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ComEd

March 19, 1998

JMHLTR: #98-0017

U.S. Nuclear Regulatory Commission
Attention: Document Control Desk
Washington, D.C. 20555

Subject: Dresden Unit 2 Hydrogen Water Chemistry Hotcell Results on Fuel Performance / Final Transmittal of Requested Information

Reference:

1.) Dresden letter from S. Perry to U.S. NRC, "Dresden Nuclear Power Station Unit 2 - Hydrogen Water Chemistry Fuel Surveillance - NRC Docket No. 50-237," JSPLTR #96-0222 dated November 25, 1996.

2.) Dresden letter from S. Perry to U.S. NRC, "Dresden Nuclear Power Station Unit 2 - Hydrogen Water Chemistry Fuel Surveillance - NRC Docket No. 50-237," JSPLTR #97-0194 dated November 25, 1997.

The Reference letters provided updates to the NRC on the joint ComEd, EPRI, and GE program to monitor fuel performance in a hydrogen water chemistry (HWC) environment at Dresden Unit 2. This has been an extensive program dating back to 1983 and four cycles of Lead Test Assembly (LTA) irradiation in Unit 2 over cycles 9 through 12. The final hotcell examinations on both fuel and water rods have now been completed at the GE Vallecitos laboratory. The attached results on hydrogen uptake are being provided to the NRC per your request as outlined in the NRC's 1983 Safety Evaluation Report (SER) supporting HWC at Unit 2.

Note that fuel rod crud loading and composition was within expectations and fuel rod hydrogen uptake was low. However, a water rod exposed to four cycles of HWC exhibited higher than expected corrosion and hydrogen uptake in its upper spans. ComEd has met with GE and EPRI personnel on this and confirmed the corrosion and hydrogen uptake findings by additional examination of the subject water rod. GE believes the effect may be related to neutron fluence rather than HWC, however, this effect cannot easily be determined with complete certainty. No fuel bundle performance problems were encountered during operation, and none would have been expected based on the results of this examination. Furthermore, Dresden Unit 2 (with HWC) and Dresden Unit 3 (without HWC) have both shown good fuel performance during the past decade.

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Excerpts from the EPRI report (TR-108782, "Hotcell Postirradiation Examination of Dresden-2 Fuel and Water Rods After Four Cycles of Hydrogen Water Chemistry") related to hydrogen uptake are attached for close out of this fuel surveillance program on HWC. If the NRC has questions or desires a meeting to review the data, ComEd will coordinate this with EPRI and GE.

Note that ComEd continues to be involved with our fuel vendors and EPRI to monitor fuel performance on a wide range of issues to extend our excellent fuel performance record. As evidenced by this 14 year effort, we have a strong commitment to excellent fuel reliability.

If you have any questions concerning this letter, please contact Frank Spangenberg, Regulatory Assurance Manager, at (815) 942-2920, extension 3800.

Sincerely,

JMHeffley

J. M. Heffley
Site Vice President
Dresden Station

cc: A. Bill Beach, Regional Administrator, Region III
L.W. Rossbach, Dresden Project Manager, NRR (Unit 2/3)
K. Riemer, NRC Senior Resident Inspector - Dresden
Department of Nuclear Safety

# Attachment

Excerpts from EPRI Report "Hotcell Postirradiation Examination of Dresden-2 Fuel and Water Rods After Four Cycles of Hydrogen Water Chemistry," TR-108782

# ABSTRACT

The hydrogen water chemistry fuel surveillance program at Dresden-2 is briefly described and the results of site inspection activities at the end of Cycle 12 are presented.

Selected fuel rods and water rods were retrieved for hotcell examination. The rods were sectioned at an intermediate hotcell and fission gas analysis data collected at that time are reported.

Nondestructive and destructive post-irradiation examination studies were performed at the GE Vallecitos Nuclear Center. The results are presented and discussed.

The corrosion behavior of Zircaloy-2 fuel cladding was excellent through four cycles of hydrogen water chemistry, but accelerated corrosion and hydrogen pickup was observed in water rod material. It is suspected, but not confirmed, that this was an effect of neutron fluence rather than hydrogen water chemistry.

No fuel bundle performance problems were encountered during operation and none would have been expected based on the results of this examination.

A need for additional diagnostic testing is noted and further fuel surveillance programs are recommended.

# REPORT SUMMARY

The use of hydrogen water chemistry (HWC) has been monitored to evaluate its impact on the performance of Zircaloy fuel cladding and components. This report presents the results of poolside and hotcell postirradiation examinations of several Dresden-2 fuel and water rods after four cycles of HWC injection. The results indicate that the corrosion and hydriding characteristics of the fuel rods were within the expected ranges, and HWC did not adversely affect cladding material properties.

## Background

Since 1983, EPRI has sponsored research to assess whether the addition of hydrogen to the reactor feedwater degraded the corrosion and hydriding performances of Zircaloy fuel components and whether the characteristics and quantity of the crud deposits were substantially changed to affect fuel performance. The results after one, two, and three cycles of HWC—previously documented in EPRI report NP-6956-D—showed that neither Zircaloy corrosion nor crud deposition behaviors in Dresden-2 were adversely affected by the hydrogen additions. EPRI initiated a limited hotcell program in 1996 to characterize four-cycle HWC fuel rods (with a burnup of approximately 38 GWd/MTU) and selected water rods in order to answer any lingering questions about the impact of HWC on the performance of Zircaloy cladding and components at the current high burnup regime.

## Objectives

To evaluate the effects of HWC on the corrosion and hydriding characteristics of fuel and water rods and the distribution of crud on fuel rods at high burnup.

