

# **CENTER FOR NUCLEAR WASTE REGULATORY ANALYSES**

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## **TRIP REPORT**

**SUBJECT:** American Society of Testing and Materials (ASTM) C26 Fuel Cycle Committee Meeting and Workshop on Hydride Reorientation in Zirconium Alloys  
Project No. 20.06002.01.322; AI No. 06002.01.322.703

**DATE/PLACE:** January 29–February 1, 2007, Anaheim, California

**AUTHOR:** Y.-M. Pan [Center for Nuclear Waste Regulatory Analyses (CNWRA)]

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# CENTER FOR NUCLEAR WASTE REGULATORY ANALYSES

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## TRIP REPORT

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**AUTHOR:** Y.-M. Pan (CNWRA)

### PERSONS PRESENT:

Y.-M. Pan (CNWRA) and K. Chan from Southwest Research Institute® (SwRI®) attended the meeting. The participants included researchers from Pacific Northwest National Laboratory (PNNL), Argonne National Laboratory (ANL), Savannah River Laboratory, and Electric Power Research Institute and representatives from various countries and organizations such as CEA–France and Japan Nuclear Energy Safety Organization. Because of travel restrictions, U.S. Nuclear Regulatory Commission (NRC) staff members T. Ahn (High-Level Waste Repository Safety Division), C. Brown, and C. Interrante (Spent Fuel Storage and Transportation Division) participated in the workshop through teleconference connection.

### PURPOSE OF TRIP:

The meeting of ASTM Committee C26 was held during the January 2007 ASTM Committee week in Anaheim, California, January 29–February 1, 2007. The workshop on Hydride Reorientation in Zirconium Alloys was part of the meeting. The purpose of the trip was to participate in the ASTM C26.13 Subcommittee, which is primarily involved in the development of standard methods, guides, and practices for activities related to spent fuel and high-level waste. Another purpose was to attend the workshop. K. Chan made a presentation, co-authored by Y.-M. Pan, titled Cladding Stresses for Hydride Reorientation and Delayed Hydride Cracking. The work was funded by a focused internal research and development project at SwRI.

### SUMMARY OF PERTINENT POINTS:

#### ***ASTM C26.13 Subcommittee Meeting***

The author of this trip report participated in the discussions of two C26.13 Subcommittee task groups (i.e., C1174 Revision Task Group and Spent Nuclear Fuel Dissolution Task Group). The meeting agenda of Committee C26 is attached as Appendix I of this report. A brief summary of the pertinent points of these meetings is provided next.

Tom Thornton led the discussion on revision of ASTM C1174-04—Standard Practice for Prediction of the Long-Term Behavior of Materials, Including Waste Forms, Used in Engineered Barrier Systems for Geological Disposal of High-Level Radioactive Waste. He reported the status of the most recent draft revision. Extensive comments on the current and previous ballots were discussed, including suggested additions and clarifications to enhance utilization of

the standard and comments provided by the NRC staff. These comments will be resolved through e-mail discussions prior to the next meeting. Note that this standard has been widely quoted by the U.S. Department of Energy in the Analysis and Model Reports. As stated in the standard, this practice provides methods for developing models that predict material behavior over the long periods of time pertinent to a geological repository as part of the basis for repository performance assessment.

Brady Hanson (PNNL) presented a draft standard test method for Measuring the Dissolution Rate of Unirradiated and Spent Nuclear Fuel in Dilute Aqueous Solutions Using the Single-Pass Flow-Through Test Method. The development of this standard is intended to be generic (i.e., applicable for various types of waste forms). He plans to gather comments from international experts and then submit the draft for balloting in few months. In addition, round robin testing using unirradiated samples is planned and will be discussed in the June 2007 meeting.

### ***ASTM Workshop***

The two-day workshop included a plenary opening session with a number of invited presentations by experts on the latest technical information related to hydride reorientation, followed by a series of working group sessions. The objective of the workshop was to formulate an expert framework of ideas resolving uncertainties concerning various parameters associated with hydride reorientation. The following three critical questions were identified and discussed in working group sessions:

- Working Group #1: What factors affect hydride reorientation of zirconium alloy cladding?
- Working Group #2: What is the impact of the microstructure on the mechanical properties of zirconium alloy cladding?
- Working Group #3: How do we use the mechanical properties to assess the continued integrity of the cladding during fuel handling, transportation, storage, and disposal?

The workshop agenda and a list of participants are included in Appendix II of this trip report. A brief summary of some of the more pertinent presentations and working group discussions is provided next.

