# Advances in Ultrasonic Fuel Cleaning

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## Background

The economics of electric generation is requiring PWR plant operators to consider higher fuel duty and longer cycles. As a result, sub-cooled nucleate boiling is now an accepted occurrence in the upper spans of aggressively driven PWR cores.

Thermodynamic and hydraulic factors determine that the boiling surfaces of the fuel favor deposition of corrosion products. Thus, the deposits on high-duty fuel tend to be axially distributed in an inhomogeneous manner. Axial offset anomaly (AOA) is the result of axially non-homogeneous distribution of boron compounds in these axially variable fuel deposits.

Besides their axial asymmetry, fuel deposits in boiling cores tend to be qualitatively different from deposits on non-boiling fuel. Thus, deposits on moderate-duty PWR fuel are generally iron rich, predominating in nickel ferrites. Deposits on cores with high boiling duty, on the other hand, tend to be rich in nickel, with sizeable fractions of NiO or elemental nickel. Other unexpected compounds such as *m*-$ZrO_2$ and Ni-Fe oxyborates have been found in significant quantity in deposits on boiling cores.[2]

Most attempts at mitigating AOA have been directed at either reducing the source term of the corrosion products available for deposition, or minimizing the local concentration of boron at the deposition sites. Special chemistry/temperature protocols for end-of cycle shutdown evolutions have also been developed to facilitate removal and subsequent cleanup of fuel corrosion product deposits.[3] These chemistry evolutions tend to be much less effective on the nickel rich deposits on boiling cores than they have been for the non-boiling cores for which the procedures were originally developed. For these reasons, a number of mechanical cleaning methods have been proposed for removing corrosion product deposits from reload fuel.

This paper describes the ultrasonic fuel cleaning technology developed by EPRI. Data will be presented to confirm that the method is effective for removing fuel deposits from both high-duty and normal-duty fuel. The report will describe full-core fuel cleaning using the EPRI technology for Callaway Cycle 12 reload fuel. The favorable impact of fuel cleaning on Cycle 12 AOA performance will also be presented.

## EPRI's Ultrasonic Fuel Cleaning Technology

Ultrasonics is the preferred method for mechanical fuel cleaning, because it can remove deposits from a fully-intact fuel assembly and the process does not produce any ancillary wastes other than the dislodged deposits themselves. Earlier efforts at ultrasonic fuel cleaning have had limited success, however, because the planar ultrasonic technology used for these techniques could not direct energy effectively onto the inner fuel rods without simultaneously exciting the peripheral rods excessively. Concern for fuel pellet integrity was therefore added to questions of cleaning adequacy.

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[2] *Characterization of Corrosion Products on the Callaway Cycle 9 PWR Core,* EPRI, Palo Alto, CA: 2001. Report 1003129

[3] *PWR Shutdown Chemistry Practices,* EPRI, Palo Alto, CA: 1998. Report TR-109569

The EPRI ultrasonic fuel cleaning technique has resolved the shortcomings of earlier methods through use of an optimum arrangement of special transducers. The resulting ultrasonic energy field is able to "see around" the intervening fuel rods into the very center of the assembly, in effect producing an energy field of relatively uniform intensity throughout the fuel matrix. The interior rods of a fuel assembly can thus be cleaned effectively, while limiting the energy intensity on peripheral rods to maintain pellet and cladding integrity.

## System Description

The EPRI fuel cleaning system consists of a cleaning chamber and a waste-collection module. The two sub-systems are interconnected with a flexible hose so the installation can be adapted to the space available in the always-crowded spent-fuel storage pool. The cleaning chamber consists of a rectangular channel that contains the fuel assembly to be cleaned, surrounded by the matrix of ultrasonic transducers. The transducers are powered and controlled from an instrument console located on the pool deck. Pool water is drawn into the open top of the cleaning chamber, carrying away the dislodged corrosion products to the bottom, through the flexible hose, through a bank of disposable cartridge filters, and back to the pool. The pump providing flow for the water is mounted between the flexible hose and the filter bank. Operation of the pump and filter module is through a second instrument console situated on the pool deck. The spent cartridge filters are designed to encapsulate the collected corrosion products and can be stored in the pool or processed as radioactive waste at the option of the utility. A schematic diagram of one possible deployment of the fuel cleaning system is shown in Figure 1.