## Approach

Investigators performed a poolside inspection of a lead test bundle after four cycles of HWC at Dresden-2 to measure the cladding oxide thickness of selected rods and collect crud samples. The hotcell examination of six fuel rods and three water rods included fission gas analysis, neutron radiography, metallography, quantitative hydrogen analysis, and analysis of the loading and chemical composition of the crud deposits. Electron microscopic examination of the Zircaloy water rod material was performed to evaluate the root cause of higher-than-expected hydrogen concentration in one water rod. Investigators compared the results of the poolside inspection and hotcell examination with lower exposure data obtained earlier in this program.

## Results

The oxide thickness as well as hydrogen content and distribution in the four-cycle fuel cladding were low and within the range expected for fuel rods at an exposure of 38 GWd/MTU. The crud loading on the fuel rods increased from the three-cycle data in proportion to the longer in-reactor residence time, but was within the expected range. No fuel bundle performance problems were encountered during operation, and none would have been expected based on the results of this examination.

One water rod after four HWC cycles showed a deviation in the hydriding characteristics near the 100- to 110-in elevations at the burnup range of 38 GWd/MTU. With a maximum measured hydrogen content of 600-800 ppm, this peak hydrogen location deviated from the one-, two-, and three-HWC-cycle water rods and from water rods exposed to three cycles of normal water chemistry, where the peak hydrogen location was at 30- to 40-in elevations and less than 100 ppm.

## EPRI Perspective

The Dresden-2 four-cycle fuel rod data suggested that HWC with hydrogen addition of about 1.5 ppm in the feedwater has not adversely affected the corrosion and hydriding behavior of Zircaloy-2 fuel cladding, cladding material properties, or characteristics of crud deposits on the fuel rods.

The axial distribution pattern and the maximum local hydrogen content of one four-cycle water rod suggest a change in hydriding characteristics of the rod. While the maximum hydrogen content is significant, it is not expected to impact the mechanical integrity of the rod, as the radial distribution of the hydrides was uniform in this nonheated component. The root cause of the hydriding behavior of the four-cycle water rod cannot be discerned given the available data. Material variability, high burnup material property changes, and interaction between neutron irradiation and HWC at high burnup are just a few possibilities. Utilities can apply the information in this report to support plant-specific HWC programs to the current fuel burnup range. For higher fuel burnup and/or higher hydrogen injection rates, additional data on the hydriding behavior of nonfuel components will help clarify the root cause of the anomalous hydriding data discovered under this program.

