INTRODUCTION OF ZIRLO™ AS A STRUCTURAL COMPONENT MATERIAL IN PWR FUEL

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INTRODUCTION

The current nuclear fuel operating conditions are more and more severe. Features like higher discharge burnups, higher peaking factors, longer fuel cycles as well as elevated lithium concentrations and increased coolant temperatures, have turned corrosion and irradiation growth into one of the most limiting factors for the Zircaloy-4 fuel cladding. Such increases in fuel duty has necessitated the use of advanced alloys like ZIRLO™ (*).

There are many reasons why ZIRLO™ fuel is so successful. Mainly, ZIRLO™ fuel exhibits excellent corrosion behavior in the most severe scenarios. ZIRLO™ also has improved dimensional stability over that of Zircaloy-4 due to lower irradiation growth and creep while keeping all other physical properties the same.

The improvement in properties of ZIRLO™ as compared to Zircaloy-4 is also applicable to the fuel assembly structural components (guide thimbles, instrument tubes, and grids) where dimensional stability is critical to maintain control rod insertion and to minimize grid-to-grid interaction.

The object of this paper is to present the current operating experience with ZIRLO™ as structural material in PWR fuel assemblies, to highlight its advantages in comparison to Zircaloy-4 and to add specific information about the irradiation and verification programs that either support these advantages or will further help to validate the existing information.

ZIRLO™ OPERATING EXPERIENCE

ZIRLO™ is a zirconium- based alloy with 1.0 % niobium, 1.0 % tin, and 0.1 % iron, and was developed as a fuel rod cladding material by Westinghouse in the mid 1970's (1). Since that time there have been numerous irradiation programs with ZIRLO™ clad demonstration assemblies and full core reloads of all ZIRLO™ fuel (clad, guide thimbles, instrument tubes and grids) such that the irradiation experience of ZIRLO™ fuel today is quite extensive (2, 3, 4, 5).

ZIRLO™ fuel in demonstration programs has been irradiated for up to three 18 month cycles in high temperature, high lithium coolant to assembly average burnups up to 62 GWD/MTU in several 17x17 PWR plants. ZIRLO™ reload fuel has also been irradiated to date for up to three 18 month cycles in similar operating conditions to region average assembly burnups of 52 GWD/MTU and climbing. ZIRLO™ was fist introduced in Spain in two different demonstration programs in Almaraz II and Vandellós II in the years 1991 and 1994 respectively and, as of March 1997, this ZIRLO™ fuel has operated successfully for assembly average burnups up to 48 GWD/MTU. So successful is the ZIRLO™ fuel that it is soon to be considered the standard cladding for 17x17 PWR fuel design supplied for the Spanish nuclear power plants.

Westinghouse began introducing reload regions of ZIRLO™ fuel in 1991. As the PWR utilities increased fuel duties with higher lithium concentrations, higher coolant temperatures and longer fuel cycles, the percentage of ZIRLO™ fuel delivered to utilities has increased relative to Zircaloy-4 fuel.

Table 1 presents information on the fuel delivered by Westinghouse through December 31, 1997; while Table 2 shows the committed Westinghouse reloads as of January 1, 1998.

From these tables it can be observed that for a total of 3622 fuel assemblies with ZIRLO™ cladding delivered before the end of 1997, approximately 90 % included ZIRLO™ guide thimbles and instrument tubes, and approximately 67 % incorporated also ZIRLO™ structural mid grids. This trend changes in 1998 increasing to 100% of the 16785 delivered assemblies with ZIRLO™ guide thimbles and instrument tubes, and to more than 91% of the delivered assemblies with ZIRLO™ structural mid grids.

In the case of the Spanish plants, as the Spanish utilities also push to higher lithium concentrations, higher coolant temperatures and longer fuel cycles, the percent ZIRLO™ fuel as compared to Zircaloy-4 fuel has also continued to increase. The incorporation of ZIRLO™ as both cladding and structural material is evidenced from the delivered and committed reloads for ENUSA. As can be seen in Table 3, a similar trend as indicated above is observed for Spanish Plants.

As evidenced by the trends for more ZIRLO™ fuel being delivered each year, the commitment to meet the operating needs of the utility customer is achieved with the incorporation of ZIRLO™ fuel.

