Extensive Programs Demonstrate ZIRLO™ Cladding's Performance Benefits

S4

Commercial PWR Demonstration Program

The drive toward greater efficiencies of PWR nuclear steam supply systems has led to higher fuel burnups, extended cycles with higher lithium levels, and higher coolant temperatures. These operational changes lead to more severe fuel duties and, coupled with irradiation-enhanced corrosion of Zircaloy-4 fuel cladding at higher burnups, have resulted in the identification of waterside corrosion as the most limiting factor currently restricting achievable burnup levels. The ZIRLO™-clad composition, Zr-1.0Nb-1.0Sn-0.1Fe, was developed as a superior corrosion resistant material for use in high-burnup fuel.

Recognizing the desirability of demonstrating ZIRLO cladding performance in a commercial PWR, a program was initiated in 1987 in the Virginia Power Company's North Anna Unit 1 reactor. This unit was considered an extremely appropriate facility for performing ZIRLO cladding evaluation, since plant operation provided 18-month fuel cycles, a high power density core and relatively high coolant temperatures.

The demonstration program utilized two fuel assemblies, each containing a number of ZIRLO-clad rods. For comparative purposes, each assembly also contained both conventional and improved Zircaloy-4 rods.

A review of the various program test results for both cycles appears on these pages.

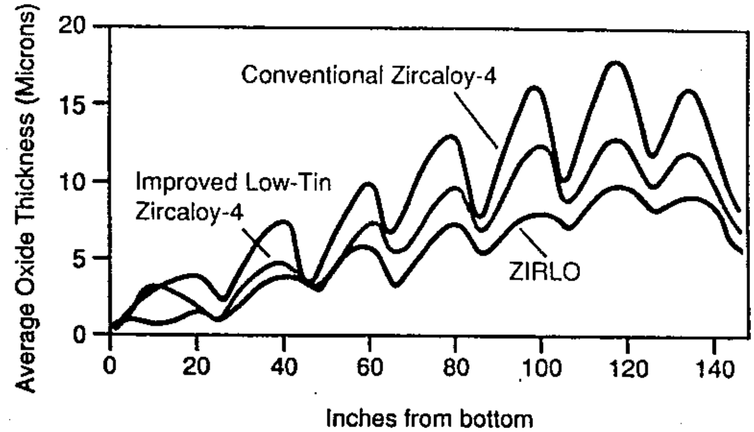
Commercial PWR Demonstration Program

ZIRLO-clad rods were placed in two fuel assemblies along with conventional and improved Zircaloy-4 rods in the North Anna demonstration program. Improved Zircaloy-4 is similar to conventional Zircaloy-4, except that the alloy chemistry is more carefully controlled (low-tin) and interstitials are restricted, and clad processing and annealing parameters are adjusted to achieve an optimized microstructure.

