Grid
- High Burnup Inconel Bottom Grid
- Inconel Protective Bottom Grid
- Tube-in-Tube Thicker Guide Thimble Tubes

It should be noted that the 16STD used in KRSKO employs some the advanced features used in the 16NGF design. These features include ZIRLO™ fuel rods and guide thimbles, removable top nozzle, debris filter bottom nozzle and annular axial blankets. As shown in Table 1, the use of these features allows the 16STD for Krsko to acheive a higher batch average burn-up and longer cycle lengths compared to Angra-1 and/or Kori-2.

The main benefit of each of these features are shown in Table 2.

Table 2. Main Benefit of 16x16 Advanced Fuel Assembly Design Features

Item	Current Design 16STD Angra-1 and Kori-2	Current Design 16STD Krsko	16NGF	Enhancement/Benefit
Fuel Rod	**Zirc-4**	**ZIRLO™ Axial Blanket**	**ZIRLO™ Clad Optimized Rod Diameter Axial Blanket (Optional)**	**High Burnup (>70 GWD/MTU) Neutron Economy**
Mid & IFM Grid	**Inconel Mid Grid No IFMs**	**Inconel Mid Grid No IFMs**	**ZIRLO™ Mid Grid New Spring/Dimple Optimized Mixing Vane Enhanced IFMs**	**Neutron Economy Fretting Wear Resistance DNB Margin(>20%)**
Guide Thimble	**Zirc-4 Swaged Dashpot**	**ZIRLO™ Swaged Dashpot**	**ZIRLO™ Tube-in-Tube**	**Resistant to Bowing**
Top Nozzle	**Welded to Skeleton**	**Removable Top Nozzle (RTN)**	**Modified Integral Clamp Top Nozzle (ICTN) with RTN**	**Spring Screw Failure Free Reconstitutible**
Bottom Nozzle	**Debris Filter Botton Nozzle (DFBN) / Standard**	**DFBN**	**DFBN**	**Debris Filtering**
Protective Grid	**None**	**None**	**Protective Grid**	
End Plug	**Standard End Plug**	**Standard End Plug**	**Long Solid End Plug**	

3.1 Optimized Fuel Rod Diameter

A detailed fuel rod optimization program was undertaken as a part of the 16NGF program (Reference 5). The current 16STD design has a less-than-optimal neutronic design with respect to neutronic and burnup considerations due to a relatively low Hydrogen/Uranium ratio (H/U ratio). The low H/U ratio results in a harder neutron spectrum that is more compatible with plutonium recycling than the once-through fuel cycle that is the current fuel cycle requirement in Slovenia, Brazil and Korea. The low H/U ratio also has the effect of reducing the bundle reactivity relative to a bundle optimized for a once-through fuel cycle. For 16NGF, the Fuel Rod Diameter Optimization study analyzed a reduction in fuel rod diameter, keeping the same rod pitch for geometric compatibility reasons. By increasing the H/U ratio it is possible to obtain a net gain in reactivity due to higher moderation, leading to a stronger neutron thermalization. Notwithstanding the superior neutronic results, the optimized fuel rod diameter must also satisfy reactor safety requirements. The trend of the nuclear industry is to extend the cycle length and increase enrichment by using advanced fuel designs as discussed in Section 2. It must be emphasized that this design change gives rise to economical advantages, for example, reduced costs for uranium utilization and enrichment with a net gain in reactivity. When combined with the balance of the 16NGF changes, the 16NGF bundle also increases thermal margin and operating margins.

The reference Fuel Rod Outside Diameter (FROD) for the 16STD-fuel assembly by Westinghouse is 0.374 inch (9.500 mm). To determine the optimized FROD for the 16NGF, it was proposed to make a systematic perturbation on the values of the FROD. The lowermost reload cost for the same cycle length was the goal for the FROD, which complies with the economic optimization requirements. The following fuel rod diameters were selected for evaluation: 0.335, 0.345, 0.350, 0.356, 0.360, 0.364 inch (8.509, 8.763, 8.890, 9.042, 9.144, 9.246 mm) and the current product FROD, 0.374 inch (9.500 mm) as the reference case.

