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SELECTION AND DEVELOPMENT OF ADVANCED NUCLEAR FUEL PRODUCTS

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ABSTRACT

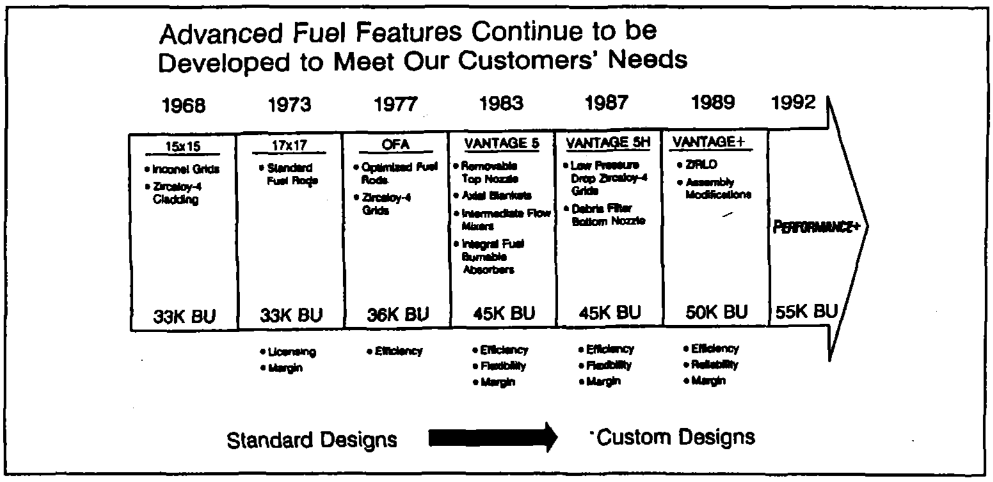
The highly competitive international marketplace requires a continuing product development commitment, short development cycle times and timely, on-target product development to assure customer satisfaction and continuing business. Westinghouse has maintained its leadership position within the nuclear fuel industry with continuous developments and improvements to fuel assembly materials and design.

This paper presents a discussion of the processes used by Westinghouse in the selection and refinement of advanced concepts for deployment in the highly competitive US and international nuclear fuel fabrication marketplace.

DISCUSSION

The competitive environment for nuclear fuel supply in the Westinghouse NSSS segment has resulted in significant technical and economic advantages to the electric utility industry and their respective

Figure 1
Westinghouse Fuel Product Development

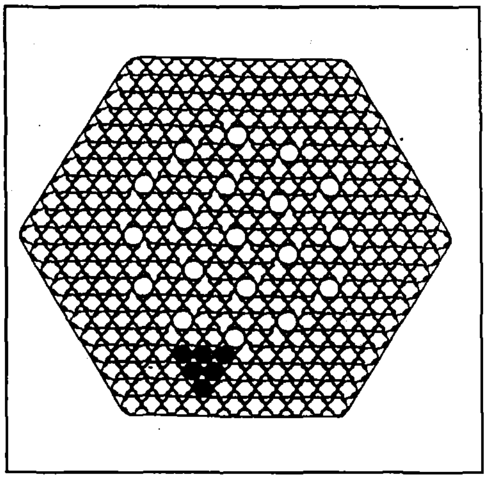


ratepayers. Advanced product development has been a continuous process at Westinghouse responding to the electric utility's needs for improved fuel cycle cost, zero-defect reliability, extended cycle lengths and ultra-high discharge burnup. Figure 1 illustrates the continuous fuel product development at Westinghouse since the early 1970s.