**TR-108782**

**Interest Category**
Fuel assembly reliability and performance

**Keywords**
BWR
BWR fuel cladding corrosion
Hydriding

# 1

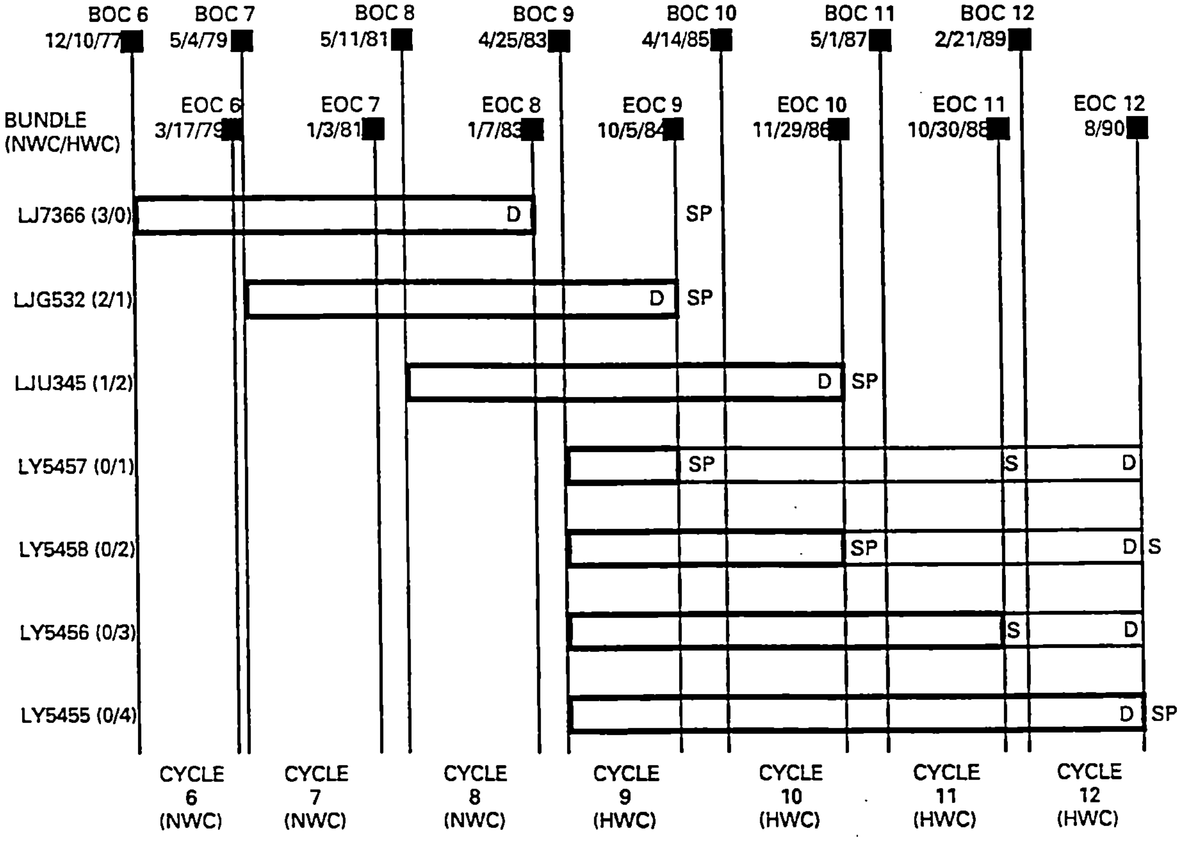
# INTRODUCTION

Hydrogen water chemistry is applied in BWRs to reduce the risk of intergranular stress corrosion cracking (IGSCC) in austenitic stainless steels. To address the impact of hydrogen water chemistry on the performance of Zircaloy fuel cladding and components, an extensive surveillance program sponsored by EPRI (RP C101-14) was begun in 1983 at the Dresden-2 Nuclear Power Station (beginning of Cycle 9). The main objectives were to assess whether the addition of hydrogen to the reactor feedwater degraded the corrosion and hydriding performances of the Zircaloy fuel components, and whether the characteristics and quantity of the crud deposits were substantially changed to affect fuel performance.

Four assemblies with well-characterized cladding materials were inserted into the reactor at the beginning of Cycle 9 and were examined successively after one, two, three and four cycles of hydrogen water chemistry. This surveillance program was augmented with examinations of assemblies with prior exposure under normal water chemistry conditions. Thus, fuel and water rods exposed to various combinations of normal water chemistry (NWC) and hydrogen water chemistry (HWC) were characterized. The rods were visually examined at the reactor site to determine nodular oxide coverages and scanned with eddy current liftoff probes to determine corrosion film thicknesses. Crud samples were collected and analyzed. In addition, selected fuel rods and water rods were destructively examined in the GE Vallecitos hotcells to measure oxide thicknesses and hydrogen pickups.

Results through three cycles of HWC have been reported in detail[1,2]. It was concluded that neither Zircaloy corrosion nor crud deposition behaviors in Dresden-2 were adversely affected by the hydrogen additions. However, the program was interrupted before the fourth cycle examination results were reported and there were no destructive examination results on fuel rods with more than two cycles of exposure to HWC. In order to answer any lingering questions about the impact of HWC on the performance of Zircaloy cladding and components, a limited hotcell program to characterize four-cycle HWC fuel rods and selected water rods was contracted in August 1996.

The objective of the current workscope was to extend this study of the corrosion and hydrogen pickup behavior of Zircaloy-2 fuel cladding and water rods through four cycles of HWC.