Two parallel studies were conducted, one for 48 Feed Assemblies and 430 EFPD (16 month fuel management scheme), and the other for 40 Feed Assemblies (FA) and 340 EFPD (annual cycle fuel management scheme). Self-generating core models with equilibrium cycles for 430 and 340 EFPD and reload batches of 48 and 40 FA, respectively, were calculated in order to obtain the reload cost of each case. Using a fixed cost economic model, the total reload fuel cost will be driven by Total U-loading (decreases with decreasing pellet OD), and U235 enrichment costs (increases with decreasing pellet resulting from the increased mid-zone enrichment to maintain fixed energy output). Other associated costs with the fuel assembly manufacture were fixed. The results of the economic analysis of the fuel rod diameter optimization study are presented in Table 3.

Table 3. Reloads Cost for each Fuel Rod Outside Diameter (Refernce 5)

Fuel Rod Diameter	**Relative Reload Cost**	
	48 FA – 430 EFPD	**40 FA – 340 EFPD**
0.374 inch (9.500 mm)	1.000 (reference)	1.000 (reference)
0.364 inch (9.246 mm)	0.969	0.969
0.360 inch (9.144 mm)	0.961	0.959
0.356 inch (9.042 mm)	0.955	0.953
0.350 inch (8.890 mm)	0.950	0.947
0.345 inch (8.763 mm)	0.951	0.947
0.335 inch (8.509 mm)	0.958	0.956

Figures 1 and Figure 2 summarize the economic approach for 430 and 340 EFPD and reload batch of 48 and 40 FA, respectively.

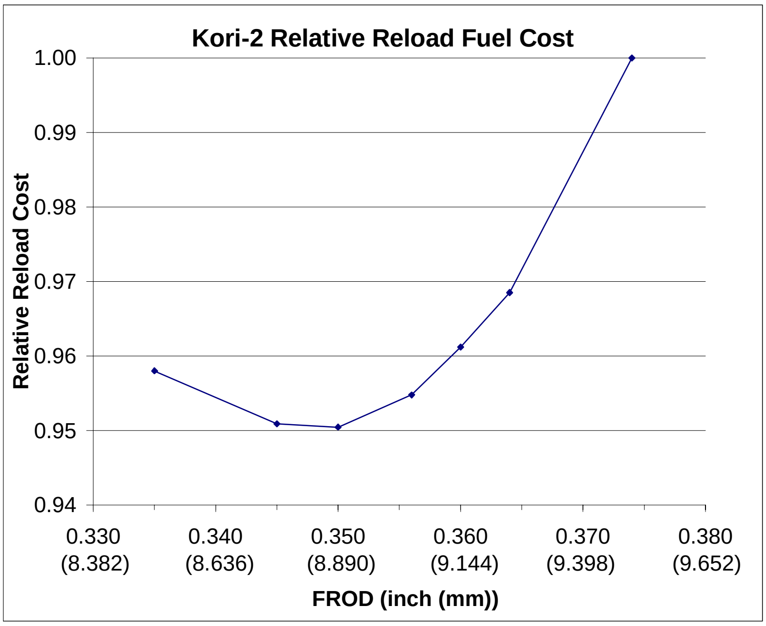

Figure 1. Relative Reload Uranium Cost for 430 EFPD and Reload Batch of 48 FA (Reference 5)

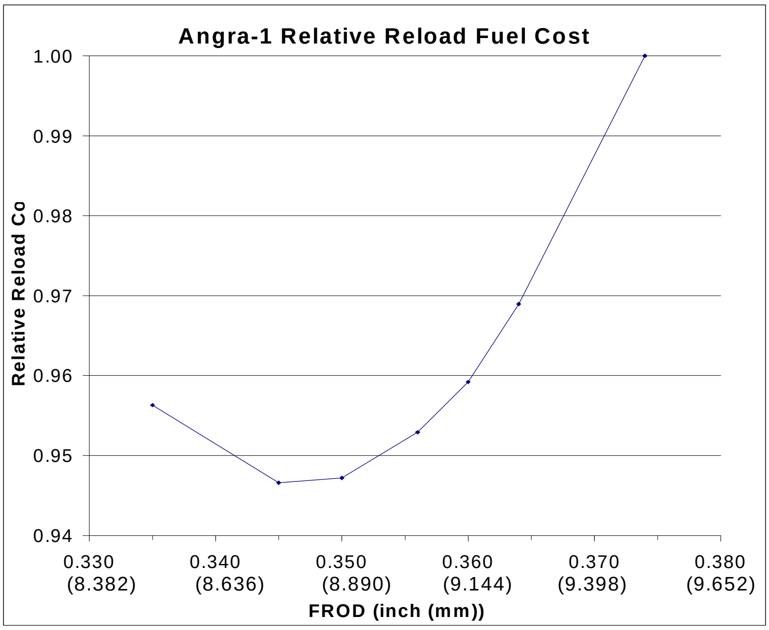

Figure 2. Relative Reload Uranium Cost for 340 EFPD and Reload Batch of 40 FA (Reference 5)

