DPO Case File for DPO-2016-002

The following pdf represents a collection of documents associated with the July 5, 2016 submittal and disposition of a differing professional opinion (DPO) from an NRC employee involving concerns about the evaluation and communication of Boral degradation effects in deployed spent fuel casks.

Management Directive (MD) 10.159, “The NRC Differing Professional Opinions Program,” describes the DPO Program. http://www.internal.nrc.gov/policy/directives/toc/md10.159.htm

The DPO Program is a formal process that allows employees and NRC contractors to have their differing views on established, mission-related issues considered by the highest level managers in their organizations, i.e., Office Directors and Regional Administrators. The process also provides managers with an independent, multi-person review of the issue (one person chosen by the employee). After a decision is issued to an employee, he or she may appeal the decision to the Executive Director for Operations (EDO).

Because the disposition of a DPO represents a multi-step process, readers should view the records as a collection. In other words, reading a document in isolation will not provide the correct context for how this issue was considered by the NRC.

The records in this collection have been reviwed and approved for public dissemination.

Document 1: DPO Submittal
Document 2: Memo Establishing DPO Panel
Document 3: DPO Panel Report
Document 4: DPO Decision

Document 1: DPO Submittal

NRC FORM 680
(09-2015)
NRCMD 10.159

U.S. NUCLEAR REGULATORY COMMISSION

DIFFERING PROFESSIONAL OPINION

DPO Case Number	DPO-2016-002
Date Received	7/5/2016

Name and Title of Submitter	Organization	Telephone Number (10 numeric digits)
Donald E. Carlson, Senior Project Manager	NRO/DEIA/ARPB	(301) 415-0109

Name and Title of Supervisor	Organization	Telephone Number (10 numeric digits)
Diane Jackson, Branch Chief	NRO/DEIA/ARPB	(301) 415-5641

When was the prevailing staff view, existing decision or stated position established and where can it be found?

Date April 21, 2016 **Where (i.e., ADAMS ML#, if applicable):** Email correspondence copied in Appendix A of the attachment

Subject of DPO

Evaluation and communication of Boral degradation effects in deployed spent fuel casks

Summary of prevailing staff view, existing decision, or stated position. (Use continuation pages or attach Word document)

Reason for DPO, potential impact on mission, and proposed alternatives. (Use continuation pages or attach Word document)

Do you believe the issue represents an immediate pubic health and safety concern? ☐ No ☑ Yes, (Explain on continuation page(s) or attach Word document).

Is the issue directly relevant to a decision pending before the Commission? ☑ No ☐ Yes, Reference Document (i.e., ADAMS ML#)

☑ **Informal discussions took place (Identify with whom and time frame of discussions)**

With the NMSS/DSFM director and several of his staff on several occasions between March 2014 and May 2016.

☐ **Extenuating circumstances prevented informal discussions**

Proposed panel members are (in priority order):

1. Dennis Damon
2. Amy Hull
3. Paul Clifford

☐ **No names of potential panel members will be provided.**

When the process is complete, I would like the DPO case file: ☐ Non-Public ☑ Public

SIGNATURE OF SUBMITTER	DATE
Donald E. Carlson	7-03-16
SIGNATURE OF CO-SUBMITTER (If any)	DATE

SCAN THE SIGNED AND DATED FORM (INCLUDE ANY CONTINUATION PAGES OR WORD DOCUMENTS) AND E-MAIL TO: DPOPM.Resource@nrc.gov

SIGNATURE OF DPO PROGRAM MANAGER	DATE
Renée Pedersen	7/6/2016

Delete Continuation Page ☐ DPO accepted ☐ DPO returned Add Continuation Page

NRC FORM 680
(09-2015)
NRCMD 10.159

U.S. NUCLEAR REGULATORY COMMISSION

DIFFERING PROFESSIONAL OPINION (Continued)

DPO Case Number: DPO-2016-002

Date Received: 7/5/2016

1. Please see the 52-page supporting document attached.

2. Please feel free to use the following contact information after my retirement on July 22, 2016:

- Donald E. Carlson, [redacted]; Mobile phone: [redacted] home phone: [redacted] email: [redacted], [redacted]

- After my move in August to Vienna, Austria, mail to the above street address will be forwarded to my new street address in Austria. The above private email accounts will remain active.

Differing Professional Opinion

Evaluation and Communication of Boral Degradation Effects in Deployed Spent Fuel Casks

Dr.-Ing. Donald E. Carlson
Senior Project Manager for Advanced Reactors
NRC Office of New Reactors (NRO)[1]

Submitted June 29, 2016
Edited July 1, 2016

1. Introduction

This Differing Professional Opinion (DPO) contests the executive decisions behind the agency's longstanding and continuing failure to adequately evaluate and communicate the safety, operational, and non-compliance implications of Boral™ degradation in deployed spent fuel casks. Although known elsewhere within the NRC since the late 1970s, the degradation phenomena of interest first came to the attention of U.S. cask vendors and NRC cask design reviewers in early 2001 after a number of potentially affected cask designs had already been certified and some deployed.

Boral is a hot-rolled composite sheet product in which a porous sintered mixture of aluminum powder and boron carbide particles is sandwiched by thin aluminum cladding. After rolling to the desired thickness, the Boral sheets are sheered to the desired final length and width, thereby leaving sheet edges that expose the porous central mixture to the local environment.

Boral has been produced with wide ranges of sheet thicknesses and with widely varied nominal percentages of boron carbide in the sintered mixture. Such product specification variables are known to significantly influence how Boral degrades under the service condition sequences in casks. Degradation phenomena are further influenced by details of the Boral fabrication process that have varied over time.

Boral has been used as a neutron absorber in spent fuel pool racks since the 1970s and in spent fuel casks since the 1980s. A typical cask design's fuel basket holds 21 to 32 pressurized water reactor (PWR) fuel assemblies or up to 68 boiling water reactor (BWR) fuel assemblies. Boral sheets are attached by thin steel wrappers to the basket cell walls of many approved cask system designs in order to safely prevent nuclear criticality when the fuel basket is flooded. Criticality without flooding is impossible even in the absence of neutron absorbers.

Cask loading is generally performed in a spent fuel pool. After wet loading, the cask is then closed, pressure tested, drained, and vacuum dried under high-temperature conditions that we now know can potentially cause the Boral to swell, blister, or even delaminate before the closed cask ever leaves the pool area. The worst instances of such Boral degradation are likely to be found in cask designs that were approved or certified before ~2002.

In many dual- or multipurpose cask system designs, the loaded fuel basket is contained within a seal-welded canister that can be deployed with a shielded cask overpack designed for either storage or transport. In other designs, the fuel basket is contained in a bolted cask without

[1] This DPO concerns issues outside the purview of NRO where I currently work. I first raised these issues nearly 16 years ago while working in another part of NRC on spent fuel cask design certification reviews.

canister. Beyond their presently approved uses in storage and/or transport cask systems, it is generally understood that at least some currently loaded cask baskets may see continued service in future disposal or processing settings.

I will try in the remaining sections to document this DPO in a thorough manner that will hopefully support the completion of its review and disposition after my upcoming July 22, 2016, retirement to accept a position with the International Atomic Energy Agency in Vienna, Austria.

2. Overview

It is my professional view that the Division of Spent Fuel Management (DSFM), including the organizations that have preceded it within the NRC Office of Nuclear Material Safety and Safeguards (NMSS), has for many years failed to adequately evaluate and communicate the safety, operational, and non-compliance implications of Boral degradation in spent fuel casks. This DPO concerns the series of NRC executive decisions behind those failures.

The latest decisions of interest are as follow:

(i) DSFM considered and rejected my recently repeated suggestion to issue a generic communication (e.g., Information Notice) on the potential safety, operational, and compliance implications of Boral degradation in deployed spent fuel casks.

(ii) DSFM considered but did not issue a recommended "user need" request to have the NRC Office of Nuclear Regulatory Research (RES) address some of the outstanding data needs that were highlighted in 2007 as follow-up actions for closing out Generic Safety Issue GSI-196, "Boral Degradation." [2]

I find these decisions and those that preceded them to be unworthy of our ISOCCER values.[3] Openness and Service demand that we effectively communicate to stakeholders what we know about Boral degradation effects in spent fuel casks. Integrity, Commitment, Excellence, and Respect demand that we now fulfill our documented commitment to learn more about these degradation effects and their safety, operational, and non-compliance ramifications through research tasks like the following:

1. Identify all cask baskets potentially affected to date and describe relevant design details.
2. Characterize the Boral sheets used in each basket design with regard to sheet specifications and, to the extent practicable, when and how the sheets were fabricated.
3. Characterize how the baskets were loaded and dried, especially with regard to the potential for Galvanic and other chemical reactions in pool water and, as applicable, the sequence of chemical, pressure, and temperature conditions imposed on the Boral sheet and its wrapper and wall attachments (e.g., welds) during fuel loading, pressurized leak testing, draining, and hot vacuum drying.
4. Perform testing on representative or worst-case Boral basket cell configurations and service condition sequences as needed to estimate the extent of Boral blistering and swelling, wrapper bulging, and eventual wall detachment that may have occurred before the loaded cask baskets left the pool area.
5. As warranted, perform testing to study how the initially degraded Boral sheet, wrapper, and wall attachment can further degrade or fail under normal, off-normal, and accident

[2] An email message with my comments on a draft of the proposed RES "user need" addendum is appended. GSI-196 is further discussed and referenced later in this document.

[3] Our ISOCCER values: Integrity, Service, Openness, Commitment, Cooperation, Excellence, Respect

conditions of extended basket service, including in particular all re-flooded basket operating and accident conditions associated with storage, transport, eventual processing, and disposal.

6. As warranted, evaluate the resulting issues of safety and regulatory compliance.

Two associated safety issues are discussed subsequently herein. These involve:

(a) Preventing nuclear criticality during (i) eventual wet handling or processing operations and (ii) postulated basket re-flooding events and accidents.

(b) Facilitating safe operations and keeping worker radiation exposures as low as reasonably achievable (ALARA) during eventual planned or unplanned efforts to retrieve bound fuel assemblies or fuel cans from affected baskets.

These issues must ultimately be evaluated for the entire population of affected cask baskets under normal and off-normal service conditions that span their planned or potential uses throughout all relevant phases of spent fuel management. Absent information to the contrary, it is reasonable to expect at least some affected baskets to see extended service in storage and transport followed by further service in eventual processing or disposal settings.

To my knowledge, no potentially affected casks have ever been reopened or examined anywhere in the world to date. Moreover, none of the dry storage technology demonstrations underway since the mid-1980s address the cask materials and loading conditions of interest.

As stated in recent discussions with DSFM management, my limited technical understanding is such that I would be surprised should results from the recommended research reveal degradation effects severe enough to fully negate all explicit and implicit margins of criticality safety. Even then, my preliminary view is that risk insights and targeted compensatory measures may still make it possible to safely address even worst-case criticality safety issues without having to reopen affected casks for eventual fuel retrieval and repackaging.

Aside from any criticality concerns, there are compelling needs to address the safety-related operational ramifications of fuel binding caused by Boral degradation. The inability to readily retrieve bound fuel from an affected cask returned to the spent fuel pool for servicing could affect worker safety, could make the pool's cask pit unavailable for loading new casks or for servicing other deployed casks, and could eventually necessitate extended plant shutdown.

In any event, it is clear that the recommended research is essential for identifying all potentially affected casks and determining what actions may be warranted by the NRC and industry. Appendices B and C further detail the recommended research.

3. Discussion

In an email response dated April 21, 2016, the DSFM director offered the following brief summary of the latest NRC staff positions:[4]

> "We don't see a safety issue that necessitates issuing a dry storage generic communication or expending valuable research resources. We may include a brief reference in the final version of ISG-2."

The last part of the above statement refers to the new Revision 2 of DSFM's Interim Staff Guidance (ISG) for assessing compliance with the following requirement of 10 CFR 70.122(l) (i.e., Title 10 of the Code of Federal Regulations, Part 72, Subsection 122, Paragraph (l)):

[4] A copy of that email is provided here as Appendix A.

> "*Retrievability*. Storage systems must be designed to allow ready retrieval of spent fuel … for further processing or disposal."

The previous versions of ISG-2 reflect the review guidance applied to all cask designs certified or otherwise approved to date. DSFM's recently issued Revision 2 of ISG-2 does not mention Boral degradation or fuel binding.[5]

I take issue with the words "dry storage" where the DSFM Director refers above to "issuing a *dry storage* generic communication." I have in fact never proposed and would not support issuing a communication that is limited to dry storage. Instead, my proposal is to issue a communication that recognizes the full scope of reasonably foreseen potential uses of loaded baskets throughout all remaining phases of spent fuel management. The baskets of interest include those deployed within various so-called single-, dual-, and multipurpose cask system designs. The full range of basket service conditions to be considered must therefore encompass at least those for storage and transport. With details yet to be determined, we must also acknowledge the generally understood fact that some affected baskets may see further service in future disposal systems and at the front ends of future handling and processing operations. The respective rules in 10 CFR Parts 50, 72, 71, 70, and 63 provide spent fuel regulatory coverage that can be difficult to implement in a seamless and comprehensive manner. Such difficulties, however, do not release us from our statutory and ethical duties to consider how affected baskets will perform throughout all remaining phases of spent fuel management.

The users of potentially affected casks have yet to be given any clear information on the potential safety, operational, or compliance issues of Boral degradation. For example, we have given cask users little or no reason to suspect what we have known for many years, namely that cutting tools might well be needed to retrieve Boral-bound fuel assemblies and fuel cans from affected baskets. On the contrary, our past findings of compliance with 10 CFR 72.112(l) clearly communicate a belief that no such special measures will be needed. This makes it all the more essential that we finally tell our stakeholders that subsequent information has cast great doubt on those findings and especially those for cask designs certified before ~2002.

Most importantly, we have so far failed to adequately evaluate the full scope of Boral degradation effects and their safety-related operational ramifications for all potentially affected cask baskets. As noted in the historical outline that follows, the staff committed in 2007 to pursue investigatory research that would rectify our imposed failure to complete this vital work in the context of GSI-196.

3.1 History of Actions and Decisions on Cask Boral Degradation Effects

For practical reasons, the most immediate focus of this DPO is on the latest decisions made in response to my renewed "open door" discussions with NMSS management over the past two years. Inevitably, however, this DPO likewise concerns the full sequence of bad decisions on this issue over the past ~16 years. These are outlined in their historical context as follows:

1. I first identified and raised the issue of Boral degradation in spent fuel cask baskets in August 2000 while I was working as a senior criticality and shielding engineer in NMSS's Spent Fuel Project Office (SFPO). SFPO was later reorganized as the NMSS Division of Spent Fuel Storage and Transport (SFST) and most recently as DSFM.
    i. This cask issue stems in part from a failure of NRC knowledge management.[6] In particular, I discovered that, until that time in August 2000, the cask reviewers in

[5] Revisions 1 and 2 of ISG-2 are publicly available at www.adams.nrc.gov/wba/ under ADAMS Accession Nos. ML100550861 and ML16117A080, respectively.

NMSS, myself included, had been unaware of the U.S. and international experience with Boral blistering and fuel binding in spent fuel pool storage racks. The materials reviewers had therefore failed to consider such information in reaching their incorrect review findings that the Boral in casks would not degrade substantially under cask basket service conditions.[7]

ii. Moreover, the NMSS reviewers had accepted at face value the misleading claims made in various cask vendor submittals to the effect that (a) Boral had served for decades in SFPs without significant degradation, and (b) Boral service conditions in casks are less demanding than in pool racks.

iii. After speaking with the NRC's lead materials reviewer for spent fuel pools and studying his file of Boral information, I concluded in August 2000 that the cask vendors' claims about Boral were not accurate and that severe Boral blistering would almost certainly occur during the routine wet pressurized leak testing, draining, and hot vacuum drying of freshly loaded cask baskets, with the result that the Boral would already be severely degraded by the time the freshly loaded cask basket leaves the pool area.

2. The cask materials reviewers in NMSS initially disputed my concerns and tried to defend their prior review conclusions on Boral. My concerns were nevertheless soon validated by a December 2000 event report from Spain.

   i. The event report stated that severe Boral blistering had occurred during the mockup testing of a NAC International basket design that was being used in Spain and similar to one that had been reviewed by NMSS. The tested service conditions sought to mimic the cask loading sequence of pool soaking, pressure testing, draining, and heated vacuum drying.[8]

   ii. Similar events with Boral blistering in loaded spent fuel pool racks were first observed in the U.S. in the 1970s and early 1980s. These events were first discovered when racked fuel assemblies were found to be firmly bound in place by bulging of the seal-welded steel wrappers (a.k.a., cover plates) that affixed the Boral sheets to the rack walls. Those early events were summarized in an NRC Information Notice issued in 1983.[9]

   iii. The bulging-induced fuel rack binding could be reversed in all cases by cutting vent holes in the wrappers to relieve the pressure of hydrogen gas produced by chemical reactions of pool water with the sintered aluminum powder in Boral. It is important to understand that some binding events occurred within the first days or weeks of pool rack service.

---

[6] Spent fuel pools are regulated by the NRC Office of Nuclear Reactor Regulation (NRR). Accordingly, the agency's expertise on Boral in pools resided in NRR, not NMSS. NMSS's failure to recognize this cask issue from the outset can thus be attributed in large part to poor knowledge sharing between offices.

[7] Because this issue concerns only casks, it was deemed outside the defined scope of the NRC's recent generic letter on neutron absorber material monitoring in spent fuel pools (public ML16097A169).

[8] The Boral binding event in Spain has since been described in the Electric Power Research Institute's *Handbook on Neutron Absorber Materials for Spent Nuclear Fuel Applications*, along with a similar event in the 1980s involving a transport cask in Canada. The now apparent fact that all U.S. cask vendors and all NRC cask reviewers, including me, had been unaware not only of all pool events but also a clearly relevant cask event in Canada points to serious failures of knowledge management on all sides.

[9] See NRC Information Notice 83-029, *Fuel Binding Caused by Fuel Rack Deformation*, May 6, 1983.

   iv. Further pool rack binding events have since been reported in several other countries. Of particular note was a rack binding event that occurred in 2000 in the spent fuel pool at South Africa's Koeberg plant. Then still unaware of any history of pool rack binding events, I learned of the Koeberg event from a South African colleague during a July 2000 meeting at the International Atomic Energy Agency (IAEA) in Vienna. It was that revelation that then led me to seek more information from NRR.

3. I observed over the months that followed that SFPO management had no discernable strategy or plan for assessing and addressing the full scope of the issue. Instead, SFPO seemed content to rely on voluntary initiatives by individual cask vendors to address the potential for future Boral degradation as observed in Spain. For example:

   i. One cask vendor, Holtec, eventually decided to start phasing out Boral from both its pool rack and cask product lines.

   ii. Another cask vendor, NAC International, provided design information and eventually test results showing that the Boral used in its latest basket designs should not experience blistering like that reported in Spain.[10]

4. In general, SFPO chose not to subject the voluntary vendor information to detailed technical review by the staff. Moreover, such information was used without staff review in responding to related concerns raised by the Spanish regulator.[11]

5. Missing entirely from SFPO's actions was any attempt to do the following:

   i. Identify the full population of potentially affected cask basket designs, including in particular those that had been already certified or deployed.

   ii. Assess in each case the potential extent of Boral degradation and the resulting implications for safety, safety-related operations, and compliance.

   iii. Determine appropriate regulatory responses in each case (e.g., no action versus withdrawing or amending the cask certificate of compliance or requiring user contingency plans for in-pool cask servicing with retrieval of Boral-bound fuel).

6. Even after moving from NMSS to RES in May 2001, I continued to air my concerns in "open door" discussions with the SFPO deputy director and his staff but failed to persuade them to change course.

7. In 2003, SFPO management continued to effectively block any thorough staff evaluation of the issue by refusing to docket for staff review the voluntary submittal of a directly relevant Electric Power Research Institute (EPRI) report on Boral degradation testing.[12] SFPO justified the refusal by noting that the report had not been submitted as part of a cask certification or licensing process. This refusal made it impossible for the staff to formally review the report and ask necessary questions. Given the potential severity of Boral degradation effects and the uncounted multitude of potentially affected cask baskets, including those in casks already deployed, it was and is my dissenting view that SFPO was shirking its clear duty to facilitate, not block, our review of the EPRI report.

[10] Letter from T.C. Thompson, NAC International, to R. Karas, NRC/SFPO, Subject: Summary of NAC Boral Testing Program, March 22, 2002. (public ML021000245)

[11] Letter from M.J. Virgilio, NRC/NMSS, to J.B. Vernet, Consejo de Seguridad Nuclear, Spain, Subject: NRC Response to a Concern of Blistering of BORAL™ in NAC Cask Designs in the United States, March 17, 2004. (public ML040840555)

[12] *Boral Behavior under Simulated Cask Vacuum Drying Conditions*, EPRI ID: 1008441, 08-Sep-2003. <u>Note: In my opinion, it is inexcusable that we still do not have this essential report in house.</u>

8. In late 2003, after achieving no success by other means, I began trying to use the agency's RES-managed NRC Generic Safety Issues (GSI) program to rectify the situation. However, because the GSI program in RES was chartered to address only safety issues as opposed to issues of compliance, it was determined in 2004 that only the cask criticality safety aspects of the issue could be addressed within that program. This limited aspect of the issue then became GSI-196, "Boral Degradation."[13] As such, GSI-196 sought to incorporate a risk-informed assessment of cask criticality accidents.

   i. Other aspects not addressed by the selected GSI-196 process include 10 CFR 72.122(l) fuel retrievability compliance and associated operational complications involving ALARA and worker safety, as well as potential considerations involving environmental impacts, Continued Storage (formerly Waste Confidence), and openness in public engagement.

   ii. As the proposer of GSI-196, I developed a 16-page Task Action Plan for assessing the relevant criticality safety issues throughout the potential service lifetime of the loaded basket.[14] The first parts of the plan focused on identifying the deployed cask basket designs likely to be affected and characterizing the potential severity of Boral degradation effects in each deployment. The six proposed research tasks listed in the Overview section summarize the contents of that plan.

   iii. However, that 16-page plan was subverted at the final RES concurrence step when SFPO's deputy director for technical review interjected his strong opposition to GSI-196. With RES functioning as a "service organization" and NMSS being viewed as its client office in this case, the NMSS/SFPO deputy director had no trouble persuading the RES division director to replace the 16-page plan with a 2-page plan for quickly closing out the issue.[15] Presented to RES without explanation, the imposed 2-page plan called for the cursory assessment of only existing information.

   iv. The GSI team members, my RES branch chief, and others in RES joined me in expressing outrage at this blatant subversion of the GSI process, yet none of us chose at that time to submit a non-concurrence or a DPO and thereby run the perceived risk of marginalizing our careers. I nevertheless promised myself and those like-minded RES colleagues (all since retired) that I would someday revisit the issues. I have now been trying to fulfill that promise since early 2014.

   v. There was more than a little headshaking when the SFPO deputy director, having previously disallowed staff review of EPRI's testing report, then retired shortly after subverting the GSI-196 process to take a position at Holtec International. Yet, to my knowledge, none of us chose at that time to face the kinds of career damage (i.e., stigma, unpopularity, shunning) that might result from reporting his apparent misconduct to NRC's Office of the Inspector General (OIG).

   vi. GSI-196, "Boral Degradation," was closed in early 2007 after cursory review by the NRC Advisory Committee on Nuclear Waste (ACNW). The primary technical basis for closure was a letter report prepared for RES by criticality safety expert Dr. Calvin Hopper of Oak Ridge National Laboratory (ORNL). Dr. Hopper reviewed only Part 2

[13] See GSI-196, Boral Degradation, and search ADAMS for document titles containing "Boral" or "Boral degradation."

[14] The 16-page task action plan was not issued (see item 8.iii above) but nevertheless appears in ADAMS-P8 as a WordPerfect file (non-public ML050280145), a copy of which is included as Appendix B.

