Note to requester: The attachment is immediately following this email.

From: Hiser, Matthew
Sent: Wed, 31 May 2017 19:55:53 +0000
To: Frankl, Istvan
Subject: RE: Workshop Summary Report
Attachments: Harvesting Workshop Summary Report draft 5-26-17 (IF) mah incorp.docx

Hi Steve,

Thank you for reviewing and providing input. I just wanted to share responses for a couple comments and questions.

Thanks!
Matt

Matthew Hiser
Materials Engineer
US Nuclear Regulatory Commission | Office of Nuclear Regulatory Research
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Phone: 301-415-2454 | Office: TWFN 10D62
Matthew.Hiser@nrc.gov

From: Frankl, Istvan
Sent: Tuesday, May 30, 2017 5:55 PM
To: Hiser, Matthew
Subject: RE: Workshop Summary Report

Thanks Matt.

This is a well-written report. Please see my attached editorial revisions and comments.

Steve

From: Hiser, Matthew
Sent: Friday, May 26, 2017 9:18 AM
To: Purtscher, Patrick <Patrick.Purtscher@nrc.gov>; Tregoning, Robert <Robert.Tregoning@nrc.gov>; Hull, Amy <Amy.Hull@nrc.gov>; Frankl, Istvan <Istvan.Frankl@nrc.gov>
Subject: RE: Workshop Summary Report

I have incorporated significant input from Amy and Pat on the Harvesting Workshop Summary Report. The latest version of the report is attached.

My plan is to send this complete draft to the workshop participants for review and comment by Wednesday, May 31. Please provide any further input or comments by next Wednesday to be incorporated in the draft sent to workshop participants.

I will ask for feedback from workshop participants by the end of June with the intent to finalize this summary report by mid-July.

Please let me know if you have any questions or suggestions on how to best move this effort forward.

Thanks!
Matt

Ex-Plant Materials Harvesting Workshop Summary Report

Workshop held on March 7-8, 2017 at NRC headquarters in Rockville, MD

NRC staff: Matthew Hiser, Patrick Purtscher, Amy Hull, Robert Tregoning

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Background

On March 7-8, 2017, the Office of Nuclear Regulatory Research of the United States Nuclear Regulatory Commission (NRC) hosted a 2-day workshop on the topic of "Ex-Plant Materials Harvesting." NRC staff worked in close coordination with staff from the U.S. Department of Energy (DOE) and the Electric Power Research Institute (EPRI) to plan and arrange the workshop.

The decision to organize this workshop was driven by developments in the U.S. and global nuclear industry. In the U.S., there is strong interest in extending plant lifespans through subsequent license renewal (SLR) from 60 to 80 years. Extended plant operation and SLR raise a number of technical issues that may require further research to understand aging mechanisms, which may benefit from harvesting. Meanwhile, in recent years, a number of nuclear plants, both in the U.S. and internationally, have shut down or announced plans to shut down. Unlike in the past when there were very few plants shutting down, these new developments provide opportunities for harvesting components that were aged in representative light water reactor (LWR) environments. In a related development, economic challenges for the nuclear industry and limited government spending have limited the resources available to support new research, including harvesting programs. Given this constrained budget environment, aligning interests and leveraging with other organizations is important to allow maximum benefit and value for future research programs.

Commented [FI1]: Is there any info from the related PLiM abstract that can be borrowed/ added to this paragraph or other applicable section?

I actually used this paragraph as a starting point for the PLiM abstract. I don't want to make them too similar, since this is ostensibly a non-public workshop summary for participants, while the PLiM is in the open literature. Not that the message is very different, but I'd rather them be somewhat different.

Objective and Approach

The objective of the workshop was to generate open discussion of all aspects of ex-plant materials harvesting, including:

1. Deciding whether to harvest,
2. Planning and implementing a harvesting program,
3. Using the harvested materials in research programs.

Through presentations and open discussion, the workshop was organized to allow for all participants to be better informed of the benefits and challenges of harvesting as well as to identify potential areas of common interest for future harvesting programs. Workshop sessions were aligned in broad topics to cover all aspects of harvesting that allowed the participants to drive the discussion.

To help accomplish the workshop objectives, the workshop organizers intentionally sought a diverse group of participants. There are a large number of decommissioning plants and interested researchers outside the U.S., so the organizers focused on outreach to international participants through organizations such as the International Atomic Energy Agency (IAEA), Organization for Economic Cooperation and Development Nuclear Energy agency (OECD/NEA), and existing professional contacts. In addition, a key goal for this workshop was to capture the broader practical perspective from plant owners and decommissioning companies, which are vital to any successful harvesting program, but may sometimes be overlooked in researcher-driven discussions. Workshop participants were also diverse in terms of technical area of focus, with metal components such as the reactor pressure vessel (RPV) and internals being discussed along with concrete and electrical components. The final list of workshop participants can be found at the end of this report in Appendix I.