ZIRLO™ ADVANTAGES AS STRUCTURAL COMPONENT MATERIAL COMPARED TO ZIRCALOY-4

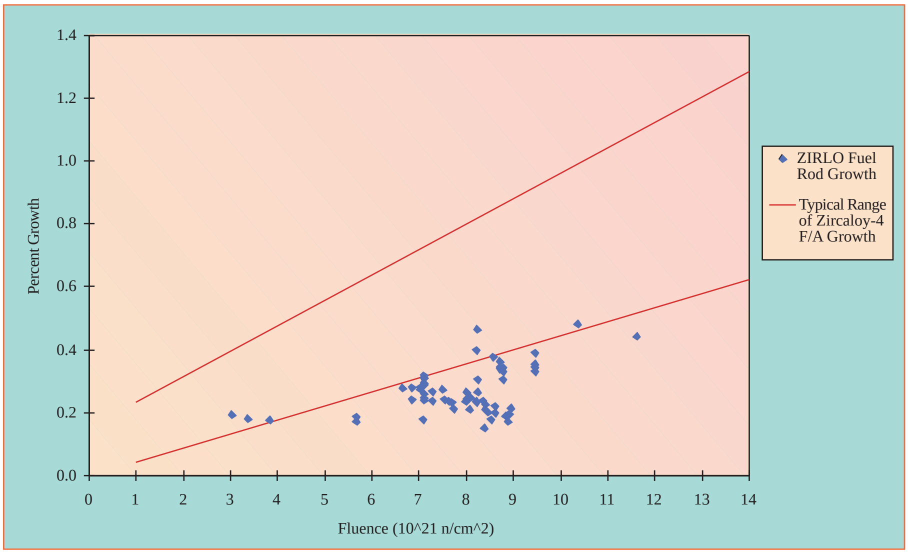
The reason why ZIRLO™ fuel continues to meet the customer needs for structural components for plants that operate with higher lithium concentrations, higher coolant temperatures and longer fuel cycles, is based on the improved dimensional stability of ZIRLO™ over that of Zircaloy-4.

The key properties that provide ZIRLO™ materials with irradiation performance improved to Zircaloy-4 materials are reduced irradiation growth, reduced irradiation creep, and reduced corrosion. In addition, the enhanced dimensional stability of ZIRLO™ material helps mitigate growth and creep related phenomena like incomplete control rod insertion and grid-to-grid interaction.

TABLE 1- Fuel delivered by Westinghouse using Zirlo™ as of december 31, 1997

COMPONENT	NUMBER OF PLANTS	NUMBER OF FUEL ASSEMBLIES	NUMBER OF REGIONS
CLADDING	32	3622	59
GUIDE THIMBLES	28	3279	53
GRIDS	23	2443	38

(*) ZIRLO™ is a registered trademark of Westinghouse Electric Company.



F I- ZIRLO Fuel Rod Growth

• Growth performance of Zirlo™ structures

Cold Worked Stress Relief Annealed (CWSRA) material is used in fuel rod cladding because of its inherent high strength, and Recrystallize Annealed (or RXA) material is used for structural components because of its lower in-pile growth than CWSRA material.

As can be seen in Figure 1, CWSRA ZIRLO™ provides 50% lower growth than CWSRA Zircaloy-4. Also, as can be seen in Figure 2, RXA ZIRLO™ provides a further reduction in growth.

As can be seen by Figures 1 and 2, ZIRLO™ material has improved growth resistance over that of Zircaloy-4 whether in either the CWSRA condition as a fuel rod or in the RXA condition as a structural component (guide thimble or grid).

• Creep performance Zirlo™ structures

Recrystallize Annealed (or RXA) material is also used for structural components because of its lower thermal and irradiation creep than CWSRA material.

The out-of-pile and in-reactor creep of ZIRLO™ guide thimble tubes has been measured, and the data continues to show the dimensional stability of ZIRLO™ materials over that of Zircaloy-4 material. This is supported by Table 4 that shows the thermal creep results obtained from both biaxial and uniaxial tests performed on ZIRLO™ guide thimble tubes. From these results, it can be seen that the thermal creep is at least 50 % lower in RXA ZIRLO™ material than in RXA Zircaloy-4 material.

The out-of-pile data is well supported by in-reactor data. For example, data collected on ZIRLO™ guide thimble and instrument tubes at assembly average discharge burnups of 51 GWD/MTU, have demonstrated that the irradiation creep of ZIRLO™ material is 50% that of the irradiation creep of Zircaloy-4. As can be seen in Figure 3, the trend of lower creep in fuel rods for ZIRLO™ versus Zircaloy-4 is also apparent.