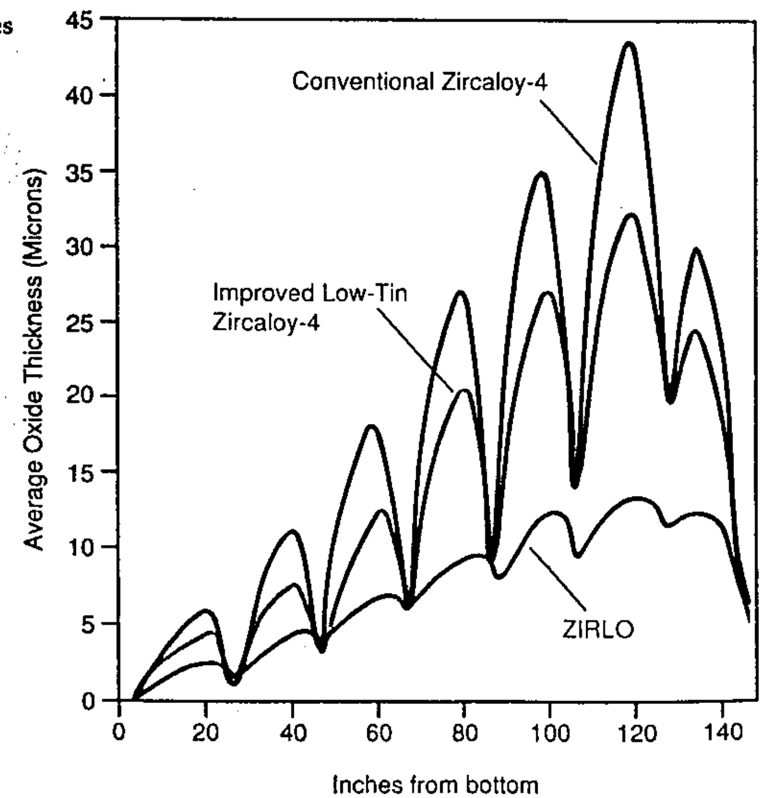
Corrosion Measurements

(Average of multiple rods as a function of axial position)

One Cycle

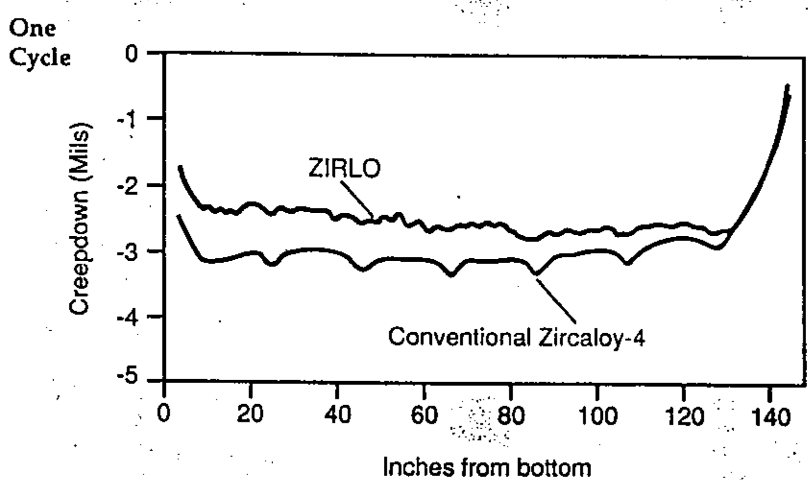


Two Cycles

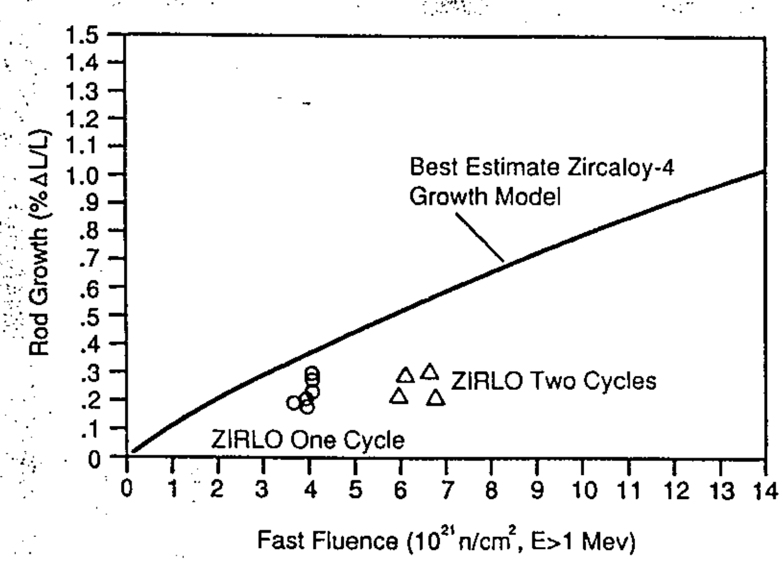


ZIRLO-clad rods have operated through two rigorous 18-month fuel cycles. Results clearly indicated ZIRLO's superior characteristics compared to the two Zircaloy-clads on the important performance measurements—corrosion resistance, irradiation creep and rod growth rates.

Creep Measurements



Rod Growth Measurements



Summary of PWR Demonstration Test Results

After the first and second cycle of ZIRLO-clad operation at the North Anna Unit 1 reactor, important characteristics were evaluated. Eddy-current scans provided measurements of oxide thickness, and confirmed the superior corrosion performance of ZIRLO cladding.