[15] NRC memorandum from F. Eltawila to C.J. Paperiello, *Task Action Plan for the Technical Assessment of Generic Safety Issue 196, "Boral Degradation,"* February 22, 2006 (ADAMS ML050550229, public)

of EPRI's testing report and was not granted the opportunity to ask questions.[16] He concluded (correctly in my view) that the extent of Boral blistering and wrapper bulging revealed by those EPRI tests would not result in substantial erosion of cask basket criticality safety margins.[17]

vii. Although Dr. Hopper's letter report had several apparent shortcomings, as I noted at the time in the comments included here as Appendix C, his remarks also correctly noted that the testing described in the reviewed EPRI report was performed only on certain "new" Boral sheets as opposed to a more comprehensive selection of "old" and "new" Boral sheets with different specified thicknesses, boron-10 areal densities, and associated carbide volume fractions and porosities. This alludes to the diversity of Boral sheet product specifications used in different cask basket designs as well as the broad variation of Boral fabrication and treatment processes over many years of production.

viii. Especially noteworthy in the closure memo for GSI-196 is the statement under "Follow-Up Actions" that any testing of "old" Boral sheets was considered "…beyond scope of the Generic Issues Program and would be more appropriately studied as an investigatory research program." [18] We must now acknowledge that the sole purpose of this statement was to flag the arbitrarily excluded scope for follow-up action under the agreed terms for closing out GSI-196. In other words, the basis for closing out GSI-196 included a staff commitment to pursue follow-up research.

ix. As requested by the ACNW, the follow-up actions in the GSI-196 closure memo also committed the staff to monitor the IAEA's SPAR-II coordinated research project for related developments. Although it now appears that no one was ever assigned to pursue any of the follow-up actions, one can now readily verify that the project's final report contains nothing of relevance.[19]

x. More information related to GSI-196 can be found by doing an advanced search in Public ADAMS or ADAMS-P8 for document titles containing "Boral."

The curtailed assessment of GSI-196 concluded in 2007 that there are still unmet testing needs for Boral degradation effects and especially those for "old" Boral. Without such test data, we cannot exclude the possibility that certain cask baskets might have experienced Boral degradation effects far more severe than indicated in the EPRI testing report and perhaps similar to the extreme effects seen in the photo provided here in Appendix D. Moreover, we have yet to adequately consider how early Boral degradation effects could worsen over time under normal and off-normal conditions of extended basket service in dry storage, transport, and subsequent phases of spent fuel management.

9. Early in 2014, NRO management approved my request to devote occasional working hours to my renewed pursuit of this old issue with NMSS.

---

[16] *Boral Behavior under Simulated Cask Vacuum Drying Conditions (Part 2 Test Results)*, EPRI ID: 1009696, 16-Nov-2004. Note: We have only this Part 2 report in house. We still do not have the Part 1 report that SFPO refused to docket for review.

[17] C.M. Hopper, *Final Letter Report: Review of BORAL™ Degradation-Related Literature Survey*, ORNL under contract to NRC/RES, July 13, 2006. (non-public ML062490254)

[18] NRC memorandum from B.W. Sheron to L.A. Reyes, *Closure of Generic Issue 196, "Boral Degradation*," February 22, 2007. (non-public ML070090182)

[19] See IAEA-TECDOC-1680, Spent Fuel Performance Assessment and Research: Final Report of a Coordinated Research Project (SPAR-II), Vienna, 2012.

i. I began my renewed pursuit in March 2014 by requesting an open door meeting with the director of NMSS's Waste Confidence Directorate. As expressed in that meeting, my most immediate concern was that intervenors might resurface the issue during the Waste Confidence proceedings and use our questionable actions and lack of accountability on that front to undermine our perceived credibility and integrity.

ii. I then had two open door meetings with the director of NMSS/SFST (now DSFM) in March and July 2014, followed by a meeting with him and several of his staff in August 2014. The cordial discussions in those meetings and in a subsequent meeting in March 2016 were accompanied by several email exchanges. The latter included my granted requests for the opportunity to comment on any pending DSFM actions concerning these specific issues.

iii. I also contacted auditors in the NRC Office of Inspector General (OIG) in October 2014 to volunteer my inputs to their then ongoing audit review of spent fuel pool safety. As I summarized in a lengthy follow-up email to OIG that I then shared with NRO and DSFM management, those inputs concerned cask Boral degradation in terms of its potential nexus with pool safety while affected casks are loaded or reopened in pools. But the bulk of those OIG audit inputs covered my longstanding concerns over apparent deficiencies in the criticality safety analyses for spent fuel pools.[20]

iv. When the DSFM director read one of my emails describing the history of my Boral issue, he responded to let me know that he had contacted the investigatory arm of OIG to report the allegations that my message seemed to contain of apparent wrongdoing in the past management decisions and actions taken to disallow staff review of the EPRI Boral testing report and subvert the GSI-196 process.[21]

v. In March and April of 2014, I also initiated a phone call and email exchanges with current members of the GSI team in RES to learn of any progress made since 2007 on the follow-up actions noted in GSI-196 closure memo. I was told there had been no progress on those actions.

vi. In January 2015, DSFM allowed me to review a draft user need addendum asking RES to add studies of Boral degradation to its broader work on degradation of cask neutron absorbers during extended storage. The draft addendum is provided here in Appendix E along with my emailed comments. Although the scope of the requested Boral work was insufficiently explicit, I proposed adding a sentence identifying the request with the heretofore neglected follow-up item for closing out GSI-196 in 2007.

vii. As noted previously, DSFM ultimately decided not to issue the user need addendum.

10. My discussions and email exchanges on this front seemed for a while to have generated interest among DSFM management and staff. Yet the DSFM director has nevertheless decided against my renewed proposals to pursue necessary follow-up research and openly communicate both what we know and what we want to learn. As noted above, his stated rationale is that DSFM doesn't see a safety issue that necessitates such actions.

[20] Those pool criticality safety analysis issues were documented by me in 2009 (public ML15005A208) and finally acknowledged and discussed in 2016 (public ML16117A080). Like the cask Boral issue, those issues reflected a history of inconsistencies and poor knowledge sharing between NMSS and NRR.

[21] The email correspondence ono the DFSM director's contact with OIG is provided here as Appendix F.

3.2 Implications for Nuclear Criticality Safety

The sole function of cask Boral is to help prevent nuclear criticality. The incomplete degradation testing reviewed to date shows that the neutron-absorbing boron carbide particles in Boral remain largely in place even after severe blistering. It would therefore seem reasonable to expect more comprehensive testing to further show only fairly limited losses of carbide particles in worst-case blistered or delaminated Boral sheets. While that is indeed my stated expectation as a nuclear engineer with little experience and formal training in materials engineering, it amounts to little more than conjecture.

Degradation effects that could significantly reduce or negate criticality safety margins include the following:

1. Loss of boron carbide particles from Boral sheets. Various aging effects could conceivably make this effect become much more significant over decades or longer of pre-blistered or pre-delaminated Boral service in storage and subsequent phases of spent fuel management. Likewise for the transient effects of subsequent mechanical shock, quenching, soaking, and potential hydrogen combustion in postulated cask flooding accidents or eventual in-pool servicing or processing operations.
2. Detachment from basket cell walls. This effect concerns the potential shifting or gross relocation of Boral sheets, or eventual sheet fragments, loose carbide particles, etc., made possible by the Boral-swelling-induced stressing and failure of steel wrappers or their attachment stitch welds, seal welds, etc. Note that Boral sheets are generally much thicker and stiffer than their wrappers. Note also that the Boral sheets are significantly shorter than the cask's fuel cavity in many basket designs. This means that the axial shifting of detached Boral sheets could result in a substantial loss of coverage of the active fuel. As with the loss of carbide particles (see preceding item), the potential for such detachment effects could conceivably be exacerbated by aging, transient, and accident phenomena.
3. Displacement of water by hydrogen gas in Boral blisters and bulging wrappers. This effect could either increase or decrease criticality safety margins depending on basket design details such as the use of neutron flux traps.
4. Depletion of the boron-10 isotope by neutron absorption. This nuclear aging effect could become significant only after centuries or millennia of Boral service in extended storage or permanent disposal.

The very real potential for extreme degradation effects is evident from the photo provided in Appendix D. There, the gross swelling and delamination shown on the left was the immediate result of soaking and rapid heating of previously pristine Boral samples. Although those samples are stated to have been heated faster than they would be during vacuum drying in a cask, one has to wonder whether slower heating could inflict similar damage on "old" Boral from earlier fabrication eras or on Boral with different product specifications such as sheet thicknesses and mixing fractions of boron carbide. One must also wonder whether the subsequent effects of aging, quenching, re-soaking, and other transient and accident conditions on such initially delaminated Boral could result in significantly greater potential for boron carbide particle loss, sheet fragmentation, and sheet detachment from the basket wall. Moreover, it seems possible that such extreme Boral swelling and delamination could by itself suffice to cause fuel binding, even in the absence of wrapper bulging by unvented hydrogen gas or steam.

The existence of Boral degradation effects not addressed by the criticality safety calculations for the respective certified cask designs would clearly tend to render those calculations and certifications invalid. It is thus fortunate that the approved calculations generally incorporate large margins of safety that may be credited where needed through supplemental calculations.

Explicit criticality safety margins for conservatively analyzed cask flooding conditions typically amount to at least 5 percent delta-k/k.[22] Additional implicit margins accrue from the various conservative modelling assumptions typically used in approved cask safety calculations of flooded reactivity over the entire range of allowed fuel loadings. These assumptions include:

i. Conservative modelling of fuel compositions. The approved criticality calculations for most, if not all, of the affected casks have conservatively neglected the effects of fuel burnup by modelling the irradiated fuel as fresh fuel of maximum allowed initial enrichment and without fixed burnable poisons. Such simple models clearly bound the maximum possible reactivity of all allowed loadings of fresh or irradiated fuel. The resulting conservatism can range from a few percent to over 20 percent delta-k/k, with the exact amount depending on the particular fuel loading and cask design. It should be possible to eliminate much of this conservatism by performing supplemental burnup credit calculations (e.g., using applicable guidance in ISG-8 [23]) over ranges of actual fuel loadings in specific cask designs.

ii. Conservative modelling of fuel and basket dimensions and flooded conditions. The dimensions of spent fuel rod spacers, cladding, and pellets are typically modeled as those of pristine, room-temperature fuel at its most reactive dimensional tolerance limits. This appears to be conservative for fuel burned beyond very low levels of burnup. The dimensions of all basket components, including Boral sheets, are likewise modelled at their most reactive pristine tolerance limits. Furthermore, typical models of flooded cask conditions conservatively assume flooding of the gap that exists on fabrication between the fuel pellet and cladding. Replacing all of these conservatisms with greater realism may yield calculated reactivity reductions on the order of 1 to 3 percent delta-k/k.

iii. Conservative modelling of boron-10 content in Boral. The boron-10 areal density in approved cask calculations has been typically modelled as uniformly distributed at 75 percent of its assured minimum value. The past NMSS review guidance calling for this reduced modelling credit has been based in part on old published test results showing that the boron carbide granularity effects of neutron streaming and channeling can reduce the effective attenuation of fixed thermal neutron beams by an amount that equates to lowering the boron-10 areal density by up to 25 percent. More recent testing and analyses show that such granularity effects are much less pronounced where Boral is used for reactivity reduction instead of beam attenuation. Uniform modelling at 90 percent or more of the assured minimum boron-10 areal density may thus be warranted with resulting reductions of conservatism on the order of 1 percent delta-k/k.

It thus appears that supplemental calculations with more realistic modeling assumptions may eventually be able to demonstrate residual margins of criticality safety for at least some, and perhaps all, of the affected casks. Yet without necessary research, including more comprehensive test data and analysis, we cannot even identify all of the potentially affected casks; much less find reasonable assurance of residual subcritical safety margins in all cases.

The currently applicable regulatory requirements for criticality safety during the cask storage, transport, eventual processing, and disposal phases of spent fuel management are as follow:

[22] The term "delta-k/k" stands for the relative change in the effective neutron multiplication factor k_{eff}. Criticality analysts commonly refer to this as a reactivity change.

[23] DSFM ISG-8, Revision 3, Issue: Burnup Credit in the Criticality Safety Analyses of PWR Spent Fuel in Transportation and Storage Casks, September 26, 2012. (public ML12261A433)

- An application for an Independent Spent Fuel Storage Installation must demonstrate that the system meets the criteria for nuclear criticality safety [10 CFR 72.124].
- An application for a spent fuel storage cask must demonstrate that spent fuel is maintained subcritical under credible conditions [10 CFR 72.236(c)].
- A fissile material transportation package application must demonstrate that a single package is subcritical with water in-leakage [10 CFR 71.55(b)].
- A fissile material transportation package application must demonstrate that a single package is subcritical under normal conditions of transport and hypothetical accident conditions [10 CFR 71.55(d) and (e), 71.71, and 71.73].
- A fissile material transportation package application must demonstrate that arrays of packages are subcritical under normal conditions of transport and hypothetical accident conditions [10 CFR 71.59, 71.71, and 71.73].
- Fuel cycle facilities must perform and maintain an integrated safety analysis that addresses the prevention of nuclear criticality accidents as well as criticality accident monitoring, detection, and response [10 CFR 70.62].
- The preclosure safety analysis for the geologic repository operations area must address the means to prevent criticality [10 CFR 63.112(d)].
- Quality assured design control measures must be applied to the means for preventing or controlling criticality in the geologic repository facility [10 CFR 63.142(d)].

Note that the regulatory requirements of 10 CFR 50.68 for the pool storage phase of spent fuel management are not listed here. This is because10 CFR 50.68(c) invokes the applicable requirements of 10 CFR Part 71 or Part 72 for fuel that still resides within an in-pool transport package or a storage cask, respectively.

It is important to note that the potential for severe Boral degradation effects was not considered in the NRC's pilot risk assessment for dry storage cask systems.[24] Preliminary risk insights were developed in the screening analysis for GSI-196.[25] But those insights addressed only criticality, which may not be the dominant source of risk.

3.3 Implications for Operating Logistics, Operational Safety, and ALARA

Even in cases where we ultimately find reasonable assurance of ample subcritical safety margins, there remains a more pressing need to address the operating logistics and operational safety issues of Boral-degradation-induced fuel binding. Two types of fuel binding need to be considered: "soft" binding and "hard" binding.

Soft binding in casks resembles the fuel binding seen repeatedly in Boral spent fuel pool racks worldwide since the late 1970s. Caused by the buildup of hydrogen gas (and perhaps steam pressure in the case of casks) behind bulging seal-welded wrappers, experience shows that this type of binding can be quickly reversed by simply snipping or drilling small vent holes near the tops of the wrappers. Especially if anticipated, the ramifications of such binding for operational logistics and ALARA worker doses should prove readily manageable.

[24] NUREG-1864, *Pilot Probabilistic Risk Assessment of a Dry Cask Storage System at a Nuclear Power Plant*, NRC, March 2007. (public ML071340012)

[25] NRC memorandum from J.E. Rosenthal to C.J. Paperiello, *Results of Initial Screening of Generic Issue 196, "Boral Degradation,"* November 19, 2004. (public ML042670379)

Hard binding would result where Boral swelling and delamination become so extreme that they can firmly bind the fuel in place even without the help of wrapper bulging. Cask fuel retrieval in that case would potentially call for highly innovative and time-consuming in-pool operations with special cutting tools. Especially if unplanned, such complex in-pool operations could entail significant economic risk to the plant owner as well as new considerations on ALARA dose controls for plant workers. In view of our continuing failure to adequately evaluate this fuel binding issue and communicate it to cask and plant stakeholders, it is doubtful that any plant owners have foreseen the eventual need to plan for such in-pool operating contingencies.

The extended inability to readily retrieve hard bound fuel from an affected cask would become a significant concern should a concurrent need arise to handle a second damaged or defective cask in the same spent fuel pool. This is problematic simply because spent fuel pools are generally equipped with only one cask handling pit. DSFM's recent revision of ISG-2 notwithstanding, it is likewise generally the case that storage pools cannot accommodate more than one large spent fuel canister at a time. It is thus clear that hard fuel binding could result in the extended inability to effectively deal with more than one leaking or damaged cask at a reactor plant site. This could then result in excessive radionuclide releases over time from leaking casks that cannot be serviced in the plant's obstructed pool pit. The need for an affected cask to reside long-term in the pool's cask pit could also eventually necessitate plant shutdown because of the resulting inability to transfer fuel from full pool racks to new dry storage casks.

Although such fuel binding issues could clearly afflict the continuing use of loaded baskets in subsequent phases of spent fuel management, the only relevant regulatory requirements for fuel retrievabilitity are those that follow for the cask storage phase of spent fuel management:

- Storage systems must be designed to allow ready retrieval of spent fuel for further processing or disposal [10 CFR 72.122(l)].
- The spent fuel storage cask must be compatible with wet or dry spent fuel loading and unloading facilities [10 CFR 72.236(h)].
- In the design of spent fuel storage casks, consideration should be given to compatibility with the removal of the stored spent fuel from a reactor site, transportation, and ultimate disposal by the Department of Energy [10 CFR 72.236(m)].

It bears emphasizing here that the staff has found all storage cask designs certified do date to be in compliance with these rules as interpreted in Revision 0 or Revision 1 of ISG-2. As such, the staff has effectively told all stakeholders that no special equipment or processes will be necessary for retrieving individual fuel assemblies or fuel cans from deployed cask baskets.

I thus find it unconscionable that we continue to let our stakeholders believe what we no longer firmly believe for a still unknown population of deployed casks. It has become more and more clear that our continued negligence in this regard could have significant safety and environmental consequences and bring undue damage to the NRC's sound reputation.

4. Concluding Remarks

I have devoted much of my 40-year nuclear engineering career to the development, safety analysis, and eventual licensing of passively safe modular high temperature gas-cooled reactors (HTGRs).[26] Having started down that unusual career path in 1978 as a post-graduate

[26] See for example my journal article: D.E. Carlson and S.J. Ball, *Perspectives on Understanding and Verifying the Safety Terrain of Modular HTGRs*, Nuclear Engineering and Design, in press, available online 4 February 2016, http://www.sciencedirect.com/science/article/pii/S002954931600025X

researcher in Germany, I have since watched with frustration and dismay as the German originators of what many believe to be a uniquely meltdown-proof reactor technology have lost public trust within Germany because of their apparent failures to openly analyze and learn from those few research findings and test results that, although clearly not showstoppers, proved somewhat less favorable or conclusive than expected. The resulting vacuum was ultimately filled by ruthless anti-nuclear opponents whose politically driven agenda was to inflate residual uncertainties into showstoppers and destroy reputations, both individual and institutional.

To paraphrase Peter Sandman: *The only way to earn public trust is to make it unnecessary; and the only way to do that is through complete openness and unfailing integrity*. What this means in practice is that you must always take public ownership of your bad results along with the good and then publicly embrace and broadcast the not-so-good results for the learning opportunities and problem solving challenges they present. It distresses me when anyone entrusted with nuclear safety, and especially the NRC, seems to be doing anything less.

As I prepare to retire next month from the NRC, I am confident that our ISOCCER values will guide those charged with resolving the issues of this DPO after I'm gone.

APPENDICES

Appendix A

Email Correspondence Stating the DSFM Decisions Contested by this DPO

Appendix B

Subverted Task Action Plan for GSI-196

Appendix C

Comments on “Review of BORAL™ Degradation-Related Literature Survey” a report submitted to NRC/RES by ORNL on August 14, 2006

Appendix D

Email from AAR with Photo of Delaminated Boral, December 11, 2003

Appendix E

Non-Issued Request for NRC Research

Appendix F

Email Correspondence on DSFM Reporting to OIG on my Allegations of Past Wrongdoing.

Appendix A

Email Correspondence Stating the DSFM Decisions Contested by this DPO

The following pages copy the subject email correspondence.

From:	Lombard, Mark
To:	Carlson, Donald
Cc:	Hsia, Anthony; Pham, Bo; Chung, Donald; Wong, Emma
Subject:	RE: Discussion of potential DPO concerning Boral blistering and fuel binding in deployed casks
Date:	Thursday, April 21, 2016 8:55:23 PM

Don,

We don't see a safety issue that necessitates issuing a dry storage generic communication or to expend valuable research resources. We may include a brief reference in the final version of ISG-2.

Mark

From: Carlson, Donald
Sent: Friday, April 15, 2016 10:50 AM
To: Lombard, Mark <Mark.Lombard@nrc.gov>
Cc: Hsia, Anthony <Anthony.Hsia@nrc.gov>; Pham, Bo <Bo.Pham@nrc.gov>; Chung, Donald <Donald.Chung@nrc.gov>; Wong, Emma <Emma.Wong@nrc.gov>
Subject: Discussion of potential DPO concerning Boral blistering and fuel binding in deployed casks
Importance: High

Hi Mark,

Many thanks again for our cordial discussion on March 28.

As stated, I have decided to submit a DPO and would now like to confirm the following points from what we discussed:

- You will not issue an information notice or other generic communication on the binding issue. I still think you should.

o Instead, you may insert a blurb on the binding issue in the upcoming FRN for the final revised ISG-2.

o The blurb may refer to the reported binding event in Spain in late 2000.

o You may offer me a chance to comment on a draft of the FRN blurb. I would appreciate that.

- You considered but did not issue a user-need addendum to have RES evaluate vacuum-drying blistering of older Boral.

o The close-out memo for GSI-196 called out the need to examine this. I believe we are still accountable for this.

o Criticality safety could become more of concern if blistering proves a lot worse with older Boral.

- We briefly noted there are potential 72.122(l) compliance and enforcement aspects to the binding issue.

o I have not yet given much consideration to those aspects.

o My main concerns are for NRC openness and accountability.

o I also have moderate safety concerns with regard to:

▪ operational ALARA for future processing

▪ criticality safety in casks with older Boral.

Please let me know if you think I have missed or mischaracterized anything.

Thanks and have a great weekend,

Don

[redacted]

From: Lombard, Mark
Sent: Tuesday, March 22, 2016 1:46 PM
To: Carlson, Donald <Donald.Carlson@nrc.gov>
Cc: Hsia, Anthony <Anthony.Hsia@nrc.gov>; Damiano, Debra <Debra.Damiano@nrc.gov>; Rahimi, Meraj <Meraj.Rahimi@nrc.gov>; Pham, Bo <Bo.Pham@nrc.gov>
Subject: RE: Potential DPO - Communicating the potential need to use cutting tools to retrieve Boral-bound fuel from deployed casks

Thanks Don. I would be happy to meet with you. As we have discussed previously, we don't see there is a safety issue for storage, especially in light of our revision of ISG-2, but are happy to discuss with you again.

Mark

-----Original Appointment-----
From: Carlson, Donald
Sent: Tuesday, March 22, 2016 10:50 AM
To: Lombard, Mark
Cc: Hsia, Anthony; Damiano, Debra

Appendix B

Subverted Task Action Plan for GSI-196

The following pages present the 16-page Task Action Plan for GSI-196 that was replaced at the final concurrence step by a 2-page plan dictated by NMSS/SFPO's deputy director for technical review. That replacement constituted what the first four individuals listed on concurrence then called a blatant subversion of the GSI process.

MEMORANDUM TO: Carl J. Paperiello, Director
Office of Nuclear Regulatory Research

FROM: Farouk Eltawila, Director
Division of Systems Analysis and Regulatory Effectiveness
Office of Nuclear Regulatory Research

SUBJECT: TASK ACTION PLAN FOR RESOLVING GENERIC SAFETY ISSUE 196, “BORAL DEGRADATION”

A task action plan has been developed for establishing the technical basis for resolving Generic Safety Issue (GSI) 196, “Boral Degradation.” GSI-196 addresses the degradation of Boral neutron absorber plates under anticipated sequences of service conditions in spent fuel cask systems and any resulting increase in the potential for accidental criticality involving such systems. The issue applies to all existing and planned spent fuel casks and canisters in the U.S. that use Boral plates to help prevent nuclear criticality under normal, off-normal, and accident conditions. Included are all such storage and/or transport systems now in service or in various stages of licensing, fabrication, or pre-deployment.

This new GSI has passed the prioritization screening process. The attached Task Action Plan documents our current path for issue resolution. It should be noted that contractors will be used only for those tasks that require the use of testing facilities. All other tasks will be performed in-house.

If you have any questions or require additional information on this proposed plan, please contact Harold Vandermolen, 415-6236.

Attachment: As stated

MEMORANDUM TO: Carl J. Paperiello, Director
Office of Nuclear Regulatory Research

FROM: Farouk Eltawila, Director
Division of Systems Analysis and Regulatory Effectiveness
Office of Nuclear Regulatory Research

SUBJECT: TASK ACTION PLAN FOR RESOLVING GENERIC SAFETY ISSUE 196, "BORAL DEGRADATION"

A task action plan has been developed for establishing the technical basis for resolving Generic Safety Issue (GSI) 196, "Boral Degradation." GSI-196 addresses the degradation of Boral neutron absorber plates under anticipated sequences of service conditions in spent fuel cask systems and any resulting increase in the potential for accidental criticality involving such systems. The issue applies to all existing and planned spent fuel casks and canisters in the U.S. that use Boral plates to help prevent nuclear criticality under normal, off-normal, and accident conditions. Included are all such storage and/or transport systems now in service or in various stages of licensing, fabrication, or pre-deployment.