Workshop Organization and Sessions

The workshop was held at NRC headquarters in Rockville, MD. Due to limited space in the meeting room and the need for a limited group size for discussion, a webinar was used to allow remote observers to benefit from the workshop. Workshop sessions were organized topically with about half the time dedicated to presentations and the remaining time set aside for discussion. Presentations were solicited from participants to cover a range of perspectives and technical areas. The final workshop agenda can be found at the end of this summary report in Appendix II.

The workshop was organized into five sessions as follows:

- Session 1. Motivation for Harvesting
- Session 2. Technical Data Needs for Harvesting
- Session 3. Sources of Materials
- Session 4. Harvesting Experience: Lessons Learned and Practical Aspects
- Session 5. Future Harvesting Program Planning

Summary of Workshop Discussion

The subsections below will summarize the presentations and discussion in each session and highlight the key takeaways from the session.

Session 1. Motivation for Harvesting

Session 1 focused on the motivation for harvesting and why workshop participants are interested in harvesting. As shown in Appendix II with presentation titles, speakers for this session included:

- Richard Reister from DOE,
- Sherry Bernhoft from EPRI,
- Robert Tregoning from NRC,
- Uwe Jendrich from the Gesellschaft für Anlagen- und Reaktorsicherheit (GRS) in Germany, and
- Taku Arai from the Central Research Institute of the Electric Power Industry (CRIEPI) in Japan.

Presentation Summaries

DOE described the role of harvesting within the Light Water Reactor Sustainability (LWRS) Program, including the benefits and challenges associated with harvesting. Benefits include the opportunity to fill knowledge gaps where there is limited data or experience and to inform degradation models with data from actual plant components. Challenges include cost, complexity, scheduling, logistics, limited opportunities, acquiring sufficient material pedigree information, and potential negative results impacting operating plants.

EPRI discussed the role of harvesting within the context of aging management for Long-Term Operations (LTO), including their experience from past harvesting programs and criteria for future harvesting. Their experience emphasized the challenges of cost, schedule, logistics, complicated contracting and acquiring material pedigree information. EPRI's criteria for harvesting focus on demonstrating value to their members by addressing a prioritized need that cannot be addressed through other means. For EPRI, a well-developed project plan that covers funding, risk management, exit ramps, and clear roles and responsibilities is essential.

NRC shared its perspective on the benefits and challenges of harvesting in regulatory research. Harvested materials are valuable due to the representative nature of their aging conditions, which may reduce the uncertainty associated with the applicability of the results to operating plants compared to tests with alternative aging conditions. Harvested materials may be the best option to address technical data needs identified for extended plant operation. With increasing harvesting opportunities from decommissioning plants, a proactive approach to harvesting planning can optimize benefits by identifying the right material with the right aging conditions for the identified knowledge gap. There are significant challenges associated with harvesting, including cost, schedule, and logistics, but hopefully these can be mitigated or avoided by leveraging resources with other organizations and learning from past experience.

GRS described its role as the main technical support organization in nuclear safety for the German federal government. GRS provides technical assessment and knowledge transfer for decommissioning activities, aging management, and long-term operation for German federal and international organizations.

CRIEPI discussed its view of how harvested materials and laboratory prepared materials contribute to addressing technical issues. Harvested materials provide exposure to actual plant conditions, but are more limited in availability and the size of the data set that can be generated. Laboratory prepared materials general involve accelerated or simulated aging conditions, but can be used to produce larger data sets and varying parameters can allow understanding of the effect on the mechanism or property of interest. Harvested materials offer fact finding of actual plant conditions as well as confirmation and verification of results from laboratory prepared specimens.

Discussion Summary

The discussion following the presentations in this session focused on clearly identifying the need to be addressed by a harvesting project and the myriad cost, schedule, and logistical challenges associated with harvesting. Leveraging with other organizations to defray costs can also help improve the value of a given program, but also adds complexity as another organization may have a different set of priorities that changes the focus of the harvesting effort.

Session 2. Technical Data Needs for Harvesting

Session 2 focused on discussing the technical data needs for harvesting and what specific knowledge gaps organizations are interested in addressing through harvesting. This discussion included general perspectives on how to determine when harvesting should be pursued rather than other types of research. As shown in Appendix II with presentation titles, speakers for this session included:

- Pradeep Ramuhalli from the Pacific Northwest National Lab (PNNL),
- Matthew Hiser from NRC,
- Keith Leonard from Oak Ridge National Laboratory (ORNL),
- Rachid Chaouadi from the Belgian Nuclear Research Centre (SCK-CEN) in Belgium, and
- Arzu Alpan from Westinghouse.