After one cycle (21,200 MWD/MTU)

- ❑ ZIRLO corrosion rates were typically 40% lower than conventional Zircaloy-4 and 25% lower than improved low-tin Zircaloy-4.
- ❑ Irradiation growth rates of ZIRLO were typically 40% lower than conventional Zircaloy-4.
- ❑ ZIRLO irradiation creep rates were approximately 20% less than conventional Zircaloy-4.

After two cycles (37,800 MWD/MTU)

- ❑ Corrosion rates of ZIRLO were typically 67% lower than conventional Zircaloy-4 and 58% lower than improved low-tin Zircaloy-4.
- ❑ ZIRLO irradiation growth rates were typically 60% lower than conventional Zircaloy-4.

Extensive Programs Demonstrate ZIRLO™ Cladding's Performance Benefits (continued)

The commercial PWR demonstration program in North Anna Unit 1 attests to the superior characteristics of ZIRLO™ versus Zircaloy-4 with regard to irradiation creep and rod growth as well as corrosion resistance. ZIRLO-clad rods were noticeably shorter than the Zircaloy-4 rods, verifying ZIRLO's improved growth characteristics—see the comparison photos at the right on page 5.

Further irradiation plans also call for the use of ZIRLO as a guide thimble tube material. In this regard, as growth is reduced, dimensional stability of the fuel assembly is expected to be enhanced. Fuel handling at the reactor site is eased and growth margin for ultra-high burnups is provided.

These current, ongoing commercial PWR demonstration programs substantiate ZIRLO cladding's superiority. Preceding these findings were tests conducted out-of-pile and in the BR-3 reactor in Belgium, comparing ZIRLO with conventional Zircaloy-4 and improved low-tin Zircaloy-4. The results of these earlier tests—that also proved ZIRLO superiority with rod average burnups up to 68,000 MWD/MTU—are covered in greater detail below.

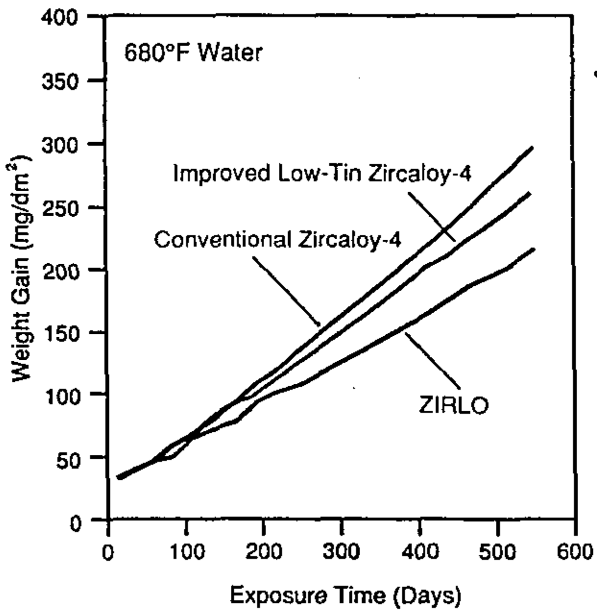
ZIRLO™ Cladding Out-of-Pile and Test Reactor Performance

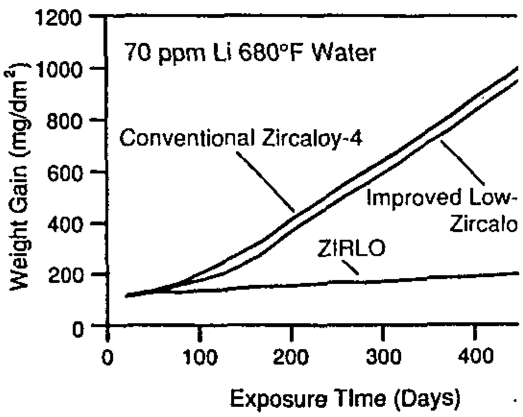
Out-of-Pile Corrosion Test Results

The Westinghouse program to develop a superior zirconium-based cladding alloy involved a detailed analysis of 35 different compositions of elements representing zirconium alloy systems with niobium, molybdenum, vanadium, copper, manganese, germanium and tin.