One of the most powerful influences in new product development at Westinghouse is a formal process of customer communication. These processes include both the Westinghouse Fuel Users Group (FUG) for fuel products and the Westinghouse Technology Users Group (TUG) for technology products. The FUG meets semiannually and provides feedback on the performance of current products as well as advice and reaction to advanced fuel product concepts. The FUG and TUG are comprised of the users of Westinghouse fuel and technology products throughout the world consisting of both Westinghouse NSSS owners and non-Westinghouse NSSS owners. The non-Westinghouse NSSS include PWRs designed by Asea Brown Boveri-Combustion Engineering (ABB/C-E) and Babcock and Wilcox (B&W). The FUG will also include ČESKE´ ENERGETICKE´ ZÁVODY (CEZ), the newest member of the Westinghouse fuelled PWR's that is building the Temelin VVER-1000. Communication was a critical aspect of receiving the Temelin fuel award and will continue to be crucial in the completion of the design and fabrication of the hexagonal VVER-1000 fuel assembly on the three year schedule of the project. An illustration of the VVANTAGE-6 fuel assembly for the VVER-1000 is presented in Figure 2.

The TUG represents a parallel customer communication pathway to the FUG. Like the FUG, the TUG is an international organization with representation from all continents with nuclear power plants. The TUG provides feedback on the performance of Westinghouse technology products including the most comprehensive core design, thermal hydraulic design, fuel rod design software and training package offered anywhere in the world. The TUG provides a framework for continuous feedback on constantly evolving software technology, such that the end user has access to the most current technology available without the added cost and complication of maintaining methods development, software configuration management, quality assurance and

Figure 2
Westinghouse VVANTAGE-6 Fuel



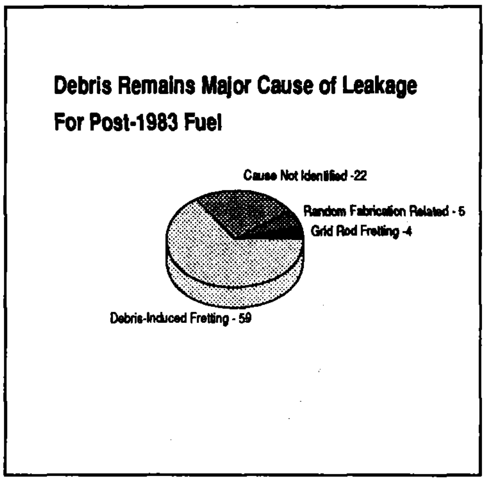
network management personnel on full-time staff.

Electric utility companies are under increasing pressure for more efficient and lower cost operation of power stations in general and nuclear stations in particular throughout the world. The selection and development of advanced nuclear fuel products can have a significant positive impact toward achieving their cost improvement goals. The technology and value-added in nuclear fuel fabrication can significantly reduce not only fuel cycle costs but also operation and maintenance (O&M) costs and radiation exposure to plant personnel (ALARA). Westinghouse has continuously developed advanced fuel products as illustrated in Figure 1. Each aspect of the fuel assembly design has been considered as part of the design optimization process. This development process has resulted in the series of fuel product features starting with standard fuel 15x15 and 17x17 to the current-day PERFORMANCE+ fuel. The transition from the early fuel designs to the most recent has been driven by the customized needs of each electric utility customer and their respective sensitivities -- fuel cycle cost, reliability, thermal margin, operating costs, uranium commodity contractual commitments, replacement power cost, optimal fuel cycle length and discharge burnup as well as many others.

Westinghouse attempts to identify each individual customer need and combine a custom set of fuel design features which best match the set of needs. Throughout this process, close communication with utility engineering and operations staff is maintained by the various Westinghouse engineering disciplines from mechanical, thermal-hydraulic and core design through safety analysis, licensing and plant interface disciplines. The result is a closely-tailored fuel design which reflects the essential needs of the electric utility customer.

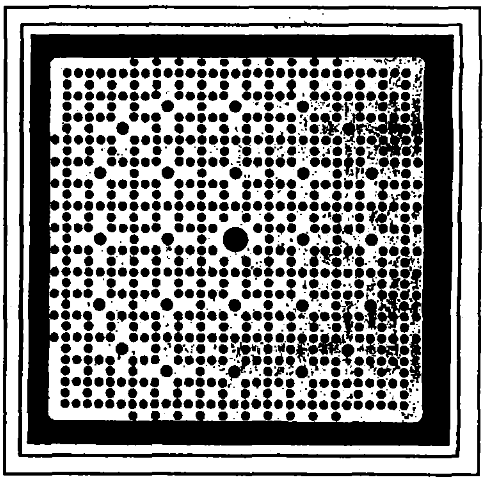
The most powerful driver of electric utility companies of late is reducing O&M costs. This directly leads to a drive for goal of zero-defect fuel performance. The zero-defect fuel performance goal is achieved through the combination of the elimination of manufactured defects and design improvements which essentially eliminate non-manufacturing related fuel leakage. In recent years, the majority of fuel leakage has been due to non-manufacturing related cladding perforation. A breakdown of fuel rod leakage mechanisms for Westinghouse fuel manufactured after 1983 is illustrated in Figure 3 by the number of confirmed leaking fuel rods.