Presentation Summaries

PNNL presented their work, under a small NRC contract, to develop a systematic approach to prioritize data needs for harvesting. PNNL proposed five primary criteria for prioritizing harvesting:

- Unique field aspects of degradation
  - For example, unusual operating experience or legacy materials (composition, etc.) that may be no longer available
- Ease of laboratory replication of degradation scenario (combination of material and environment)
  - For example, simultaneous thermal and irradiation conditions may be difficult to replicate or mechanism sensitive to dose rate may not be good for accelerated aging
- Applicability of harvested materials for addressing critical gaps
  - Prioritize harvesting for critical gaps over less essential data needs
- Availability of reliable in-service inspection (ISI) techniques for the material / component
  - If inspection methods are mature and easy to apply to monitor and track degradation, perhaps the effort of research with harvested materials is not needed.
- Availability of materials for harvesting
  - The necessary materials / components must be available to be harvested.

PNNL then presented their application of these criteria to four materials degradation issues as an example: electrical cables, cast austenitic stainless steel (CASS), reactor vessel internals, and dissimilar metal welds. Based on applying these criteria to the examples, PNNL concluded that electrical cables, CASS, and reactor internals are all higher priority for harvesting due to unique aspects of the degradation that are challenging to replicate in the lab. Meanwhile, dissimilar metal welds are of low priority due to the ease of replication in lab aging studies as well as the significant body of knowledge and research on the phenomena.

NRC presented a summary of data needs it is interested in pursuing through harvesting. These included RPV materials to validate fluence and attenuation models and to demonstrate the conservatism of regulatory approaches for transition temperature prediction. Other metal components of interest for harvesting would address data gaps in irradiated stainless steels, as well as improve understanding of inspection capabilities and fatigue life calculations. Electrical components of interest include low and medium voltage cables and other electrical components for degradation studies, and electrical enclosures and cables for fire research. Concrete components of interest include irradiated concrete, concrete undergoing alkali-aggregate reactions, post-tensioned structures, reinforcing steel, tendons, and spent fuel pool concrete to assess potential boric acid attack.

DOE/ORNL presented their perspective on data needs for harvesting and its role in providing validation of experimental and theoretical research. DOE/ORNL performed a significant RPV harvesting program at the Zion nuclear power plant to reduce uncertainties in the Master Curve methodology, validate modeling predictions and study flux and fluence attenuation effects. The harvesting is largely complete, but the testing program is currently underway. DOE/ORNL also indicated interest in using harvested materials to validate its models for swelling and microstructural changes of stainless steel internals under LWR irradiation conditions. Harvesting concrete components would be of interest due to lack of literature data and the multiple dependent variables that may affect concrete performance. Finally, DOE/ORNL has been involved in harvesting cables from the Crystal River and Zion plants to address cable aging as a function of material composition and environment.

SCK-CEN presented their interest in an international cooperative program to harvest RPV materials. SCK-CEN presented their survey of the literature for past testing programs of harvested RPV materials, and

the limitations of these past program. Key limitations include a lack of archive materials, generally lower temperatures, and poor surveillance programs and dosimetry. SCK-CEN then shared some thoughts on their criteria for a new harvesting efforts, including higher fluence levels and temperatures, available archive materials and reliable information on operating history, dosimetry and surveillance program. Other topics relevant to a new RPV harvesting effort include technical issues such as material variability and irradiation conditions as well as logistical and financial considerations.

The final presentation in Session 2 by Westinghouse focused on the need for harvesting irradiated concrete to better understand the threshold radiation level for significant strength reduction. Westinghouse has installed ex-vessel neutron dosimetry (EVND) at a number of plants in the world and proposed to use these dosimetry measurements to validate fluence model calculations to better understand the uncertainty in these calculations. Figure 1 shows a schematic of the EVND setup. If concrete can be harvested at one of these plants with EVND data, then irradiated concrete properties from testing can be paired with fluence data to improve research benefits.

