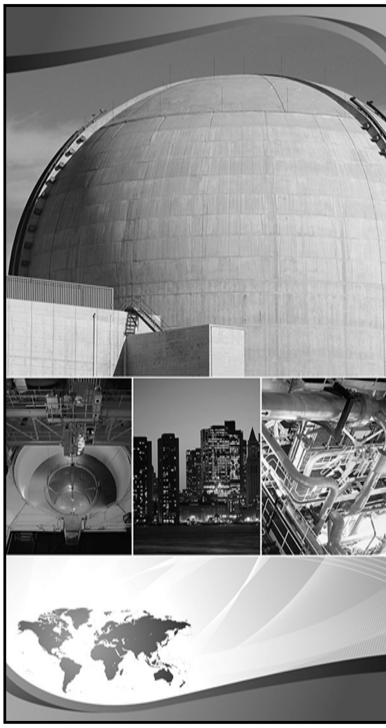

ELECTRIC POWER RESEARCH INSTITUTE

NRC Information Meeting

Neutron Absorbing Material Technology

February 27, 2009
Washington DC

Ray W. Lambert

Purpose of the Meeting

- Provide background and understanding on where neutron absorber technology now stands
- Define the historical roles that EPRI and utilities have played in developing the technology
- Provide current status and experience base for the materials now in use

ELECTRIC POWER RESEARCH INSTITUTE

Early History

- Boraflex was introduced in the later 1970s and dominated the market through the 1980s
  - Cost and ease of fabrication were the main advantages
  - About 75 spent storage pools worldwide installed Boraflex
- Problems emerged after a few years in service
  - Embrittlement at relatively low radiation doses
  - Cracking and shrinking were observed
- Minimal technical support was available to utilities
  - Manufacturer was unwilling/unable to assist
  - Rack vendors denied any responsibility
  - Search of qualification information produced only minimal and inconsistent data

EPRI | ELECTRIC POWER RESEARCH INSTITUTE

Early History (continued)

- Insufficient information existed for utilities to perform root-cause analyses
- Utilities requested EPRI help in 1986
  - NETCO selected as contractor by EPRI because of background in criticality analyses, fuel design and material sciences
- EPRI formed the Boraflex Working Group (BWG) to fund and provide oversight to Boraflex-related R&D activities
- Early charter was aimed at:
  - Developing understanding of Boraflex degradation mechanisms
  - Develop techniques to measure and manage degradation

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EPRI | ELECTRIC POWER RESEARCH INSTITUTE

Early History (continued)

- Utilities have always been highly motivated to support materials R&D
  - Pool safety is the paramount concern
  - Pool storage space is critical to keeping reactors operating
  - Alternatives to pool storage have long lead times and are very expensive
- The Boraflex quagmire had a reasonably good outcome
  - Material behavior was modeled as a function of variables
  - Gap growth was understood and was predictable
  - Comprehensive test programs were put in place
    - Penn State
    - Irradiations at AFRRI
    - Full-scale panel tests at Beaver Valley 2
    - Multiple coupon tests
  - RACKLIFE model and BADGER equipment were developed to predict and measure degradation

The NRC/EPRI Interface

- NRC became aware of issue in the mid-1980s and issued the first Information Notice in September 1987
- Situation, however, lacked clarity in 1987
  - Boraflex manufacturer was exiting the business
  - No technical support available from rack vendors
  - NRC had no R&D underway
  - EPRI's R&D program had begun and first information was beginning to emerge
- Major decision was made by BWG to share information with NRC on a real-time basis
  - NRC actually attended portions of BWG workshops
  - Reports were shared with NRC as produced
  - NRC Generic Letter (dated June 1996) was issued after full consideration of EPRI R&D

The NRC/EPRI Interface (continued)

- The BWG program resulted in the Boraflex issue being managed both safely and efficiently
  - Several pools are still taking credit (partial) for their remaining Boraflex
  - Comprehensive database has been developed that supports RACKLIFE and BADGER

Follow-On Work to the BWG

- Boraflex was superseded by other neutron absorbing materials, primarily Boral®
- The scope of the BWG was expanded to cover all absorbing materials and the group was renamed the Neutron Absorber Users Group (NAUG)
- The observed shortcomings in Boral shifted NAUG's focus of activity to:
  - Exploring and qualifying new materials such as Metamic
  - Developing comprehensive testing and qualification protocols for new neutron absorbing materials
  - Development of the Neutron Materials Handbook (being updated in 2009)
    - Materials described with engineering parameters
    - Experience listed for all materials
    - Factors to be considered in using neutron absorbing materials

Current Status of NAUG

- Still going strong with membership representing over 60 reactors in the U.S. plus 1 international utility member
- Less than 20% of NAUG activities are now related to Boraflex
- Have held 24 workshops for NAUG members with number 25 scheduled for this coming August
- Have produced some 70 reports and papers
- Have spent over $4M on neutron absorber R&D

Conclusion

- Utilities and EPRI have been major players in the development and use of neutron absorbing materials technology
- Monitoring material performance, testing of materials, and exploring new materials continue to receive high utility priority
- Continuity of effort has been maintained through the utility support of the EPRI NAUG and by the long-term relationship between EPRI and NETCO
- After a shaky start, the intelligent use of neutron absorbing materials is now a well understood technology
- However, vigilance is still required in order to maintain adequate performance and safety margins

NETCO NORTHEAST TECHNOLOGY CORP

NRC Information Meeting Neutron Absorber Materials

In-Service Performance of Boraflex

Ken Lindquist

2/27/09

Rockville, MD

NETCO

Outline - Performance in Spent Fuel Racks

- What is Boraflex in the as-manufactured condition?
- What is Boraflex after service in the spent fuel pool environment?
- What tools are available to monitor service environment induced changes in Boraflex?
- Defense-in-depth approach for managing changes in Boraflex.