This new GSI has passed the prioritization screening process. The attached Task Action Plan documents our current path for issue resolution. It should be noted that contractors will be used only for those tasks that require the use of testing facilities. All other tasks will be performed in-house.

If you have any questions or require additional information on this proposed plan, please contact Harold Vandermolen, 415-6236.

Attachment: As stated

Distribution

ARREB R/F	JCraig	JRosenthal	JDanna
DSARE R/F	SBahadur	CAder	DCarlson
JStarefos	MMayfield	JIbarra	PTorres

C:\Don04a\Criticality\Boral\GSI 196 Task Action Plan Carlson r3.wpd
*See previous concurrence
OAR in ADAMS? (Y or N) Y ADAMS ACCESSION NO.: ML050280145 TEMPLATE NO. RES-006
Publicly Available? (Y or N) N DATE OF RELEASE TO PUBLIC N/A SENSITIVE? N
To receive a copy of this document, indicate in the box: "C" = Copy without enclosures **"E"** = Copy with enclosures **"N"** = No copy

OFFICE	ARREB*	ARREB*	ARREB*	C:ARREB*	D:DSARE
NAME	DCarlson:dfw	HVandermolen	JKauffman	JRosenthal	FEltawila
DATE	01/ 26/05	01/26 /05	01/2705	01/27/05	01/ /05

OFFICE	SISP Review	SISP Review
NAME	DCarlson	JRosenthal
DATE	01/27/05	01/ /05

TASK ACTION PLAN
GENERIC ISSUE 196
"BORAL DEGRADATION"

WORK SCOPE

The issue pertains to the degradation of Boral neutron absorber plates under anticipated sequences of service conditions in spent fuel cask systems and any resulting increase in the potential for accidental criticality involving such systems. The issue applies to spent fuel casks or canisters in the U.S. that use Boral plates to help prevent nuclear criticality under normal, off-normal, and accident conditions.

STATUS

This issue has passed the screening stage and is at the beginning of the technical assessment stage.

System Applicability: Spent fuel casks or canisters in the U.S. that use Boral plates to help prevent nuclear criticality. A comprehensive listing of such spent fuel systems will be developed as part of the early technical assessment activities for this GSI.

Task Manager: Paulette Torres, RES/DSARE/ARREB

GSI-196 Technical Assessment Plan

The approach begins with information gathering and review activities to (1) evaluate and summarize the existing knowledge base of test data and operating experience pertaining to Boral degradation effects in casks and related systems; (2) identify and describe the cask systems that use Boral, including the respective material configurations, relevant fabrication and deployment histories, and associated service condition sequences; and (3) summarize the significant variations over time in the processes for fabricating and pre-treating the Boral plates used in the various cask systems. The GSI will then be reevaluated as significant insights emerge from these initial assessment activities. If the GSI is found to be resolved without further information, no further assessment activities will be necessary and the GSI will be closed with appropriate documentation of the technical basis for resolution.

If the GSI cannot be resolved based on insights gained from the review of existing information, detailed plans for obtaining necessary additional information will be developed and implemented as needed. These plans will call for work in two basic areas: criticality safety analysis and material degradation testing. Criticality calculations will first be performed on models of representative cask designs and contents to evaluate any increase in the potential for accidental criticality that would result from a range of postulated Boral degradation and relocation scenarios. From these postulated scenarios, a set of credible worst-case scenarios will be identified based on the preceding assessment of existing information. If analysis of the initial calculation results show that accidental criticality will occur at a frequency below the minimum frequency criterion established in the screening phase, no further information will be needed and the GSI will be closed. Otherwise, the detailed plans will call for the conduct of Boral degradation testing and supplemental criticality analyses as needed for issue resolution.

Attachment

Revised estimates and screening analysis of the frequency of accidental criticality will be provided when needed as significant new insights emerge from the testing and analysis efforts.

The technical assessment plan is further detailed in the following task descriptions.

Task A. Information Gathering and Evaluation

Overview: Gather, review, and summarize the information needed for evaluating Boral degradation effects in casks and their potential impacts on the estimated frequency of accidental criticality. This will entail the following three activities:

Task A-1. Gather and summarize existing information on Boral degradation effects.

Task Resource and Schedule Estimates:
NRC effort: 2 staff-months
Contract funds: None
Earliest start date: 3/05
Duration: 4 months

Task Description: Gather, evaluate, and summarize the existing knowledge base of test data and operating experience pertaining to Boral degradation effects in casks and related systems. The information to be evaluated should include for example (a) any recent reports on Boral testing performed for cask vendors, the Boral vendor, the Electric Power Research Institute, or others; (b) U.S. and foreign event reports involving Boral in spent fuel pools, casks, or other relevant systems (e.g., December 2000 cask event in Spain); (c) NRC inspection reports and associated correspondence (e.g., IR 72-1014/2003-101); (d) NRC Information Notices (e.g., IN 83-29); and (f) any related reports from past research conducted by the NRC or others (e.g., Idaho cask demonstration project; research from the late 1970s and early 1980s on Boral blistering and coverplate bulging in pools racks).

Task Deliverable: Summary report with a copy of each key reference.

Task A-2. Identify cask systems that use Boral and describe service condition sequences.

Task Resource and Schedule Estimates:
NRC effort: 2 staff-months
Contract funds: None
Earliest start date: Concurrent with or after Task A-1
Duration: 4 months

Task Description: Identify cask or canister systems in the U.S. that contain Boral, and gather and summarize the following information for each system:

(a) Provide a description of the Boral plates used in that system, including plate dimensions (overall thicknesses, widths, lengths), the minimum and/or nominal poison areal densities (i.e., in grams of boron or boron-10 per square centimeter), and any other available information about the specific plates or plate material constituents, plate fabrication processes, or any treatments applied. For deployed cask or canister systems, determine or estimate when the Boral plates were fabricated (i.e., in relation to Task A-3 below).

(b) Describe how the Boral plates are configured in relation to other cask internals. For example, indicate or show how the Boral plates are attached to the basket walls (e.g., by vented or sealed coverplates) and note the material compositions of the baskets, attachments, welds, cavity walls, fuel contents, and any other internal components (e.g., heat conductor elements) that could affect the Galvanic or other chemical reactions that may occur with Boral while the system is immersed in pool water during loading or for eventual reopening. Note in particular any details on the coverplate welds or other attachment features whose failure as a result of Boral degradation (e.g., swelling) and/or other service conditions could lead to significant relocation or shifting of the Boral plates (or eventual plate fragments) away from their intended positions. Include also generic information, or site-specific information as appropriate, on pool water chemistry (e.g., boric acid concentrations in PWR pools, solution pH, etc.) and conditions (e.g., water temperatures and immersion depths or pressures) inside the cask during loading operations.

(c) Describe the conditions experienced by the Boral and other cask internals during (I) initial in-pool cask loading, wet or dry hydrostatic pressure-testing (if any), draining, drying, inert gas filling, and transfer procedures, (ii) storage and/or transport service and operating events, and (iii) eventual re-immersion in pool water for cask unloading, inspection, or repair. Included should be wet and dry pressure and temperature transients (especially peaks), heatup and cooldown rates, residual moisture content, long-term temperatures and pressures, any mechanical loads, and long-term gamma and neutron irradiation levels. Indicate also the allowed or expected number of duty cycles (e.g., multiple duty cycles in the case of reusable transport casks). In the event that the information given in available documents is incomplete regarding such conditions, provide estimates based on stated assumptions and supplemental analyses as needed. Note that the specific loading and handling procedures used for existing cask systems of a given design may vary depending on when and where they were deployed.

Task Deliverable: Staff report with summary tables and a copy of each key reference.

Task A-3. Identify changes over time to Boral fabrication and treatment processes.

Task Resource and Schedule Estimates:
NRC effort: 1 staff-month
Contract funds: None
Earliest start date: Concurrent with or after Task A-1
Duration: 2 months

Task Description: Gather and summarize information on how the processes for fabricating and treating Boral plates have changed over the years. Note any significant process changes that could systematically affect Boral degradation characteristics (e.g., composition, porosity, grain size, bonding, pre-oxidation, etc.) and when they occurred. This information will be used in Task C below, together with associated cask-specific information (see Task A-1 above), to assess the need to evaluate Boral samples from different fabrication eras.

Task Deliverable: Short staff memo report.

Task B. Analysis of Boral Degradation Effects on the Potential for Accidental Criticality

Overview: Perform criticality calculations and analysis to estimate the increase in the maximum neutron multiplication factor, k-effective, that would result from Boral degradation effects in casks and to evaluate any increase in the potential for accidental criticality.

Task B-1. Phase I Criticality Analyses

Task Resource and Schedule Estimates:
NRC effort: 3 staff-months
Contract funds: None
Earliest start date: On finishing Task A-1
Duration: 6 months

Task Description: Phase I of the analysis efforts, which can be performed independently of any Boral testing efforts in Tasks C and D, should provide scoping estimates of the increases in k-effective that would be caused by credible ranges of types and degrees of Boral degradation and relocation in representative cask designs under flooded conditions with representative or bounding ranges of fuel contents. The selection and modeling of the cask designs and contents considered in this initial scoping analysis should be based on the review of cask design information gathered under Task A-2 above. The initial determination of what ranges of Boral degradation effects are deemed credible should be consistent with any insights gained from the information evaluated under Tasks A-1 and A-3.

Task Deliverable: Staff report on Phase I criticality analyses

Task B-2. Phase II Criticality Analyses (as needed)

Task Resource and Schedule Estimates:
NRC effort: 2 to 6 staff-months
Contract funds: None
Earliest start dates: After Tasks A-1 and B-1 and part way through Task D-1; subsequently as needed
Durations: 4 to 12 months

Task Description: Phase II of the analysis efforts will be performed on an as-needed basis to provide more design-specific evaluations of any increase in the potential for accidental criticality resulting from the types and degrees of Boral degradation and relocation indicated by the test results emerging from Task C above.

Task Deliverables: Staff reports on interim and final Phase II criticality analyses (as needed)

Task C. Specifications and Planning for Boral Degradation Testing Program

Overview: Using information summarized under Tasks A and B, develop technical specifications and options for a Boral testing program. Included should be specifications for representative sets of Boral plate samples, test articles, testing media, test condition sequences, test equipment, and associated measurements. For example, the test article specification should note any needs to address Galvanic reactions among the wetted cask internals as well as any damage to the Boral coverplates or coverplate attachment welds that could result from Boral swelling or other interactions.

The test plans should identify the specific cask systems to which the respective tests are intended to apply and should be prioritized to first address those Boral plates, test articles (including simulated attachments), and service condition sequences expected to produce the greatest degradation effects (e.g., those with wet hydrostatic pressure testing followed by high-temperature vacuum drying, or those with multiple cycles of wetting and drying sequences).

Task C-1. Phase I Test Planning (as needed)

Task Resource and Schedule Estimates:
NRC effort: 2 staff-months
Contract funds: None
Earliest start date: On finishing all of Task A and Task B-1
Duration: 4 months

Task Description: The first phase of the planned degradation testing should simulate the effects on the Boral plates, and on features (e.g., coverplate welds) that secure the plates to other basket components, from one or more cycles of wet loading, wet pressure testing, drying, and transfer operations and should exclude the long-term effects of irradiation and other storage conditions.

Task Deliverable: Staff report on Phase I test specifications and plans

Task C-2. Initial Phase II Test Planning (as needed)

Task Resource and Schedule Estimates:
NRC effort: 1 staff-month
Contract funds: None
Earliest start date: Part way through Task D-1
Duration: 2 months

Task Description: Subsequent tests may be necessary to address the further degradation resulting from long-term conditions with irradiation in combination with transient short-term conditions addressed in the Phase I testing. Initial planning should identify and describe potential sources of the irradiation services that may be needed.

Task Deliverable: Staff letter report on potential irradiation facilities for Phase II testing

Task C-3. Final Phase II Test Planning (as needed)

Task Resource and Schedule Estimates:
NRC effort: 2 staff-months
Contract funds: None
Earliest start date: On finishing Task C-2
Duration: 4 months

Task Description: Develop test plans and specifications for degradation testing to simulate the combined sequential and/or cyclic effects of transient short-term condition sequences and long-term conditions with irradiation on the Boral plates and the design features (e.g., coverplate welds) that secure or locate the plates in relation to other basket components.

Task Deliverable: Final staff report on Phase II test specifications and plans

Task D. Boral Sample Acquisition, Degradation Testing, and Evaluation

Overview: Place and execute the necessary contract work for acquisition of Boral samples, assembly of test articles and equipment, conduct of tests and measurements, and evaluation and reporting of test results.

Task D-1. Phase I Boral Degradation Testing (as needed) - Without Irradiation:

Task Resource and Schedule Estimates:
NRC effort: 3 staff-months
Contract funds: $150K
Earliest start date: On finishing Tasks B-1 and C-1
Durations: 2 to 9 months needed for SOW and contract placement; followed by 3 months by contractor for sample acquisition, detailed test planning, and preparation of test articles and equipment, followed by 6 months for conduct of testing.

Task Description: Phase I testing should simulate the short-term effects from one or more cycles of wet loading, wet pressure testing, drying, and transfer operations and should exclude the long-term effects of irradiation and other storage conditions.

Task Deliverables:
Contractor's detailed test plan for staff review
Interim and final contractor reports on tests
Retrievable test samples and test articles

Task D-2. Phase II Boral Degradation Testing (as needed) - With Irradiation

Task Resource and Schedule Estimates:
NRC effort: 4 staff-months
Contract funds: $250K
Earliest start date: Part way through Task D-1

Durations: 3 to 9 months needed for SOW and contract placement, followed by 3 months by contractor for detailed test planning and preparation of test articles and equipment, followed by 3 years for conduct of testing with irradiation

Task Description: Conduct Boral degradation testing to simulate the combined sequential or cyclic effects of transient short-term condition sequences and long-term conditions with irradiation.

Task Deliverables:

Contractor's detailed test plan for staff review
Interim and final contractor reports on tests
Retrievable test samples and test articles

Task E. Technical Evaluation of Safety Issue with Recommendations

Overview: Using insights emerging from the review, analysis, and testing work completed under Tasks A, B, and D, provide updated estimates of the frequency of accidental criticality involving casks with degraded Boral plates. Establish and apply appropriate screening criteria to the updated criticality accident frequency results. As warranted by the frequency estimates and screening results, either close the GSI (with appropriate documentation) or identify options and provide recommendations for technical and regulatory measures to resolve it.

Task E-1. Interim Frequency Analysis and Screening Evaluations

Task Resource and Schedule Estimates:

NRC effort: 2 to 5 staff-months
Contract funds: None
Earliest start dates: On completion of Task A, with further screening updates when needed as insights emerge from necessary work under Tasks B and D.
Durations: 2 months for each screening update and 4 months for closure documentation, review, and transmittal; 4 to 12 months total

Task Description: As significant insights emerge from the review, analysis, and testing efforts, provide updated estimates of the frequency of accidental criticality involving casks with degraded Boral plates. Establish and apply appropriate screening criteria to the updated criticality accident frequency results, and proceed as follows:

(a) When the updated frequency estimates fall below the screening criterion, terminate any further work under the above tasks and close the GSI with appropriate documentation of the basis for closure.

(b) When the updated frequency estimates fall above the screening criterion, apply any insights gained from the frequency analysis to guide any further efforts under Tasks B and D.

(c) If, after completing necessary work under Tasks B and D, the final frequency estimates remain above the screening criterion, proceed to Task E-2.

Task Deliverables: Interim staff reports on frequency and screening analysis for GSI-196, and closure documentation (if warranted).

Task E-2. Final Evaluation with Recommendations (if needed)

Task Resource and Schedule Estimates:
NRC effort: 3 staff-months
Contract funds: None
Earliest start date: On completing necessary work under Task E-1.
Durations: 3 months for draft final report, 4 months for ACRS/ACNW review and finalization, 3 months for transmittal of recommendations to EDO or NMSS for regulatory action

Task Description: This task will be performed only in the event that the GSI cannot be closed based on the screening evaluations performed under Task E-1. Provide a final evaluation of the estimated frequency of accidental criticality and develop options and recommendations for measures needed to reduce the frequency. Such measures might include, for example, a requirement that borated water be used in any pools in which the casks are to be opened. For casks not yet fabricated or deployed, such measures might also include changes to the absorber plate material or plate design, the cask basket design, the allowed fuel contents, or the procedures for cask loading, draining, drying, and eventual reopening. Document the final evaluation and recommendations in a final report. The staff should present a draft of the final report to the ACRS and/or ACNW for review and comment, with comments to be addressed as necessary in the finalized report.

Task Deliverable: Final staff report on GSI-196 technical evaluation and recommendations

Summary of GSI-196 Task Action Plan with Preliminary Resource Estimates and Implementation Schedule

TASKS	NRC Staff-Months	Contract Funds ($K)	Earliest Task Starts	Earliest Deliverable Dates
A-1. Summarize existing information on Boral degradation effects	2	0	TBD	4 months after task start
A-2. Identify cask systems that use Boral and describe service condition sequences	2	0	during or on finishing Task A-1	4 months after task start
A-3. Identify significant changes over time to Boral fabrication & treatment processes	1	0	during or on finishing Tasks A-1 or A-2	2 months after task start
B-1. Perform initial scoping analysis of potential Boral degradation impacts on cask criticality safety	3	0	on finishing Tasks A-1 and A-2	6 months after task start
B-2. Perform interim and final analyses of Boral degradation impacts on criticality safety (as needed)	2 to 6	0	when new insights emerge from testing under Task D	4 months after the start of each interim analysis campaign needed
C-1. Develop Phase I test specifications and plans (as needed)	2	0	on finishing Task B-1	4 months after task start
C-2. Develop initial Phase II test specifications and plans (as needed)	1	0	part way thru Task D-1	2 months after task start
C-3. Develop final Phase II test specifications and plans (as needed)	2	0	on finishing Task C-2	4 months after task start
D-1. Conduct Phase I Boral degradation testing - no irradiation (as needed)	3	150	on finishing Task C-1	12 to 18 months after task start

TASKS	NRC Staff-Months	Contract Funds ($K)	Earliest Task Starts	Earliest Deliverable Dates
D-2. Conduct Phase II Boral degradation testing - with irradiation (as needed)	4	250	part way thru Task D-1, after Task C-3	24 to 48 months after task start
E-1. Provide interim frequency and screening analyses (as needed) with GSI closure report (as needed).	2 to 5	0	on finishing Tasks A; when needed as insights emerge from Tasks B-1, B-2, D-1, and D-2	2 months after start of each screening update (assume 1 to 4 updates)
E-2. Provide final GSI evaluation with regulatory recommendations and final report (as needed).	3	0	on finishing all Task E-1	10 months after task start

Appendix

Preliminary Considerations for Assessing Generic Issue 196, "Boral Degradation."

1. Scope and Regulatory Background

This issue concerns Boral plates as they are used to prevent criticality in dry casks for storing and transporting spent fuel. To better understand the scope and regulatory context of this issue, it may be helpful to note the following:

(a) In most cases we are dealing with dual-purpose cask systems with canisters designed for use in both storage and transport. The loading of spent fuel assemblies into a dual-purpose canister generally occurs inside the storage pool at a reactor site and is typically completed over a period of several days. Each canister typically holds 24 to 32 PWR assemblies or about 68 BWR assemblies. After draining, drying, and sealing, the loaded canisters can then be moved as needed between shielded storage, transfer, and transport overpacks, which comprise the remainder of the dual-purpose cask systems.

(b) Note that, while the canisters are generally referred to as "multi-purpose canisters," or MPCs, they are in fact only dual-purpose (i.e., for storage and transport) since they do not meet technical requirements for the third major purpose of disposal in a geologic repository. Therefore, after being used for storage and transport, all canisters will ultimately be opened at the geologic repository to have their spent fuel contents transferred into special disposal canisters and disposal overpacks. The need may also arise for damaged or degraded canisters to be reopened in a pool either before leaving the reactor site or ISFSI (independent spent fuel storage installation) site, or, in the rare event of a damaging transport incident, while en route to a storage or repository facility.

(c) The relevant regulatory requirements pertaining to cask design and/or cask operations are those in 10 CFR Parts 50 (storage pools), 72 (storage casks), 71 (transport casks), and 63 (disposal systems).

(d) The eventual regulatory responses to any Boral degradation issues in casks may vary from case to case, depending on factors such as the specific design of the cask and canister system and its operational and licensing status. With regard to the latter, one should note that the licensing of dual-purpose canisters for on-site dry storage under Part 72 (and Part 50) has generally preceded by a few years their licensing for transportation under Part 71. In principle, this two-step licensing process could result in the disapproval for transport of "dual purpose" canisters already approved and used for storage. This situation could arise, for example, in cases where, before completion of the Part 71 review and approval process, new information comes to light (e.g., concerning Boral degradation) that invalidates the submitted licensing-basis safety analysis.

(e) Any potential for major Boral degradation within the storage and transport canisters could have significant impacts on the technical design and operational requirements for the repository transfer facilities. Such impacts would concern criticality safety, spent fuel retrieval provisions, and associated worker radiation protection (i.e., considering the potential added difficulty of retrieving Boral-bound fuel assemblies). Regarding criticality safety, the wet fuel transfer facilities at the repository might have to use highly borated water to prevent nuclear criticality when opening any casks whose Boral plates might have experienced extensive degradation and/or detachment from the basket walls. Similar considerations would also arise in the event that a cask has to be reopened in a reactor spent fuel pool. For example, while the storage pool water at BWR plants is normally not borated, the eventual need to reopen such a cask in a BWR pool could necessitate borating the pool water solely for that purpose.

2. Past, Present, and Future Considerations

This issue is both forward looking and backward looking. Many Boral-containing casks of various designs have already been deployed in dry storage and/or transport settings. Obviously, any changes to the Boral product line, the canister system designs, or their loading and handling procedures cannot affect what was already fabricated or deployed before such changes were implemented. To evaluate the potential extent of Boral degradation effects in the full fleet of affected casks, it is important to consider the factors that affect Boral degradation and how these factors can vary. As discussed below, these factors depend on details concerning the Boral itself, the canister system in which the Boral is used, the history of fabrication and deployment, etc.

(a) Subtle changes over time to the Boral product line and fabrication processes may significantly affect degradation characteristics. Past and recent changes to Boral include those arising from variations in the Boral constituent specifications (Al powder, B_4C granules, Al cladding), the heating and rolling processes, and the use of passivation procedures. Therefore, otherwise identical Boral plates fabricated at different times, using subtly different constituents and processes, may degrade differently in response to a given service condition sequence.

(b) The Boral plates used in the various NRC approved canister designs cover a wide range of standard and nonstandard design specifications. The main design specifications for Boral plates (in addition to the cut width and length) are the plate thickness (i.e., 0.075 to 0.270 inches) and the poison areal density (e.g., 1 to 6 milligrams of ^{10}B per cm^2). To a significant degree, plate thickness and poison areal density can be varied independently by varying the volume fraction of B_4C granules in the composite material over a broad range (e.g., with carbide volume fractions ranging from 0.15 to 0.65).[1] It is thought that Boral degradation phenomena are likely to vary most significantly with (I) variations in the nominal plate thickness and (ii) variations in the volume fraction of B_4C granules in the Boral composite material.

(c) The service condition sequences that Boral plates undergo in casks are known to vary significantly among the various cask and canister designs and can also vary for a

---

[1] In principle, the poison areal density of Boral plates could also be increased by using B_4C that is enriched in the ^{10}B isotope, but this apparently has never been done.

given canister design due to changes or variations in the canister loading procedures and spent fuel contents. Relevant variations and changes in canister designs, loading procedures, storage conditions, and contents involve the following:

(i) The choices and configurations of basket structural materials (e.g., stainless steel) and heat conductor elements (e.g., copper) can affect the Galvanic reactions with Boral that occur in pool water during loading and reopening. Such Galvanic reactions were found to be potentially significant in past evaluations of Boral pitting and blistering in spent fuel pool racks.

(ii) The choice of a vented versus a sealed design of the Boral coverplate (i.e., the steel coverplate that attaches the Boral plate to the steel walls of the basket) greatly affects how Boral is exposed to chemical and physical reactions with water during in-pool loading and reopening operations. Note that some cask designs that were initially approved with a seal-welded Boral coverplate design were later changed to use a vented coverplate design. This change happened in the case of an NRC approved canister designed by NAC International in response to a swelling/bulging event reported in late 2000 involving an essentially identical NAC design used in Spain. This historical development resembles the past evolution of Boral coverplate bulging issues involving spent fuel pool racks in the U.S. and abroad.