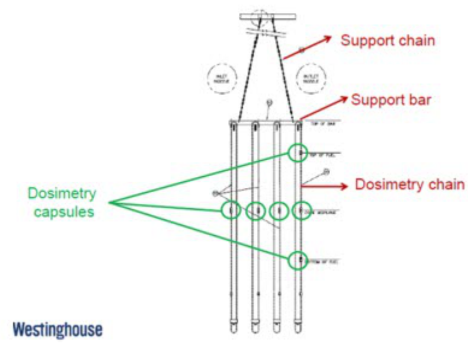

Figure 1 Schematic of Westinghouse ex-vessel neutron dosimetry (EVND)

Discussion Summary

The discussion following Session 2 presentations touched on a number of topics. EPRI shared that they developed a report related to the topics of Session 2, but more narrowly focused on pressurized water reactor (PWR) internals. MRP-320, “Testing Gap Assessment and Material Identification for PWR Internals,” focuses on prioritizing opportunistic harvesting of stainless steel reactor internals components that may be removed from service following MRP-227 inspections. The methodology and approach in this report may be relevant to the broader harvesting data needs discussion. This report is not publicly available, but is available to EPRI member utilities.

Workshop participants discussed the criteria proposed by PNNL in the first presentation. One additional criteria suggested by EPRI was to consider fleet-wide vs. plant-specific applicability. More broadly applicable materials would be of greater interest for harvesting than those that represent conditions at only a few plants. Another criteria suggested is the availability of material pedigree information, such as composition, processing, environmental conditions (temperature, humidity, fluence, etc.). Another suggested criteria was the ease of harvesting, which includes the concept of weighing costs vs. benefits as well as project risk. For example, highly irradiated internals are probably much more difficult and expensive to harvest than electrical cables or unirradiated concrete. Further discussion touched on the idea that different organizations may prioritize the various criteria differently, but all will probably at least want to consider the same set of criteria.

Another key theme from this discussion was that a successful program should be guided by a clearly defined objective or problem statement to be addressed. This objective should be well-understood at the initiation of a program and used to guide decision-making through implementation of a harvesting

project. This also raises a related point or potential criteria: the timeliness of the expected research results relative to the objective. If the results are needed in the next two years, but a harvesting project will not provide results for at least five years, that should be a strong consideration.

Session 3. Sources of Materials

Session 3 focused on discussing sources of materials for harvesting. This discussion covered previously harvested materials as well as sources for new harvesting programs from operating or decommissioning plants. Both domestic and international sources of materials were discussed in this session. As shown in Appendix II with presentation titles, speakers for this session included:

- Matthew Hiser from NRC,
- Al Ahluwalia from EPRI,
- Tom Rosseel from DOE/ORNL,
- John Jackson from DOE/Idaho National Laboratory (INL),
- Gerry van Noordennen from EnergySolutions,
- Arzu Alpan from Westinghouse,
- Uwe Jendrich from GRS, and
- Daniel Tello from the Canadian Nuclear Safety Commission (CNSC).

Presentation Summaries

NRC presented their perspective on sources of materials for harvesting. First, NRC shared information on some of the harvested materials from past research programs that may be available, including irradiated stainless steel internals, RPV materials, nickel alloy welds, neutron absorber material, and electrical components. NRC then summarized the recently and planned shutdown U.S. plants, including their design, thermal output, and years of operation, to provide participants with an idea of the potential sources from decommissioning U.S. plants. Finally, NRC shared a list of information that would be helpful to acquire from decommissioning plants to determine the value of components for harvesting. This information included plant design information (component location and dimensions), environmental conditions (temperature, fluence, humidity, stress, etc.) and operating history, material pedigree information (fabrication records), and inspection records (for interest in components with known flaws).

The next presentation from EPRI covered harvesting opportunities at decommissioning plants in Korea and Sweden. In Korea, Kori-1 is a Westinghouse 2-loop PWR (sister plant is Kewaunee) that will shut down in 2017 after 40 years of operation. Korea Hydro and Nuclear Power Central Research Institute (KHNP-CRI) is planning a comprehensive research program on long-term materials aging based on harvesting from Kori-1 and is seeking international participation in the harvesting effort. KHNP-CRI's plan is focused on metallic components, including RPV, internals, primary system components, steam generator materials. Harvesting is expected to occur in 2024 with testing to follow through 2030.

In Sweden, Vattenfall is currently harvesting in 2017-2018 RPV material from the decommissioning Barseback boiling water reactor (BWR) units. This work is focused on irradiation embrittlement, including comparison of surveillance data to actual RPV properties, as well as thermal aging embrittlement. In the future, Vattenfall will be shutting down Ringhals 1 and 2 in 2020 and 2019, respectively. Ringhals 1 is a BWR and Ringhals 2 is a Westinghouse 3-loop PWR design. Of particular note, Ringhals 2 has the second oldest replaced Alloy 690 RPV head and steam generators. Other harvesting opportunities at Ringhals include RPV material with a significant surveillance program, thermal aging effects on low alloy steel from the pressurizer, as well as concrete structures. Vattenfall is open to working with partners that are interested in joining them for harvesting at Ringhals.