S: SITE INSPECTION
P: HOT CELL EXAMINATION
D: DISCHARGED

**Figure 2-1. Chronological Summary of HWC Surveillance Fuel Bundle Irradiation and Inspection Histories**

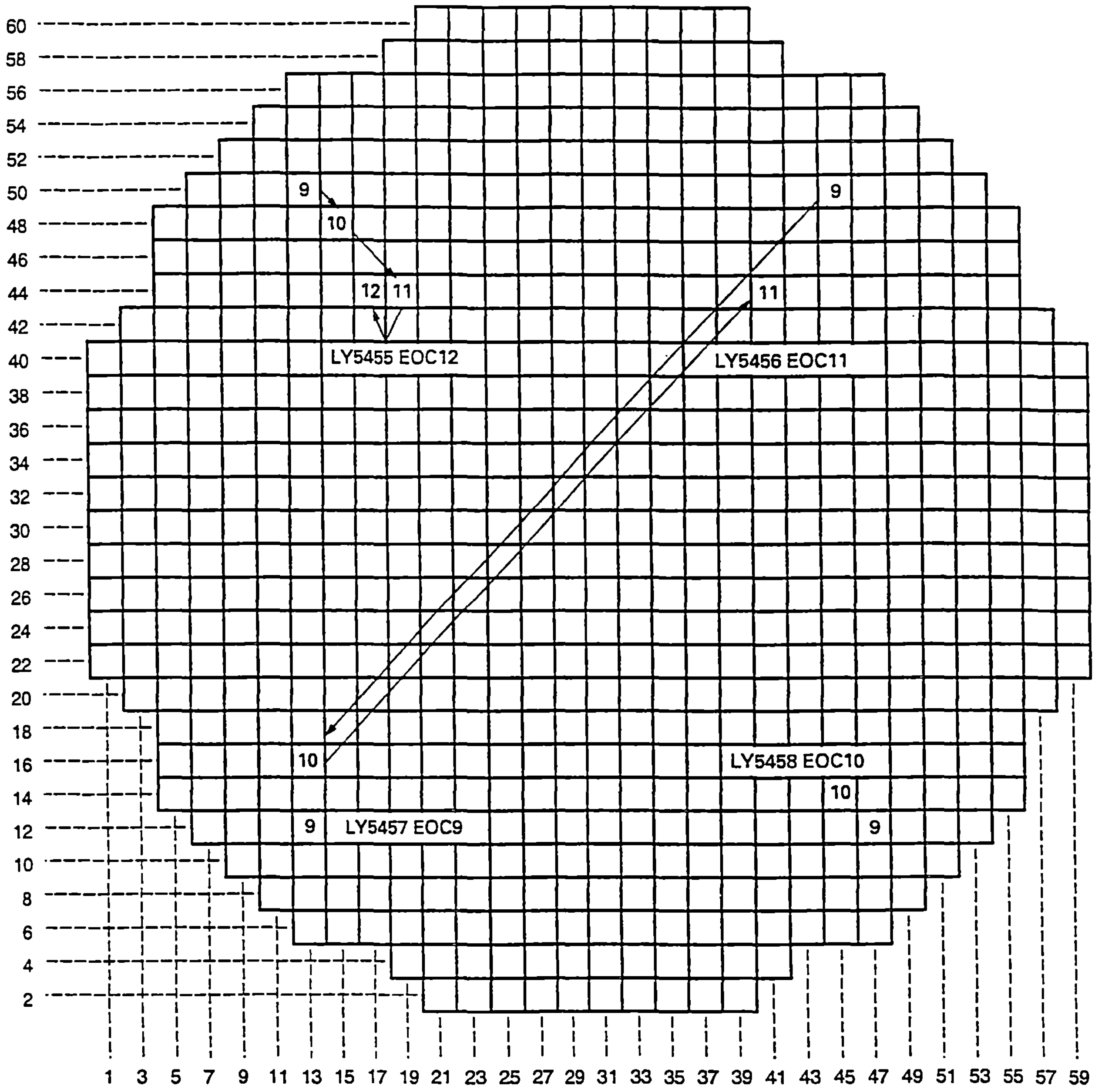


**Figure 2-2.** **Dresden-2 Core Locations of Precharacterized Surveillance Bundles Prior to Inspection After 1, 2, 3, and 4 Cycles of HWC, Respectively**

# 7
# DISCUSSION

## Site Inspection and Nondestructive Examination Results

Visual inspection and eddy current liftoff measurements performed at the site on Dresden-2 fuel rods after four cycles of HWC indicated low levels of corrosion and no significant discrimination between the corrosion-resistant (Type A) and nonresistant (Type B) claddings. In addition, there were no indications that HWC had any significant effect on the crud characteristics. Iron comprised more than 97% of the crudding elements and $\alpha$-$Fe_2O_3$ remained the predominant phase.

Three fuel rods and three water rods were examined in the Vallecitos hotcells. Visual examination results were consistent with the site inspection results. Fuel rod corrosion appeared to be light. Corrosion 'rosettes', light circular patches often surrounding small oxide nodules, were prevalent on the lower sections of the fuel rods.

Neutron radiography of selected fuel rod sections showed no evidence of unusual concentrations of hydrogen in the claddings.

## Metallography and Hydrogen Analysis

Metallographic examination and cladding hydrogen analysis of three fuel rods and one water rod from the specially characterized LY5455 bundle are described in Section 5. The results after four cycles of HWC are compared below with those from identical bundles after one, two and three cycles of HWC(1,2).

Consistent with the site inspection results, fuel cladding oxide thicknesses (Table 5-1) were low and there was little or no discrimination between the corrosion-resistant cladding (e.g., rods A1 and D2) and the nonresistant cladding (e.g., rod H3). Metallographic measurements of cladding oxide thickness are compared with site liftoff measurements in Table 7-1. The latter over-predicted corrosion layer thicknesses, especially for thin layers, but the trends were the same. [The liftoff over-prediction was probably a consequence of small amounts of residual crud on the cladding surfaces(7).]

Fuel cladding hydrogen contents were also low, as determined by the LECO inert gas fusion method (Table 5-3) and confirmed by metallography. In contrast, the hydrogen content of the E4 water rod was very high (Table 5-4 and, e.g., Figure 5-79). Four-cycle fuel rod and water rod results are plotted for comparison in Figure 7-1.

The hydrogen contents of the four-cycle water rod samples are compared to similar measurements collected after one, two and three cycles of irradiation in Figure 7-2. Not only were the hydrogen contents much higher than previous measurements, but the axial distribution was different, peaking towards the top of the rod instead of near the bottom.

Metallographic oxide thickness measurements on the four-cycle water rod (Table 5-2) are compared to those on identical water rods after one(8), two(6) and three(1) cycles in Figure 7-3 (outer surface) and Figure 7-4 (inner surface). Accelerated oxidation on both surfaces occurred towards the top of the rod.

The hydrogen pickup fraction has also changed significantly between the third and fourth cycle. After three cycles, maximum hydrogen pickups were around 20%(1,2). After four cycles, hydrogen pickups ranged up to 73%. [Note: The 2/1 and 1/2 water rod hydrogen pickups in Table 5-6 range above 20%, but these are not identical materials and have different irradiation histories.]

Calculated fuel cladding hydrogen pickups (Table 5-5) show considerable scatter, due to uncertainties in both hydrogen contents and some of the oxide thicknesses. Nevertheless, hydrogen pickups after four cycles were clearly enhanced compared to reported results (<2.5% HPU) after two cycles(1,2).

Hydrogen concentration data collected during the current campaign are summarized and added to a previously reported plot(1,2) in Figure 7-5. This shows that the pre-characterized (HWC) fuel cladding hydrogen contents plateaued at a low level after just one cycle, but water rod hydrogen levels continued to increase through four cycles. The trend towards high hydrogen levels was already evident after two and three cycles. [Note: The lines connecting the points are not mathematically fitted curves.]

## STEM Results

The accelerated corrosion and hydrogen pickup towards the top of the four-cycle water rod suggested that this behavior might be an effect of neutron fluence rather than HWC. STEM characterization of the water rod material was added to the workscope to determine if the observed behavior could be related to irradiation-induced changes in the microstructure.

The STEM results indicated that irradiation had caused severe depletion and dispersion of the Fe from the $Zr(Fe,Cr)_2$ and $Zr_2(Fe,Ni)$ second phase particles (SPPs). Also shrinkage of both $Zr(Fe,Cr)_2$ and $Zr_2(Fe,Ni)$ SPPs was observed. The distribution of SPPs and the grain size was not changed relative to unirradiated archive material. Importantly, there appeared to be only small differences in irradiation effects between material at the 20.4-inch and 100.4-inch locations, even though significant corrosion/hydriding differences were noted at these elevations. So, after this STEM investigation, it is not possible to ascribe a microstructural cause to the observed accelerated corrosion and hydrogen pickup.