(iii) Any hydrostatic pressure testing of the canister closures that is done while the canister contains Boral plates and water will tend to push more water into the porous Boral composite material. This can add greatly to the degradation effects (e.g., steam and/or hydrogen blistering) that may occur subsequently. The use of such hydrostatic pressure testing depends on the canister design and may be modified over time for a given design as loading and handling procedures are changed and implemented by the cask vendors and users. For example, it is possible that some cask designs that once included wet hydrostatic pressure testing of canister closures in their procedures may no longer do so today; or that such testing is or was done by cask users at some U.S. or foreign sites and not at others. In any case, water pressure is expected to be an important aspect in the service condition sequences experienced by Boral. (Note that normal water pressure near the bottom of a pool is about 2 bars; i.e., atmospheric pressure of 1 bar plus 1 bar from the weight of ~10 meters of water).

(iv) The procedures used during the draining, drying, and transfer of loaded canisters determine the effectiveness of drying and govern the temperature and pressure transients experienced by the Boral plates during such procedures. These procedures likewise vary among canister vendors and designs and may also change over time and from site to site for a given design. It is worth noting that canister drying procedures have received significant attention in recent years in view of the need to limit the peak cladding temperatures experienced by high-burnup spent fuel during drying. To address such issues, the prevalent use of high-temperature vacuum drying procedures has been replaced in some cases with gas-purging or other drying procedures intended to reduce peak temperatures and heatup transients in the canister. The rate of Boral heatup and the maximum temperatures reached during cask draining and drying are thought to significantly affect the resulting extent of steam and/or hydrogen blistering (i.e., the delamination of B_4C/Al composite material from the aluminum skin). Furthermore, it is not clear how effective the various draining and drying procedures are at eliminating residual moisture within and around the Boral plates. The existence of residual moisture could affect the long-term progression of further Boral degradation phenomena over many years of storage at elevated temperatures.

(v) Long-term storage conditions can also vary considerably among the various cask designs and contents. Controlling variables include the choice of fill gas and fill-gas pressure and the design of the canister basket, heat conducting elements, and storage overpack. The resulting Boral service conditions during long-term storage are then defined in terms of computed temperatures, radiation environments, and the assumed or inferred presence of any residual moisture (and other impurities). It is thought that the long-term effects of gamma radiation on Boral might potentially include such phenomena as radiolytically assisted corrosion cracking.

(vi) Together with the thermal design features of the cask system, the decay heat power of the spent fuel contents also affects the temperature history of Boral during canister draining and drying operations and in long-term storage. The decay heat power of spent fuel varies mainly as a function of fuel burnup level and cooling time and is often a limiting factor in determining what contents can be loaded into the in the cask system without exceeding short-term and long-term fuel cladding temperature limits.

3. Further Information Needed

Necessary insights into Boral degradation phenomena in casks can be gained from a testing program that exposes representative Boral plate specimens to representative or bounding sequences of simulated cask service conditions. To determine what would constitute the appropriate sets of Boral specimens, test articles, and service condition sequences, the following types of information will have to be gathered and evaluated.

(a) Identify and list all existing and planned cask and canister systems that use Boral. (There are more than a few.) Included should be all NRC-approved cask designs (and amended designs) for spent fuel storage and/or transport. Any readily available information on similar cask systems used in other countries should also be noted.

(b) For each cask system design (and amended design version), get information on the history of its fabrication and use. This should include information on when the casks and their Boral plates were or are being fabricated and when and where the casks were or are being deployed. Note the existence of any site-specific differences or variations in components, contents, loading procedures, or handling procedures that could substantially affect the sequence of Boral service conditions, including temporary water pressures, heatup rates, peak temperatures, residual moisture, wet chemistry conditions (e.g., those influencing corrosion and Galvanic reactions), and longer term temperatures and pressures. Any wet hydrostatic pressure testing is especially important to note.

(c) Based on analysis in the SAR, or supplemental analysis as needed, evaluate or estimate the Boral temperature histories (i.e., heatup rates, peak temperatures) during draining and drying operations. Look for worst cases and note that such loading and handling procedures may change over time and vary somewhat from site to site. Also evaluate Boral temperatures during subsequent long-term storage and the pre-quenching Boral temperatures upon subsequent opening in a pool facility.

(d) Gather and list from each of the cask SARs and supporting technical documents necessary detailed information on the Boral plates themselves, how they are configured in the fuel basket, and what other materials are nearby (i.e., materials in the basket structure or heat conduction elements, as important for their potential Galvanic effects with Boral in pool water). Especially important specifications for the Boral plates are the overall plate thickness, the nominal or minimum poison areal density, and, if available, the B_4C volume fraction in the Boral composite material. Note that the B_4C volume fraction can be inferred or estimated from the plate thickness and poison areal density.

(e) For casks already built or in service, try to determine or estimate when the Boral plates were fabricated. As available, note any additional cask-specific Boral material specifications, including any information on the B_4C granules, Al powder, and Al skin constituents and the plate fabrication and passivation processes.

(f) From the Boral vendor, AAR, and its associates, gather information on how the Boral constituent specifications (e.g., B_4C granules, Al powder, Al skin) and Boral fabrication and treatment processes (e.g., heating, rolling, passivation) have varied and changed over the years. Note the time frames when any important changes occurred that would likely affect degradation phenomena (e.g., blistering). The purpose here is to evaluate the potential need for any Boral test specimens from different fabrication eras (e.g., pre-1995 or whatever).

(g) Gather representative and/or bounding information on pool water chemistry and the in-cask water conditions during loading operations in the pools.

(h) From the cask design drawings and documents, note the details of any features relied upon to secure the Boral plates in their intended positions within the cask basket geometry. Note also the maximum extent to which any failure of such features (e.g., coverplates or coverplate tack welds) due to eventual Boral swelling in combination with other in-cask service conditions could result in shifting or relocation of the Boral plates or eventual plate fragments.

4. Test Program Design

Test articles: For example, Boral plate specimens mounted on simulated basket walls with vented, tack-welded, stainless-steel coverplates, and with simulated copper (or other) heat conducting elements.

Test conditions: The testing done on these test articles should simulate one or more cycles of the following service condition sequences:

- In-cask soaking in pool water at a pressure of at least 2 bars (i.e., 1 atmosphere plus 10 meters of water) for several days, with decay heat from fuel
- Wet hydrostatic pressure testing (if this was done for any casks), with heating
- Canister draining, with heating
- High-temperature vacuum drying (if done) or purge-drying or other drying processes with heating
- Gas filling/pressurization, with heating
- Transfer handling and long-term dry storage, with heating (and radiation)
- Transfer handling and transport, with heating
- Canister opening and quenching in pool water

Some dual-purpose canisters may experience just one such cycle, which ends upon opening in the repository transfer facilities. Defective or damaged canisters may undergo two such cycles if they have to be reopened in water before reaching the repository. Reusable transport or storage systems may experience multiple duty cycles.

Test rationale: Initial testing should be done without irradiation. If gross degradation occurs in the absence of irradiation, no further testing is needed to show that Boral will degrade. If the Boral samples sustain little damage in the initial tests, subsequent testing with irradiation may be needed.

Measurements and observations on test articles: Boral blistering, cracking, dimension changes, weight changes, hydrogen gas production, deformation, cracking, or failure of Boral attachment features, etc.

5. Criticality Analysis

Using BEAU (best estimate and uncertainty) methods and assumptions on selected cask designs and contents, perform criticality calculations to evaluate the increase in k-effective and the potential for reflood recriticality with various types and degrees of assumed or test-indicated Boral plate degradation (e.g., swelling and reduction of flux traps, relocation or loss of boron from plates,...) and plate detachment with relocation.

Appendix C

Comments on "Review of BORAL^{TM} Degradation-Related Literature Survey" a report submitted to NRC/RES by ORNL on August 14, 2006

The following pages present the comments that I provided in November 2006 on the subject ORNL letter report for what the RES GSI team members and I felt was a dictated premature closeout of GSI-196. The final 6 pages of comments are omitted because they consist of an appendix very similar to that in the subverted GSI-196 Task Action shown in Appendix A.

Comments on "Review of BORAL™ Degradation-Related Literature Survey"
a report submitted to NRC/RES by ORNL on August 14, 2006

Donald E. Carlson
November 8, 2006

Comments on the ORNL report, "Review of BORAL™ Degradation-Related Literature Survey," are provided below and are followed by an appendix with some related earlier observations on Boral degradation in the context of GSI-196.

1. pp.9-10: The scenario description does not adequately describe what are probably the two most significant factors affecting the initial Boral blistering that may occur during cask deployment, i.e., (1) the soaking pressure and duration and (2) the temperature transient during draining and drying. For example, I recall hearing more than once that at least some loading operations for casks deployed in the U.S. (and elsewhere) have included hydrostatic pressure testing of the closed cask before water draining. Furthermore, it is well known that cask deployments in the U.S. (and elsewhere) have used various kinds of internal drying procedures, including high-temperature vacuum drying, that have produced a wide range of characteristic temperature transients and maximum temperatures. Again, these may be the two most important service condition variables affecting Boral degradation.

2. Another potentially important service condition variable neither described here nor addressed in the reviewed body of Boral test data is that associated with Galvanic interactions between the Boral and the basket and fuel materials (cover panels, welds, basket walls, basket heat conducting structures, fuel structural materials, etc.). Such Galvanic interactions have been noted in the related literature on Boral blistering in pool racks.

3. In order to evaluate the GSI 196 criticality issue (or the related operational safety issues of fuel binding and hydrogen generation during the loading and unloading of casks with blistered Boral), it is essential to first identify the full range of deployed Boral-bearing casks in the U.S. and describe the relevant conditions that arose during their respective loading and deployment operations. Note that loading procedures vary not only between cask designs but have also varied over time among specific deployments of identical or similar cask designs at various sites. To my knowledge, a compilation of such information has never been performed and was clearly not included in what ORNL reviewed for this report. Such a compilation would necessarily include details on such important factors as any wet pressure testing that may have been performed as well as subsequent drying procedures. Lacking such essential information, it is not possible to compare the reviewed Boral test condition sequences to the range of Boral condition sequences experienced in the fleet of deployed casks. No conclusions of any kind on Boral degradation in the context of GSI-196 can be drawn or supported in the absence of such comparisons.

4. The report does not evaluate how well the tested Boral samples represent of the ranges of Boral plates used in the deployed fleet of casks. Of course, such an evaluation is not

possible absent the cask information compilation mentioned in the preceding comment. Here again, essential information is lacking to support conclusions of any kind that would apply to the entire deployed U.S. fleet of potentially affected casks per GSI-196. The conclusions may eventually be found to apply to certain populations of deployed casks, but more information is needed to identify those casks.

5. The three categories of Boral mentioned in the report appear to be an oversimplification. Degradation effects clearly depend on basic Boral plate design specifications, including plate thickness and poison areal density (and corresponding carbide volume fraction), as well as the specific fabrication ingredients and processes and any treatments applied to the fabricated plates. Important Boral fabrication and post-treatment details have varied over time, resulting in changes to meat porosity and other potentially important plate attributes that can greatly affect in-service degradation.

6. p. 13: The final sentence ("This result is predicated upon...") means in effect that these testing results are at best applicable to only a portion of the deployed cask population. GSI-196 (and also the related issue of operational safety of eventual cask unloading operations with Boral-bound fuel and hydrogen generation) applies to all casks, including casks that have already been deployed, few if any of whose Boral plate specifications and fabrication details (and service conditions sequences) are shown to be addressed by this testing.

7. Another very important body of information that was not reviewed for this report is that associated with the December 2000 cask event in Spain. The limited information I have seen about this event indicates that severe Boral blistering and panel bulging occurred with just one cycle of pressurized wetting and drying. Data from this cask event needs to be acquired, evaluated, and reconciled with the testing data that was reviewed for this report.

8. Further attention may need to be given to the effects of wetting-pressurizing-drying-quenching cycles in combination with the long-term effects of gamma and neutron irradiation at elevated temperatures (potentially including radiolytic effects with trapped residual H_2O). Such radiation effects were not addressed in the reviewed test data.

9. Note that GSI-196 as currently framed is a criticality safety issue, not a regulatory or compliance issue per se, and therefore may not be limited in scope to, for example, the conditions explicitly considered for cask licensing under Parts 72 and 71. The following developments in DOE are noteworthy in this regard: (a) DOE/RW is still considering the eventual of opening of some or all such casks at the repository surface facilities in order to transfer their contents into special disposal canisters. (b) At the March 2006 RIC, DOE/RW stated that they are also considering options for loading the deployed cask canisters (in addition to the future TAD canisters) into the repository without opening them, meaning that the service lifetime of the Boral baskets may be very long indeed (i.e., many millennia), in which case the neutronic depletion of B-10 in Boral does become significant, contrary to what this report claims. (c) DOE/NE's GNEP is planning to eventually open all deployed casks for reprocessing of the spent fuel contents. Both

scenarios (a) and (c) have implications for various aspects of Boral-related operational safety (potentially including criticality).

10. The report's analysis of the reactivity effects of Boral degradation needs to be supplemented to better address the full scope and extent of potential degradation effects, including: (a) the reduced flux trap effectiveness resulting from the displacement of water by blisters and by gas potentially accumulating behind the cover panels (not all of which are vented in certain deployed casks), and (b) the potential lateral and vertical relocations of the Boral plates made possible by Boral-swelling-aided stressing and failure of the cover panels or the stitch welds that attach the cover panels, and thus the Boral plates, to the cask basket walls. Note that, since Boral plates are generally much thicker and more rigid than the very thin cover panels, consideration must be given to the potential that Boral swelling and warping might lead to stress-induced failure of the cover panels or panel stitch welds. Note that in all cask designs the Boral plates are substantially shorter than the cask's fuel cavity. This means that the axial shifting of detached Boral plates could "expose" substantial lengths of active fuel between neighboring fuel assemblies. These effects will be cask-design specific.

11. To the extent that the conclusions can be seen as supported, they apply at best, and as stated, only to a limited portion of the potentially affected deployed cask population. In my opinion, this report and its conclusions do not provide a basis for the closeout of GSI-196 as a criticality safety issue. Of course, I do agree with the final closing statement on the operational safety implications (fuel binding, hydrogen generation) of Boral degradation in casks.

12. I agree with those who would prefer to pursue Boral degradation as either (a) a Part 72.122(l) (i.e., fuel retrievability) compliance issue or, much more appropriately, (b) an operational safety issue potentially arising whenever and wherever affected casks may be opened (e.g., in a reactor storage pool for cask repairs necessitated by storage or transport events, at a repository surface facility, at a fuel reprocessing facility as envisioned in GNEP), with potential applicability to the various associated regulatory domains (i.e., Parts 50, 63, 70, 71, 72, etc.). Nevertheless, since GSI-196 has been raised as a criticality safety issue, I would recommend putting it on hold for now rather than trying to close it out without a strong technical basis. My recommendation would be to continue pursuing Boral degradation as a new Generic Issue on operational safety potentially arising in all situations that involve the opening of casks with Boral. This recommendation is based on two observations. First, it appears that operational safety issues would apply in many cases where we might ultimately conclude that criticality safety is not a significant issue. Second, it is technically much more difficult to evaluate the real likelihood of criticality than it is to evaluate the operational safety issues. It would make sense to go first for the low hanging fruit (operational safety issue) and then subsequently apply insights gained to the more difficult task of resolving the criticality safety issues.

Appendix D

Email from AAR with Photo of Delaminated Boral, December 11, 2003

The following pages present a December 11, 2003, email received from Boral producer AAR, Inc., that includes a photo showing delaminated Boral samples on the left.

[redacted]

From: <[redacted] <[redacted]>
Sent: Thursday, December 11, 2003 2:04 PM
To: Christopher Brown; Christopher Regan
Cc: Dallas Mayfield; Jeff Moore; Mark Denton
Subject: Boral Improvement Program Status
Attachments: Alloy B.JPG

Chris and Chris,

Thought you guys might be interested in the following update that we are sending out to our customers:

--------------------- Forwarded Message: --------------------
From: [redacted]
To:
Subject: Boral Improvement Program Status
Date: Thu, 11 Dec 2003 18:18:39 +0000

Gentlemen,

As you know, AAR implemented a Boral Improvement Program in June 2003 to test new processes and materials in an effort to make Boral more resistant to blister formation. Research by AAR and several other organizations has determined that the root cause of blisters is water ingress into the porous Boral core, which causes oxidation of the aluminum powder in the core, which traps water inside the core matrix. There are two mechanisms for blister formation. In spent fuel pools, blisters are formed by the hydrogen released from the aluminum oxidation process. In dry casks and canisters, Boral is susceptible to blisters caused by the trapped water turning to steam during vacuum drying.

AAR's Boral Improvement Program consists of three parts: process control and improvement, evaluation of alternative materials, and credit for 90% of the B-10 contained in Boral. Following is a summary of our progress to-date:

1. Process control and improvement – an AAR engineering and management team reviewed the current Boral production process to identify process variations which could potentially affect the quality of the finished product. The team found inconsistency in the heat-up of ingots prior to rolling. To assure adequate heat-up and consistency in the process, AAR purchased an additional furnace and changed the heating requirements and procedure (longer minimum heat-up time at a higher temperature). All other processes (powder blending, ingot production, annealing, shearing, testing) were evaluated and determined to be acceptable. As a potential new process improvement, AAR is currently testing the effect of a high temperature soak after rolling the sheets. Since aluminum oxidation in air increases at increased temperatures, this may passivate the exposed aluminum in the core. The effect of a high temperature soak is currently being tested at NETCO.

2. Alternative materials – AAR is in the process of testing over 20 new materials (i.e., matrix alloys and other compositions; other neutron absorber materials) for the conventional Boral design and in metal matrix composites. For scoping studies of alternative designs/material for Boral, AAR tests sample material to failure. We know that we can force blisters and/or delamination to occur in Boral under extreme conditions, such as soaking a sample in water and then immediately placing the sample into a hot oven (400ºF+). Therefore, our first go/no-go qualification test for a new material is to compare its time to failure with Boral. We soak samples of Boral and the new material in hot (170ºF) de-min water for 1-2 months, then place the samples into the oven pre-heated to 400ºF+. Typically, the Boral samples will blister within 5 to 10 minutes.

Several samples with different alloy powder have demonstrated significantly greater resistance to failure compared to conventional Boral samples. A photo of samples from a test completed this week on six Boral and six “Alloy B” samples is attached. All of the Boral samples blistered/delaminated as expected. All six of the Alloy B samples survived without any deformation, even after several hours in the oven. However, one Alloy B sample failed in a previous test, so it is not blister-proof, but indications are that it is considerably more resistant to blisters compared to conventional Boral. We will perform confirmation testing on this material (and others) after the first of the year. If the improved performance is confirmed by additional tests, we will continue with a complete material qualification program.

3. Credit for 90% of the B-10 in Boral – it is NRC practice to limit the credit for the boron-10 present in a neutron absorber to only 75%, unless comprehensive measures are implemented to establish the presence, uniformity, and effectiveness of the neutron absorber material. AAR has contracted with NETCO to perform neutron attenuation tests on samples taken from about 120 sheets of Boral (two samples per sheet) from a 3,000 sheet production run. Tests have been completed for more than 200 samples, which show that the B-10 in Boral is uniformly distributed and effective in absorbing thermal neutrons. The remainder of the samples will be tested next week. A report analyzing the data to demonstrate the presence of B-10 at a 95/95 confidence level will be completed early next year. Credit for 90% of the B-10 will allow AAR to modify the sheet design (reduce the core thickness and increase the clad thickness of Boral) to provide more resistance to blister formation.

The combination of improved processes, corrosion resistant materials, and more robust cladding will reduce or eliminate the occurrence of blisters in the improved Boral product in both spent fuel and dry cask/canister applications.

If you have any questions, please let me know.

Happy Holidays,
Jim

Appendix E

Non-Issued Request for NRC Research

The following pages copy a draft request for NRC research that was prepared by DSFM staff. My two proposed added sentences are highlighted. This is then followed by an email with my comments on the draft. The DSFM director later decided not to issue the request.

User Need Amendment 2015

Neutron absorbing materials in canisters for long term use

Background

Currently, neutron absorbing materials (NAM) in dry storage systems are boron-containing materials used to prevent criticality of the high-density fuel assembly arrangement during transportation, loading, and retrieval, particularly in the event of flooding or moderator introduction. Neutron absorbing materials may or may not be load bearing components depending on the design of the basket and integration of the NAM into the fuel basket structure as panels between assemblies. The materials known to be in use include borated aluminum alloys (BorAluminum), metal-matrix composites (Metamic and Bortec), borated stainless steel (NeutroSorb and Neutronit), and aluminum boron carbide laminate composites (Boral). Neutron absorbers are designed to ensure subcriticality in conditions of loss of moderator exclusion, but their degradation may also affect retrievability and thermal performance functions of the system.

Some areas of interest were identified in the "Identification and Prioritization of the Technical Information Needs Affecting Potential Regulation of Extended Storage and Transportation of Spent Nuclear Fuel" report (ML14043A423) where more information is needed in order to fully assess if these areas will need to be further evaluated in Extended Storage and Transportation (EST) timeframes. These include:

- Creep
- Metal fatigue caused by temperature fluctuations
- Wet corrosion and blistering
- Thermal aging effects
- Embrittlement and cracking

If these degradation phenomena do occur, then it could pose a safety issue during:

- Accident scenarios where the absorber is credited
- Transportation
- Retrievability

Materials

There has been some operational experience that would indicate there may be a potential issue with Boral. Boral consists of a porous matrix of aluminum and boron carbide hot rolled between a cladding of fully dense aluminum. However, the edges of the porous matrix are not covered by cladding, allowing for water ingress when submerged. There has been blistering and bulging seen in the Boral material in wet applications and after vacuum drying. During vacuum drying, if the procedures are not followed properly or depending on the vintage and porosity of Boral, there is the possibility of blistering and bulging occurring. Also if there is residual water in the canister, then there is the possibility that blistering or bulging may occur during the EST period. This is not certain. Short-term effects of vacuum drying on Boral have been previously considered in the context of NRC Generic Safety Issue (GSI) 196, "Boral degradation." It bears noting that the closure memorandum for GSI-196 [ML070090182] included a follow-up action for testing of early-generation (“pre-improved-production-process”) Boral.

On the other hand, borated aluminum alloys, metal-matrix composites, and borated stainless steels have essentially no porosity due to the nature of their processing. Currently, there is no degradation type operational experience for these other materials. However, performance of these materials in the long term is not known, and there may be potential degradation mechanisms that could apply. This needs to be examined further.

Task information:

Part A

The materials known to be in use include borated aluminum alloys (BorAluminum), metal-matrix composites (Metamic and Bortec), borated stainless steel (NeutroSorb and Neutronit), and aluminum boron carbide laminate composites (Boral). In order to prioritize the order in which the materials should be evaluated and develop bounding conservative conditions for analysis, NMSS requests that RES determine the extent to which each material has been used in the industry. This would include:

- All existing and planned cask and canister systems that use each material
    - History of its fabrication and use
    - How many canisters at each site use each material
    - When the casks and their NAM were fabricated
    - At each site, differences or variations in components, contents, loading procedures, or handling procedures that could substantially affect the sequence of NAM service conditions, including temporary water pressures, heat up rates, peak temperatures, residual moisture, wet chemistry conditions (e.g., those influencing corrosion and Galvanic reactions), and longer term temperatures and pressures. Any wet hydrostatic pressure testing is especially important to note.
    - The v~~V~~acuum drying procedure ~~was~~ used
    - How full are the canisters loaded? What is the loading pattern?
- Material information per vintage of material in each canister
    - Material properties (e.g., B_4C granules, Al powder, Al skin)
    - Design specifications
        - Overall plate thickness
        - Nominal or minimum poison areal density
    - Manufacturer
    - Fabrication and treatment processes (e.g., heating, rolling, passivation)
    - Structural or non-structural component?
    - Determine the material’s temperature histories (i.e., heat-up rates, peak temperatures) during draining and drying operations. Also determine the materials temperatures during subsequent long-term storage and the pre-quenching materials temperatures

- Details on the configuration of the NAM relative to the fuel basket, and what other materials are nearby (e.g., materials in the basket structure, heat conduction elements, components to secure the material in the basket (non-structural)).
- Coupons installed? Any surveillance?
- Any other pertinent information

Upon compilation of the information, NMSS and RES will decide on the prioritization of the materials to be evaluated and bounding conditions.