The next presentation by DOE/ORNL focused on several harvesting programs that DOE's LWRS program has been involved with. DOE/ORNL has led the harvesting of components from the Zion [redacted] (b)(4)
(b)(4) plant [redacted] in the U.S. From Zion, DOE/ORNL has harvested electrical cables and components, a large RPV section, and a significant number of records to provide information on material fabrication, in-service inspection and operating history. Cables from Zion include CRDM, thermocouple, and low and medium voltage cables. DOE/ORNL indicated some thermocouple cables from Zion may be available for other researchers to use in collaborative studies. [redacted] (b)(4)
(b)(4)
(b)(4)
DOE/ORNL is also participating in efforts to harvest cables from Crystal River (led by EPRI) and concrete from the Zorita plant in Spain (led by NRC).

The next presentation by DOE/INL described INL's Nuclear Science User Facilities (NSUF) and the Nuclear Fuels and Materials Library (NFML). NSUF is coordinated by INL and facilitates access to nuclear research facilities around the world, including neutron and ion irradiations, beamlines, hot cell testing, characterization and computing capabilities. NFML is a Web-based searchable database sample library that captures the information from thousands of specimens available to NSUF. NFML is designed to maximize the benefit of previously irradiated materials for future research. Researchers can propose new research projects under NSUF using specimens in NFML using DOE funding. As seen in Figure 2, the information captured in NFML aligns well with the goal of this session to potentially develop a database of previously harvested materials.

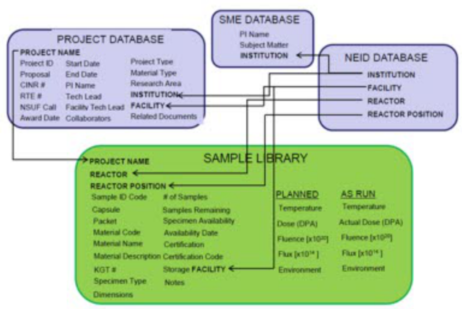

Figure 2 Nuclear Fuels and Materials Library (NFML) Database Design

The next presentation by EnergySolutions offered a more practical perspective on considering sources of materials for harvesting. From the plant owner perspective, there is no financial incentive to support harvesting during decommissioning, therefore researchers need to absorb the costs of harvesting and have a clear scope for harvesting. Flexibility in funding for harvesting activities is essential as the decommissioning process and schedule may change quickly.

EnergySolutions provided valuable perspective on the timing in the decommissioning process for harvesting different components. For instance, the harvesting of RPV surveillance coupons should take place when the RPV internals are cut and removed. Harvesting of RPV materials is only possible from larger RPVs, as smaller RPVs are shipped intact to the disposal facility, rather than cut into pieces. Spent fuel rack neutron absorber coupons must be harvested either before or after the dry storage campaign to remove spent fuel from the spent fuel pool. Harvesting actual spent fuel rack neutron absorber material must come after the pool is completely empty. Electrical cables and other components from mild environments may be harvested at any time (once temporary power is established and plant power is shut off), while the harvesting of electrical components from high radiation environments will depend on the timing of source-term removal schedules. Concrete cores are best harvested when other cores are being taken for site characterization to develop the License Termination Plan. Highly irradiated concrete from the biological shield wall would need to come later in decommissioning after the RPV is removed.

In terms of upcoming decommissioning plants, EnergySolutions indicated that San Onofre and Vermont Yankee will be entering active decommissioning in 2018 and 2019, respectively. Kewaunee, Crystal River, and Fort Calhoun also may enter active decommissioning in the next 2 years. If researchers are interested in harvesting from any of these plants, they should be reaching out to plant owners immediately to begin planning and coordination.

Westinghouse followed up their presentation in Session 2 by describing an opportunity to harvest concrete from the Mihama 1 plant in Japan. Westinghouse installed and analyzed additional neutron dosimetry in the reactor cavity for one cycle, which were used to validate the radiation transport calculations. Mihama was shutdown in 2015 and is in contact with Westinghouse about the possibility of extracting concrete cores from the biological shield wall. Westinghouse is seeking partners interested in joining this harvesting effort.