Although the observed magnitude of dissolved Fe levels and the clustering of Cr at the locations of previous crystalline SPPs was unusual (or, at least, in an advanced state), without conducting STEM studies at lower fluences, we cannot say that those features contribute to the in-reactor performance. It is noted that earlier work(9) indicated that increased corrosion and hydrogen pickup fraction occurred at about the time that nearly complete SPP dissolution occurred; that was not the case for the four-cycle Dresden water rod.

## Summary and Recommendation

A comprehensive fuel surveillance program had previously shown no deleterious consequences of HWC through three cycles of operation in the Dresden-2 reactor. The current study extended the program through four cycles.

The corrosion behavior of the fuel cladding continued to be excellent, but accelerated corrosion and hydrogen pickup by the water rod material was observed after the fourth cycle. The axial elevation of the maximum hydrogen pickup, around 100 inches, argues that this result is a neutron fluence effect (rather than a HWC effect), but this could not be confirmed by microstructure and microchemistry studies on the water rod material. Additional diagnostic studies are required to elucidate the precise mechanisms of the accelerated corrosion and hydrogen pickup.

Based on this experience and the evolution of plant water chemistries, it is recommended that hotcell studies be included in surveillance plans to monitor the performance of modern fuel designs operating to high exposures in different environments.

## Table 7-1
## Comparison of Oxide Thickness Measurements with Site Liftoff Measurements

| Rod Location | Rod Average Liftoff * (μm) | Elevation (in.) | Local Average Liftoff ** (μm) | Metallographic Oxide Thickness *** (μm) |
|---|---|---|---|---|
| **A1** | 8.9 | 20 | 6.1 | 2.7 |
| | | 30 | 5.6 | 1.4 |
| | | 50 | 6.4 | 1.8 |
| **D2** | 15.5 | 20 | 13.2 | 5.5 |
| | | 30 | 16.5 | 13.3 |
| | | 50 | 10.2 | 4.0 |
| **H3** | 13.5 | 20 | 7.9 | 2.8 |
| | | 30 | 7.6 | 2.6 |
| | | 50 | 14.5 | 6.3 |

* From Figures 2-3, 2-6 and 2-15.
** From data input to above figures.
*** From Table 5-1.