Two analyses were initially carried out in order to select the optimum FROD. In the first one, as mentioned above, the cost optimization as well as the nuclear reactivity was considered. In that scenario the 0.350 inch (8.890 mm) FROD seems to be the optimized one. In addition, the analysis also considered the fuel cycle management point of view. In this analysis, FROD less than 0.360 inch (9.144 mm) was shown to be undesirable for a cycle length longer than 18 month resulting from the fact that the U^{235} w/o enrichment approaches the upper bound licensing limit.

Figure 3 summarizes the fuel cycle management approach for Numbers of Feed Assemblies versus EFPD for reloads batches of 40, 44, 48, and 52 FA. All the cases considered 5 w/o U^{235} enrichment. Note, Krsko has recently transitioned to a 15-month cycle length and, in the future, will transition to an 18-month cycle length.

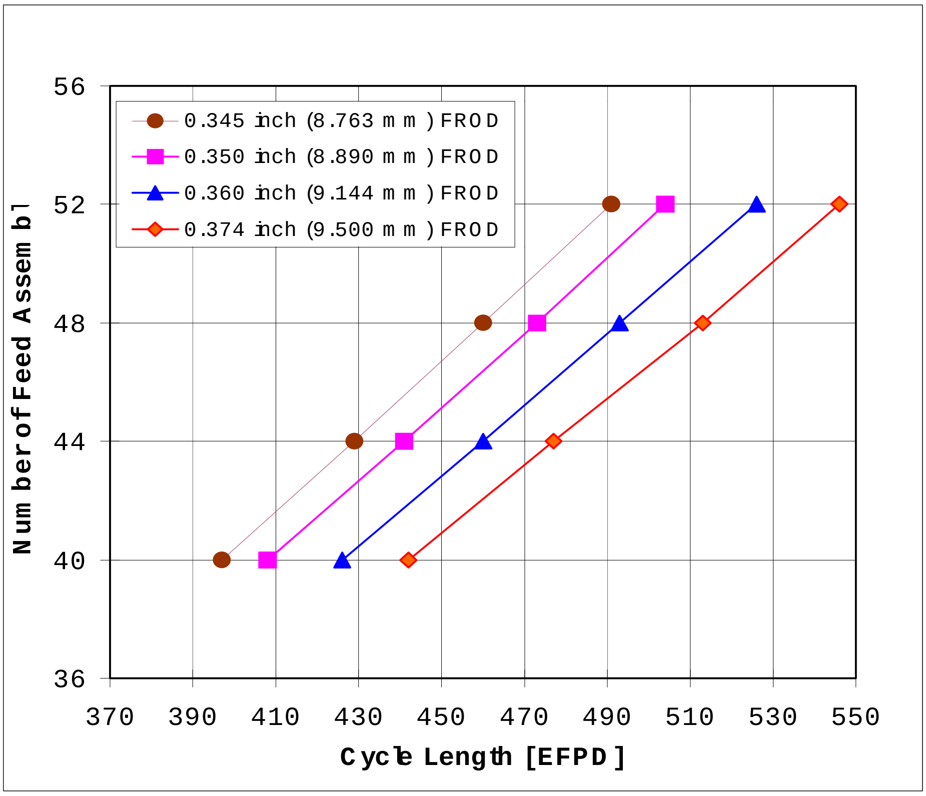

Figure 3. Fuel Cycle Management Approach for Numbers of Feed Assemblies versus EFPD for Reload Batches of 40, 44, 48, and 52 FAs (Reference 5)

The design objective of 16NGF regarding the FROD is to select the diameter that gives the best neutron economy for a fixed energy output based on the current and projected fuel management schemes for the 16x16 lattice.. As a consequence the rod diameter selected would meet the lowest fuel assembly cost which takes into account total uranium and U^{235} enrichment requirements. In conclusion, due to the customer's requirement for longer cycles and the upper limit that exists in the enrichment to be used in Kori 2, Angra 1 and KRSKO, as well as Westinghouse previous experience, the FROD of 0.360 inch (9.144 mm) was considered as optimized. Based on the past 10 years experience with FROD 0.360 inch (9.144 mm) used in 17x17 Westinghouse optimized PWR type designs, the 16NGF FROD should not be less than 0.360 inch (9.144 mm).