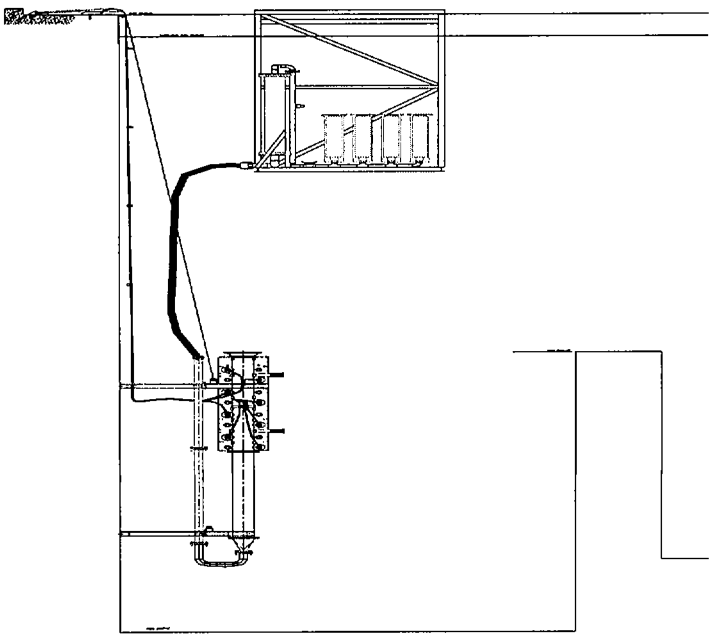

**Figure 1**
**Schematic of EPRI's ultrasonic fuel cleaning system.**

## Fuel Cleaning Efficacy

The prototype ultrasonic cleaning system was thoroughly tested and evaluated with a mockup fuel assembly in the laboratory. Simulated corrosion products were deposited on the mock-up fuel rods, and these were "cleaned" using the actual transducer configuration considered for the full scale cleaning system. Removal of the simulated deposits was rapid and uniform throughout the mock-up assembly. It was estimated that no more that ten minutes of cleaning time was required to remove most of the deposits from the fuel rods.[4] The mockup assembly was also instrumented to provide data for a detailed vibration analysis to confirm that the vibrations induced by the ultrasonic energy where at all times and in all locations within the bounds permitted by the fuel vendor.[5]

Based on the successful laboratory results, construction of the full-scale prototype fuel cleaning system was authorized by AmerenUE for use at its Callaway plant. The equipment was successfully demonstrated on discharged Callaway fuel in April and August 1999, followed by cleaning of sixteen reload assemblies during October 1999. These cleaned assemblies were found to perform well during the ensuing fuel cycle 11, with neither fuel failures nor evidence of local AOA.

The cleaning efficacy of the prototype cleaner was definitively demonstrated on spent fuel assemblies at Callaway during October 2001. These tests consisted of sampling the fuel deposits on a discharged (un-cleaned) fuel assembly, cleaning the assembly with the prototype ultrasonic cleaner, followed by a second sampling of the cleaned assembly. Comparison of the activity of deposits before and after cleaning provided a measure of the degree of removal of corrosion products from actual fuel. The percentage of activity removed from the various rods and spans used in the comparison ranged between 41 and 100%, but with many values of 75% or higher. The percent of activity removed from the four highly crudded spans of each rod were averaged, and the averages indicated that over 75 % of the activity was removed from each rod. For some rods over 90% was removed. The combined averages of the activity removed from the two sampled assemblies indicate that about 86% of the initial activity was removed by use of the ultrasonic cleaning process.

## Full-Reload Cleaning Results

Based on the excellent performance of the sixteen cleaned reload assemblies in Cycle 11, AmerenUE elected to clean the entire reload inventory prior to loading the core for Cycle 12. These 96 once-burned fuel assemblies were returned to the reactor with feed fuel to constitute the Cycle 12 core.