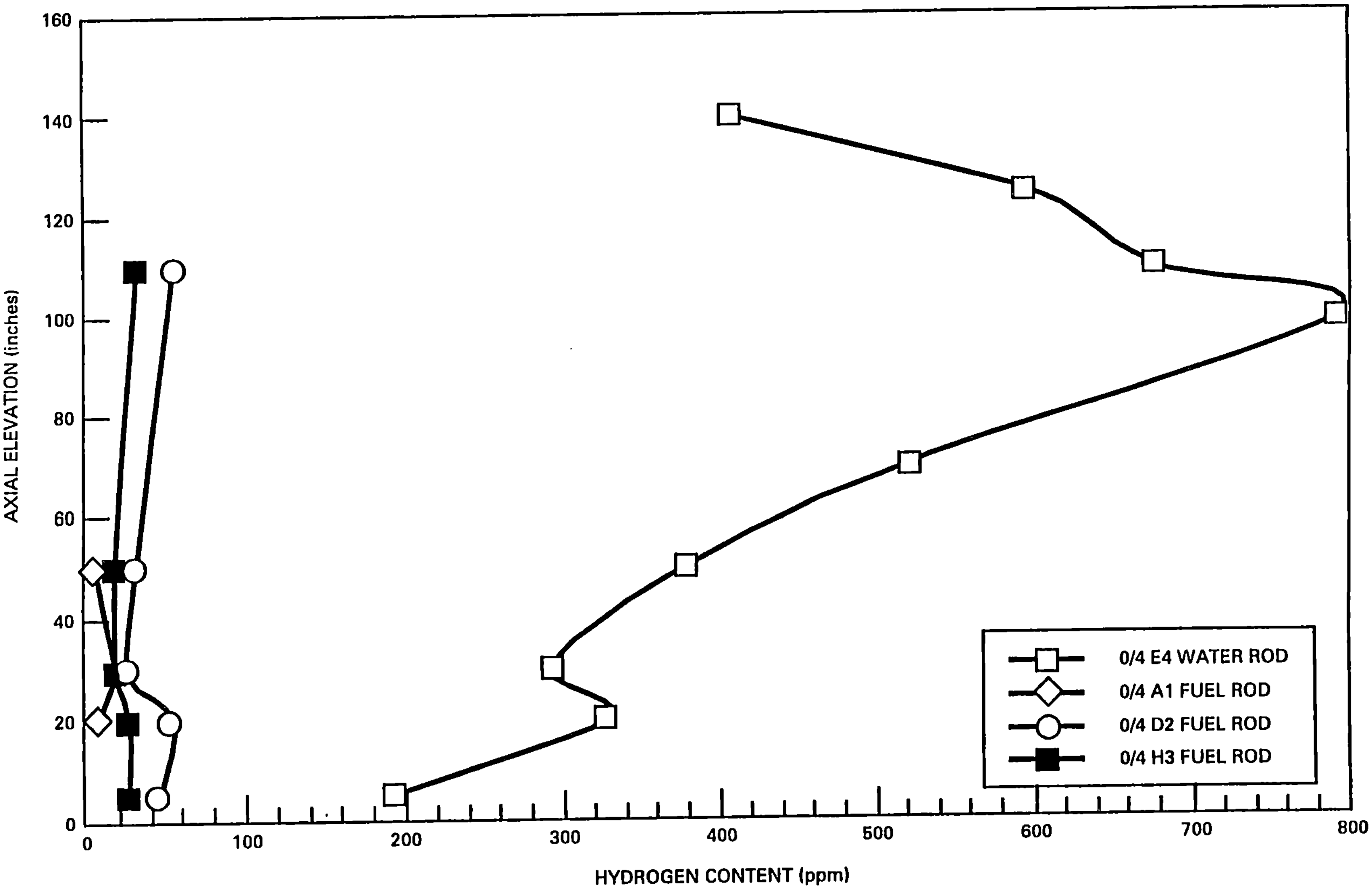


Figure 7-1. Hydrogen Distributions in LY5455 (0/4) Water Rod and Fuel Rods

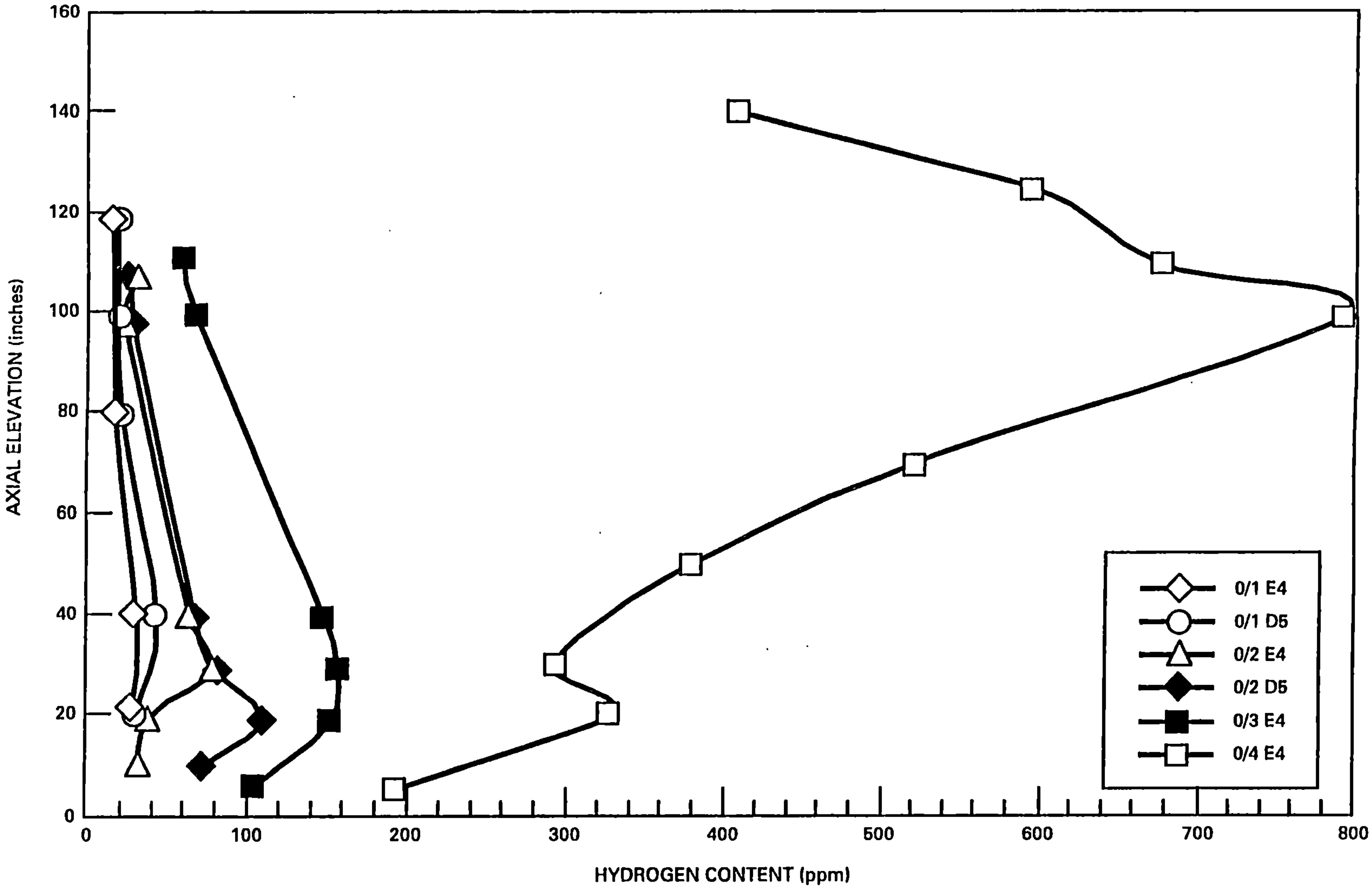


Figure 7-2. Hydrogen Distributions in LY5455/E4 Water Rod (0/4) Compared to Earlier Water Rod Results (1,2)