Figure 3
Westinghouse Fuel Leakage Mechanisms



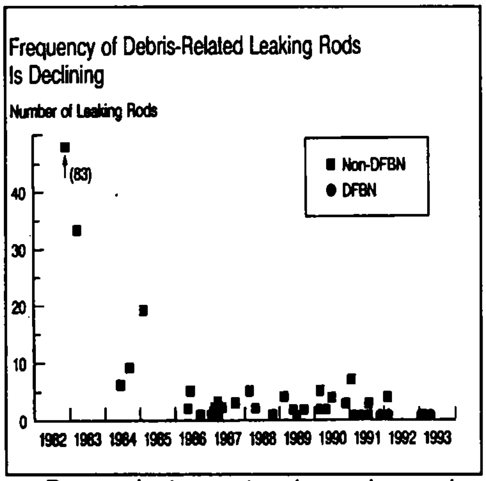
As illustrated, the single largest fuel rod leakage mechanism has been debris-induced fuel rod fretting. The fretting is

Figure 4
Debris Filter Bottom Nozzle



caused by small particles of foreign material in the reactor coolant water which becomes entrained by the coolant flow and trapped in a grid assembly where the high velocity coolant induces vibration, and the debris frets through the fuel rod cladding. Westinghouse has introduced a series of design features specifically aimed at removing debris from the flow stream prior to the debris reaching vulnerable areas of the fuel rod. The first of these features in the Debris Filter Bottom Nozzle (DFBN) illustrated in Figure 4. The DFBN was designed in close consultation with our customers and has dramatically reduced the incidence of fuel rod leakage due to debris-induced fretting as illustrated in Figure 5.

Figure 5
Debris Filter Bottom Nozzle



Power plant operators have also made a significant impact in the occurrence of debris related fuel leakage, due to their increased sensitivity to "good housekeeping" and improved machining operations. With the introduction of PERFORMANCE+ fuel, Westinghouse has extended debris protection to include two additional levels. The first of these PERFORMANCE+ features is the protective grid which is illustrated in Figure 6. The protective grid serves as an efficient sieve for debris particles that penetrate the debris filter bottom nozzle (DFBN). The straps of the protective grid bisect the flow holes of the DFBN to

Figure 6
PERFORMANCE+ Protective Grid

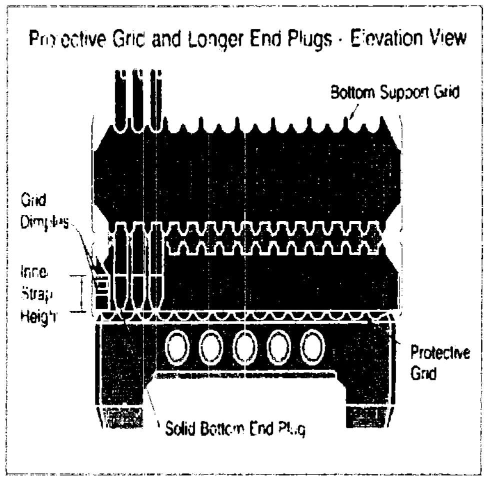
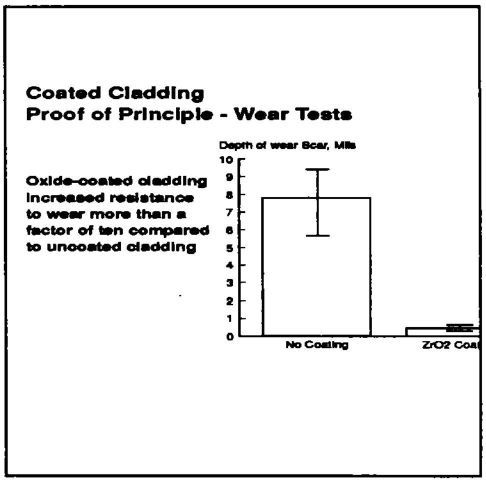