2

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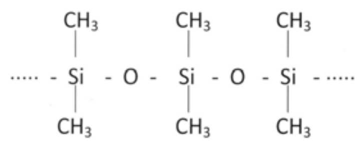
Chemical Form and Composition of As-Manufactured Boraflex

PDMS Matrix (Silicon Rubber)



Composition

Matrix: 25 w/o

Fillers:

B_4C 50 w/o

Silica 25 w/o (Min-u-Sil 5 Crystalline Silica)

3

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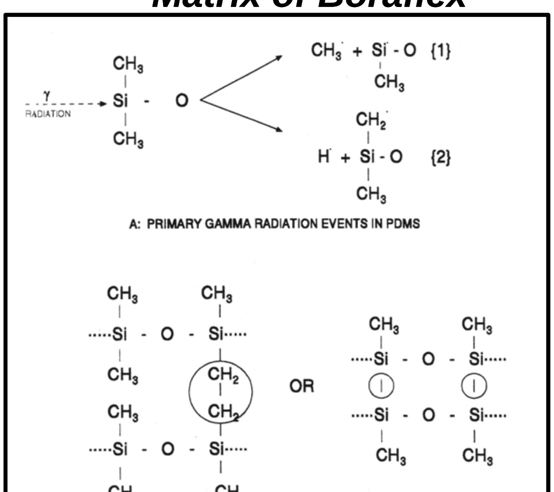
Effect of Gamma Radiation on Polymer Matrix of Boraflex



A: PRIMARY GAMMA RADIATION EVENTS IN PDMS

B: SUBSEQUENT CROSSLINK BOND FORMATION

4

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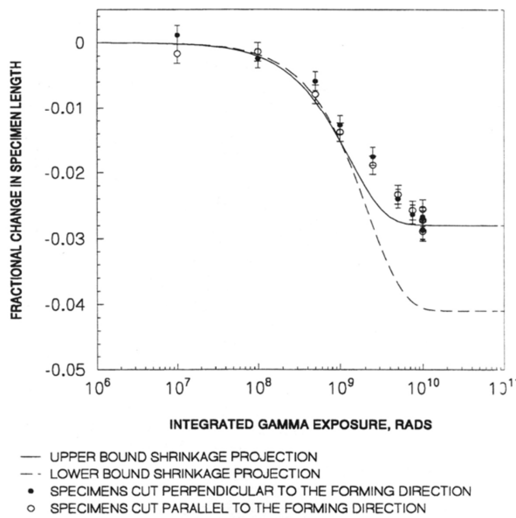
Cross-Linking Induced Shrinkage of Boraflex



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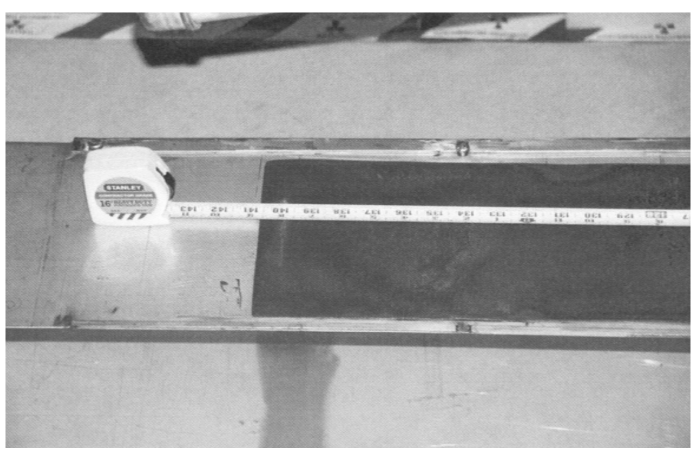
In-Service Shrinkage of Boraflex



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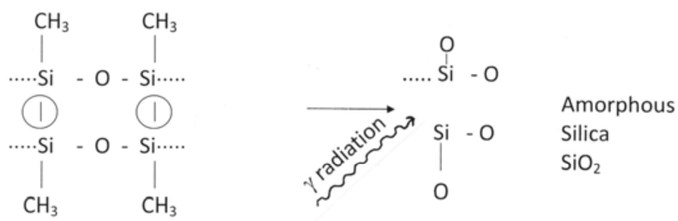
Highly Cross-Linked PDMS

- Vacancies created by abstraction of CH_3 + H radicals immobilized by high number of cross-link bonds and cannot form additional crosslinks
- Free oxygen from pool water scavenged by vacancies
- Concurrent chain scissioning of the Si - O - Si back bone of the polymer by gamma radiation



- Composition after Exposure to Service Environment:

B_4C - 50 w/o | Crystalline Silica - 25 w/o
Residual Organics - 5 w/o | Amorphous Silica - 20 w/o

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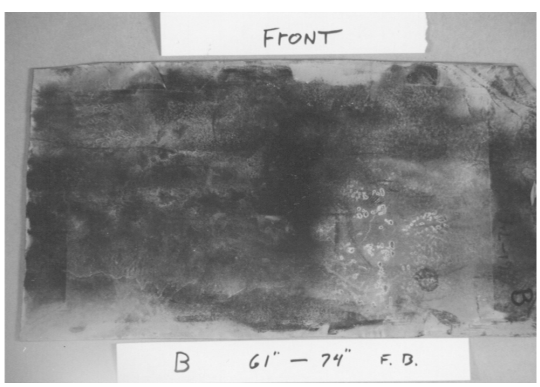
Boraflex Removed from Spent Fuel Racks



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Tracking the Performance of Irradiated Boraflex