### **Summary of Plenary Presentations**

The plenary opening session started with a presentation from R. Einziger and C. Brown (NRC). The presentation provided an overview of the regulatory requirements and concerns about hydride reorientation for the transportation of high burnup spent nuclear fuel. They pointed out that there are limited data available for hydride reorientation of irradiated Zircaloy cladding and essentially no data for irradiated non-Zircaloy zirconium alloys. To support the licensing reviews for transportation of high burnup fuel, the need for testing high burnup fuel cladding to assess its structural integrity as the result of hydride reorientation was emphasized.

M. Aomi (Japan Nuclear Energy Safety Organization) discussed the fuel cladding property test results obtained during 2004–2005 to evaluate hydride reorientation behavior in interim dry storage. The testing program included hydride reorientation and mechanical property tests

using both high burnup irradiated Zircaloy-2 and Zircaloy-4 cladding. The degree of hydride reorientation mainly depended on the applied hoop stress and test temperature. Within the limited range of cooling rates evaluated, the effect of cooling rate on hydride reorientation was found to be insignificant.

R. Daum (ANL) discussed the testing program supported by the NRC Office of Nuclear Regulatory Research to assess hydride reorientation and embrittlement of high burnup Zircaloy-4 cladding. Radial hydride-induced embrittlement was observed to be the predominant failure mechanism of irradiated ring samples subjected to diametrical compression. Future work includes testing of new fuel cladding materials such as ZIRLO and M5.

In the absence of C. Cappelaere (CEA–France), J. Abrefah (PNNL), the workshop chair made a presentation titled PRECCI Project: Hydride Reorientation Studies. The studies were carried out on unirradiated Zircaloy-4 cladding tubes to assess the critical conditions leading to radial hydride precipitation and its effect on the mechanical strength of the cladding. The results showed that the critical hoop stress for radial hydride precipitation depends on the test temperature (about 100 MPa at 350 °C, 80 MPa at 400 °C, and 60 MPa at 470 °C). Additional studies to evaluate the formation of radial hydride for irradiated Zircaloy-4 cladding and other zirconium alloys are planned.

K. Chan (SwRI) discussed the uncertainties of cladding stresses for the onset of hydride reorientation and delayed hydride cracking in high burnup cladding. Transient stresses induced during power ramps, transportation accidents, or seismic events could extend cladding cracks by delayed hydride cracking, leading to uncertainties in crack length and threshold stress. A predictive methodology for treating uncertainties in cladding stresses and hydride-induced cladding failure is being developed.

T. Ahn (NRC) presented hydride effects in the cladding performance for the safe geological disposal of high-level waste. Potential issues associated with hydride-induced cladding embrittlement were discussed, including radiation damage, local stresses from fuel and cladding interactions, cooling rate, and seismic-induced stresses. As a result, cladding protection in the long-term repository performance could be compromised.

### Working Group Summaries

Working Group #1 focused its discussion on factors that may affect hydride reorientation of zirconium alloy cladding. The group identified a list of primary factors that might influence hydride reorientation, including material type and chemistry, fuel rod internal pressure, reactor operation properties, and cladding fabrication history. To address the data needs for irradiated cladding materials, the group recommended building a database on unirradiated materials with a few spot tests on irradiated materials to confirm the applicability of unirradiated material tests. In addition, it may be necessary to develop standard test methods for determining a criterion and/or a quantitative measure for hydride reorientation.

Working Group #2 focused its discussion on mechanical properties and testing of zirconium alloy cladding. There was agreement regarding the need to establish a number of mechanical properties of cladding, including constitutive stress-strain relation, local ductility for crack initiation, fracture resistance, and the effects of temperature and strain rate. The group recommended a testing program for irradiated and unirradiated specimens to determine the

convergence of the data to reduce scope and cost of irradiated material testing. Confirmatory testing of few fueled specimens was also suggested to determine the fracture and dispersal behavior of the fuel.

Working Group #3 focused its discussion on assessing fuel cladding integrity under hypothetical accident conditions during transportation applications. Other scenarios of interest to storage and disposal (such as handling accidents during preclosure operations) were considered to be similar to those for transportation. The group recognized that assessment of cladding integrity under hypothetical accident conditions requires the use of models that simulate phenomena occurring over a timeframe of the order of 10 milliseconds. This assessment, however, should be performed on a generic basis taking into account specific properties for different types of cladding materials.

**CONCLUSIONS:**

The assistance to the ASTM Committee meeting was useful in keeping current with the development of international standards related to high-level waste. The workshop provided an excellent opportunity to follow the main topics associated with hydride reorientation in zirconium alloys and to obtain feedback from technical experts on the assessment of cladding integrity during spent nuclear fuel handling and disposal.

**PROBLEMS ENCOUNTERED:**

None.

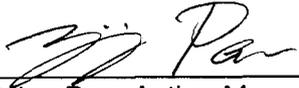
**PENDING ACTIONS:**

None.