Furthermore, with this extensive experience of Westinghouse in the use of this OD in similar reactors, it will be possible to take advantage of similar results from the safety analysis carried out by Westinghouse for this fuel rod diameter in other reactors. Therefore, since 0.360 inch (9.144 mm) is very close to the optimized diameter, this one was selected as the optimized one for use in Krsko, Angra-1 and Kori-2. Additional consideration would be the increased DNB penalty for a rod thinner than 0.360 inch (9.144 mm) as described in Section 3.4.

3.2 High Burnup Capability

A higher discharge burnup means better uranium utilization, reducing the uranium requirements and the amount of fuel assemblies disposed during the utility life. The peak rod burnup up to 75 GWd/MTU and region batch burnup up to 55 GWd/MTU are the targets for the 16NGF fuel. In this new design, many features are implemented to reach this goal.

An important feature is the use of ZIRLO™ cladding tubes for the fuel. ZIRLO™ features a balanced combination of good corrosion performance, superior mechanical properties, and dimensional stability. ZIRLO™ is resistant against operation with high lithium in the coolant, as well as abnormal coolant chemistry conditions, and has characteristics compatible with long term spent fuel storage. The excellent performance and robustness of ZIRLO™ has been proven over 15 years of experience. More than 2.5 million rods have been irradiated in 48 commercial power reactors, up to over 70 MWd/kgU. Hence, ZIRLO™ is the advanced cladding of choice for high duty operation, including uprating, extended burnup, longer cycles, and modern coolant chemistries.

All the mechanical components are designed taking in account the higher fluence that will be achieved. In addition, the fuel rods have to accommodate more gaseous fission products that are released to the plenum region.

3.3 Low Parasitic Neutron Absorption Using ZIRLO™ Mid and IFM Grids

The 16NGF design uses ZIRLO™ instead of Inconel in the grids in the active length of the fuel (Mid Grids and IFM Grids). This is to take advantage of the lower neutron absorption in the ZIRLO™ material, leading to a reduction in the fuel cycle cost (Reference 5).

Two core models were evaluated to quantify the benefit of using ZIRLO™. One used Mid Grids made of ZIRLO™ and the other Inconel. Both cases considered full core with 16NGF at equilibrium cycle and cycle length fixed in 444 EFPD. The result showed an economic benefit of 1.6% using ZIRLO™ (see Table 4).

Table 4. Fuel Cycle Cost for Core Models using Inconel and ZIRLO™ Mid Grids (Reference 5)

Core Models (Case)	Mid Grid Material	**Mid-zone FA U^{235} Enrichment (w/o)**	Relative Fuel Cycle Cost
1	Inconel	4.664	1.000
2	ZIRLO™	4.600	0.984

Table 5 gives a brief description of the grids in the 16NGF and 16STD designs.

Table 5. 16NGF and 16STD Grids Types (Reference 5)

Grid Type	**16NGF**	**16STD**
	Material	**Material**
Top Grid	Inconel	Inconel
Mid Grid	ZIRLO™	Inconel
IFM Grid	ZIRLO™	---
Bottom Grid	Inconel	Inconel
Protective Grid	Inconel	---

3.4 Improved Thermal Margin

In support of obtaining the maximum thermal margin with the 16NGF fuel assembly design, the following information shows the reasons for choosing the 16NGF Mid and IFM grid vane patterns, the 16NGF Mid and IFM grid vane shapes, and the number of IFM's to be added. Consideration was given for the Mid / IFM grid vane patterns to minimize both fuel assembly and fuel rod vibration. Also consideration was given for the Mid / IFM grid vane features for improved flow mixing and resultant improved DNB margin.

One of the goals of the 16NGF program is to increase DNB performance by 20% over 16STD (10% in power). Adding IFM's improves DNB performance by approximately 20% due to the increase in turbulence and mixing based on tests with other designs. Conversely, reducing the rod diameter penalizes DNB performance since there is less heat transfer surface area available for the same power. For example, a reduction from 0.374 to 0.360 inch (9.500 to 9.144 mm) decreases DNB performance by about 8%. Therefore, the net DNB benefit in this example would be 20-8 = 12%. To meet the program objective of 20% DNB margin benefit, mid-grid design optimization was performed to increase DNB performance. Therefore, the effect of the grid design on DNB margin should also be taken into account. This effect is called "grid benefit".