- Surveillance Coupon Testing
- Monitor Pool Soluble Silica Levels
- Compare with Industry Performance Data
  - Annual Workshops
  - EPRI Pool Silica Database
- BADGER Testing
- RACKLIFE Simulation

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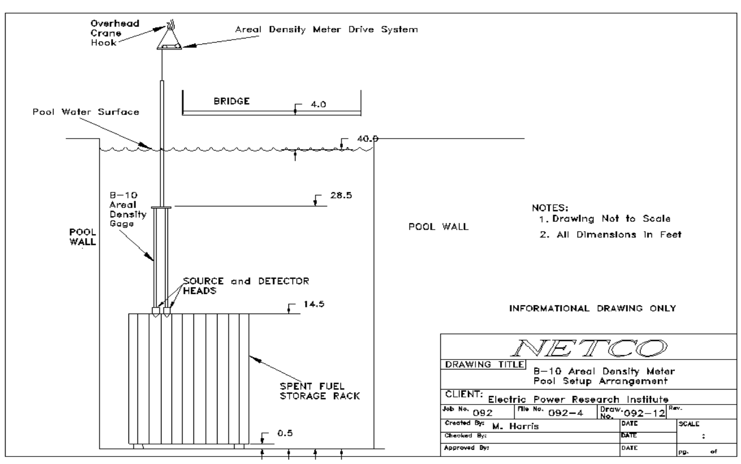
BADGER - Boron-10 Areal Density Gage for Evaluation Racks



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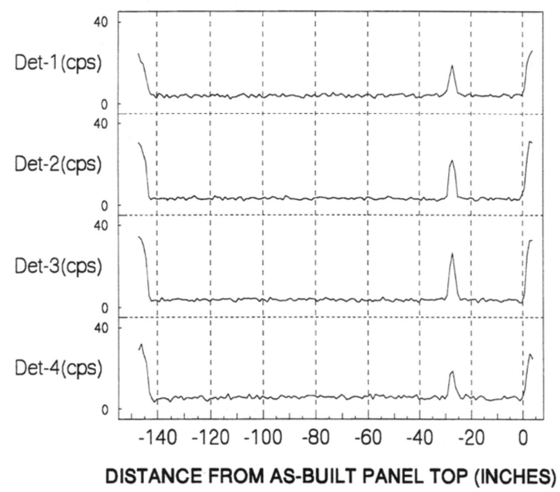
BADGER Detector Outputs



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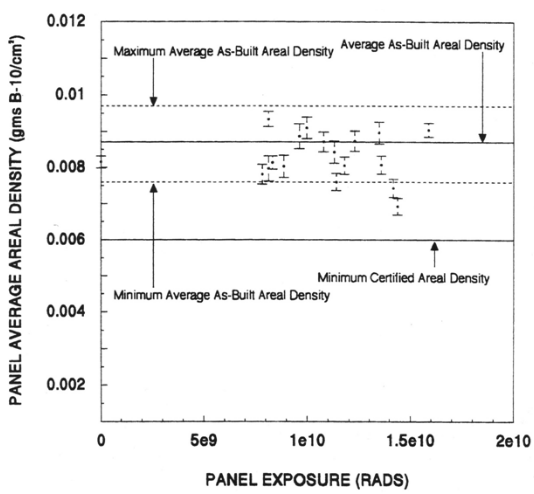

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RACKLIFE

- Mass balance of one decomposition product (soluble silica) of degrading Boraflex from rack cavities containing Boraflex to bulk pool volume
- Mass balance is based on first principles
- Very large Windows® based program - keeps track of B_4C loss from all panels of Boraflex in a pool (as many as 8000 in some cases)

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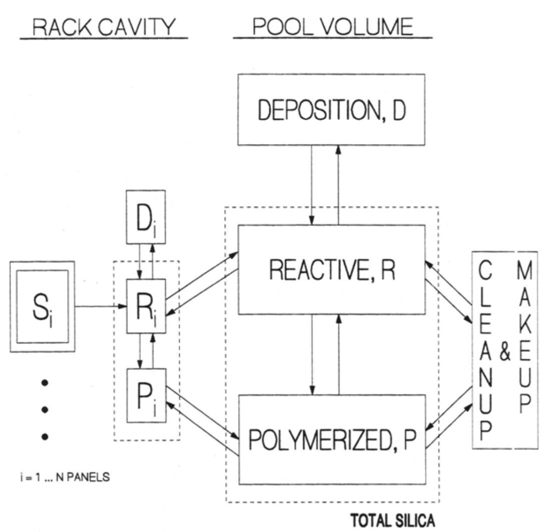
Kinetics of Silica Transport in a Spent Fuel Pool



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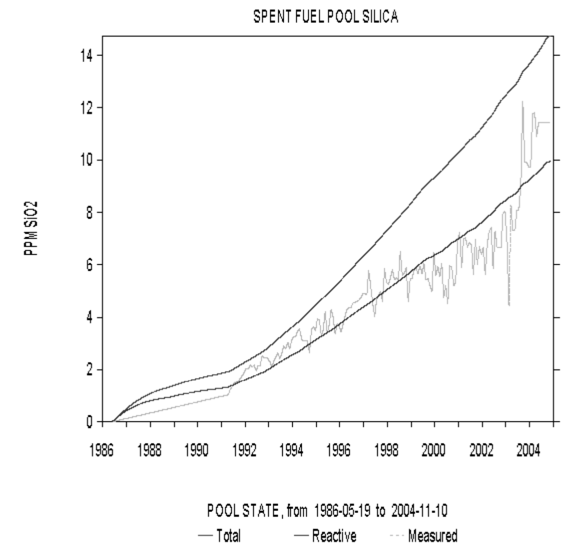
Spent Fuel Pool Silica