The next presentation by GRS covered opportunities for harvesting from German plants. Regulations in Germany require plants to either immediately dismantle or dismantle after a period of safe enclosure, which is largely consistent with options in the U.S. GRS detailed the status of German commercial reactors, which are predominantly BWR and PWR designs. Seventeen reactors are currently undergoing decommissioning, while seven more are currently shutdown and await a decommissioning license. Eight reactors are still operating with scheduled shutdown dates between 2017 and 2022. German RPVs tend to have lower fluence than U.S. designs due to a larger water gap in the downcomer region. Germany has limited experience with harvesting from decommissioning plants. One question that GRS will follow-up on is the "rumored" cable surveillance programs that may be used in Germany and could provide experience and lessons learned for other countries.

The final presentation in Session 3 was by CNSC on harvesting opportunities in Canada. Atomic Energy Canada Limited (AECL) has harvested seven concrete cores from the 20 megawatt electric (MWe) Nuclear Power Demonstration Plant (NPD), which shutdown in 1988 after 25 years of operation. CNSC and AECL are also considering opportunities to harvest concrete from other decommissioned reactors in Canada such as Gentilly-2, Douglas Point, and Whiteshell Reactor 1. In addition to concrete, CNSC and AECL are currently harvesting electrical cables from the 675 MWe CANDU-6 Gentilly-2 reactor, which shutdown in 2012 after 29 years of operation. The purpose of this work is to study cable degradation from thermal aging and radiation damage and validate environmental qualification of the cables. CNSC described some of the challenges with this harvesting effort, such as working with plant owners, records, accessibility and contamination of the materials and budgeting with unexpected delays in harvesting.

A future harvesting opportunity is from the National Research Universal (NRU) reactor at Chalk River, which will shut down in 2018 after operating since 1957. AECL is currently taking an inventory of irradiated materials that can be harvested from NRU in decommissioning. Potential materials for

harvesting include metals (steels, nickel alloys, zirconium, aluminum), concrete, graphite, active equipment (pumps, etc.), graphite seals, electrical cables, and thermocouples.

Discussion Summary

Following the presentations, there was some discussion of lessons learned from DOE's Zion harvesting effort. DOE worked with a former senior reactor operator at Zion to identify and acquire the appropriate records from Zion for the components being harvested. DOE also described their flexible approach to acquiring RPV samples by sending a large chunk of material (weighing ~90 tons) to EnergySolutions' facility in Tennessee, where smaller pieces (weighing ~500 pounds) were cut to send to ORNL. Most of the decontamination was performed at Zion, with minimal additional cleaning (as well as cladding removal) taking place at EnergySolutions' facility.

There was also discussion of acquiring materials from sources other than commercial nuclear facilities. DOE has considered harvesting concrete from other DOE nuclear facilities, but determined that there were compositional differences between the DOE facilities and commercial facilities that would make the concrete from DOE facilities not useful. DOE/INL mentioned that the Advanced Test Reactor (ATR) replaces their core internals every ten years. The ATR internals are composed primarily of 347 stainless steel and achieve very high fluence levels after ten years of service.

Another key discussion topic was the possibility of developing a database for previously harvested materials or those available for future harvesting. DOE/INL indicated that their NSUF sample library may be a good starting point for such a database, although any materials in that library should be freely available for use in the research community. CNSC, NRC, and PNNL also expressed interested in working to develop a harvesting database.

Session 4. Harvesting Experience: Lessons Learned and Practical Aspects

Session 4 focused on lessons learned and practical aspects of harvesting. Presenters shared their experience with past harvesting programs, particularly common pitfalls to avoid and successful strategies to overcome them. Presentations also covered the practical aspects of harvesting from the plant owner and decommissioning company perspective. As shown in Appendix II with presentation titles, speakers for this session included:

- Jean Smith from EPRI,
- Tom Rosseel from DOE/ORNL,
- Matthew Hiser from NRC,
- Taku Arai from CRIEPI,
- Gerry van Noordennen from EnergySolutions, and
- Bill Zipp from Dominion.

Presentation Summaries

EPRI presented their experience and lessons learned from past harvesting programs, particularly harvesting reactor internals and concrete from Zorita and electrical cables from Crystal River. From the Zorita reactor internals experience, EPRI emphasized that harvesting projects take significant time, encounter both material retrieval and on-site challenges, and shipping issues. As shown in Figure 3, the Zorita Internals Research Project (ZIRP) took about 10 years to go from initial planning to final results, which included about 5 years of project planning, 2 years for material extraction (on-site logistics and shipping), and 3-4 years for testing. EPRI's experience was that decommissioning activities were the top priority and that harvesting was secondary, subject to schedule and logistical challenges based on the changing decommissioning schedule. Shipping issues were also challenging due to sending activated materials (which were classified as "waste") across international borders, from the reactor in Spain to the testing facility in Sweden. Currently, further planned shipments of the Zorita materials beyond the initial program continue to be impacted by export license challenges in Sweden. More positively, EPRI emphasized that the Zorita reactor internals materials harvesting showed excellent cooperation among many organizations and are now providing valuable technical information to numerous research projects.