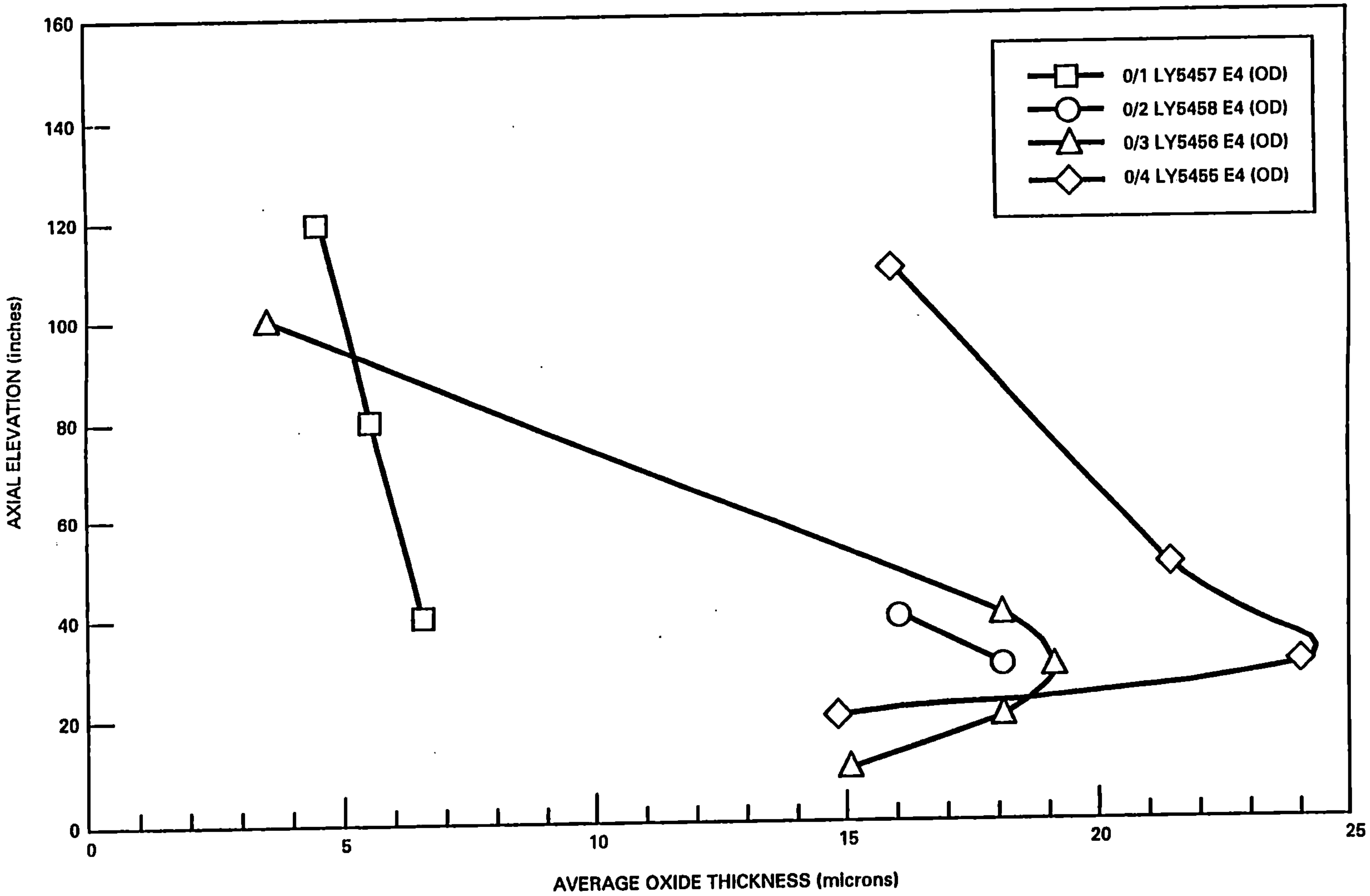


Figure 7-3. Water Rod Outer Surface Oxide Thickness versus Elevation After 1, 2, 3 and 4 Cycles of Hydrogen Water Chemistry