Callaway's ultrasonic fuel cleaning system was readily re-activated after having been idle in the fuel pool since October 1999. The fuel cleaning operation was generally trouble-free and effective in removing corrosion products from the once-burned fuel assemblies. Approximately 48 hours were expended for cleaning the 96 assemblies, including retrieval of the assembly from the spent fuel storage rack and insertion into the cleaner, the actual cleaning operation, and return of the cleaned assemblies to the storage rack. The rate of activity buildup on the waste collection filters suggested that, on average, a dose rate increase of approximately 5R/hr occurred, primarily as $^{58}Co$ and $^{60}Co$, on each of four parallel filter cartridges from cleaning each assembly. Waste handling considerations dictated that the filter bank be changed out when the filter activity reached approximately 132 R/h, even though the cartridges still had ample reserve waste collection capacity at that point. Thus, the corrosion products from all cleaned assemblies could be captured on four banks of four filter cartridges each. A total of 16 cartridges were expended to capture the corrosion products released from the 96 once-burned reload fuel assemblies.

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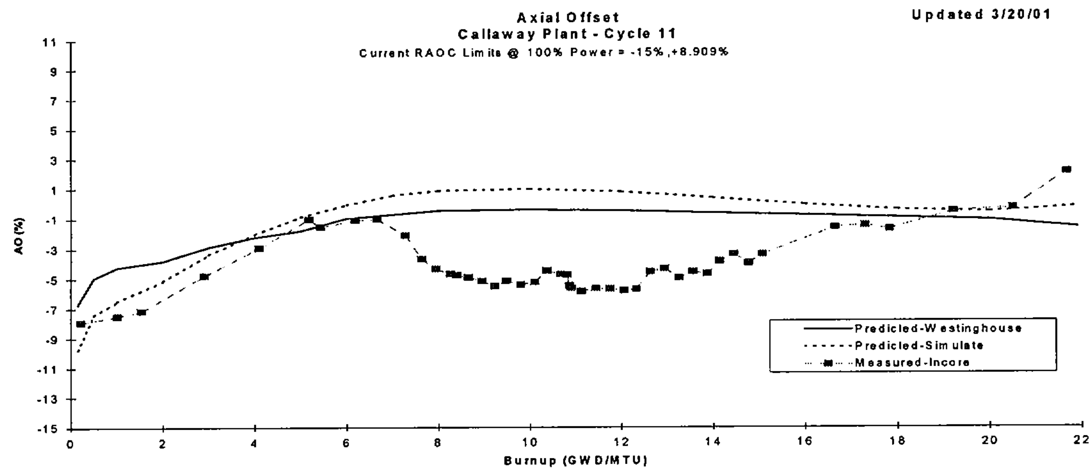
[4] *Pressurized Water Reactor Fuel Cleaning Using Advanced Ultrasonics*, EPRI, Palo Alto, CA, and AmerenUE, Fulton, MO: 2000. Report 1001052.

[5] *Fuel Pellet Integrity Assessment for the EPRI Ultrasonic Fuel Cleaning Device*, EPRI, Palo Alto, CA, and AmerenUE, Fulton, MO: 2000. Report 1001095.

## Callaway Cycle 12 Performance

Callaway Cycle 12 has been in service since May 2001. A direct comparison of Cycle-11 and -12 performance illustrates the effect of loading clean reload fuel because both cycles are of similar power-duty design. Figure 2 compares the axial offset for the two cycles. As of December 2001, Cycle 12 is free of AOA, while the AOA effect had become significant at the same burnup into Cycle 11. It is especially encouraging that no AOA was observed following a control-rod exercise test in November 2001, an event that has initiated or aggravated AOA in prior cycles at this plant.