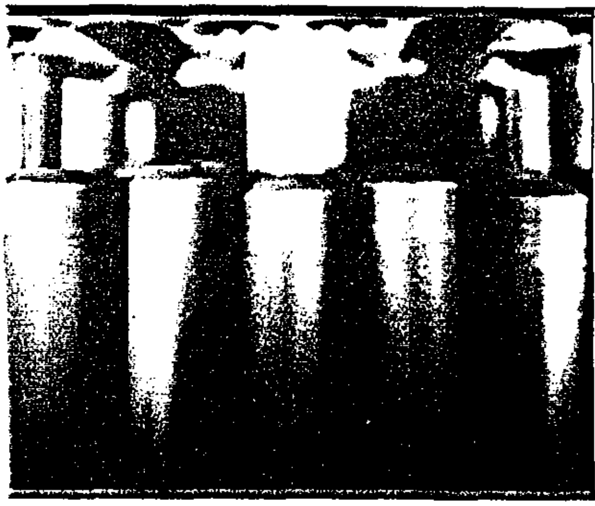
Results indicated that the most promising system was a zirconium-niobium-tin alloy—Zr-1.0Nb-1.0Sn-0.1Fe—named ZIRLO™.

ZIRLO, along with four other alloys, then became part of a developmental study to compare corrosion resistance. This was determined by means of a series of tests conducted in the BR-3 reactor in Belgium.





ZIRLO material was found to be highly resistant to corrosion in lithiated water, being nearly 75% lower after 450 days in the autoclave.



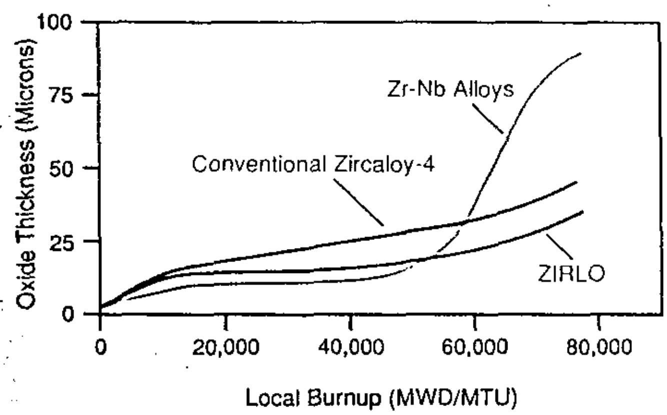
Commercial PWR Demonstration Program Rod Growth Comparisons

Demonstration assembly rod tops from the North Anna Unit 1 reactor are shown after two cycles in the left photo; and rod bottoms in the right photo.

The two ZIRLO-clad rods are noticeably shorter than the Zircaloy-4 clad rods—indicating ZIRLO's superior resistance to irradiation growth.

Performance of ZIRLO™ Cladding in the BR-3 Test Reactor

The BR-3 high power, high burnup tests indicated that ZIRLO offered better fuel performance characteristics than Zircaloy-4. Both cladding creep and irradiation growth were lower for ZIRLO. Waterside corrosion resistance of ZIRLO was superior to Zircaloy-4, with greater benefits as power levels increased. Binary alloys Zr-1.0Nb and Zr-2.5Nb were similar in behavior and showed very low uniform corrosion; however, these two alloys became susceptible to nodular corrosion at high burnup, and had localized oxide thicknesses of a nature not observed on ZIRLO and Zircaloy-4. Hydrogen pickup fraction was similar for all alloys. These results from the BR-3 irradiation test indicated that ZIRLO was the superior alloy for today's demanding high burnup applications.



Test Results

ZIRLO™ corrosion resistance was superior to Zircaloy-4. At peak power levels,.ZIRLO oxidation was approximately 40% lower than Zircaloy-4 oxidation. No nodular corrosion was observed on either alloy.

Due to heavy oxidation in autoclave testing, the alloy Zr-0.5Nb was discharged after one cycle.

Nodular corrosion was observed in the alloys Zr-1.0Nb and Zr-2.5Nb at burnups in excess of approximately 55,000 MWD/MTU.