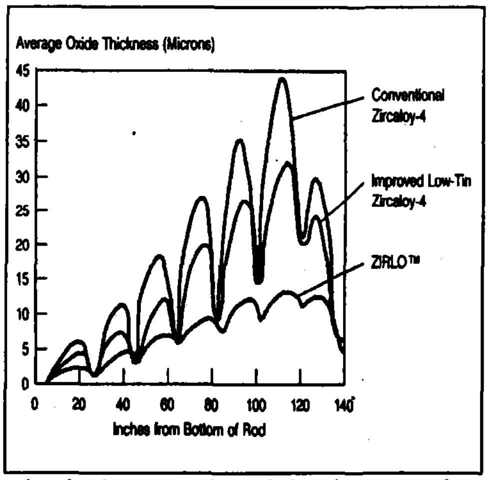
Figure 7
Westinghouse Debris Resistant Cladding Coating



reduce the effective flow area for solid particles and thus, greatly improve the probability of debris entrapment within the protective grid which is located over the solid zircaloy end cap of the fuel rod. The second PERFORMANCE+ feature is the coated cladding. The effectiveness of the coated cladding is illustrated in Figure 7 and compared to uncoated cladding under identical conditions. Both the protective grid and coated cladding were developed using a utility working group in combination with Westinghouse development engineers. The utility working group was an integral part of the development process from start to finish.

Another case study in cooperative fuel design development has been the commercialization of ZIRLO™, the nuclear industry's only new fuel assembly alloy in over thirty years. Westinghouse has been

Figure 8
Two Cycle ZIRLO™ Corrosion Performance



a leader in research and development of new reactor materials initiating the ZIRLO™ development process in the late 1960s. Commercialization of new reactor materials has required significant Westinghouse resources, extensive out-of-pile testing, and test reactor irradiation for over ten years before the opening discussions with commercial power reactor owners were initiated. Westinghouse realized some time ago that the material limitations of Zircaloy-4 were being encroached as evidenced by higher than expected corrosion rates on both fuel rods and structural components. A two phased development process was initiated for both the short and long terms to improve fuel performance an continue to extend fuel discharge burnup capability. The short term process involved the optimization of Zircaloy-4 chemistry and processing such that marginal increases in discharge burnup would continue to be possible. Westinghouse has lead the industry in the introduction of Improved (Low-Tin) Zircaloy-4 with optimization of processing parameters which has allowed discharge burnup to increase to about 48 GWD/MTU with some restrictions still present for plants with core exit temperatures above 315 °C and/or fuel residence time at power/temperature approaching 40,000 hours.