• Corrosion performance of Zirlo™ structures

The corrosion behavior of ZIRLO™ structural components has been measured on fuel assemblies that have reached average assembly burnups for ZIRLO™ of up to 50 GWD/MTU. Figure 4 shows a comparison chart for in-reactor corrosion thickness of different structural component materials versus operating temperature. It can be observed that the corrosion thickness for ZIRLO™ is well below the Zircaloy-4 corrosion thickness data. In addition, because RXA ZIRLO™ has a lower corrosion oxide thickness than Zircaloy-4, the in-pile hydriding levels will be correspondingly lower.

SUPPORT AND VERIFICATION PROGRAMS TO DEMONSTRATE THE ZIRLO™ IMPROVED BEHAVIOR

The existing ZIRLOTM operating experience as structural material can be summarized in the following sections.

• Irradiation programs where behavior of Zirlo™ structural components have been characterized

Those Programs where the structural ZIRLOTM outstanding performance has been characterized to date are the following:

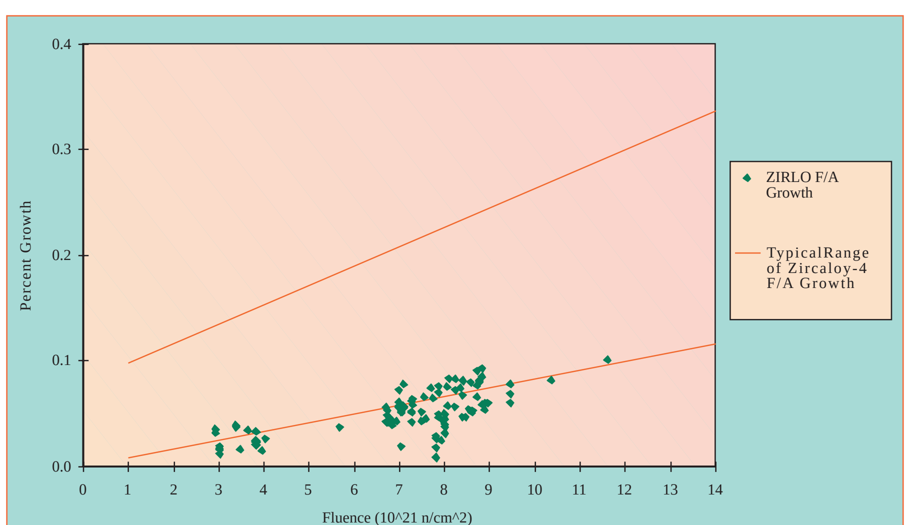
Growth of ZIRLO™ Guide Thimble tubes with assembly average burnups up to 62 GWD/MTU.

- Growth of ZIRLO™ Instrument tubes with assembly average burnups up to 51 GWD/MTU.
- Growth of ZIRLO™ Grids with assembly average burnups up to 50 GWD/MTU.
- Creep of ZIRLO™ Guide Thimble tubes with assembly average burnups up to 51 GWD/MTU.
- Corrosion of ZIRLO™ Guide Thimble tubes with assembly average burnups up to 51 GWD/MTU.
- Corrosion of ZIRLO™ grids with assembly

TABLE 2- Westinghouse committed Zirlo™ reloads after january 1, 1998

COMPONENT	NUMBER OF PLANTS	NUMBER OF FUEL ASSEMBLIES	NUMBER OF REGIONS
CLADDING	46	16785	242
GUIDE THIMBLES	46	16785	242
GRIDS	41	15416	222

F II- ZIRLO Fuel Assembly Growth



F III- FUEL ROD PROFILOMETRY DATA. Average Creepdown - One Cycle Burnup Rods

TABLE 3- Fuel delivered (D)/ Committed (C) by ENUSA is Spain using Zirlo™

COMPONENT	NUMBER OF PLANTS		NUMBER OF FUEL ASSEMBLIES		NUMBER OF REGIONS	
	(R)	(C)	(R)	(C)	(R)	(C)
CLADDING	7	5	381	248	7	5
GUIDE THIMBLES	2	3	106	180	3	3
GRIDS	1	2	2	124	1	2

TABLE 4- Out-of-pile thermal creep of Zirlo™ versus Zircaloy-4

MATERIAL	STRESS (KSI)	TEMPERATURE (ºF)	CREEP RATE (%/100 h)
ZR4 RXA	15.6 (Biaxial)	725	0.06
Zirlo™ RXA	15.6 (Biaxial)	725	0.03
ZR4 RXA	25.0 (Uniaxial)	625	0.87
Zirlo™ RXA	25.0 (Uniaxial)	625	0.20

average burnups up to 50 GWD/MTU.