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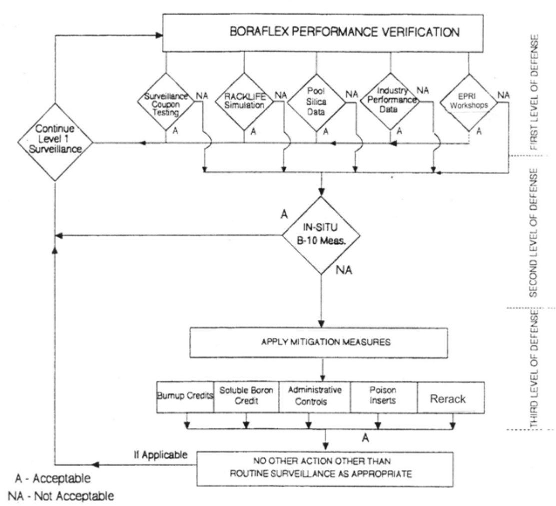
Defense-in-Depth Strategy for Managing Irradiated Boraflex



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Conclusions: Boraflex In-Service Performance

- The polymer matrix of Boraflex is subject to in-service degradation
- The industry has developed tools to track and manage Boraflex degradation
- Mitigation measures are available to restore reactivity holddown of racks with degraded Boraflex

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NRC Information Meeting
Neutron Absorber Materials

In-Service Performance of BORAL®

Ken Lindquist
2/27/09
Rockville, MD

NETCO

Outline - BORAL® Performance in Spent Fuel Racks & Casks

- What is BORAL®?
- Where has BORAL® been used?
- What are the performance issues with respect to BORAL®?
- What has been done to mitigate these performance issues?

2

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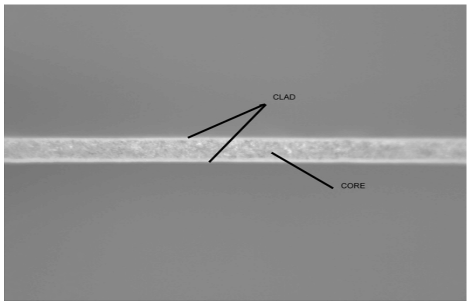
BORAL® Cermet Composite



CLAD: AA1100 alloy typically 0.010” thick on both sides

CORE: AA1100 alloy and B_4C mixture plus some porosity

CORE Composition:

- Has been produced with 30 - 60 w/o B_4C
- Now typical B_4C loading is ~50 w/o B_4C

3

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BORAL® Used Extensively for Wet and Dry Storage Since 1964

Partial List of LWRs Where BORAL® Has Been Used in Spent Fuel Storage Racks

Pool	Plant Type	DES/MAN	Cells	Country
BEAVER VALLEY 1	PWR	Holtec	1621	USA
BELLEFONTE 1	PWR	Westinghouse	1058	USA
BRAIDWOOD 1&2	PWR	Holtec	2984	USA
BROWNS FERRY 1	BWR	GE	3471	USA
BROWNS FERRY 2	BWR	GE	3471	USA
BROWNS FERRY 3	BWR	GE	3471	USA
BRUNSWICK 1	BWR	Holtec	1839	USA
BYRON 1&2	PWR	Holtec	2984	USA
CALLAWAY	PWR	Holtec	1302	USA
COMANCHE PEAK 1	PWR	Holtec	222	USA
COMANCHE PEAK 2	PWR	Holtec	219	USA
CONN YANKEE	PWR	Holtec		USA
COOK 1&2	PWR	Holtec	3613	USA
COOPER	BWR	NES		USA
CRYSTAL RIVER 3	PWR	Westinghouse	932	USA
DAVIS BESSE 1	PWR	Holtec	1624	USA
DRESDEN 1	BWR	CECO	3537	USA
DRESDEN 2	BWR	CECO	3537	USA
DRESDEN 3	BWR	CECO	3537	USA
DUANE ARNOLD	BWR	PAR	1898	USA
DUANE ARNOLD	BWR	Holtec	1254	USA
FERMI 2	BWR	Holtec	559	USA
FITZPATRICK	BWR	PAR	2797	USA
FITZPATRICK	BWR	Holtec		USA
FT. CALHOUN	PWR	Holtec	160	USA
HARRIS 1: Pool B	PWR	Holtec	484	USA
HATCH 1	BWR	GE	5830	USA
HATCH 2: Unit Pool	BWR	GE	2765	USA
HOPE CREEK	BWR	Holtec	3998	USA
HUMBOLDT BAY 3	BWR	Unknown		USA
INDIAN POINT 3	PWR	UST&D	1340	USA
KEWAUNEE	PWR	Holtec	215	USA

4

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Partial List of LWRs Where BORAL® Has Been Used in Spent Fuel Storage Racks