Figure 9
Three Cycle ZIRLO™ Corrosion Performance

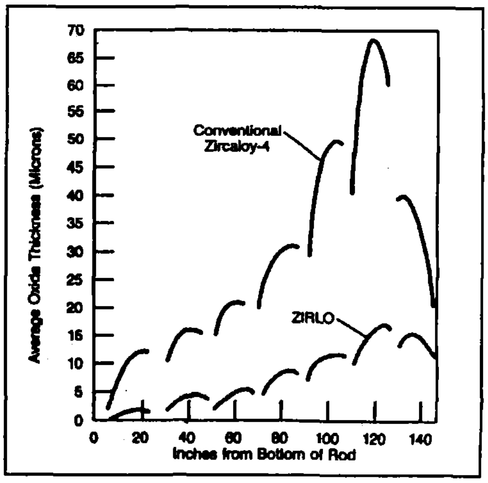
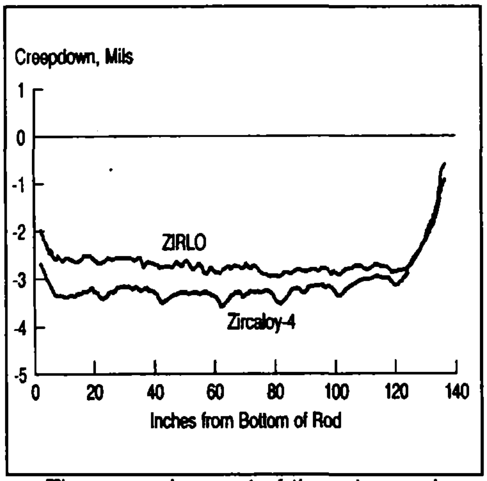
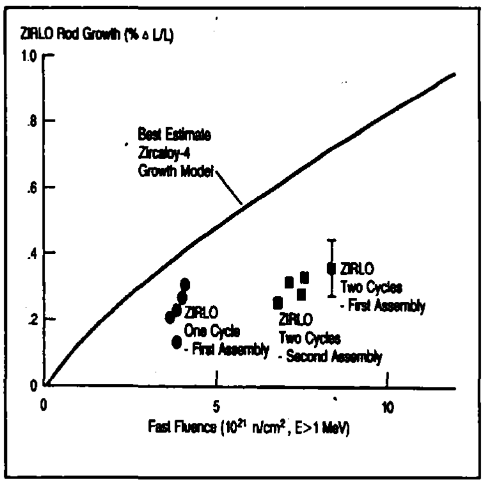


Figure 10
ZIRLO™ Irradiation Creep Comparison



The second aspect of the advanced material development program was the long term solution to ever increasing fuel discharge burnup and fuel cycle length extension. ZIRLO™ has provided the material properties and increased irradiation tolerance to extend fuel discharge burnups to approximately 55 GWD/MTU while substantially removing corrosion concerns resulting from high temperature plant conditions and extended fuel cycles. The process from the deployment of Advanced Alloy Lead Use Assemblies (LUA) at Virginia Power's North Anna station has been a totally cooperative process starting in 1987. The North Anna LUAs contained a wide range of materials and process treatments ranging from ASTM Standard Zircaloy-4, Improved Zircaloy-4, Beta-Quenched Zircaloy-4, ZIRLO™ as well as others. Virginia Power has cooperated in the introduction, licensing and Post Irradiation Evaluations (PIE) of the LUA bundles which have verified the superior irradiation performance of ZIRLO™ under very-limiting actual plant conditions. Figures 8 and 9 compare the corrosion performance of ZIRLO™ with Standard and Improved Zircaloy-4 after two and three cycles of irradiation. These illustrations demonstrate the superior corrosion performance of ZIRLO™ in a very limiting plant on 18-month fuel cycles. The hydrogen pickup fraction for ZIRLO™ remains comparable to that of zircaloy for equal oxide thickness. The result of comparable hydrogen pickup fraction and much lower oxide thickness is a much reduced hydrogen pickup and consequently improved high burnup waterside corrosion. The advantages of ZIRLO™ are not limited to superior corrosion resistance but also include a fifty percent reduction in irradiation induced growth and a twenty percent reduction in irradiation induced creep as illustrated if Figures 10 and 11, respectively. The ultimate generic licensing of ZIRLO™ would not have been possible without the close cooperation of Virginia Power during the North Anna LUA program as well as the commitment of other utilities during the initial deployment of ZIRLO™ in reload region quantities. As a result of the cooperative development program, ZIRLO™ has achieved equal licensing status with Zircaloy-4 and remains the only fully licensed, advanced alloy available to the nuclear fuel industry.

Figure 11
ZIRLO™ Irradiation Growth Comparison



SUMMARY

In summary, advanced fuel product development and selection at Westinghouse depends heavily upon customer direction and cooperation. The development schedules are designed to include all disciplines which will be impacted by the product development, including customers, early in the development process. This process has resulted in much improved product acceptance as well as shorter and more efficient development schedules.

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