Part B

For each material of interest, the following needs to be evaluated for potential impacts on degradation of NAM during the EST time period:

- Creep
    - Amount of possible creep over EST period
    - Amount of creep needed to impact safety functions
- Metal fatigue caused by temperature fluctuations
    - Only applies to structural NAM
    - Effect of metal fatigue and effect on performance of NAM during DBA
    - Note: this may need additional information from a thermal model which is being completed by NMSS
    - Note: work on this may be being done overseas; should be checked before embarking on additional work
- Wet corrosion and blistering
    - For Boral: Amount of water trapped in Boral, mechanisms for blister formation, blistering due to corrosion related H_2 production by residual water in pores
    - All: Galvanic corrosion
- Thermal aging effects
    - Only applies to structural NAM
    - Degree of reduction in mechanical properties and phase instability
- Embrittlement and cracking
    - Effect of radiation embrittlement
    - Effect of cracking of cermet materials as cracking may allow streaming

A method of evaluation may be to determine how each of the above affects criticality using bounding conditions (conservative scoping) such as:

- When fuel is most reactive during cooling (use existing model to determine)
- Bounding limit on blistering
- How much are the canisters loaded? Could be less than full due to thermal load or just under loaded

Timeline

From:	Carlson, Donald
Sent:	Monday, January 12, 2015 5:58 PM
To:	Wong, Emma
Cc:	Kallan, Paul; Csontos, Aladar; Velazquez-Lozada, Alexander; Lombard, Mark; Hsia, Anthony
Subject:	RE: Draft user need amendment on neutron absorbing materials
Attachments:	Closure of GSI-196 RES Memo to EDO Feb 2007 ML070090182.pdf; User need EST amendment010215_DCarlson comments.docx; GSI 196 Task Action Plan Carlson r3 (rejected by NMSS-SFPO decree) Jan 2005.pdf

Hi Emma,

Thanks for returning my phone call today. As we discussed, you will be out the rest of this week and I will be away the following two weeks. So the best we can do is to have our meeting in early February.

The draft RES user need addendum is still evolving, as you note, but it looks like a very good start. A few comments follow:

1. For my own benefit, it would be helpful to also see the original user need memo and any related correspondence as background.

2. I would suggest adding a reference to GSI-196 and its attached closure memo. I've added some proposed words at the bottom of the first page of the edited Word file.

   As described in your draft, the requested RES work could eventually address the GSI-196 closure memo's Follow-Up Actions on the testing of "old" Boral. Given the apparent fact that RES has otherwise completed none of these GSI-196 follow-up actions, noting the work's linkage to the follow-up actions could help elevate its priority.

3. I think RES may eventually find it helpful to consider the attached pdf of my 16-page draft GSI-196 task action plan [ML050280145] (i.e., the one that NMSS demanded be replaced with its 2-page version) as RES develops detailed work plans in response to your user need addendum.

Thanks again for the chance to comment on the draft. I look forward to discussing this and any other DSFM ideas for addressing the Boral issue.

Best regards,
Don

Dr.-Ing. Donald E. Carlson
Senior Project Manager
Advanced Reactor and Policy Branch
Division of Advanced Reactors and Rulemaking
NRC Office of New Reactors
Office: 301-415-0109
Mobile: [redacted]
Room T-6F06, MS T-6E04

Appendix F

Email correspondence on DSFM reporting to OIG on my allegations of past wrongdoing.

The following pages copy the subject email correspondence.

From: Lombard, Mark
To: Carlson, Donald
Subject: RE: Past Boral degradation in deployed canisters
Date: Wednesday, July 09, 2014 4:14:51 PM

How about 11 to 12? The items I want to discuss have nothing to do with your pursuit of resolution of concerns as you are doing what you are supposed to do in exhibiting a questioning attitude, but do relate to statements in the email below including staff was not allowed to review documentation pertinent to their review, subversion of the GSI-196 process, and RES not allowing staff to do things that irritate client office bosses. These could indicate wrongdoing and they must be looked into to determine if it did occur and take appropriate actions. That would be the topic of Friday's conversation.

Thanks,

Mark

From: Carlson, Donald
Sent: Wednesday, July 09, 2014 11:00 AM
To: Lombard, Mark
Subject: RE: Past Boral degradation in deployed canisters

Yes. My calendar is free just about all day till 5:30. When would be a convenient time for you?

Thanks,
Don

From: Lombard, Mark
Sent: Wednesday, July 09, 2014 10:56 AM
To: Carlson, Donald
Subject: RE: Past Boral degradation in deployed canisters

We should talk. Are you in on Friday?

From: Carlson, Donald
Sent: Wednesday, July 09, 2014 9:31 AM
To: Lombard, Mark
Subject: RE: Past Boral degradation in deployed canisters

Hi Mark,

May I ask which concerns you brought OIG's attention?

(a) Subversion of the process for GSI-196 by SFPO and RES management back in 2006 (i.e., replacing the 16-page task action plan with a 2-pager without any stated justification)
(b) Something I've done since starting to follow through on these old issues with NMSS using the Open Door Policy.
(c) Something else.

Thanks,

Don
Office: 301-415-0109
Mobile: [redacted]

From: Lombard, Mark
Sent: Thursday, July 03, 2014 1:34 PM
To: Carlson, Donald
Subject: RE: Past Boral degradation in deployed canisters

Thanks for understanding. There were some new items brought up in your email that crossed a threshold in my mind. I discussed it with our Deputy Office Director, and we decided the concerns needed to be brought to OIG's attention, so we did so late yesterday. I just wanted you to know.

Mark

From: Carlson, Donald
Sent: Wednesday, July 02, 2014 5:19 PM
To: Lombard, Mark
Cc: Wong, Emma; Rahimi, Meraj; Rubenstone, James; Piccone, Josephine; Hsia, Anthony
Subject: RE: Past Boral degradation in deployed canisters

Mark,

Thanks for clarifying the situation.

Of course, my intent is not to direct anyone's work but rather to fulfill my ethical duty to draw NMSS's attention to these outstanding issues and to inform and monitor whatever steps NMSS decides to take to deal with them.

It is also about OCWE and keeping an old promise I made to my former supervisor and three GSI team members back in RES (all since retired) to someday follow through on these issues. As Tony knows, I am grateful to my NRO management chain for allowing me to devote some occasional working hours to this effort. Otherwise I would have to do it entirely on my own time.

Will Josie or Jim be participating in our July 21st meeting? If not, then perhaps I should request separate meetings with them.

Best,
Don
Office: 301-415-0109
Mobile: [redacted]

Document 2: Memo Establishing DPO Panel

July 19, 2016

MEMORANDUM TO: Mark S. Lesser, Panel Chairperson
Region II

Chris S. Tripp, Panel Member
Office of Nuclear Materials Safety and Safeguards

Matthew G. Yoder, Panel Member
Office of Nuclear Reactor Regulation

THRU: Patricia K. Holahan, Director ***/RA/***
Office of Enforcement

FROM: Renée M. Pedersen ***/RA/***
Sr. Differing Professional Views Program Manager
Office of Enforcement

SUBJECT: AD HOC REVIEW PANEL - DIFFERING PROFESSIONAL OPINION ON BORAL DEGRADATION EFFECTS IN DEPLOYED SPENT FUEL CASKS (DPO-2016-002)

In accordance with Management Directive (MD) 10.159, "The NRC Differing Professional Opinion Program;" and in my capacity as the Differing Professional Opinion (DPO) Program Manager; and in coordination with Patricia Holahan, Director, Office of Enforcement; Scott Moore, Acting Director, Office of Nuclear Materials Safety and Safeguards; and the DPO submitter; you are being appointed as members of a DPO Ad Hoc Review Panel (DPO Panel) to review a DPO submitted by a U.S. Nuclear Regulatory Commission (NRC) employee.

The DPO (Enclosure 1) involves concerns related to the evaluation and communication of Boral degradation effects in deployed spent fuel casks. The DPO has been forwarded to Mr. Moore for consideration and issuance of a DPO Decision.

CONTACTS: Renée Pedersen, OE
(301) 415-2742

Marge Sewell, OE
(301) 415-8045

The DPO Panel has a critical role in the success of the DPO Program. Your responsibilities for conducting the independent review and documenting your conclusions in a report are addressed in the handbook for MD 10.159 in Section II.F and Section II.G, respectively. The DPO Web site also includes helpful information, including interactive flow charts, frequently asked questions, and closed DPO cases, including previous DPO Panel reports. We will also be sending you additional information that should help you implement the DPO process. Because this process is not routine, we will be meeting and communicating with all parties during the process to ensure that everyone understands the process, goals, and responsibilities. Disposition of this DPO should be considered an important and time sensitive activity. The timeliness goal for issuing a DPO Decision is 120 calendar days from the day the DPO is accepted for review. In this case, the DPO was accepted for review on July 6, 2016 and therefore, the timeliness goal for issuing this DPO Decision is November 3, 2016.

Process Milestones and Timeliness Goals for this DPO are included as Enclosure 2. The timeframes for completing process milestones are identified strictly as goals—a way of working towards reaching the DPO timeliness goal of 120 calendar days. The timeliness goal identified for your DPO task is 75 calendar days.

Although timeliness is an important DPO Program objective, the DPO Program also sets out to ensure that issues receive a thorough and independent review. The overall timeliness goal should be based on the significance and complexity of the issues and the priority of other agency work. Therefore, if you determine that your activity will exceed your 75-day timeliness goal, please send an e-mail to Mr. Moore with a copy to DPOPM.Resource@nrc.gov and include the reason for the extension request and a proposed completion date for your work. Mr. Moore can then determine if he needs to submit an extension request for a new DPO timeliness goal to the Executive Director for Operations for approval.

An important aspect of our organizational culture includes maintaining an environment that encourages, supports, and respects differing views. As such, you should exercise discretion and treat this matter appropriately. Documents should be distributed on an as-needed basis. In an effort to preserve privacy, minimize the effect on the work unit, and keep the focus on the issues; you should simply refer to the employee as the DPO submitter. Avoid conversations that could be perceived as "hallway talk" on the issue and refrain from behaviors that could be perceived as retaliatory or chilling to the DPO submitter or that could potentially create a chilled environment for others. It is appropriate for employees to discuss the details of the DPO with their co-workers as part of the evaluation; however, as with other predecisional processes, employees should not discuss details of the DPO outside the agency. If you have observed inappropriate behaviors or receive outside inquiries or requests for information, please notify me.

On an administrative note, please ensure that all DPO-related activities are charged to Activity Code ZG0007.

We appreciate your willingness to serve and your dedication to completing an independent and objective review of this DPO. Successful resolution of the issues is important for NRC and its stakeholders. If you have any questions or concerns, please feel free to contact me or Marge Sewell. We look forward to receiving your independent review results and recommendations.

Enclosures:
1. DPO-2016-002
2. Process Milestones and Timeliness Goals

cc: w/o Enclosures:
S. Moore, NMSS
M. Dapas, RIV
D. Carlson, NRO
L. Wert, RII
J. Peralta, NRR
M. Kotzalas, NMSS
P. Holahan, OE
M. Sewell, OE

stakeholders. If you have any questions or concerns, please feel free to contact me or Marge Sewell. We look forward to receiving your independent review results and recommendations.

Enclosures:
1. DPO-2016-002
2. Process Milestones and Timeliness Goals

cc: w/o Enclosures:
S. Moore, NMSS
M. Dapas, RIV
D. Carlson, NRO
L. Wert, RII
J. Peralta, NRR
M. Kotzalas, NMSS
P. Holahan, OE
M. Sewell, OE

ADAMS Package: ML16201A168
MEMO: ML16201A165
Enclosure 1 - ML16189A180
Enclosure 2 – ML16201A174 OE-011

OFFICE	OE: DPO/PM	OE: D
NAME	RPedersen	PHolahan
DATE	7/19/2016	7/19/2016

OFFICIAL RECORD COPY

Document 3: DPO Panel Report

UNITED STATES
NUCLEAR REGULATORY COMMISSION
REGION II
245 PEACHTREE CENTER AVENUE NE, SUITE 1200
ATLANTA, GEORGIA 30303-1257

September 14, 2016

MEMORANDUM TO: Marc L. Dapas, Director
Office of Nuclear Material Safety and Safeguards

FROM: Mark S. Lesser, Panel Chair ***/RA/***
Christopher S. Tripp, Panel Member ***/RA/***
Matthew G. Yoder, Panel Member ***/RA/***

SUBJECT: DIFFERING PROFESSIONAL OPINION PANEL REPORT ON EVALUATION AND COMMUNICATION OF BORAL DEGRADATION EFFECTS IN DEPLOYED SPENT FUEL CASKS (DPO-2016-002)

In a memorandum dated July 19, 2016, the Senior Differing Professional Views Program Manager appointed us as members of a Differing Professional Opinion (DPO) Ad Hoc Review Panel (DPO Panel) to review a DPO regarding the evaluation and communication of Boral degradation effects in deployed spent fuel casks. The DPO Panel has reviewed the DPO in accordance with the guidance in Management Directive 10.159, The NRC Differing Professional Opinions Program.

The DPO Panel's evaluation of the concerns raised in the DPO is detailed in the enclosed DPO Panel Report, and is submitted for your consideration. The DPO Panel concluded that Boral degradation in dry spent fuel storage systems does not appear to represent a significant safety concern. Criticality margins in dry spent fuel storage and transport casks with Boral are not sufficiently eroded by the Boral degradation observed to date to constitute a significant safety concern. However the DPO Panel also concluded that uncertainty exists with older Boral due to lack of data and a unique opportunity currently exists for some limited testing of older Boral to close this knowledge gap. The DPO Panel concluded that retrievability of spent fuel and increased radiation exposure resulting from bound fuel assemblies are adequately addressed in the current staff guidance. The DPO Panel concluded that communications to spent fuel cask users on precautions for hydrogen generation and combustion in storage systems are adequate to inform stakeholders of the potential hazards. The DPO panel concluded that NRC can improve its communication to spent fuel cask stakeholders of industry recommended limitations on reflooding cycles for dry spent fuel casks which use Boral as a neutron absorber.

The DPO Panel recommends communicating to stakeholders the results of Boral testing in dry spent fuel cask applications, that fuel loading, pressure draining and vacuum/drying/heating has caused degradation of the Boral. Repeated cycles can cause a licensee to be outside of its licensing basis for subcritical margin. The DPO Panel recommends additional investigation be

CONTACT: M. Lesser, RII/DFFI
(404) 997-4700

performed on older Boral and that NRC management take advantage of a unique opportunity currently available and consider testing the Zion Boral material under dry storage environments to obtain degradation data on older Boral.

Please do not hesitate to contact us if you have any questions regarding the enclosed report.

Enclosure:
DPO Panel Report

cc:
Donald Carlson

performed on older Boral and that NRC management take advantage of a unique opportunity currently available and consider testing the Zion Boral material under dry storage environments to obtain degradation data on older Boral.

Please do not hesitate to contact us if you have any questions regarding the enclosed report.

Enclosure:
DPO Panel Report

cc:
Donald Carlson

DISTRIBUTION:
M. Lesser, RII
C. Tripp, NMSS
M. Yoder, NRR
M. Lombard, NMSS
P. Holahan, OE
R. Pedersen, OE

☐ PUBLICLY AVAILABLE ☒ NON-PUBLICLY AVAILABLE ☐ SENSITIVE ☒ NON-SENSITIVE
ADAMS: ☒ Yes ACCESSION NUMBER:ML16259A015 ☒ SUNSI REVIEW COMPLETE ☒ FORM 665 ATTACHED

OFFICE	RII:DFFI	HQ:NRR	HQ:NMSS				
SIGNATURE	/RA/	/RA/	/RA/				
NAME	MLesser	MYoder	CTripp				
DATE	9/14/2016	9/14/2016	9/14/2016	9/ /2016	9/ /2016	9/ /2016	9/ /2016
E-MAIL COPY?	YES NO	YES NO	YES NO	YES NO	YES NO	YES NO	YES NO

OFFICIAL RECORD COPY DOCUMENT NAME: HTTP://FUSION.NRC.GOV/REGIONS/RII/DFFI/DPO DOCUMENTS/DPO COVER LETTER.DOCX

Differing Professional Opinion (DPO) On Evaluation and Communication of Boral Degradation Effects in Deployed Spent Fuel Casks (DPO-2016-002)

DPO Panel Report

/RA/

Mark S. Lesser, Panel Chair

/RA/

Christopher S. Tripp, Panel Member

/RA/

Matthew G. Yoder, Panel Member

Date: September 14, 2016

Enclosure

Introduction

Differing Professional Opinion (DPO-2016-002) was received on July 5, 2016. The DPO concerns involved the evaluation and communications of Boral degradation effects on deployed spent fuel casks.

The memorandum from the Senior Differing Professional Views Program Manager, Office of Enforcement, establishing the Differing Professional Opinion Panel (DPO Panel or Panel) was issued on July 19, 2016. The memorandum tasked the Panel with conducting an independent review of the issues in accordance with Management Directive (MD) 10.159, "NRC Differing Professional Opinion Program."

The Panel met with the submitter on August 10, 2016, to establish and approve a concise statement of the concerns. The submitter approved the statement of concerns on August 21, 2016. The Panel performed its review by interviewing the submitter, reviewing documents, and interviewing staff members based upon the following agreed upon summary of issues:

Summary of Issues

Based on a review of the DPO submittal and associated references and an interview with the submitter, the following concerns were identified by the Panel:

1. Spent fuel storage / transportation cask stakeholders have not been adequately informed by the NRC of safety and operational problems that may result from Boral degradation. Such problems include erosion of subcritical margins, hydrogen generation, and maintaining radiation exposures as low as reasonably achievable if fuel assemblies are bound, which can be challenged by pool cask pit unavailability for loading or servicing casks, and the possible need for cutting tools to retrieve bound fuel assemblies.

2. The NRC's closure of Generic Safety Issue (GSI) 196, Boral Degradation, was primarily based on a report by criticality safety expert, Calvin Hopper of ORNL. He concluded that Boral degradation revealed by testing would not result in substantial erosion of criticality safety margins. Testing was performed on new Boral sheets and did not include old sheets. A followup action indicated that since testing of older Boral sheets was beyond the scope of the GSI program, older Boral sheets should be studied as an investigatory research program. This followup action was not performed.

Evaluation

Background

Boral is used as a neutron absorber to control reactivity in spent fuel pool racks and in dry spent fuel storage systems. Boral is a hot-rolled composite plate product consisting of a mixture of boron carbide particles and aluminum (B_4C-Al) that are clad with aluminum cover plates on the two large external surfaces forming an aluminum bonded "sandwiched" plate. The remaining four edges of the porous Boral plate are in direct contact with the ambient environment.

Boral has experienced degradation in spent fuel pools and in dry storage casks. Degradation mechanisms in spent fuel pools have resulted in plate deformation and cladding blisters, which has caused fuel assembly binding during lifting operations. This problem has historically been documented in NRC generic communications and continues to be addressed in spent fuel pool applications. Boral used in dry spent fuel casks has also experienced degradation (cladding blisters) from one cycle of pressure draining and vacuum drying/heating in spent fuel casks.

Typically a multipurpose canister (MPC) is contained in a transfer overpack when it is placed in the spent fuel pool for fuel loading. During fuel loading, the MPC is flooded with pool water. After fuel loading, a stainless steel cover plate is seal welded to the MPC, the MPC is evacuated with pressurized water and the MPC and transfer overpack are removed from the pool. Subsequently, the MPC is drained of water and typically vacuum dried. The vacuum drying is intended to remove residual moisture. Following drying, the internal volume of the MPC is backfilled with inert helium fill gas. At this point, the MPC is transferred to a concrete or steel storage cask or fitted with a transport overpack with impact limiters if the MPC is scheduled for shipment. It is important to note that in dry storage applications, the neutron absorbers are required for reactivity control only for the relatively short period of time while the cask is flooded with water during fuel loading (or possibly during fuel unloading). Once the cask has been drained, dried and inerted, the absence of moderating hydrogen atoms renders the fuel in the MPC subcritical by a substantial margin. Some casks are analyzed for upset conditions during transportation, which assume water intrusion, and rely on Boral to maintain subcritical margin. During a fuel loading operation, the porous Boral is in contact with water, which permits water to penetrate the voids. Subsequent vacuum drying and high temperature has caused steam formation, expansion, and blistering of the cladding. Additionally the aluminum-water reaction produces aluminum oxide and hydrogen, which can also cause blistering. The hydrogen can also be flammable. Concerns have been raised regarding the impact of blisters on the area density of the B_4C particles and subcritical margins.

Boral fabrication and conditioning processes have improved over time. Older Boral was historically manufactured prior to about 2001. Newer or “improved” Boral was manufactured to increase the void interstices in the B_4C-Al composite mixture to reduce blistering by better venting gases and to thermally treat plates to passivate the aluminum-water chemical reaction. Newer Boral was also manufactured with greater attention to plate and rolling mill cleanliness thereby reducing the incidence of plate surface scarring by B_4C particles and chemical corrosives, which contributed to pinhole water intrusion. The results of coupon testing by EPRI suggest that the “improved” Boral should be suitable for storage-only canisters where the Boral would typically be subjected to one or two wetting/drying cycles. For transportation casks where the Boral would be subjected to many wetting/drying cycles, blister formation raises a question of the suitability of Boral for such applications.

Nuclear Criticality Safety

The submitter raised concerns with the potential to erode subcritical margins as a result of Boral degradation. Boral sheets are used as fixed neutron absorbers in dry storage and transport casks to ensure they remain subcritical when flooded. As such, the sheets are ordinarily placed between fuel assemblies to limit neutron interaction between the assemblies. Blistering or slight deformation of the sheets will not affect their efficacy to limit neutron interaction so long as the boron carbide particles remain largely in place; for this purpose, only the areal density of the boron absorber, primarily ^{10}B, is important. Thus, blistering and delamination would only be a criticality concern if it resulted in exposing the boron carbide meat and rearranging or depleting the boron carbide granules sufficient to cause a significant reduction in the ^{10}B areal density.

Such a reduction in areal density would constitute a safety concern if the corresponding increase in k_{eff} were enough to cause the Upper Subcritical Limit (USL)[1] to be exceeded.

Such wholesale rearrangement or depletion of boron carbide particles has not been observed either operationally or in the samples analyzed to date (consisting of "new" Boral referred to in the contractor (Hopper) report (reference 1) as BORAL-2 and -3). The submitter stated that he "would be surprised should results from the recommended research reveal degradation effects severe enough to fully negate all explicit and implicit margins of criticality safety." He further acknowledges that "the incomplete testing reviewed to date shows that the neutron-absorbing boron carbide particles in Boral remain largely in place even after severe blistering." Document reviews and interviews by the DPO Panel indicated that there is no documented historical evidence for wholesale degradation that would be severe enough to negate criticality safety margins, though the testing did not include "old" Boral (referred to in the contractor report as BORAL-1).

Those criticality safety margins are substantial. One individual interviewed indicated that the most significant source of conservative margin is the fresh fuel assumption, which can result in margins of up to 30% in Δk_{eff}.[2] In other words, safety analyses generally do not take credit for spent fuel burnup reactivity reduction. While this varies from cask to cask, the individual stated that the older casks may have less margin due to the fresh fuel assumption, because their allowable fuel burnup was typically lower than for newer casks. However, the margin resulting from not taking credit for burnup would still be substantial. Other degrees of conservatism include conservative modeling of material and geometric tolerances, and only taking credit for 75% of the absorber loading present to account for neutron streaming due to granularity. Some of this margin is required due to uncertainty and variability in the fuel and cask material and geometry, and hence should only be considered true "conservative margin" if it exceeds what is needed to account for tolerances. In the case of neutron streaming, the submitter stated that recent testing has showed that up to 90% credit for absorbers may be warranted. While this has not been substantiated, it is certain there is substantial margin due to the fresh fuel assumption, likely there is some margin due to other conservative modeling practices, and apparently there is some allowance for variability in the absorber uniformity (e.g., granularity). The submitter determined that the net margin very likely compensates for any expected ^{10}B degradation; the individuals interviewed concurred in this determination.