**RECOMMENDATIONS:**

Staff should continue to participate at the ASTM C26 Committee meetings. The next meeting will be held in Norfolk, Virginia, on June 24–28, 2007. Participation in the ASTM spent fuel dissolution round robin testing will provide credibility to the spent fuel studies at CNWRA supported by the NRC. In addition, it is recommended to closely follow the workshop path forward to address the hydride reorientation issues and participate in the potential development of standard test methods and guides on fuel cladding.

**SIGNATURE:**



Yi-Ming Pan, Acting Manager  
Corrosion Science and Process Engineering

2/22/2007

Date

**CONCURRENCE**



Sitakanta Mohanty, Assistant Director  
Engineering and Systems Assessment

2/22/2007

Date

Attachments

YP:SM:jg

**APPENDIX I**

**ASTM COMMITTEE C26 MEETING AGENDA**



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## Meetings

### Meetings / Line Schedule

Meeting Of Committee C26  
 Sunday January 28 2007 - Thursday February 01 2007  
 Hilton Anaheim, Anaheim, CA

Meeting	Day	Start - Stop Times	Room
C26 Workshop on Hydride Re-Orientation in Zirconium Alloys	Wednesday	08:00AM - 06:30PM	Avila
C26 Workshop on Hydride Re-Orientation in Zirconium Alloys	Thursday	08:00AM - 03:15PM	Avila
C26 Main Opening	Monday	08:30AM - 09:00AM	Pacific C
C26 E10 Joint Meeting (C26 Chairs/E10 minutes)	Monday	05:00PM - 06:00PM	Palos Verdes
C26 /E10 Joint Reception	Monday	06:00PM - 07:00PM	Palisades
C26 Main Closing	Tuesday	05:00PM - 06:00PM	Huntington C
C26 Workshop/Breakout #1	Wednesday	08:00AM - 05:00PM	Salinas
C26 Workshop/Breakout #1	Thursday	08:00AM - 05:00PM	Monterey
C260100 Subcommittee on Terminology	Tuesday	03:00PM - 05:00PM	Salinas
C260200 Subcommittee on Fuels	Monday	09:00AM - 05:00PM	Pacific C

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C260200 Subcommittee on Fuels	Wednesday	08:30AM - 12:30PM	Laguna B
C260300 WM936 Task Group	Monday	08:00AM - 05:00PM	Ventura
C260300 Subcommittee on Neutron Absorber Materials	Tuesday	08:30AM - 03:00PM	Salinas
C260500 Subcommittee on Test Methods (opening meeting)	Monday	01:00PM - 05:00PM	Santa Barbara
C260500 .04 Task Group on Uranium Methods	Tuesday	08:30AM - 12:00PM	Santa Barbara
C260500 .01 Task Group on Environmental Methods	Tuesday	01:00PM - 04:00PM	Santa Barbara
C260500 .02 Task Group on Plutonium Methods	Wednesday	09:00AM - 12:00PM	Santa Barbara
C260500 .03 Task Group on Spectroscopy	Wednesday	01:00PM - 04:00PM	Santa Barbara
C260500 Subcommittee on Test Methods (closing meeting)	Wednesday	04:00PM - 05:00PM	Santa Barbara
C260700 /.13 Joint Meeting	Monday	03:00PM - 05:00PM	Santa Monica
C260800 Quality Assurance, Statistical Applications, and Reference Materials	Monday	09:00AM - 12:00PM	Santa Barbara
C260900 Nuclear Processing	Tuesday	08:00AM - 05:00PM	Ventura
C261000 Non Destructive Assay	Monday	09:00AM - 10:00AM	Malibu
C261000 NDA Good Practices Guide	Monday	10:00AM - 05:00PM	Malibu
C261000 InSitu NDA Task Group	Tuesday	09:00AM - 05:00PM	Huntington C
C261000 TGS Task Group	Wednesday	09:00AM - 05:00PM	Coronado
C261200 Subcommittee on	NOT		

Safeguards	MEETING		
C261300 Spent Fuel and High Level Waste (Full Subcommittee)	Monday	09:00AM - 03:00PM	Santa Monica
C261300 Task Group on Metallic Spent Nuclear Fuel	Tuesday	08:00AM - 10:00AM	Redondo
C261300 Task Group on Drying of Spent Nuclear Fuel	Tuesday	10:00AM - 12:00PM	Redondo
C261300 C1174 Revision Task Group	Tuesday	01:00PM - 02:00PM	Redondo
C261300 Spent Nuclear Fuel Dissolution Task Group	Tuesday	02:00PM - 04:30PM	Redondo
C261300 Task Group on Commercial Light-Water Reactor Spent Fuel	Tuesday	04:30PM - 06:30PM	Redondo
C261400 Remote Systems	Tuesday	09:00AM - 05:00PM	La Jolla
C261400 Remote Systems	Wednesday	08:30AM - 12:00PM	Ventura
C269000 Executive Committee	Sunday	03:00PM - 05:00PM	San Clemente