Figure 3 Zorita Internals Research Project (ZIRP) Timeline

Lessons learned from the Zorita concrete harvesting focused on the challenges with core sample drilling and handling contaminated concrete. Ultimately, an effective core drilling procedure was identified, but required some trial and error. Lessons learned from the Crystal River cable harvesting included material concerns, the need for on-site support, and cost. In terms of material concerns, radiation and asbestos contamination created additional challenges for harvesting. On-site support and the ability to visit the site are extremely valuable to ensure clear communication, retrieval or records for material pedigree information, and awareness of on-site developments in the decommissioning process. Cable harvesting at Crystal River was more expensive than anticipated, particularly in terms of EPRI project management time to coordinate the harvesting activities and engineering support at the plant.

DOE/ORNL presented lessons learned primarily from the experience harvesting RPV materials and electrical cables and components from the Zion plant. In terms of planning and decision-making, DOE/ORNL had several lessons learned. DOE/ORNL hosted a workshop at Zion in 2011 to discuss long-term goals and objectives, which proved very helpful in setting priorities and developing partnerships with other organizations. Partnerships were very valuable to DOE/ORNL's harvesting efforts, allowing for leveraging resources and collaboration and sharing results. There are limited opportunities for harvesting key components, so DOE/ORNL emphasized that participants should take full advantage of the opportunities that arise, understanding that there is a necessary compromise between the materials available and their value in terms of fluence or exposure to aging conditions. Another consideration is the quantity of material harvested, which should be sufficient for the objectives of the planned research as well as any collaborations or partnerships, but limited to control costs.

For implementing the harvesting program, DOE/ORNL found that flexibility was paramount to be able to adjust scope and plans in response to schedule changes and other developments, while remaining within cost constraints. Working with a former reactor operator was extremely valuable to benefit from

their in-depth knowledge of all parts of the plant, in particular the records for materials pedigree information. Regular site visits and contacts were also essential to stay aware of the latest developments in the harvesting planning and decommissioning process, with the understanding that harvesting is not the top priority for the decommissioning company. Other important considerations were hazardous materials handling, transportation, and disposal and logistics, including contracts, liability, shipping and disposal. Finally, DOE/ORNL's experience is that the total costs of a harvesting program from planning to execution to testing are very high, so they should be carefully weighed against the value of the expected data to be generated.

NRC presented their experience, including benefits from previous harvesting programs, and technical and logistical lessons learned from harvesting. As an organization, NRC has extensive experience with testing harvested materials, including RPV, primary system components, reactor internals, neutron absorbers, concrete and electrical components. NRC's experience is more limited than DOE or EPRI in terms of managing the logistics of a harvesting effort from a decommissioning plant. NRC has generally participated in a secondary role in cooperative efforts or received failed components from operating plants for research. NRC has found that previous harvesting efforts have been effective in reducing unnecessary conservatism, understanding in-service flaws more realistically for NDE and leak rate methodologies, as well as identifying and better understanding safety issues.

For technical lessons learned, NRC's perspective is that harvesting can provide highly representative aged materials for research, which may be the only practical source of such materials. Harvested materials can be effectively used to validate models or a larger data set from accelerated aging tests. It is important to understand as much as possible about the materials and their in-service environment and how this compares with the operating fleet of reactors before committing to a specific harvesting project. For logistical lessons learned, harvesting is expensive and time-consuming, so a significant technical benefit is needed to ensure the program provides value. Leveraging resources with other organizations can help minimize costs, but can also introduce challenges for aligning priorities and interests of multiple organizations. Finally, transporting irradiated materials, particularly between countries, is challenging and time-consuming and should be avoided if at all possible.

CRIEPI presented their research experience with harvested materials as well as ongoing harvesting from the Hamaoka 1 plant. The first research program involved atom probe tomography (APT) on RPV surveillance materials. CRIEPI found a correlation between the volume fraction of Ni-Si-Mn clusters and the change in nil-ductility temperature. In the second research project, CRIEPI characterized the weld and base materials harvested from Greifswald Unit 4 RPV with small-angle neutron scattering, APT, and hardness testing. In the third research project, CRIEPI performed APT on 304L stainless steel reactor internals harvested from control rod and top guide components from 3-13 dpa. Results showed a strong increase in Ni-Si clusters with increasing fluence, but little variation in Al enriched clusters with increasing fluence.

Commented [FI2]: Was this a VVER-440 in the former GDR?