With regard to the worth of the Boral sheets, and the amount of degradation necessary for the USL to be exceeded, according to the individuals interviewed, this is not normally evaluated as part of the NRC's licensing reviews. Rather, the cask is evaluated with the Boral sheets in place and demonstrated to be subcritical as designed. Rather than perform sensitivity studies on the ^{10}B loading, the practice of taking 75% credit to account for variability in the absorber uniformity is adhered to. This allowance has been set to account for granularity effects, but conservatively (the submitter stating that recent testing indicates that up to 90% credit could be taken), and so there is likely some margin to bound minor degradation of the ^{10}B areal density. The amount of margin to criticality will vary from cask to cask, as will the worth of the sheets and the amount of degradation that can be tolerated without exceeding the USL. Because of this, it is difficult to draw general conclusions that apply across the whole spectrum of transport and storage casks.

---

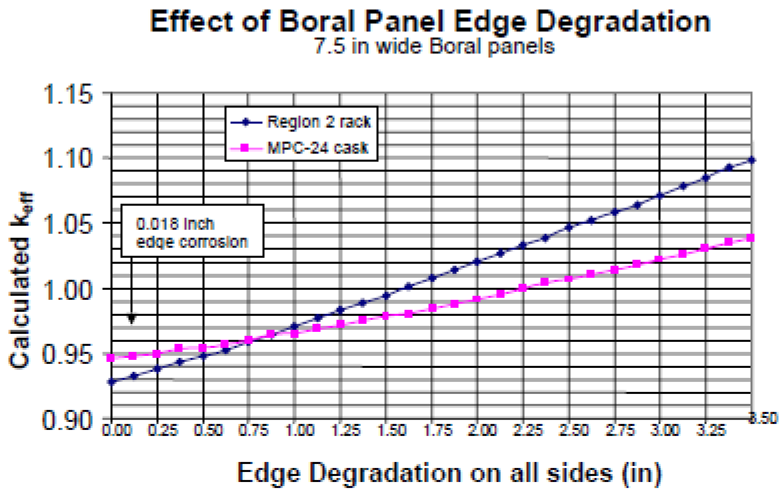
[1] The USL is the maximum k_{eff} for which we have reasonable assurance that the cask is subcritical. Typically, the requirement is that $k_{eff} + 2\sigma \leq \text{USL}$, where the USL = 0.95 – bias – bias uncertainty.

[2] It must be remembered that margins, and the reactivity worth of absorber sheets, will vary from cask to cask. The effect of credible degradation of the neutron absorbing sheets should be evaluated on a case-by-case basis.

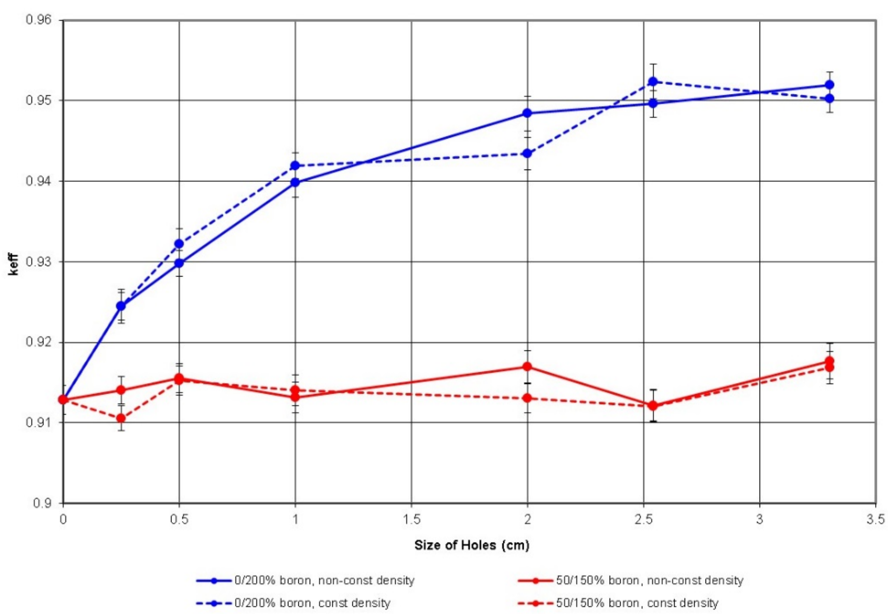
However, some generalized observations regarding the safety margin for different casks may be made. First, the main source of conservative margin is the fresh fuel assumption, which will typically result in less margin for the older casks incorporating “old” Boral (or BORAL-1), which were authorized at a lower fuel burnup than newer casks. Second, the absorber worth of Boral will typically be more important for transport vs. storage casks. Third, mechanical deformation and delamination is less likely for the older casks because of their more robust internal structure and less room to deform. These general observations are meant to qualitatively inform the risk determination, but do not substitute for a sensitivity study of the effects of Boral degradation on any particular cask.

A review of the contractor report and documents associated with GSI-196, as well as interviews with the contractor and NRC technical staff, provides reasonable assurance of subcriticality for cask designs incorporating “new” Boral (BORAL-2 and -3). The testing conducted on those samples did not indicate any substantial degradation of the ^{10}B areal density. This conclusion was restricted to “once-blistered” Boral (meaning a single cycle of pressure draining, heating, and drying) that was fabricated using improved manufacturing processes (improved cleanliness of raw materials, change in rolling-mill lubricant to eliminate corrosion pitting, dry passivation to pre-oxidize exposed surfaces and increase porosity, increased boron carbide loading). Only minor losses of boron carbide granules and aluminum binder around the exposed edges of the sheets (to a depth of about 1/16 inches) was observed, despite some inconsequential blistering around the edges and pitting on the faces. It is reasonable to suppose that “old” Boral that was fabricated prior to about 2001 using pre-improved manufacturing techniques would experience somewhat greater damage, but the extent to which this might occur has not been quantified and no direct evidence thereof has been documented.

In general, the loss of boron carbide around the edges of the Boral sheets is expected to have less of a reactivity effect than surface pitting corrosion. To quantify the reactivity effect of edge erosion, the contractor performed models in which the dimensions of the Boral sheets were gradually reduced by up to 3.5”. These calculations were performed for both an infinite planar array of fuel assemblies simulating a spent fuel storage rack and for a HOLTEC MPC-24 multi-purpose canister, both containing fresh Westinghouse 17x17 PWR fuel assemblies. Only the MPC-24 results are directly applicable to this DPO. The results showed that the effect is less significant for the canister than for a spent fuel pool, and that severe edge degradation is needed to result in a significant change in $k_{eff.}$ For example, the results showed it would take an erosion of ¾” from all sides of each Boral sheet in the MPC-24 canister to produce a Δk_{eff} of 1%. Conversely, the worst case erosion was conservatively estimated to be no greater than 1/64” per year. This was increased over the observed corrosion rate by a factor of 10 to conservatively account for any uncertainties. The results show that it would take ~48 years of being continuously flooded for each increase of 1% in Δk_{eff}. Based on these results, the contractor determined that there was no need for further study to conclude that once-blistered BORAL-2 or BORAL-3 would remain an effective neutron absorber for dry cask storage. Shown below is Figure 3 from the contractor report.



The contractor carefully limited his findings to “new” Boral and did not consider old BORAL-1 because of the lack of data concerning degradation. The findings were also limited to dry cask storage, though a similar effect might be expected for transport casks. While NRC staff stated they do not routinely conduct sensitivity studies for neutron absorber degradation as part of cask licensing reviews, an interviewee did provide some studies that were performed to examine the effect of inhomogeneity in boron loading in a Holtec HI-STAR 60 transport cask. The studies did not reduce the overall areal density of the absorber, but did increase or decrease the boron loading in adjacent square segments in a checkerboard fashion to simulate localized lumping of the boron. The calculations showed that it would take rather dramatic rearrangement of boron in the absorber meat to produce a significant Δk_{eff}. For example, it required removing all the boron from every other square (and doubling it in the remaining squares, to preserve the overall areal density) in squares at least ¼” on a side to produce a Δk_{eff} of 1%. While this study looked at the effect of merely rearranging but not removing the boron, it does indicate similar qualitative results to the contractor study for a different, this time a transport, package. Shown below is the graphed results of this study.



In the graph above, 50/150 means half of the squares in the checkerboard arrangement had 50% of the nominal ^{10}B density and half had 150% of the nominal ^{10}B density; 0/200 means half the squares had no ^{10}B and half had double the nominal ^{10}B. For constant density cases, the densities of the other materials—aluminum and carbon—were adjusted so as to preserve the overall absorber density; for non-constant cases, no such adjustment was done. As shown, this distinction makes almost no difference in the results.

Finally, other staff provided the Panel members with input decks for the NUHOMS 24PTH and 24PT4 casks. The Panel performed its own sensitivity study for the 24PTH cask, decreasing the ^{10}B loading uniformly throughout the canister, reducing the lateral dimensions of the sheets to examine edge erosion (similar to what was done in the contractor report), and modeling holes in the middle of the sheets to examine surface pitting corrosion. The results are similar to those in the studies discussed above, and are summarized in an appendix to this report. They show that it would take a large reduction in boron areal density to produce any significant $\Delta k_{eff.}$ Even total removal of all ^{10}B from the package produces a Δk_{eff} that is ~ ½ to ⅓ the margin resulting from the fresh fuel assumption.

Although the studies summarized above from the contractor, technical staff, and panel members are anecdotal, they show similar qualitative results for three different casks by two different cask manufacturers, for both dry storage and transport, and for a variety of different neutron absorber configurations using two different criticality codes (MCNP and SCALE).[3] The results confirm that a substantial degradation in ^{10}B loading is needed to produce even a modest Δk_{eff}, which is not sufficient to challenge criticality safety margins. This conclusion is caveated by the observation that the studies performed to date have been judged against the observed degradation for "new" Boral only, for a limited but representative number of cask designs.

The submitter's DPO discussed several physical phenomena that could reduce criticality safety margins: (1) loss of boron carbide particles from Boral sheets, (2) detachment of sheets from basket walls, (3) displacement of water by hydrogen gas, and (4) depletion of ^{10}B by neutron absorption. Individuals interviewed by the panel considered the generation of hydrogen gas to be inconsequential from a reactivity standpoint. Fuel bundles and casks are normally designed to be undermoderated when fully flooded, such that they have a negative void coefficient. None of the individuals interviewed thought that water displacement by hydrogen gas would increase reactivity. Similarly, the depletion of ^{10}B through neutron capture is inconsequential, due to the low neutron flux and long time period required. Though this may have a significant reactivity effect for long-term storage, it will occur whether the Boral is intact or not. The loss of particles from the sheets, or detachment of sheets from the baskets, could however be a safety concern. The scope of Generic Safety Issue (GSI) 196 is relevant to a consideration of these two phenomena. The GSI was originally framed as relating to all spent fuel casks, whether intended for transport, dry storage, or dual use (e.g., Task Action Plan (ML050550229)). However, later documents (e.g., GSI Closure Memoranda (ML062400030 and ML063520459)) limit discussion to "spent fuel dry storage casks." The submitter's DPO also noted that his concern was not limited to dry storage casks only. It is not clear how or when the scope was narrowed to only dry storage, but the distinction is relevant because (1) as indicated above, Boral is used in both dry storage and transport casks, and may be more important in the latter, and (2) transport casks are subject to a wider variety of hypothetical accident conditions. Individuals interviewed

[3] Some of these casks contain borated aluminum instead of Boral, but although not necessarily subject to the same degradation mechanisms, it can be expected to have a similar reactivity effect. The anecdotal results in this report do not substitute for a more comprehensive study of storage and transport casks that rely on "old" Boral.

from the Division of Spent Fuel Management (DSFM) indicated that degradation of the Boral sheets is not normally considered in the licensing of spent fuel storage and transport casks; among the effects are the possible compromised structural integrity of degraded sheets, and the possibility that they could fail under hypothetical accident conditions such as a transportation accident. Moreover, license renewals do not routinely consider the possible degradation of neutron absorbers. NUREG-1927, “Standard Review Plan for Renewal of Specific Licenses and Certificates of Compliance for Dry Storage of Spent Nuclear Fuel,” was specifically mentioned as a guidance document for renewal. This contains a chapter on “aging management” of dry storage casks. This guidance does not contain any discussion of neutron absorber degradation.

In considering all the available information in the submitter’s DPO, the documents referenced therein and subsequently obtained, and interviews with the contractor and NRC technical staff, two questions remain from the closure of GSI 196: (1) the narrowing of scope to only consider Boral degradation in dry storage casks, and (2) the basis for closure of the GSI. Neither is well explained in the memo dated August 31, 2006 (ML062400030). The basis for closing the GSI in particular is stated as because “this level of investigation of the Boral blistering phenomenon and its consequences…are beyond the scope of the Generic Issues Program” without further explanation. In addition, the memo noted that neutron absorber degradation was of interest to the IAEA, and said that it would be “prudent to wait” until an IAEA Coordinated Research Project (CRP) known as SPAR-II was concluded. This creates the appearance that the issues raised in GSI 196 were not considered definitively closed, but merely deferred until the additional research could be completed. However, the panel notes that neither the SPAR-II, nor the subsequent SPAR-III, final reports (IAEA-TECDOC-1680 and -1771) refer specifically to Boral degradation. This calls into question the appropriate closure of GSI-196.

In summary, the effect on criticality safety margins of the Boral degradation observed to date appears slight. The limited studies summarized above indicate that a massive rearrangement or removal of ^{10}B is needed to produce even a modest change in cask reactivity. What is known of the older casks incorporating “old” Boral (BORAL-1) is very limited, but it seems plausible that the effect would be somewhat larger than that for newer casks, for which there is some data, but there is no reason to suppose it constitutes an immediate safety issue. Even the DPO submitter does not believe that it would be sufficient to completely erode the large safety margins inherent in the cask designs. Due to the lack of data, however, a safety concern cannot be entirely ruled out. From a risk perspective, a significantly degraded storage or transport cask would have to be re-flooded to challenge criticality safety margins.[4] Determining the extent to which a package is degraded would require re-opening the package to examine the absorber sheets; no known method exists for assessing the condition of the sheets without opening the package. Doing so would expose personnel to the same ALARA concerns that the DPO submitter said would be incurred by the fuel retrievability issue. Absent any information to suggest a significant safety concern, such reopening of canisters to check the absorber integrity is not warranted. Whether additional research should be conducted to further evaluate this effect seems to be a matter of professional judgment, in light of available resources and its priority relative to competing safety concerns.

[4] The possibility that the structural integrity of the absorber sheets in a transport cask could be sufficiently compromised so they could fail during a transportation accident was discussed, but has not been officially studied.

The DPO Panel became aware that The Office of Nuclear Reactor Regulation has an ongoing test program under a User Need Request with the Office of Research to perform testing of Boral. The test program is focused on older Boral material which was harvested during the decommissioning of the Zion plant. The current test program being conducted at Savannah River National Lab is focused on spent fuel pool conditions and not necessarily dry storage environments. Given the ongoing research with the Zion absorber samples, it seems prudent that a study be made with these materials as they apply to dry storage systems to resolve performance and subcritical margin uncertainty of older Boral regarding degradation, potential boron loss, or sheet integrity/detachment, as it appears it could be done without incurring substantial risk or expense.

Hydrogen Generation

The DPO submitter raised concerns that hydrogen gas generated while Boral material is exposed to water during cask loading may result in combustion. The submitter was also concerned that the NRC has not adequately communicated this potential hazard to stakeholders. The DPO Panel found that generation of hydrogen gas during interaction of Boral with water is well documented in both spent fuel pool and cask loading environments. The panel also determined that Boral is one of many sources of potentially flammable gasses generated during the flooding of dry storage casks with borated and un-borated water.

On May 31, 1996, NRC Information Notice 96-34 was issued as notification of a hydrogen gas ignition event that occurred during the welding of the shield lid on a spent fuel storage cask at the Point Beach Nuclear Plant. In this case the hydrogen gas was generated during the interaction of zinc coatings with borated water. As a result of this incident the NRC also issued Bulletin 96-04, "CHEMICAL, GALVANIC, OR OTHER REACTIONS IN SPENT FUEL STORAGE AND TRANSPORTATION CASKS."

Bulletin 96-04 required licensees and applicants to:

> Evaluate the effects of any identified reactions to determine if any adverse conditions could result during cask operations, including loading and unloading. Consideration should be given, but not limited, to generation of flammable or explosive quantities of hydrogen or other combustible gases
>
> Evaluate the procedures for unloading the cask to consider the likely presence of hydrogen gas or precipitate inside the multi-assembly sealed basket (MSB) and the possible adverse effects of the hydrogen gas or precipitate on cask handling and performance. Inform the NRC of any changes made to the unloading procedures.

In addition to the generic communications described above, guidance on flammable gas generation is provided in NUREG 1536, Rev 1, "Standard Review Plan for Spent Fuel Dry Storage Systems at a General License Facility:"

> **8.4.19 Flammable Gas Generation (MEDIUM Priority)**
>
> The reviewer should assume the generation of hydrogen or other gases during wet loading/unloading operations occurs. Field experience has amply demonstrated that any canister design employing aluminum components as part of the fuel basket construction will have a propensity to generate hydrogen. Efforts to passivate the aluminum components have proven inadequate to eliminate the generation of hydrogen. The use

> of zinc, zinc-rich coatings, or zinc-clad materials (e.g., galvanized steel) in particular, is known to generate potentially large quantities of hydrogen gas during wet-loading in SFP.
>
> Consequently, the reviewer should verify the operating procedures contain adequate guidance for detecting the presence of hydrogen and preventing the ignition of combustible gases during cask loading and unloading operations. These procedures must be incorporated by reference into the TS.

The DPO Panel acknowledges that although no specific guidance or communications have been issued with respect to hydrogen gas generation from Boral, the agency has made it clear that the potential exists to generate large quantities of hydrogen gas during wet loading of spent fuel storage systems. As such, any hydrogen that may be generated from Boral exposure to water is bounded by the existing guidance and communications.

ALARA and Retrievability

The DPO submitter raised concerns that potential fuel binding caused by Boral degradation may create safety-related operational ramifications. The specific concern stated in the submittal is that large blisters or deformation of the Boral sheets could result in the inability to readily retrieve bound fuel from an affected cask returned to the spent fuel pool for servicing. This could affect worker safety, could make the pool's cask pit unavailable for loading new casks or for servicing other deployed casks, and could eventually necessitate extended plant shutdown.

The DPO panel reviewed the existing regulatory documents pertaining to retrievability of fuel from storage casks and found that the agency has issued guidance which directly addresses the retrievability of individual fuel assemblies from storage casks. The Division of Spent Fuel Management's Interim Staff Guidance 2, Rev. 2, revises the definition of retrievability to include removal of a canister loaded with spent fuel from a cask as well as removal of a cask loaded with spent fuel from the storage location. Under the revised guidance, the staff acknowledges that it is not required that a licensee be able to readily remove an individual fuel assembly from a cask. Therefore any binding of spent fuel assemblies caused by Boral degradation, or any other mechanism, would not violate the regulatory requirements for retrievability.

Interim Staff Guidance 2 also addresses the DPO submitter's concerns regarding worker safety and increased radiation exposures resulting from bound fuel assemblies. In fact one of the primary reasons that the revised guidance was issued was to address the difficulties in accessing the spent fuel and the interior components of some storage systems. It is acknowledged that opening a storage system is labor intensive, and exposes workers to additional dose. Further, for welded canisters opening may require breaching and reestablishing the confinement boundary with no additional safety benefit. Eliminating the need to open casks to inspect or remove fuel, as described in the Interim Staff Guidance, eliminates the concerns regarding increased radiation exposures for workers. This applies not only to potentially bound spent fuel, but to any spent fuel currently in a dry storage system.

Adequacy of NRC Communications

Boral degradation in spent fuel pool applications has been a topic in past NRC generic communications (Information Notices 83-29 and 2009-26, Generic Letter 2016-01). However, the NRC has not issued generic communications associated with Boral degradation in dry spent fuel cask applications. Industry testing has demonstrated that once blistered newer Boral will remain an effective neutron absorber provided it is not repeatedly cycled through reflooding operations that include a sequence of pressurized water evacuation and vacuum drying evolutions. Industry reports have concluded that Boral blistering becomes significantly worse after 3 cycles of operation. A higher degree of uncertainty exists for older Boral due to lack of test data. Realistically there is very little likelihood that users will engage in operations involving multiple reflood cycles. However nothing in a user's license prohibits such operations nor requires notification to the NRC upon initiating refloods. Since the licensing assumptions do not assume degraded Boral, multiple reflood cycles could result in degradation to a point where a user is outside of its licensing basis. Given the unlikelihood of licensees undertaking reflood operations at this time, there does not appear to be a compelling safety need to modify existing licenses with reflood limitations. However is does appear prudent to inform stakeholders of uncertainties regarding the effect of degradation on subcritical margins and recommendations by industry studies regarding multiple cycles of refloods. This could be done through generic communications, NRC sponsored industry meetings, or other means.

Conclusions

The DPO Panel concludes that the criticality margins in dry spent fuel storage and transport casks with Boral are not sufficiently eroded by the Boral degradation observed to date to constitute a significant safety concern. Even with substantially greater degradation such as might occur with older Boral, the substantial margin produced by evaluating casks assuming fresh fuel is expected to remain largely in place. While this issue has not been thoroughly studied it does not appear to be a sufficient safety concern to warrant re-opening of older casks or an extensive new research project.

The DPO Panel concludes that as part of GSI 196, a recommendation was made by the NRC's consultant to conduct follow-up research on the degradation of older Boral for its impact on subcritical margins. This recommendation was deemed outside the scope of GSI 196 by NRC management, and was deferred due to future research that was later conducted but did not specifically address the issue. This decision allowed some degree of uncertainty to remain regarding the degradation effects for older Boral that might experience multiple cycles of re-flooding on criticality safety margins, due to lack of data. The DPO Panel concludes that a unique opportunity currently exists to conduct some limited testing on older Boral obtained from the Zion spent fuel pool to obtain data and resolve performance and subcritical margin uncertainty of older Boral regarding degradation, potential boron loss, or sheet integrity/detachment.

The DPO Panel concludes that retrievability of spent fuel and increased radiation exposure resulting from bound fuel assemblies are adequately addressed in the current staff guidance. This conclusion applies to any bound fuel assemblies, but in the context of this DPO review specifically addresses fuel binding caused by Boral degradation.

The DPO Panel concludes that communications to spent fuel cask users on precautions for hydrogen generation and combustion in storage systems are adequate to inform stakeholders of the potential hazards. The agency has communicated concerns regarding flammable gasses, including hydrogen, via several generic communication tools including information notices and bulletins. In addition, flammable gasses are specifically addressed in the Standard Review Plan. The DPO Panel acknowledges that Boral material may introduce an additional source of hydrogen, however, the existing guidance and communications are adequate to address any potential flammable gasses generated within spent fuel storage systems.

The DPO panel concludes that NRC can improve its communication to spent fuel cask users of industry recommended limitations on reflooding cycles for dry spent fuel casks which use Boral as a neutron absorber due to uncertainties in subcritical margin.

Recommendations

The DPO Panel recommends communicating to stakeholders the results of Boral testing in dry spent fuel cask applications, that fuel loading, pressure draining and vacuum/drying/heating has caused degradation of the Boral. Repeated cycles can cause a licensee to be outside of its licensing basis for subcritical margin.

The DPO Panel recommends an investigation of older Boral material as was recommended in the closure of GSI-196. There is a knowledge gap with respect to the potential degradation mechanisms of this material in a dry storage system. Testing may serve to eliminate uncertainties and reduce concerns that a rewetting of the Boral material during fuel removal or repacking may result in a challenge to criticality safety. The DPO Panel recommends that the NRC coordinate on-going research with the Zion fuel samples and contract to have them subjected to conditions representative of multiple cycles of pressure draining, heating, and vacuum drying to simulate multiple re-floods, to determine if a more extensive safety issue exists for older Boral. The DPO Panel acknowledges that the NRC management previously determined that the benefit of such testing was not commensurate with the potential safety benefit. However, in the course of our evaluation we have identified a unique opportunity to perform testing which warrants a revisiting of the previous decision. Given the opportunity to perform testing on the specific material that is highlighted in this report, and the fact that the agency has already obtained the material and started testing, the DPO Panel recommends that NRC management consider testing the Zion Boral material under dry storage environments. Whether this testing is conducted under a new User Need Request or is added as a supplement to the existing NRR contract the DPO Panel feels that the opportunity to obtain valuable data should be not be ignored.