Pool	Plant Type	DES/MAN	Cells	Country
KOEBERG 1	PWR	Holtec		South Africa
KOEBERG 2	PWR	Holtec		South Africa
KORI-4	PWR	Holtec		South Korea
KUOSHENG 1	BWR	ENSA	1578	Taiwan
KUOSHENG 2	BWR	ENSA	1578	Taiwan
LAGUNA VERDE 1	BWR	Holtec		Mexico
LAGUNA VERDE 2	BWR	Holtec		Mexico
LASALLE 1	BWR	UST&D	4029	USA
LIMERICK 1	BWR	Holtec	2500	USA
LIMERICK 2	BWR	Holtec	2766	USA
MAINE YANKEE	PWR	PAR	1464	USA
MCGUIRE 1	PWR	Holtec	286	USA
MCGUIRE 2	PWR	Holtec	286	USA
MILLSTONE 3	PWR	Holtec	1104	USA
MONTICELLO	BWR	GE	2229	USA
NINE MILE POINT 1	BWR	Holtec	3496	USA
OYSTER CREEK	BWR	Holtec	390	USA
SALEM 1	PWR	ENC	1117	USA
SALEM 1	PWR	Holtec	1117	USA
SALEM 2	PWR	ENC	1139	USA
SALEM 2	PWR	Holtec	1139	USA
SEABROOK 1	PWR	Westinghouse	576	USA
SEQUOYAH 1	PWR	Westinghouse	2091	USA
SEQUOYAH 2	PWR	Holtec		USA
SEQUOYAH 2	PWR	PAR	2091	USA
SIZEWELL B	PWR	Holtec	1901	United Kingdom
SUMMER 1	PWR	Holtec	1712	USA
SUSQUEHANNA 1	BWR	PAR	2840	USA
SUSQUEHANNA 2	BWR	PAR	2840	USA
THREE MILE ISLAND 1	PWR	Holtec	1284	USA
TURKEY POINT 3	PWR	Holtec	131	USA
TURKEY POINT 4	PWR	Holtec	131	USA
ULCHIN 1	PWR	Holtec	1000	South Korea
VERMONT YANKEE	BWR	UST&D	2860	USA
VOGTLE 1	PWR	Unknown	1476	USA
WATERFORD 3	PWR	Holtec	2232	USA

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Partial List of LWRs Where BORAL® Has Been Used in Spent Fuel Storage Racks

Pool	Plant Type	DES/MAN	Cells	Country
WATTS BAR 1	PWR	Holtec	1610	USA
WATTS BAR 2	PWR	Holtec	1610	USA
YANKEE ROWE	PWR	PAR	721	USA
YONGGWANG 1	PWR	Holtec	1152	South Korea
YONGGWANG 2	PWR	Holtec	1152	South Korea
ZION 1	PWR	Holtec	3012	USA
ZION 2	PWR	Holtec	3012	USA
ANGRA 1	PWR	Holtec	1252	Brazil
CATTENOM-1	PWR	Framatome	2520	France
CATTENOM-2	PWR	Framatome	2520	France
CATTENOM-3	PWR	Framatome	2520	France
CATTENOM-4	PWR	Framatome	2520	France
BELLEVILLE-1	PWR	Framatome	1260	France
BELLEVILLE-2	PWR	Framatome	1260	France
NOGENT-1	PWR	Framatome	1260	France
NOGENT-2	PWR	Framatome	1260	France
PENLY-1	PWR	Framatome	1260	France
PENLY-2	PWR	Framatome	1260	France
GOLFECH-1	PWR	Framatome	1260	France
GOLFECH-2	PWR	Framatome	1260	France

6

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Partial List of LWRs Where BORAL® Has Been Used for Dry Storage Casks in the U.S.

Plant	Type	Supplier	Module Capacity	Absorber Type
ARKANSAS 2	Hi-Storm 100(MPC-32)	Holtec	32	BORAL
CATAWBA 1	UMS-24	NAC	24	BORAL
DIABLO CANYON 1	Hi-Storm 100(MPC-32)	Holtec	32	BORAL
DIABLO CANYON 2	Hi-Storm 100(MPC-24)	Holtec	24	BORAL
DRESDEN 2	Hi-Storm 100(MPC-68)	Holtec	68	BORAL
DUANE ARNOLD	NUHOMS-61BT	Transnuclear	61	BORAL
FITZPATRICK	Hi-Storm 100(MPC-68)	Holtec	68	BORAL
HADDAM NECK	MPC-24	NAC	24	BORAL
HATCH 2	Hi-Storm 100(MPC-68)	Holtec	68	BORAL
MAINE YANKEE	UMS-24	NAC	24	BORAL
PALO VERDE 1	UMS-24	NAC	24	BORAL
PEACH BOTTOM 2	TN-68	Transnuclear	68	BORAL
PRAIRIE ISLAND 1	TN-40	Transnuclear	40	BORAL
SEQUOYAH 2	Hi-Storm 100(MPC-32)	Holtec	32	BORAL
TROJAN	Hi Storm MPC(24)	Holtec	24	BORAL
SUSQUEHANNA 1	NUHOMS-61BT	Transnuclear	61	BORAL

7

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BORAL® Performance Issues

Wet Storage - Some BORAL® susceptible to:

- Generalized Corrosion
- Localized Corrosion
- Clad Blister Formation

Dry Storage - Some BORAL® susceptible to:

- Clad blister formation during vacuum drying operations

8

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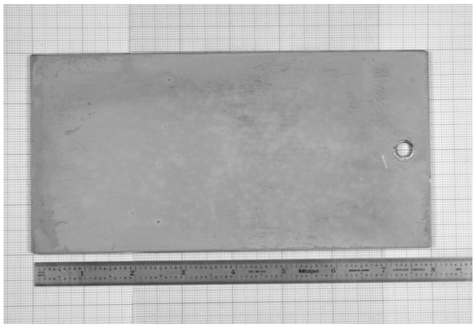
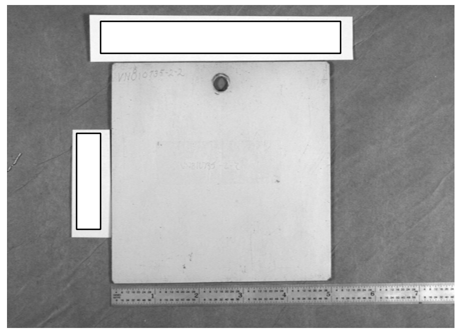
BORAL® Surveillance Coupons
Generalized Corrosion