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**APPENDIX II**

**ASTM WORKSHOP ON HYDRIDE REORIENTATION IN ZIRCONIUM ALLOYS  
AGENDA AND LIST OF PARTICIPANTS**



*ASTM Subcommittee C26.13, Spent Fuel and High Level Waste,  
Workshop on Hydride Re-Orientation in Zirconium Alloys,  
Anaheim, CA, January 31 - February 1, 2007*

**AGENDA**

**Wednesday, January 31, 2007**

<b>Time</b>	<b>Topic</b>	<b>Speaker</b>
<b>PLENARY SESSION</b>		
8:00 AM – 8:15 AM	Introductory Remarks	Dr. John Abrefah, Chair
8:15 AM – 8:40 AM	Workshop Technology Perspective	Dr. Robert Einziger by Telecon
8:45 AM – 10:45 AM	Invited Speakers	
10:45 AM – 11:00 AM	BREAK	All
11:00 AM – 11:30 AM	Q&A plus Discussion	All
11:30 AM – 12:00 PM	Formulate Issues and Form Breakout Groups	All
12:00 PM – 1:00 PM	Lunch Break	All
<b>BREAKOUT SESSIONS</b>		
1:00 PM – 3:00 PM	1 <sup>st</sup> Breakout	All Groups
3:00 PM – 3:15 PM	BREAK	All
3:15 PM – 4:45 PM	2 <sup>nd</sup> Breakout	All Groups
4:45 PM – 5:15 PM	Wrap-up for the day	Group Leads
6:30 PM	Invited to Join Group Dinner (optional)	All

**Thursday, February 1, 2007**

<b>Time</b>	<b>Topic</b>	<b>Speaker</b>
<b>BREAKOUT SESSSIONS</b>		
8:00 AM – 10:00 AM	3 <sup>rd</sup> Breakout	All Groups
10:00 AM – 10:15 AM	BREAK	All
10:15 AM – 11:30 AM	4 <sup>th</sup> Breakout	All Groups
11:30 AM - 12:30 PM	Lunch Break	All
<b>WRAP-UP SESSION</b>		
12:30 PM – 1:30 PM	Group Wrap-up	Group Leads
1:30 PM – 3:00 PM	Path Forward Discussion/Summary	All/ John Abrefah
3:00 PM – 3:15 PM	Final Remarks	John Abrefah/Gary Smith



*ASTM Subcommittee C26.13, Spent Fuel and High Level Waste,  
Workshop on Hydride Re-Orientation in Zirconium Alloys,  
Anaheim, CA, January 31 - February 1, 2007*

### Invited Presentations

Time (AM)	Topic	Speaker
8:45 – 8:50	Introduction of Invited Speakers	Chair
8:50 – 9:10	Fuel cladding property test for evaluation of hydride reorientation behavior in Interim Dry Storage	Dr. Masaki Aomi
9:10 – 9:20	Hydride Re-orientation and Embrittlement of Zircaloy-4 Cladding	Dr. Robert Daum
9:20 – 9:30	Hydride Reorientation Studies on Unirradiated CWSR Zircaloy 4 Cladding Tubes	Drs. Chantal Cappelaere/Claude Sainte-Catherine
9:30 – 9:40	Cladding Stresses for Hydride Re-Orientation and Delayed Hydride Cracking	Dr. Kwai S. Chan
9:40 – 9:50	Hydride Effects In the Cladding Performance For SNF Disposition	Dr. Tae Ahn
9:50 – 9:55	Introduction of Invited Speakers	Chair
9:55 – 10:05	Stress Orientation of Hydrides in Zircaloy 2 and 4	Dr. M.P. Louthan
10:05 – 10:15	The Ductility of Radial Hydrides	Dr. Kjell Pettersson
10:15 – 10:25	Modeling of the Formation and Damage Mechanisms of Radial Hydrides in High-Burnup Spent Fuel	Dr. Joseph Y. R. Rashid
10:25 – 10:35	Hydride Reorientation in Zircaloy Cladding: An Update from INER	Dr. Kuo Roang-Chin
10:35 – 10:45	Impact of Hydride Re-orientation on Creep-Rupture Behavior of High Burnup Cladding	Dr. Wolfgang Goll



*ASTM Subcommittee C26.13, Spent Fuel and High Level Waste,  
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Anaheim, CA, January 31 - February 1, 2007*

**Participants List - 1**

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*ASTM Subcommittee C26.13, Spent Fuel and High Level Waste,  
Workshop on Hydride Re-Orientation in Zirconium Alloys,  
Anaheim, CA, January 31 - February 1, 2007*

**Participants List – 2**

- |    |   |    |  |
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