Appendix A: Boral Degradation Study

Persons Contacted:
Donald Carlson, DPO Submitter
Andrew Barto, Senior Criticality Engineer, NMSS/DSFM/CSARB
Bernard White, Senior Project Manager, NMSS/DSFM/SFLB
Eric Focht, Senior Materials Engineer, RES/DE/CMB
Meraj Rahimi, Chief, NMSS/DSFM/CSARB
Emma Wong, Chemical Engineer, NMSS/DSFM/IOB
Veronica Wilson, Nuclear Engineer, NMSS/DSFM/CSRB
John Wise, Chief, NMSS/DSFM/RMB
Mark Lombard, Director, NMSS/DSFM
Calvin Hopper, Consultant

References Reviewed by DPO Panel

1. Review of BORAL™ Degradation-Related Literature Survey, C.M. Hopper, dated August 14, 2006
2. Handbook of Neutron Absorber Materials for Spent Nuclear Fuel Transportation and Storage Applications, EPRI
3. NUREG 1536, Rev.1, Standard Review Plan for Spent Fuel Dry Storage Systems at a General License Facility

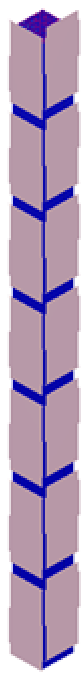
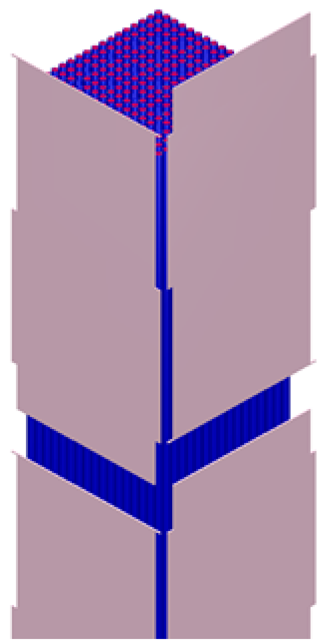
4. Task Action Plan for Resolving Generic Safety Issue 196, “Boral Degradation,” dated February 22, 2005 (ML050550229)
5. Proposed Closure of Generic Safety Issue 196, “Boral Degradation,” dated August 31, 2006 (ML062400030)
6. Closure of Generic Safety Issue 196, “Boral Degradation,” dated December 13, 2006 (ML063520459)
7. NUREG-1927, Rev. 1, “Standard Review Plan for Renewal of Specific Licenses and Certificates of Compliance for Dry Storage of Spent Nuclear Fuel,” June 2016
8. IAEA-TECDOC-1680, “Spent Fuel Performance Assessment and Research: Final Report of a Coordinated Research Project (SPAR-II),” 2012
9. IAEA-TECDOC-1771, “Spent Fuel Performance Assessment and Research: Final Report of a Coordinated Research Project on Spent Fuel Performance Assessment and Research (SPAR-III) 2009-2014,” 2015

Appendix A

BORAL DEGRADATION STUDY

The DPO Panel received a model for a typical 24 PWR fuel cask incorporating Boral sheets (Westinghouse 17x17 fuel assemblies). The particular model chosen was a loading curve calculation, done at zero burnup; it was performed to determine the maximum safe enrichment if all the assemblies were assumed to contain fresh fuel. Information received from interviewees indicates burnup credit may typically be worth 20-30% in Δk.

The figure below at left shows the cask model. The figures at right show a single fuel assembly with aluminum, stainless steel, and water removed, to show only the fuel and Boral sheets. The middle figure shows the entire length of a fuel assembly, and the right a close-up view of its top. This particular cask, denoted 24PTH, contains borated aluminum instead of Boral, but the DPO Panel was told it is very similar neutronically. It has absorber panels in staggered sections, due to having steel supports arranged along the length.

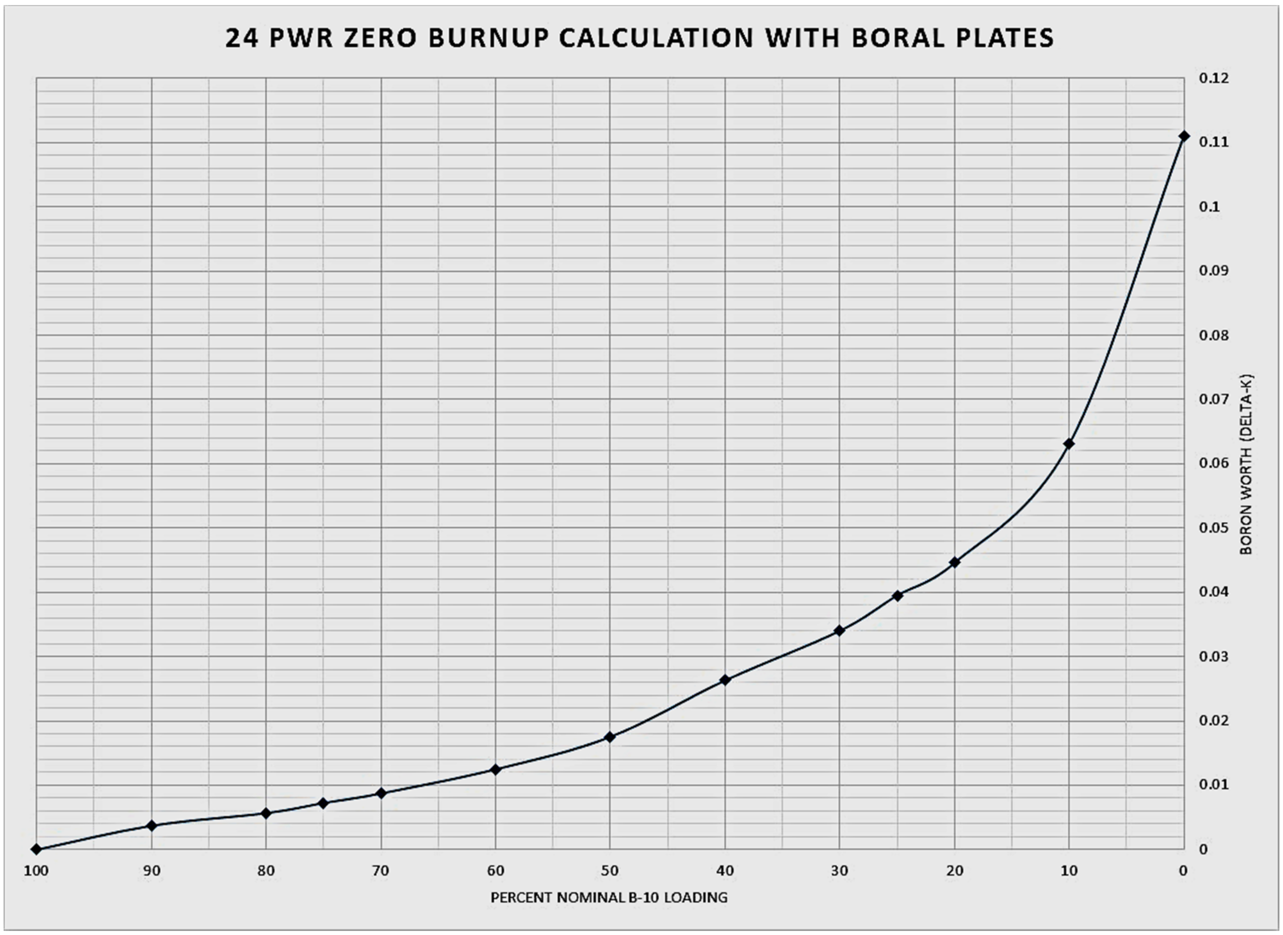




Uniform Reduction in ^{10}B Loading

The first and easiest calculation was to reduce the density of ^{10}B in the Boral material from 100 to 0%, which affected all the absorber panels equally. The results are shown in the table and figure below.

% Nominal ^{10}B*	K_{eff}	% Nominal ^{10}B	K_{eff}
100%	0.93594 ± .00067	50%	0.95333 ± .00074
90%	0.93916 ± .00092	40%	0.96217 ± .00070
80%	0.94141 ± .00078	30%	0.96983 ± .00073
75%	0.94309 ± .00072	25%	0.97503 ± .00088
70%	0.94470 ± .00066	20%	0.98016 ± 0.00085
60%	0.94835 ± .00071	10%	0.99892 ± .00072
		0%	1.04667 ± .00083

*NOTE: It appears the model was already performed at 75% credit for the absorber, to allow for neutron streaming. Thus, the boron density is reduced relative to Boral with this allowance.



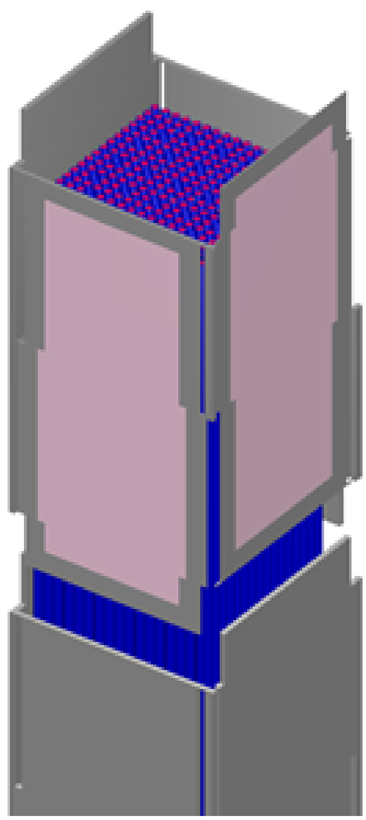
The actual k_{eff} values depend on the cask and model chosen; the values are close to the Upper Subcritical Limit (USL) because this was a loading curve calculation (assumed zero burnup and maximized enrichment till the USL was approached). This value is a little less than 0.95 due to factoring in bias and uncertainty. This particular calculation is for a cask that is fully loaded with fresh fuel at the maximum enrichment allowed by the loading curve.

Rather, it is instructive to look at the change in k_{eff} resulting from loss of ^{10}B in the graph above. At 100%, we have the full ^{10}B content (which is already reduced to 75% of nominal). As the boron density decreases, k_{eff} rises. Note that in this simple model we're changing the boron density globally, so this series of calculations show the effect of a uniform reduction in the effectiveness of all Boral sheets in the cask, which is very conservative. When the boron density is reduced by 25%, Δk is ~0.7%. When boron density is reduced by 50%, it is ~1.8%. Another way to look at this is to observe that a reduction of about 35% everywhere is needed to produce a Δk of 1%. Removal of all the boron produces a Δk of ~11%.

Note that the curve rises steeply as almost all the boron is depleted. This indicates that a little bit of boron has a big effect on k_{eff}. As we approach the full nominal loading, the curve begins to flatten out. This indicates that the sheets are effectively approaching a black absorber, which absorbs all the neutrons that impinge on it, so a small change in absorber loading has a small effect.

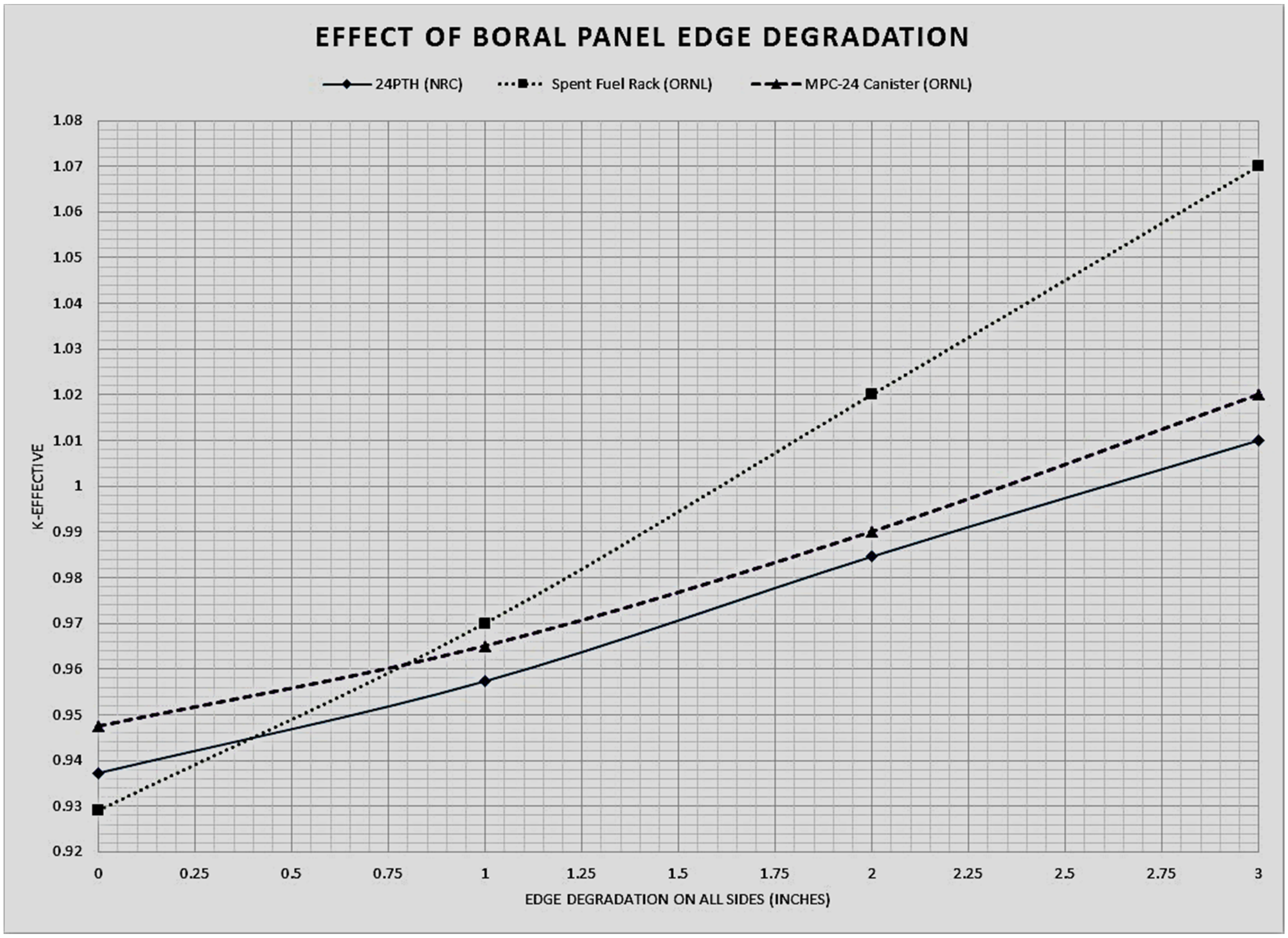
Reduction in dimensions of Boral sheets

The next series of calculations are meant to duplicate and verify the calculations done in the Hopper report, where the lateral dimensions of the Boral sheets were reduced in all directions. This is to simulate the preferential leaching from the exposed edges of the sheets, which being at the periphery is an edge effect. Since this particular cask has seven sheets arrayed along the axis of the fuel assemblies, the fact that it's confined to the exposed edges may not be very important neutronically. A cutaway view of the model, showing the Boral "meat" retracted 1" from the exposed edges of the sheets, is shown below (compare to previous figure).



The table and graph below show the calculated k_{eff} with the meat retracted the given distance from the exposed edges of the sheets. These results are compared to those from the Hopper report for comparison.

Distance Retracted from Edges	k_{eff}
0”	0.93594 ± .00067
1”	0.95598 ± .00070
2”	0.98328 ± 0.00068
3”	1.00853 ± 0.00076



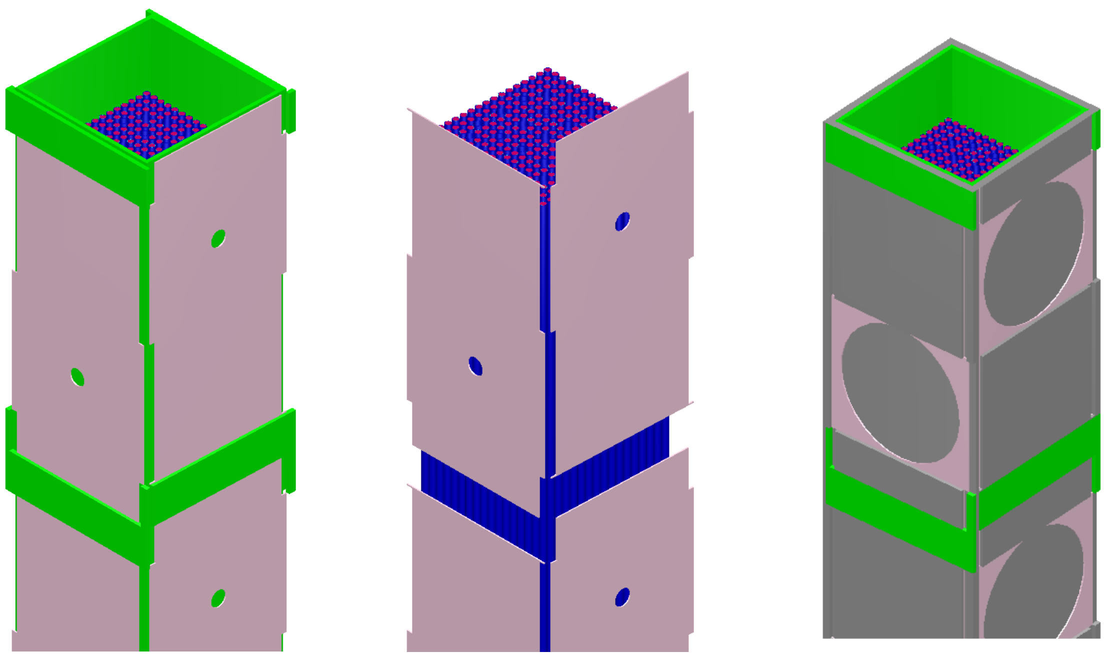
The NRC calculations using the model of the 24 PWR cask shown above (solid curve) closely tracks the contractor results from the Hopper report, for the MPC-24 canister (dashed curve). This indicates that cask differences aside, similar qualitative behavior can be expected. The results differ for that for the spent fuel pool (dotted curve), however.

Note that the Hopper report concluded there was an observed corrosion rate of the Boral meat of 0.0009” per year when submerged in water. Increasing this by a conservative factor showed no more than 1/64” per year depletion of the ^{10}B loading around the edges of the sheets.

This shows that a 1” depletion all around the exposed edges produces a Δk of ~1.5%, 2” yields ~4% in Δk, and 3” yields ~7% in Δk. This is consistent with the contractor results.

Central Hole on Faces of Boral Sheets

Finally, to simulate the possible effect of corrosion pitting/blistering in the middle of the sheets (because the reactivity effect is likely to be larger than these effects at the edges of the sheets), holes were placed in the middle of the broadest parts of each Boral sheet. These sheets are staggered, so the exact location of the holes is not important; rather, since there are 7 identical sections of Boral along the axis of each fuel assembly, on two sides of the assembly, modeling holes in this fashion will result in 14 holes per unit, as shown in the figure below. When these units are assembled into an array, the result is seven holes around each side of each fuel assembly. This is qualitatively judged sufficient to account for any surface pitting that can occur. As shown by the results below, the presence of several large holes along the length of each side of every assembly in the package only produces a modest Δk of no more than ~3%.



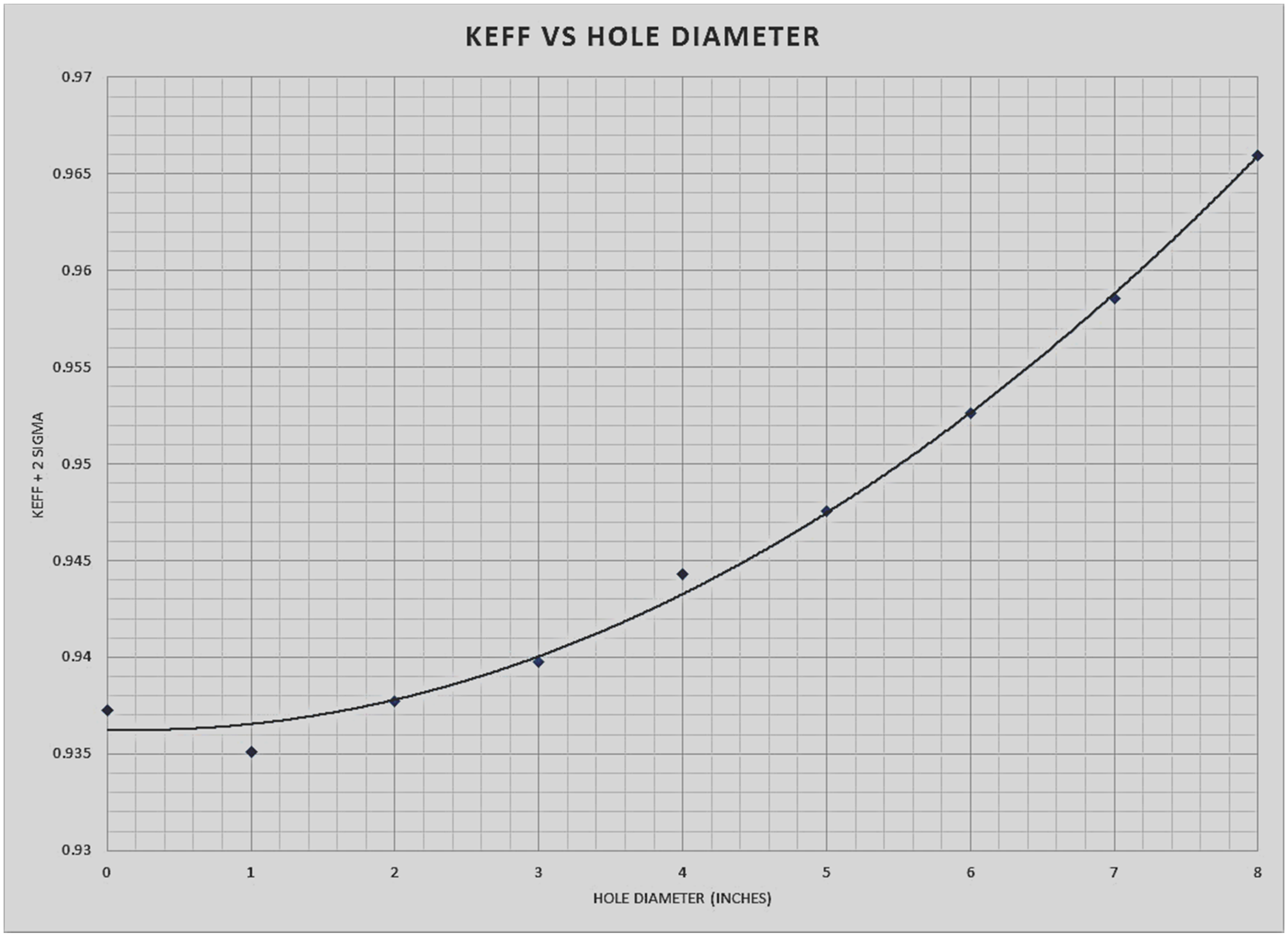
The figure on the left shows the aluminum and water removed, but the stainless steel (green) left in place, so that it can be seen that the basket structure prevents wholesale delamination or deformation of the sheets. The figure in the middle has the stainless steel removed for added clarity. The figure on the right shows the largest hole that can be bored into the side panel, with a diameter of 8.16” (these holes are 8” diameter). This figure shows only some of the aluminum cladding removed, to show more of the structure of the basket.

The table and graph below show the effect of various diameter holes in the sheets as shown.

Hole Diameter	**k_{eff}**
0”	0.93594 ± .00067
1”	0.93366 ± .00073
2”	0.93634 ± .00068
3”	0.93823 ± .00076
4”	0.94282 ± .00074
5”	0.94616 ± .00071
6”	0.95115 ± .00074

7”	0.95709 ± .00072
8”	0.96457 ± .00069

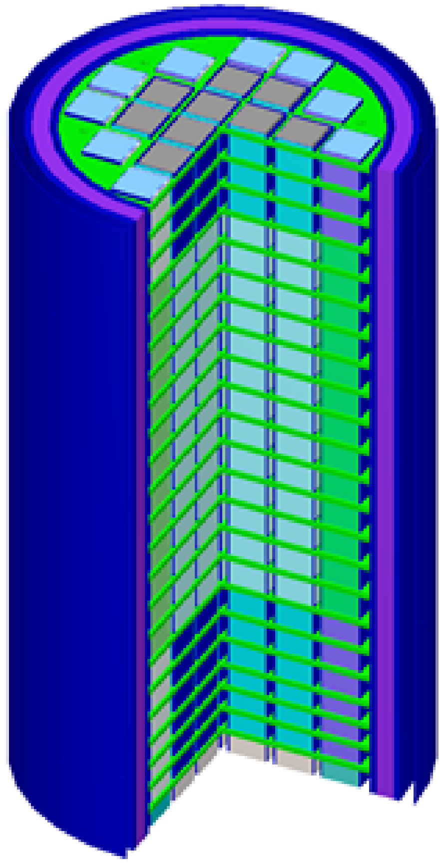
(The graph below uses a quadratic trendline instead of connecting each point because there is some fluctuation in the calculated values.)