PWR Coupon



BWR Coupon



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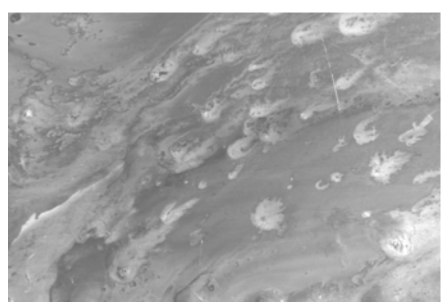
BORAL® Surveillance Coupons
Pitting Corrosion

Macro Photograph

Micro Photograph



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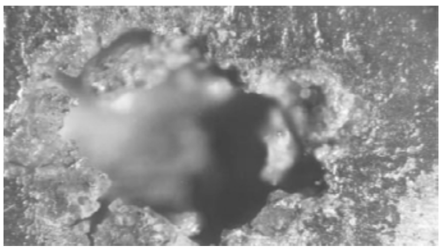
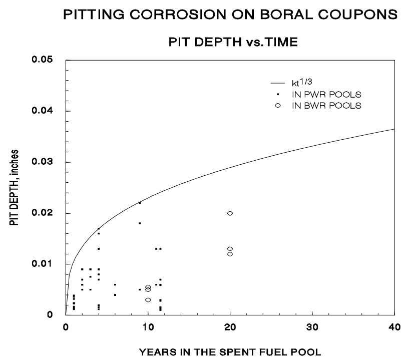
BORAL® Surveillance Coupons
Pitting Corrosion

Photo Micrograph





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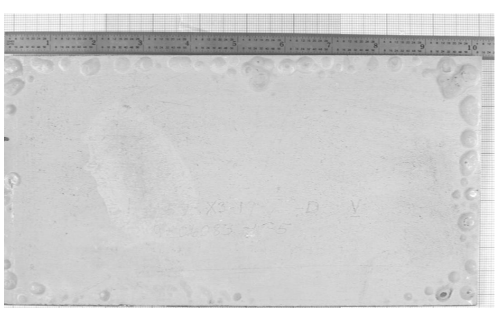
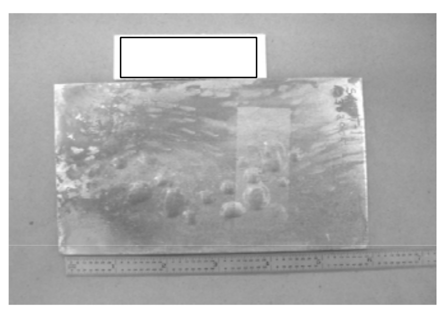
BORAL® Surveillance Coupons
Clad Blistering Wet Storage

Edge Blisters



Away from Edge Blisters



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Clad Blistering - Wet Storage Blister Formation Mechanism

- Water enters core porosity either through
  - Edge where BORAL® trimmed to size (edge blisters)
  - Through clad pit (central blisters)
- Water entry path sealed by corrosion products
- Corrosion continues on inner surface of pores - hydrogen, a corrosion product, builds up
- Subsequent hydrogen pressure causes clad to separate from core, forming a blister

NETCO

BORAL® Clad Blistering - Dry Storage

- Full size canister in Spain subject to simulated canister flooding followed by vacuum drying conditions (heating and evacuation)
- Cells of basket drag tested before and after test
- Some interference noted after testing
- Destructive examination of basket

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BORAL®
Clad Blistering - Dry Storage

15

NETCO

BORAL®
Clad Blistering - Dry Storage

- NETCO retained by EPRI, ENRESA and AAR to determine root cause of blistering
- Equipment assembled to simulate canister flooding and vacuum drying conditions in the laboratory
- AAR supplied BORAL® from several production lots
- Test conditions included both BWR (demin water) and PWR (2500 ppm boric acid) conditions
- Specimens subjected to multiple cycles

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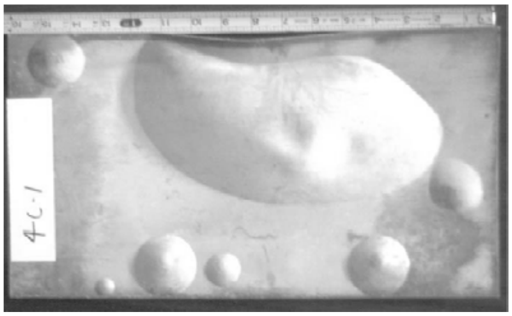
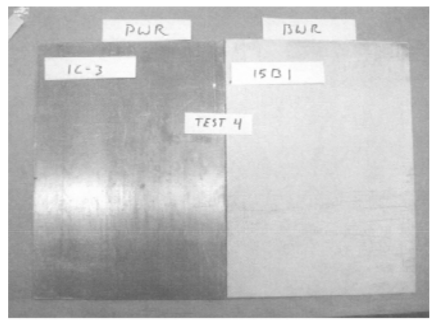
BORAL®
Clad Blistering - Dry Storage
Test Results

Blister Prone BORAL®



Blister Resistant BORAL®



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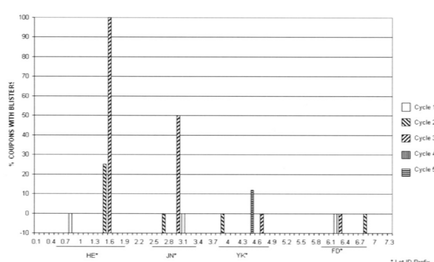
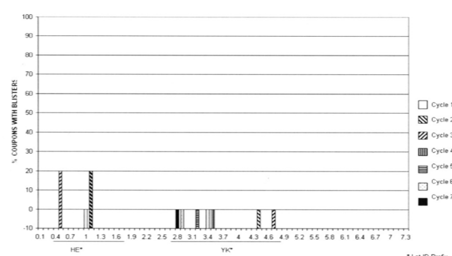
BORAL®
Clad Blistering - Dry Storage
Test Results