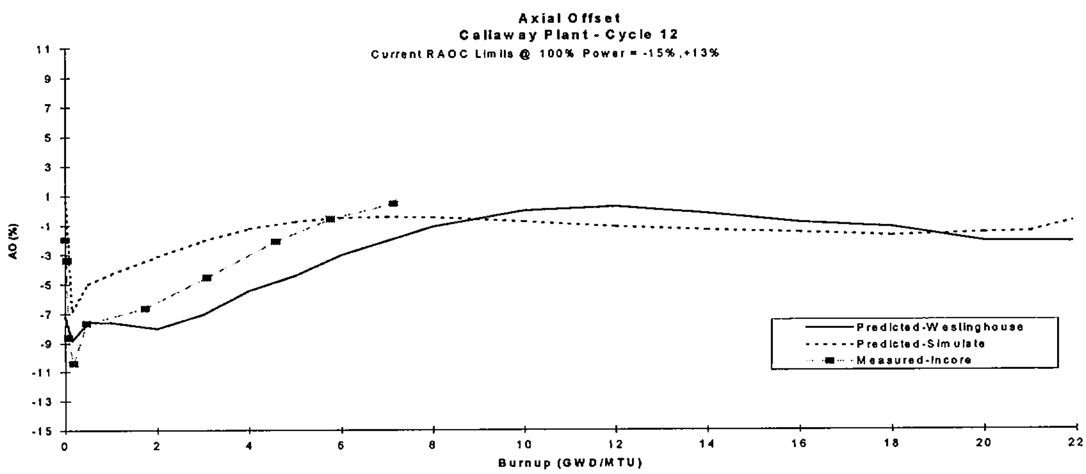




**Figure 2**
**Callaway Cycle 11 and Cycle 12 AOA**

Although mitigation of AOA is the principal benefit of ultrasonic fuel cleaning for PWRs, the reduction in corrosion product inventory can also have a beneficial effect on dose rates and personnel exposure. These ALARA benefits can increase the value of fuel cleaning in a PWR and can constitute the primary benefit for considering ultrasonic cleaning for BWRs. By way of illustration, the favorable Callaway Cycle 12 dose rate experience is compared with earlier cycles in Figure 3.

Reduced radiation fields as illustrated for a typical component in Figure 3 are expected to have a favorable impact on personnel dose. Experience at Callaway for Cycle 12 supports this expectation, as shown in Figure 4. While overall values of personnel dose as plotted in Figure 4 are affected by many factors besides operating with clean fuel, AmerenUE considers fuel cleaning to be the dominant variable impacting the difference in personnel dose for Cycle 12 compared to Cycles 10 and 11.