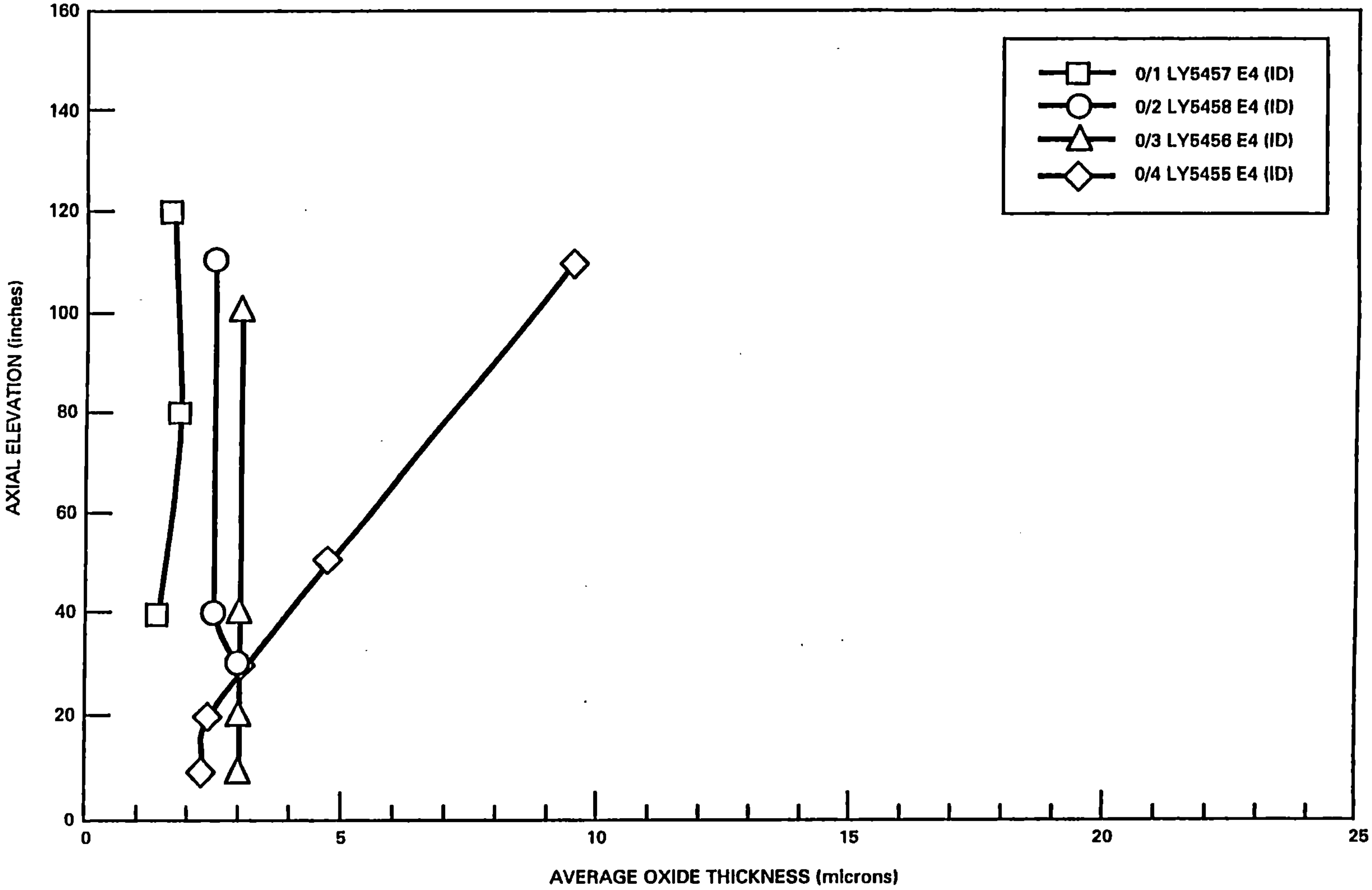


**Figure 7-4. Water Rod Inner Surface Oxide Thickness versus Elevation After 1, 2, 3 and 4 Cycles of Hydrogen Water Chemistry**

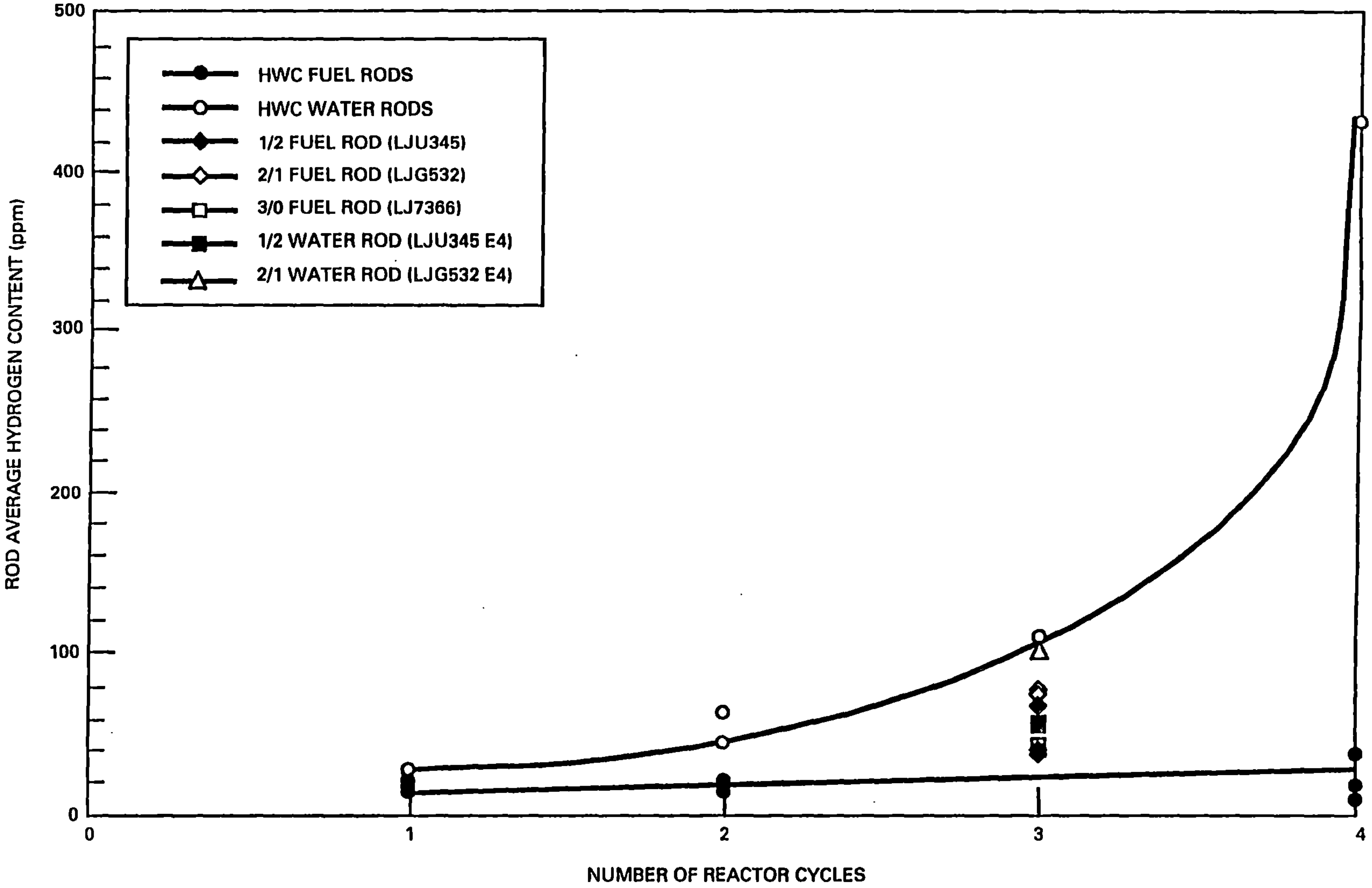


Figure 7-5. Rod Average Hydrogen Content versus Number of Cycles of Irradiation