Boric Acid



Demin Water



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BORAL®

Clad Blistering - Dry Storage Blister Mechanism

- Onset of blister formation detected at ~300°F
- Water entrained in core porosity flashes to steam causing steam pressure buildup and clad separation
- Effect of core porosity
  - High core porosity (5 - 7 %): porosity is open and well connected allowing steam to leave core without pressure buildup
  - Low core porosity (1 - 3 %): porosity is not well connected, steam flashing causes pressure buildup and clad separation
- NETCO worked with AAR to alter ingot thermal history prior to rolling to consistently produce BORAL® with high core porosity
- Today's BORAL® is blister resistant

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NETCO

BORAL® - Performance in Wet and Dry Storage Applications Conclusions

Wet Storage

- General
  - Forms a uniform oxide film that tends to be self-passivating
- Pitting Corrosion
  - Neutron attenuation and high resolution radiography measurements show no effect on neutron absorption properties
  - To date pitting corrosion has been esthetic
  - Seems to be related to certain production lots of BORAL®
  - Need to continue to monitor through surveillance programs
- Blistering
  - Mechanism understood
  - Blister resistant BORAL® produced today should produce fewer in-pool blisters
  - In Region 1, flux trap racks may introduce slight increase in reactivity - needs to be assessed on a case by case basis
  - No evidence blistering has influenced fuel assembly rack clearances

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BORAL® - Performance in Wet and Dry Storage Applications Conclusions (continued)

Dry Storage and Blistering

- Mechanism of blister formation understood
- BORAL® produced today benefits from industry/EPRI research and is blister resistant under canister loading/drying conditions

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NETCO

Degradation of B_4C Plates at Palisades

Tom Woody
Reactor Engineer
Entergy Nuclear Operations
2/27/2009

1

Objective

- Outline the approach that Palisades is taking in response to the degradation of B_4C plates in spent fuel storage racks

2

Entergy

Palisades Irradiated Fuel Storage

- Palisades SFP storage rack has two "regions"
- Region I: NUS racks that utilize Carborundum B_4C plates as neutron absorber
- Region II: Westinghouse racks manufactured with Boraflex (soluble boron is now credited rather than the Boraflex)

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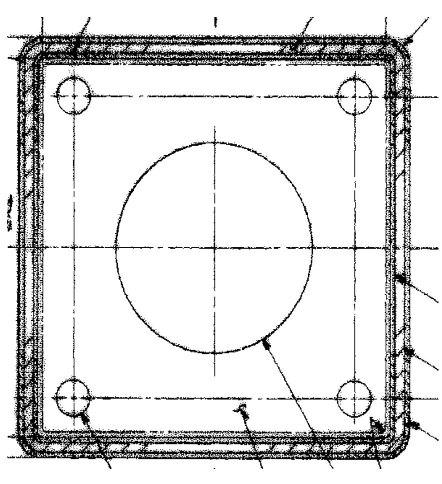
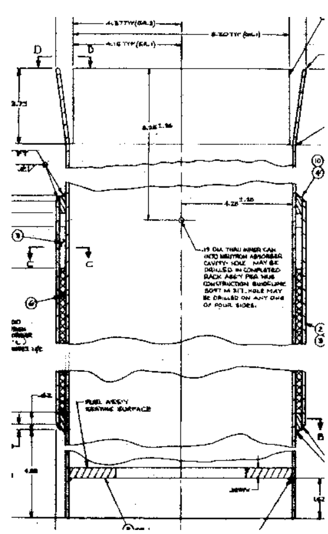
Entergy

Region I (NUS) Storage Racks





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Region I (NUS) Storage Racks

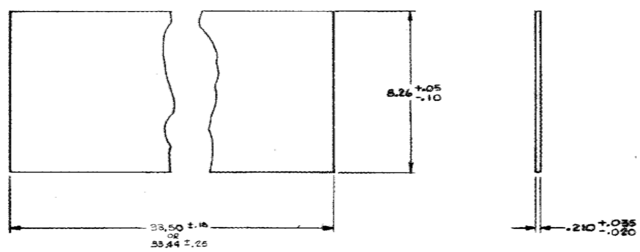

TABLE II	
PLATE REQUIREMENTS	
BORON-10 PLATE LOADING FOR ANY ONE SQUARE INCH AREA AT ANY PLATE LOCATION. (IN THE FORM OF BORON CARBIDE)	+ NOT APPLICABLE - .00959 0.0959 GMS/CM^2

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Region I (NUS) Storage Racks

- Design uses two concentric square cells with B_4C plates in gap between them
- Plates are ~8.26"x33.5" and are stacked 4 high along the height of the cell
- Plenum above the plates is vented via 1 3/16" hole on one of the 4 sides
- B_4C plates are nominal areal density of .0959 g B-10/cm^2

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Region I (NUS) Storage Racks

- In late 1970's swelling of cell walls was identified at Connecticut Yankee and NUS directed drilling of vent holes to relieve gas pressure
- Vent holes at Palisades were not effective at relieving pressure in all cells and several cells have swollen walls
- Swelling in the cell walls has resulted in 11 stuck fuel assemblies and 3 unusable locations

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Degraded Condition

Nominal Value per Manufacturing Records	.0959 g/cm^2
Value Credited in Analysis of Record	.0917 g/cm^2
Lowest Effective Areal Density Measured by BADGER Testing	.0566 g/cm^2

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Degraded Condition

- Minimum measured B-10 areal density in Region I racks is ~60% of nominal
- Measured areal density differs noticeably between B_4C plates in a given cell with no relationship to axial position (plates are stacked four high)
- No correlation between accumulated dose and degradation of B_4C
- No correlation between cell wall swelling and degradation of B_4C

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Mitigating Actions

- Confirmatory Action Letter prohibited addition of fresh fuel to the pool and movement of fuel from Region II to Region I
- Interim criticality analysis credits no B_4C in the Region I racks
- Soluble boron credit uses same limits as previously used in the Region II analysis
- New technical specification has been implemented that requires a “2 out of 4 checkerboard” pattern for fuel stored in Region I
- Site procedures revised to increase oversight of fuel moves in SFP

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How Did We Get Here?