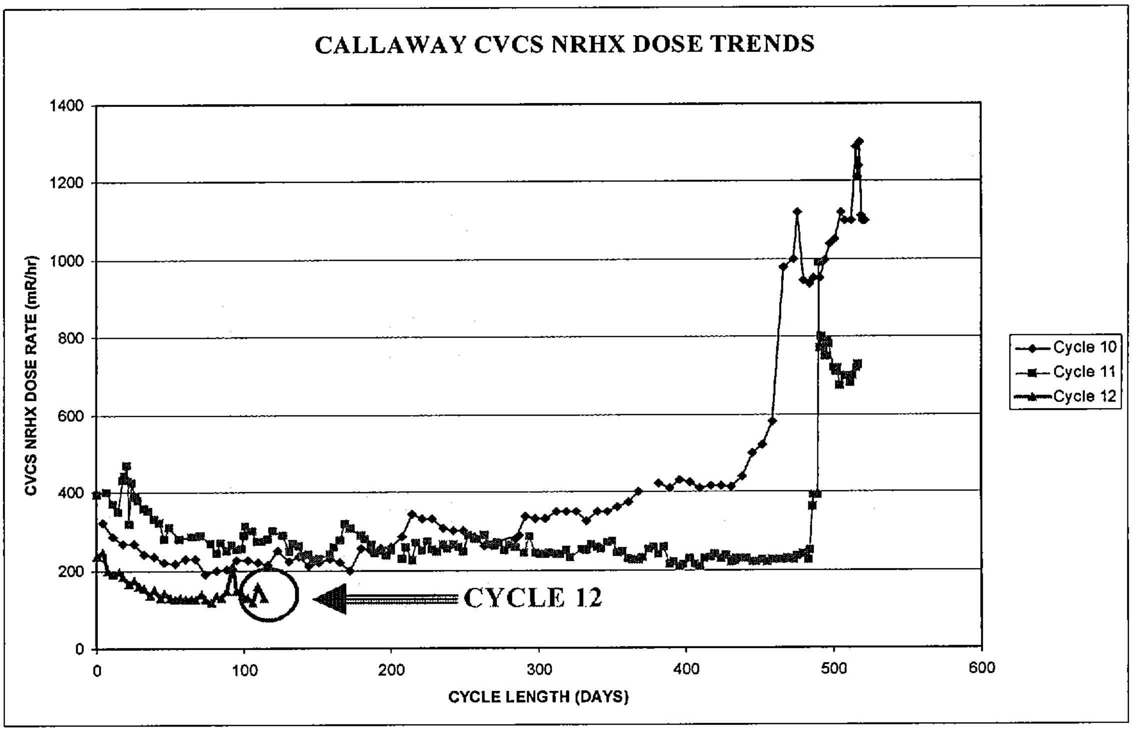



**Figure 3**
**NR Heat exchanger dose rate, Callaway Cycle 10, 11, and 12**

## Conclusions

Callaway has experienced AOA for many of its recent fuel cycles, and the plant staff has worked actively to mitigate this problem. Based on the Cycle 12 data, Callaway considers fuel cleaning to be of significant value in controlling AOA. The reduction in ex-core dose rate is a welcome secondary benefit. Based on the results described in this report, AmerenUE intends to clean all reload fuel again prior to loading the core for Cycle 13 in Autumn 2002.

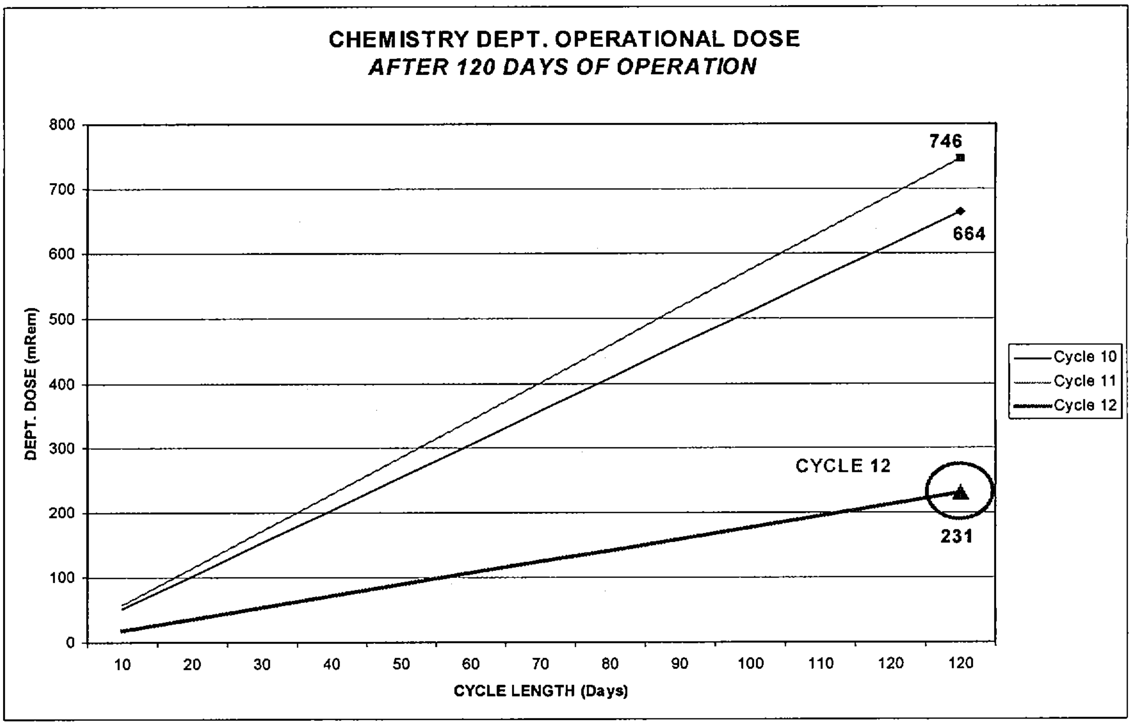



**Figure 4**
**Personnel dose, Callaway Chemistry Department, Cycle 10, 11, and 12**