The design of the 16NGF mid-grid is employing the latest Westinghouse DNB-improvement technology and lessons learned from the previous development efforts. Based on experience the optimized grid benefit ranged from 8 to 10%. In the case of the 16NGF design, this 8-10% grid benefit should offset the 8% rod diameter penalty for reducing the fuel rod diameter. Therefore, the preliminary best estimate of the DNB performance improvement for 16NGF is approximately 20-22%. These estimates are based on Westinghouse experience with currently available DNB test data. Taking this uncertainty into account, it can be concluded that a DNB margin gain of at least 20% is likely achievable through:

- The addition of IFM's.
- Appropriate mid-grid design modifications based on Westinghouse experience.

The addition of IFM grids also has the benefit of reducing the sub-cooled nucleate boiling rates in the highest powered assemblies. Since sub-cooled boiling promotes crud deposition, the addition of IFM grids will result in less buildup of crud (iron, nickel, and chromium based corrosion products released from reactor coolant system surfaces) on the fuel. Reducing the fuel crud deposition will also reduce the activation of the corrosion products and reduce radiation fields caused by transport of the activated products to other areas of the plant.

3.5 Burnable Absorber Flexibility

Burnable absorbers (BA) are neutron-absorbing materials used to compensate the excess of reactivity in the beginning of cycle and to control power peaking. To comply with the technical specification limit for MTC, the use of BA allows the reduction in soluble boron concentration needed to provide enough reactivity hold down during cycle length. Two BA types, Gadolinia, and ZrB_2 IFBA, were given the primary focus in 16NGF program. A third BA type of Wet Annular Burnable Absorber (WABA) was also considered. ZrB_2 IFBA (with annular axial blanket pellets) is curently in use by NEK for Krsko, while Gadolinium is the primary BA for consideration for the INB and KNFC designs.

4 SUMMARY AND CONCLUSIONS

During the recent years Westinghouse has improved the fuel design aiming at incorporating the design improvements that will assure a better fuel performance from an economic and safety standpoint. The front-end nuclear fuel management activities utilized by the joint development team have been presented to describe how these activities played an integral part in defining the direction of the fuel assembly design.

The 16NGF fuel team proposed to analyze all the design features already implemented and tested in different Westinghouse fuel designs and to implement those most adequate for complying with the customer design requirements (Reference 5). That was not an easy task taking into account that there are three customers to be satisfied at same time. The major improvements that give direct impact in the fuel costs can be summarized as:

- Fuel rod diameter optimization –the major task as reported in this paper. It contributes within 4 to 5% savings in the overall reload cost. Some side benefits can be achieved in the back end costs due to the use of less uranium for the same cycle length. Savings in the natural uranium consumption have not been analyzed despite being expected.
- The savings due to the use of ZIRLO™ mid grids when compared with the Inconel mid grids of the 16STD was estimated to be 1.6% in the fuel cycle costs. That evaluation took also into account the impact in the enrichment and uranium reload costs.
- The use of an optimized axial blanket could add to this economic saving evaluation an extra 1.8% in the reload cost when compared with the 16STD without this feature.
- The increase in F-delta-H due to the increase in the overpower margin, expected to be more than 10%, will provide enough flexibility for carrying out more aggressive loading pattern which certainly will give rise to a better efficiency in the use of uranium.

Besides the above, the design improvements aim is to produce flawless fuel, with better performance than the current design capable of achieving burnup up to 75 GWD/MTU.

INB, KNFC and Westinghouse have continued to focus on jointly developing advanced PWR fuel assembly products that will meet the challenge of increasing fuel duty requirements in Slovenia, Brazil and Korea. An advanced next generation fuel has been developed that will meet the future fuel duty challenges of 16x16 Westinghouse type plants. This advanced fuel design for Slovenia, Brazil and Korea utilizes proven advanced design features including mixing vane spacer grids to increase thermal performance, advanced high burnup ZIRLO™ materials to enable high-duty, high burnup fuel management, and improved fuel cycle cost.

The 16x16 next generation PWR fuel assembly development programs were truly an international effort with design, testing, process development, manufacturing and qualification activities occurring in as many as eight different locations simultaneously in Brazil, Korea, and the United States. The 16x16 next generation PWR fuel assembly design effort was collaborative between INB, KNFC and Westinghouse engineers. The result of these development programs have demonstrated that each of the design objectives has been either entirely met or exceeded as demonstrated using either INB- and/or KNFC-manufactured test assemblies. The in-reactor performance of the 16x16 next generation fuel assemblies will be confirmed using Lead Test Assembly (LTA) programs in Kori Unit 2 and Angra Unit 1 (for 16x16 LTA fuel).

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