- 1977: First Re-Rack Project using NUS Racks Begins
- 1978: Part 21 Report on gassing of NUS Racks
- 1978: Vent holes drilled prior to placing racks in pool
- 1991: First stuck assembly identified at Palisades
- 1994: Connecticut Yankee Operating Experience on degraded coupons
- 2006: Regulatory Commitment as part of License Renewal to blackness test prior to 2011
- 2007: Action to Perform Blackness Testing from Apparent Cause Evaluation for stuck fuel assembly
- 2008: BADGER Testing

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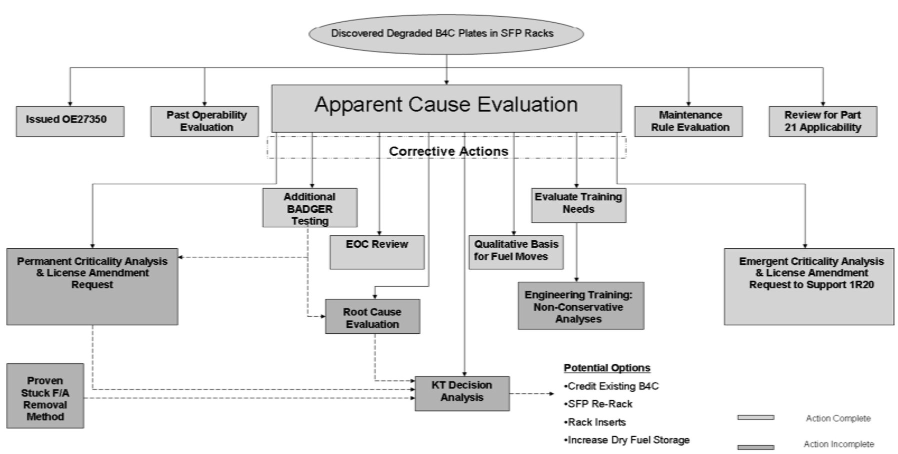
How Did We Get Here?

Palisades SFP Rack Degradation



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Current Activities

- Refueling Outage 20 (1R20) to begin in March 2009
  - Fuel stored in checkerboard pattern per recent T.S. Amendment (Region IA)
  - Stuck assemblies stored in accordance with T.S. criteria (Region IB)
  - New fuel being moved into SFP
  - Current storage pattern leaves less than 60 usable locations
  - In-Core shuffle to be performed for 1R20

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Current Activities

- Root cause evaluation to be performed on B_4C plate degradation at Palisades March 3-5
  - EPRI and NETCO to participate
  - Results will provide basis for future surveillance requirements
  - Results will provide input to future decision making

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Current Activities

- Study Phase: Stuck fuel assembly removal
  - Fuel manufacturer supporting the study
  - Will develop contingency plans
  - Success of removal effort will provide input to future decision making
  - Targeting 2010 for successful removal of stuck fuel assemblies

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Current Activities

- "Phase 2" of Criticality Analysis
  - Partial credit for B_4C
  - Burnup Credit
  - Provide input to future License Amendment Request
  - Increase number of usable cells in Region I

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Options

- Credit existing B_4C and perform periodic surveillance tests
- Continue to take no credit for B_4C and increase scope of dry fuel storage campaigns
- Implement use of rack inserts at Palisades
- Re-rack the spent fuel pool

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Conclusions

- Results of root cause evaluation, phase 2 criticality analysis, and stuck assembly removal to drive decision process
- Targeting stuck fuel assembly removal completion for 2010

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Questions

- ➢ Questions?

- ➢ Contact Info:

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NETCO
NORTHEAST TECHNOLOGY CORP

NRC Information Meeting Neutron Absorber Materials

New Materials

Ken Lindquist
2/27/09
Rockville, MD

NETCO

New Aluminum/Boron Carbide MMCs Available in North America

Product	Supplier	Status
Alcan Composite	Rio Tinto Alcan	- In use for dry storage - Qualified for wet storage by NETCO - Will be used for wet storage (NETCO Snap-In® absorber insert)
Bortec®	Ceradyne	- Qualified for wet and dry storage by NETCO for DWA Technologies - Available through Ceradyne
METAMIC®	Holtec	- In use for Holtec wet and dry storage systems - Qualified for nuclear applications by NETCO for Reynolds Metals Co.

2

NETCO

Description of New Materials

Product	Matrix	Absorber	Other	Production Process
Alcan MMC	AA1100	B_4C	Ti	Molten Metallurgy • B_4C blended in molten Al • Direct chill cast/cut to rectangular billet • Hot rolled to sheet
Bortec®	AA6091	B_4C	-	Powder Metallurgy • B_4C and atomized Al blended • Hot pressed to form cylindrical billet • Extruded and cut to make pre-form • Hot rolled to form sheet
METAMIC®	AA6061	B_4C	-	Powder Metallurgy • B_4C and atomized Al blended • Cold isostatic press to form billet • Extruded and cut to make pre-form • Hot rolled to form sheet

3

NETCO

In-Service Experience of New MMC Neutron Absorber Materials

First Surveillance Coupons to be tested in 2009:

Alcan Composite - LaSalle

METAMIC® - ANO

4

NETCO