This shows that the effect of holes in the Boral plates is relatively minor, probably because the amount of neutron interaction is a function of solid angle. It takes holes of roughly 4.5” diameter to cause an increase in k_{eff} of 1%. Even with the largest size holes that can be made in the side panels, there is only an increase of ~3% in Δk. This clearly should bound the worst conditions resulting from total ^{10}B depletion in the vicinity of large blisters.

24PT4 Cask Model

The other representative model provided is for the 24PT4 cask. A cutaway of this cask is shown below, showing the steel support structure (green), which effectively prevents the Boral sheets from deforming and/or delaminating.



The input received would not run. Probably it is an older version of SCALE that has issues of compatibility with newer versions. Interviewees indicated that this cask likely has greater reliance on boron than the previous model, so the effects above would in increased somewhat. Detailed modeling was not done because the time that would need to be invested to get the cask model to run was judged as not likely to yield new insights. While absorber worth will vary from cask to cask, the effects noted for the 24PTH cask (qualitatively similar to the MPC-24) are expected to be roughly similar from one cask to another.

CONCLUSIONS

Boral (and the neutronically similar borated aluminum) are needed to ensure subcriticality in old PWR casks—such as those discussed herein—when burnup credit is not taken. This fresh fuel assumption is said to be worth 20-30% in Δk. This margin should be more than sufficient to compensate for any credible loss of Boral in these older PWR casks. The older casks did not use burnup credit, so they would have this margin, but also would have used the “old” Boral (BORAL1) fabricated using pre-improved manufacturing methods. (Some newer casks may take burnup credit, but even so some of this margin would remain; interviewees indicated 2-3% in Δk would still remain if taking actinide-only burnup credit, for example.)

The first set of calculations, which reduced the total ^{10}B density the same everywhere, is very conservative in that it assumed *all* the Boral in the cask degrades uniformly. It seems rather obvious that if there is degradation, it would be more localized. Nevertheless, it shows that a very substantial degradation is needed to produce a Δk of any significance (e.g., 35% reduction for Δk of 1%). Even if all the boron is lost everywhere in the package, it only erodes about a third of the total margin obtained by assuming fresh fuel.

The second set of calculations confirms the Oak Ridge calculations in terms of edge effect. The effect is qualitatively similar, with a similar slope, though the actual k_{eff} is a bit higher (because a different cask was used). It also shows that a significant erosion from the exposed surfaces is needed to produce a Δk of significance (e.g., a 3" edge erosion producing Δk of 7%). This can be compared to the erosion rate evaluated conservatively at ~1/64" per year, so a 3" erosion is not expected to occur for at least 192 years of being continuously submerged).

The significance of the erosion being an edge effect is unclear. Normally, such as for fresh fuel such as in fuel fabrication, the neutron flux is reduced at the periphery, so edge effects are not significant. With spent fuel, however, the top and bottom are less irradiated and therefore less burned up than the center, so the ends of the fuel assemblies tend to be hotter. Note that in this particular cask, the Boral plates are arrayed in axial sections, so there are edges of the sheets near the center of the cask. Thus, whether corrosion at the edges of the plates or on the faces is worse (in terms of k_{eff}) is unclear.

Surface pitting can also lead to failure of the aluminum clad, and theoretically loss of ^{10}B on the faces. The blisters shown in the Hopper report appear roughly circular, so circular holes were assumed in the center of the widest part of each panel. This is conservative, because even if blistering occurs, it does not mean the clad will fail or the boron beneath the blister lost. But the results of our calculation show that even a large hole only produces a modest Δk of ~3%. This was for an 8" diameter hole, the largest that can occur given the size of the sheets, whereas the contractor report indicated most blisters were less than 1" in diameter and the largest blisters were around 2.5" (for BORAL2 and BORAL3). The model not only increased the diameter, but also had 7 such blisters arrayed along the axis on each side of each assembly, so there were a large number (roughly 7 blisters/side x 36 interior faces between assemblies = 252 blisters) of 8" diameter blisters, each of which was represented by a completely de-borated "hole." This is clearly a very conservative representation of the worst-case effect of corrosion pitting.

Whether by complete delamination and uniform depletion of all Boral sheets throughout the cask, edge erosion of the exposed surfaces, or corrosion pitting leading to large blisters on the faces, the effect of postulated (but not seen) Boral degradation seems adequately bounded by the margin due to the fresh fuel assumption. It appears that substantial degradation beyond what has been observed is needed to have an appreciable effect in cask reactivity.

Document 4: DPO Decision

UNITED STATES
NUCLEAR REGULATORY COMMISSION
WASHINGTON, D.C. 20555-0001

February 28, 2017

MEMORANDUM TO: Dr.-Ing Donald E. Carlson, former Senior Project Manager for Advanced Reactors
Office of New Reactors

FROM: Marc L. Dapas, Director
Office of Nuclear Material Safety and Safeguards

SUBJECT: DIFFERING PROFESSIONAL OPINION REGARDING THE EVALUATION AND COMMUNICATION OF BORAL DEGRADATION EFFECTS IN DEPLOYED SPENT FUEL CASKS (DPO-2016-002)

On June 29, 2016, in accordance with Management Directive 10.159, "The Differing Professional Opinions Program", you submitted a differing professional opinion (DPO) concerning the evaluation and communication of boral degradation effects in deployed spent fuel casks. In a memorandum dated July 19, 2016, from Renee Pedersen, Senior Differing Professional Views Program Manager in the Office of Enforcement, an Ad-Hoc DPO Review Panel (the Panel) was tasked with reviewing your DPO submittal and then providing me with a report documenting the Panel's conclusions and any associated recommendations. The Panel met with you on August 10, 2016, to establish a concise statement of your concerns. You approved the statement of concerns on August 21, 2016. Upon completing its deliberations, which included an interview with you, completion of a number of document reviews, and interviews with staff and managers from the Division of Spent Fuel Management (DSFM) in Nuclear Materials Safety and Safeguards (NMSS) as well as an U.S. Nuclear Regulatory Commission (NRC) contractor, the Panel provided me with its report, dated September 14, 2016, for my consideration in issuing a decision regarding the subject DPO. A copy of the report was provided to you and you sent an e-mail response to Renee Pederson and Marge Sewel on January 3, 2017.

In order to make a decision with regard to your DPO, I reviewed your DPO submittal, the Panel's report, and your e-mail communications dated July 8, 2016 (to Andrew Barto); July 19, 2016 (to the Panel members Mark Lesser, Christopher Trip and Matthew Yoder), and January 3, 2017 (to Renee Pederson and Marge Sewell).

Statement of Concerns:

(1) Spent fuel storage/transportation cask stakeholders have not been adequately informed by the NRC of safety and operational problems that may result from Boral degradation. Such problems include erosion of subcritical margins, hydrogen generation, and maintaining radiation exposures as low as reasonably achievable if fuel assemblies are

bound, which can be challenged by pool cask pit unavailability for loading or servicing casks, and the possible need for cutting tools to retrieve bound fuel assemblies.

(2) The NRC's closure of Generic Safety Issue (GSI) 196, "Boral Degradation", was primarily based on a July 13, 2006, final letter report, "Review of BORAL™ Degradation-Related Literature Survey", by criticality safety expert, Calvin M. Hopper, of Oak Ridge

National Lab (ORNL). In the subject report, Mr. Hooper concluded that Boral degradation revealed by testing would not result in substantial erosion of criticality safety margins. Testing was performed on new Boral sheets (referred to in the Hopper letter report as BORAL-2 and -3) and did not include old sheets (referred to in the letter report as BORAL-1). The GSI closure memorandum stated that since testing of older Boral sheets was beyond the scope of the GSI program, older Boral sheets should be studied as an investigatory research program. This follow-up action was not performed.

DPO Panel Conclusions:

(1) The criticality margins in dry spent fuel storage and transport casks with Boral are not sufficiently eroded by the Boral degradation observed to date to constitute a significant safety concern. Even with substantially greater degradation such as might occur with older Boral, the substantial margin produced by evaluating casks assuming fresh fuel, is expected to remain largely in place. While this issue has not been thoroughly studied, it does not appear to be a sufficient safety concern to warrant re-opening of older casks or an extensive new research project.

(2) As part of GSI-196, a recommendation was made by the NRC's consultant to conduct follow-up research on the degradation of older Boral for its impact on subcritical margins. This recommendation was deemed outside the scope of GSI-196 by NRC management, and was deferred due to future research that was later conducted but did not specifically address the issue. This decision allowed some degree of uncertainty to remain regarding the degradation effects for older Boral that might experience multiple cycles of re-flooding on criticality safety margins, due to lack of data. The Panel concluded that a unique opportunity currently exists to conduct some limited testing on older Boral obtained from the Zion spent fuel pool to obtain data and resolve performance and subcritical margin uncertainty of older Boral regarding degradation, potential boron loss, or sheet integrity/detachment.

(3) Retrievability of spent fuel and increased radiation exposure resulting from bound fuel assemblies are adequately addressed in the current staff guidance. This conclusion applies to any bound fuel assemblies, but in the context of this DPO review, it specifically addresses fuel binding caused by Boral degradation.

(4) Communications to spent fuel cask users on precautions for hydrogen generation and combustion in storage systems are adequate to inform stakeholders of the potential hazards. The agency has communicated concerns regarding flammable gases, including hydrogen, via several generic communication tools including information notices and bulletins. In addition, flammable gases are specifically addressed in the Standard Review Plan. The Panel acknowledged that Boral material may introduce an

additional source of hydrogen, however, the existing guidance and communications are adequate to address any potential flammable gasses generated within spent fuel storage systems.

(5) The NRC can improve its communication to spent fuel cask users of industry recommended limitations on re-flooding cycles for dry spent fuel casks which use Boral as a neutron absorber due to uncertainties in subcritical margin.

DPO Panel Recommendations

Based on its conclusions, the Panel made the following recommendations:

(1) The NRC should communicate to stakeholders the results of Boral testing in dry spent fuel cask applications, i.e., that fuel loading, pressure draining, and vacuum/drying/heating has caused degradation of the Boral, and repeated cycles can cause a licensee to be outside of its licensing basis for subcritical margin.

(2) The NRC conduct an investigation of older Boral material, as was recommended in the closure of GSI-196, since there is a knowledge gap with respect to the potential degradation mechanisms of this material in a dry storage system. Testing may serve to eliminate uncertainties and reduce concerns that a rewetting of the Boral material during fuel removal or repacking may result in a challenge to criticality safety. The Panel recommended that the NRC coordinate on-going research with the Zion fuel samples and contract to have them subjected to conditions representative of multiple cycles of pressure draining, heating, and vacuum drying to simulate multiple re-floods, in order to determine if a more extensive safety issue exists for older Boral. The Panel acknowledged that NRC management previously determined that the cost of such testing was not commensurate with the potential safety benefit. However, in the course of its evaluation, the Panel identified a unique opportunity to perform testing which in the Panel's view, warrants a revisiting of the previous decision. Given the opportunity to perform testing on older Boral material, and the fact that the agency has already obtained the material and started testing, the Panel recommended that NRC management consider testing the Zion Boral material under dry storage environments. Whether this testing is conducted under a new User Need Request or is added as a supplement to the existing NRC contract, the Panel felt "the opportunity to obtain valuable data should be not be ignored."

Decision and supporting rationale

After considering all of the information, I agree with the Panel's conclusions and endorse their first recommendation regarding NRC communications. With respect to the Panel's second recommendation pertaining to an investigation of older Boral material, I propose the following:

The DPO submitter challenged the basis for the closure of GSI-196, indicating that the February 22, 2007, closure memorandum from Brian Sheron to Luis Reyes contained the statement with respect to testing of "old" Boral sheets (BORAL-1), that "this level of investigation of the Boral blistering phenomenon and its consequences... are beyond the scope of the Generic Issues Program and would be more appropriately studied as an investigatory research program." The Panel also called into question the appropriate closure of GSI-196 by noting that an August 31, 2006, memorandum pertaining to the closure of the subject GSI indicated that neutron absorber degradation was of interest to the International Atomic Energy Agency (IAEA), and that it would be "prudent to wait" until an IAEA Coordinated Research Project known as SPAR-II was conducted. The Panel commented in its report that "this creates the appearance that the issues raised in GSI-196 were not considered definitively closed, but merely deferred until the additional research could be completed. However, the panel notes that neither the SPAR-II, nor the subsequent SPAR-III, final reports (IAEA-TECDOC-1680 and -1771) refer specifically to Boral degradation."

Consequently, given that there is a question regarding the adequacy of the basis for closure of GSI-196 and the fact that an evaluation of BORAL-1 was not included within the scope of the GSI, I consider it prudent for staff in DSFM within NMSS to conduct an assessment of spent fuel storage and transport cask systems that incorporated older Boral (BORAL-1) materials and that have been subjected to re-flooding operations, in order to determine whether any indications of potential significant degradation of Boral material exists. This assessment should consist of the compilation of operating experience from inspection activities, loading/unloading operations, and annual maintenance checks involving storage and transport systems that used BORAL-1. The staff should compare the results of this operating experience evaluation to the results and conclusions identified in the July 13, 2006, ORNL final letter report, "Review of BORAL™ Degradation-Related Literature Survey", from C.M. Hopper, and based on the results of that comparison, make a recommendation as to whether further testing is warranted to identify potential neutron absorber degradation mechanisms in dry storage systems. In addition, as recommended by the Panel, I propose that DFSM staff engage the Office of Nuclear Regulatory Research regarding the ongoing cooperative research project between the NRC and the Electric Power Research Institute (EPRI) pertaining to testing of Boral materials from the spent fuel pool at the Zion Nuclear Station, to determine if this testing could be feasibly expanded to include dry storage environments and the associated expense for such testing. The staff should document the results of its operating experience information assessment and evaluation of the potential feasibility for testing Zion spent fuel pool materials in a position paper that considers the safety benefits and associated costs, and provide a recommendation for the path forward.

The basis for my decision follows.

Nuclear criticality safety in the context of erosion of subcritical margins

Boral, which is a hot-rolled composite plate product consisting of a mixture of boron carbide particles and aluminum (B_4C-Al) that are clad with aluminum cover plates on the two large external surfaces forming an aluminum bonded "sandwich" plate, is used as a neutron absorber to control reactivity in spent fuel pool racks and in dry spent fuel storage systems. As you and the Panel noted in your DPO submittal and its report, respectively, Boral has experienced degradation in spent fuel pools and in dry storage casks. Degradation mechanisms in spent fuel pools have resulted in plate deformation and cladding blisters, which have caused fuel assembly binding during lifting operations. This problem has historically been documented in NRC generic communications and continues to be addressed in spent fuel pool applications. Boral used in dry spent fuel casks has also experienced degradation (cladding blisters) from one cycle of pressure draining and vacuum drying/heating in spent fuel casks. During a fuel loading operation, the porous Boral is in contact with water, which permits water to penetrate the voids. Subsequent vacuum drying and high temperature has caused steam formation, expansion, and blistering. In addition, the aluminum-water reaction produces aluminum oxide and hydrogen, which can also cause blistering. Concerns have been raised regarding the impact of blisters on the area density of the B_4C particles and subcritical margins.

As noted by the Panel in its report, for dry storage applications, neutron absorbers such as Boral are required for reactivity control only for the relatively short period of time while the cask is flooded with water during fuel loading or unloading. Once the cask has been drained, dried, and inerted with helium gas, the absence of moderating hydrogen atoms renders the fuel in the associated multipurpose canister subcritical by a substantial margin.

Your principal concern with respect to nuclear criticality safety appears to be that insufficient testing of "old" Boral material (BORAL-1) has been conducted to ensure that Boral degradation does not negate criticality safety margins. As the Panel noted in its report, Boral fabrication and conditioning processes have improved over time. Older Boral was historically manufactured prior to about 2001. Whereas, newer or "improved" Boral (BORAL-2 and -3) was manufactured to increase the void interstices in the B_4C-Al composite mixture to reduce blistering by better venting gases and to thermally treat plates to passivate the aluminum-water chemical reaction. Newer Boral was also manufactured with greater attention to plate and rolling mill cleanliness thereby reducing the incidence of plate surface scarring by B_4C particles and chemical corrosives, which contributed to pinhole water intrusion. The results of coupon testing by EPRI suggest that the "improved" Boral should be suitable for storage-only canisters where the Boral would typically be subjected to one or two wetting/drying cycles. The Panel also commented in its report that "it is reasonable to suppose that 'old' Boral that was fabricated prior to about 2001 using pre-improved manufacturing techniques would experience somewhat greater damage, but the extent to which this might occur has not been quantified and no direct evidence thereof has been documented."

The Panel continued to note in its report that "blistering or slight deformation of the Boral sheets will not affect their efficacy to limit neutron interaction so long as the boron carbide particles remain largely in place; for this purpose, only the areal density of the boron absorber, primarily ^{10}B, is important. Thus, blistering and delamination would only be a criticality concern if it resulted in exposing the boron carbide meat and rearranging or depleting the boron carbide granules sufficient to cause a significant reduction in the ^{10}B areal density.... Such wholesale rearrangement or depletion of boron carbide particles has not been observed either operationally or in the samples analyzed to date."

In its report, the Panel pointed out that criticality safety margins are substantial (particularly when considering the fresh fuel assumption i.e., no credit for spent fuel burnup reactivity reduction and noted that there is "no documented historical evidence for wholesale [Boral] degradation that would be severe enough to negate criticality safety margins...." The Panel did, however, highlight that Boral testing to date has not included "old" Boral, namely BORAL-1, and that what is known of the older casks incorporating BORAL-1 is very limited. Notwithstanding this caveat, I agree with the Panel's conclusion that a massive rearrangement or removal of ^{10}B is needed to produce even a modest change in cask reactivity, and that while it is plausible that the effect of Boral degradation on criticality safety margins for older casks would be somewhat larger than that for newer casks, "there is no reason to suppose it constitutes an immediate safety issue."

This conclusion seems to be supported by your own statement in your DPO submittal that you "would be surprised should the results from the recommended research reveal degradation effects severe enough to fully negate all explicit and implicit margins of criticality safety."

Hydrogen generation

You raised a concern that hydrogen gas generated while Boral material is exposed to water during cask loading may result in combustion. You were also concerned that the NRC has not adequately communicated this potential hazard to stakeholders.

As noted in its report, the Panel concluded that the generation of hydrogen gas during interaction of Boral with water in both spent fuel pool and cask loading environments, is well documented. The Panel also determined that Boral is one of many sources of potentially flammable gases generated during the flooding of dry storage casks with borated and un-borated water. The Panel acknowledged that although no specific guidance or communications have been issued with respect to hydrogen gas generation from Boral, the agency has made it clear in both generic communications and in NUREG-1536, "Standard Review Plan for Spent Fuel Dry Storage Systems at a General License Facility", that the potential exists to generate large quantities of hydrogen gas during wet loading of spent fuel storage systems. As such, any hydrogen that may be generated from Boral exposure to water is bounded by the existing guidance and communications.

Retrievability of bound fuel assemblies and maintaining radiation exposures as low as reasonably achievable

You raised a concern that large blisters or deformation of the Boral sheets could result in the inability to readily retrieve bound fuel from an affected cask returned to the spent fuel pool for servicing. This could affect worker safety, could make the cask pit laydown area in the spent fuel pool unavailable for loading new casks or for servicing other deployed casks, and could eventually necessitate extended plant shutdown.

As noted in the Panel's report, the NRC has revised the definition of retrievability such that a licensee must have the capability to both remove a canister loaded with spent fuel from a cask, and remove a cask loaded with spent fuel from the storage location. Consequently, a licensee is not required to be able to remove an individual fuel assembly from a cask. Therefore, any binding of spent fuel assemblies caused by Boral degradation would not violate the regulatory requirements for retrievability. As the Panel further noted in its report, one of the primary reasons that the NRC revised its guidance regarding "retrievability" was to address the difficulties in accessing the spent fuel and the interior components of some storage systems. Opening a storage system is labor intensive and exposes workers to additional dose. In addition, for welded canisters, opening may require breaching and re-establishing the confinement boundary with no additional safety benefit. Eliminating the need to open casks to inspect or remove fuel, as described in the NRC staff's guidance, eliminates the concern regarding increased radiation exposures for workers. This applies not only to potentially bound spent fuel, but to any spent fuel currently in a dry storage system.

I noted that in your e-mail dated January 3, 2017, to Renee Pederson and Marge Sewell, in response to your having received the Panel's report, that you commented, "I still see an unmet need for contingency plans for dealing with hard-bound fuel in defective or damaged casks returned to pools." You further commented, "While we can all agree with ISG-2's [Interim Staff Guidance, Revision 2's] new 'elimination of the need to open casks to inspect or remove fuel,' no rule or guidance can ever eliminate the real need for contingency plans to safely deal with multiple damaged or defective casks in pools. The potential for hard binding of intact fuel in deployed casks with degraded Boral needs to be explicitly considered in establishing such plans. To underpin the need for such plans, it might help to perform safety and environmental assessments of credible/likely events involving multiple leaking (defective or damaged) casks at a plant site and how these would be affected by an extended inability to retrieve hard-bound fuel."

In response to the comments from your e-mail that I referenced above, as well as the discussion on the retriveability of individual fuel assemblies from deployed casks in Section 3.3 of your DPO submittal, I would offer the following perspective. Notwithstanding our regulatory requirements regarding retrievability, should the need arise due to some unforeseen circumstance for a licensee to retrieve an individual fuel assembly from a cask basket, I would expect a licensee to develop a contingency plan based on appropriate consultation with the cask vendor and/or other technical service providers, that would provide for an appropriate level of safety assurance and dose minimization to involved workers (this includes the scenario where specialized cutting tools might be needed to retrieve a bound fuel assembly). I also am highly confident that any such evolution would not proceed without the appropriate NRC oversight. In addition, while I consider it unlikely, should this situation result in the placement of the affected cask in the cask laydown area of the spent fuel pool for an extended period of time, such that the ability of the licensee to load additional casks is adversely impacted, and thus creates the need for the licensee to shut down the plant, that potential outcome does not represent an NRC safety concern.

Adequacy of NRC communications

As noted by the Panel in its report, while the NRC has issued specific generic communications on Boral degradation in spent fuel pools, the agency has not issued any corresponding generic communications associated with Boral degradation in dry spent fuel cask applications. As the report further notes, industry testing has demonstrated that once blistered, newer Boral will remain an effective neutron absorber provided it is not repeatedly cycled through re-flooding operations that include a sequence of pressurized water evacuation and vacuum drying evolutions. Industry reports have concluded that Boral blistering becomes significantly worse after three cycles of operation. A higher degree of uncertainty exists for older Boral due to the lack of test data.

While I concur with the Panel's view that the probability is low that a licensee would subject a cask to multiple re-flood cycles, licensees currently do not have license conditions or Technical Specifications that prohibit such operations. I also agree with the Panel's conclusion that given the unlikelihood that a licensee would engage in multiple re-flood operations, there is not a compelling safety need to modify existing licenses to provide for re-flood limitations. I also agree with the Panel that it is prudent to inform the industry and other stakeholders of the effects of multiple re-flood cycles on Boral degradation and the associated uncertainties regarding the effect of Boral degradation on subcritical margins.

Concluding comments

Thank you for your active participation in the DPO process. Your willingness to raise concerns with our regulatory processes and associated outcomes via a DPO when previous discussions with staff and management over several years on the involved issues did not result in satisfactory resolution, is important to ensuring a healthy safety culture within the agency. I thought your DPO submittal was well-written and comprehensive in describing the issues and the bases for your concerns. I also appreciate the dedicated and thorough review conducted by the Panel and the high quality written report documenting the Panel's conclusions and recommendations. I am also glad to see that you appear to have a similar view regarding the Panel's efforts based on the comment in your January 3, 2017, e-mail indicating that you "admire and appreciate the panel's diligence and generally find their evaluation to be well balanced and thorough." Finally, when the case is closed, a summary of the DPO and associated decision will be included in the Weekly Information Report to advise interested employees of the outcome.

Enclosure:
DPO Panel Report dated September 14, 2016

cc: F. Brown, DEDM
P. Holahan, OE
R. Pedersen, OE
M. Sewell, OE
M. Lesser, RII
C. Tripp, NMSS
M. Yoder, NRR
M. Layton, NMSS