• Ongoing irradiation programs where behavior of Zirlo™ structural components will be characterized

Those Programs where the structural ZIRLOTM outstanding performance will continue to be characterized are the following:

- Corrosion of ZIRLOTM Guide Thimble tubes with assembly average burnups up to 62 GWD/MTU.
- Corrosion of ZIRLOTM Grids with assembly averages up to 58 GWD/MTU.
- Hot Cell Characterization of a full ZIRLOTM Skeleton (Grids and Guide Thimbles) with an assembly average burnup of 50 GWD/MTU.

SUMMARY AND CONCLUSIONS

The increasingly restrictive operating conditions make necessary going to optimized alloys in order to fulfill the design requirement with enough margins.

ZIRLO™ has been chosen as the most adequate structural material in the PWR fuel because of its lower irradiation growth, lower irradiation creep, and lower corrosion film thicknesses than Zircaloy-4. These properties provide an outstanding in pile dimensional stability and, hence, a highly satisfactory response to the current incidents of incomplete control rod insertion or grid interaction.

These outstanding properties are well supported by the irradiation programs where structural ZIRLO™ behavior has been characterized. In addition, there are other verification programs where the differences between ZIRLO™ and Zircaloy-4 will be further quantified.

The use of ZIRLO™ as structural PWR material follows an increasingly higher trend which is above 91 % of the PWR fuel assemblies supplied by Westinghouse from January 1998. In Spain the trend is similar with two reloads being delivered with ZIRLO (clad, guide thimbles, instrument tubes and mid grids) in the first half of 1999 for Almaraz I and Ascó II nuclear power plants.

Because of the improved dimensional stability of ZIRLO™ structural component material over that of Zircaloy-4 structural component material, it can be concluded that ZIRLO™ is the alloy that will continue to meet both current and future PWR operating conditions of higher discharge burnups, higher peaking factors, longer fuel cycles, elevated lithium concentrations and increased coolant temperatures.

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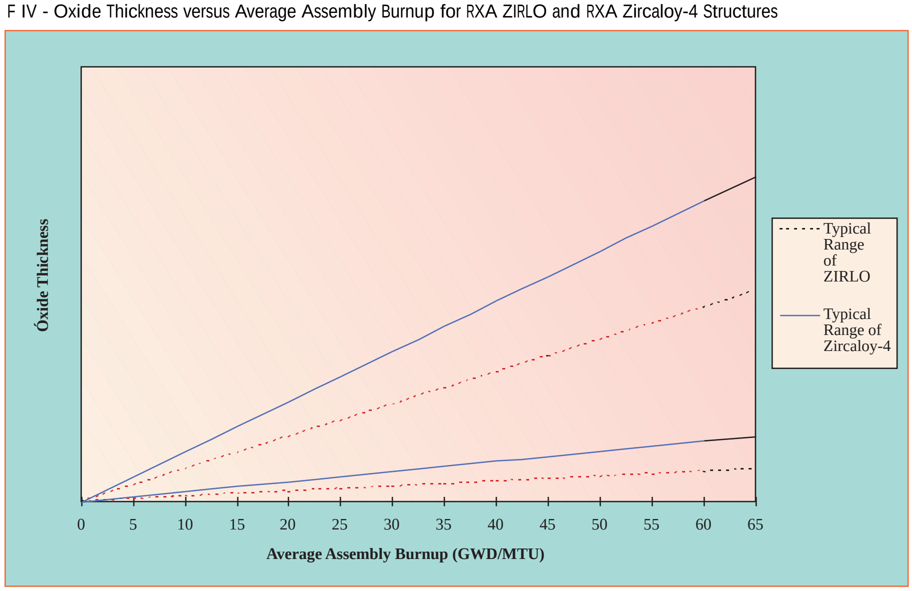
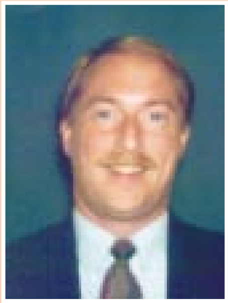
F IV - Oxide Thickness versus Average Assembly Burnup for RXA ZIRLO and RXA Zircaloy-4 Structures





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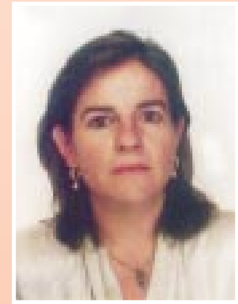

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