Yes

For future work, CRIEPI is collaborating with the DOE LWRS program to investigate RPV materials harvested from Zion [redacted] CRIEPI also presented activities underway by Chubu Electric Power to harvest RPV and concrete samples from the Hamaoka 1 plant. Hamaoka 1 is a 540 MWe BWR-4 that operated for 33 years. Harvesting began in 2015 and will continue through 2018.

(b)(4)

The final two presentations of Session 4 provided the non-researcher's perspective from a decommissioning company and plant owner. EnergySolutions, which is decommissioning the Zion nuclear plant among other facilities, presented on the decommissioning process and their experience and lessons learned from harvesting at Zion. As mentioned previously, surgical harvesting is not the top priority for decommissioning, so researchers must recognize this and coordinate closely with the decommissioning company. EnergySolutions emphasized the need to gain senior management support at the plant as well as to expect that there may be staff turnover during a multi-year harvesting effort. Changes in scope and schedule (originating from either side) can cause frustration on both sides. Early planning, efficient contracting, and frequent site visits are important to avoid lost opportunities and achieve a successful outcome.

At Zion, EnergySolutions worked with DOE to harvest RPV materials, cables, electrical components, and spent fuel storage racks. DOE hoped to harvest a particular RPV surveillance capsule, but was unable to do so due to the inability to identify the correct capsule. There were also challenges with harvesting RPV materials. The cut line on the Unit 2 RPV was too close to the weld to be used for research; fortunately, a successful specimen was harvested from Unit 1. For cabling, the initial plan was to harvest from 11 different locations, but ultimately, due to unforeseen challenges and poor communication and coordination, only 4 different cable locations were harvested. Harvesting the desired cable length (30 feet) also proved challenging, with only shorter sections recovered. Searches of plant records were largely effective at providing material pedigree information for cables. Concrete coring was initially planned to take place at Zion, but not performed due to lack of research interest. The spent fuel storage rack harvesting went smoothly, which was assisted by weekend efforts when decommissioning activities were not occurring.

The next presentation from Dominion provided its perspective on harvesting from decommissioning plants, focused on the experience at Kewaunee Power Station. The top priority (beyond safety) in decommissioning is the preservation and good stewardship of the decommissioning trust fund. Staffing is the largest drain on the trust fund, so at Kewaunee, staff was halved within a few months of shutdown and then halved again, about 16 months after permanent shutdown once offsite emergency response requirements were eliminated. Dominion described the example of harvesting the RPV surveillance capsules at this point at Kewaunee and the significant challenges that would exist. Given the reduced staffing and the current plant state (reactor coolant system drained, pumps retired, crane and radiation monitoring not maintained), it would be much more difficult than immediately after shutdown. Kewaunee considered harvesting the RPV surveillance specimens and estimated a cost of six to seven figures based on all the activities required to enable it at this point, post-shutdown, compared to a much lower cost just after shutdown. Dominion observed that some components, such as cables or electrical components, may be available and relatively easy to harvest at almost any time during decommissioning. However, other components such as highly irradiated internals or RPV may be best harvested either shortly after shutdown when staffing and capabilities on-site are high or wait until active demolition of the reactor, which may be years or decades later.

Dominion also touched on the discussion of records for plant components. Records requirements are limited to those needed for safety. Once the plant shuts down and the range of potential safety concerns decreases, systems are downgraded to non-safety and the associated records are no longer required to be maintained. For perspective, Kewaunee still has all its records four years since shutdown, but will likely not continue this much longer. Dominion closed its presentation with a broader

perspective on harvesting, emphasizing the need to clearly define a problem statement and understand what technical and regulatory purpose this harvesting will serve. Early planning focused on achieving the clear objective of the work including scope, schedule, budget and contact with plant is essential to a successful harvesting effort.

Discussion Summary

The discussion touched on the top lessons learned from past harvesting efforts, which included defining a clear objective and purpose for harvesting, early engagement with the plant, and site coordination during harvesting.

Another suggestion was to get utility management buy-in for the harvesting project by identifying a benefit to the utility. EPRI mentioned that cable harvesting at Crystal River went much more successfully once the utility recognized the potential benefits for SLR. Similarly, when harvesting from an operating plant, one must recognize and work through the challenges the plant may encounter when restarting operations.

During discussion, the question was raised regarding how it is determined whether harvested materials are waste. The discussion concluded that in the U.S. 10 Code of Federal Regulations (CFR) 37 is the important consideration. 10 CFR 37 defines when additional security requirements are imposed, based on the quantity and activity of materials to be transported. The definition of material as waste versus research materials is not as critical in the U.S. EnergySolutions indicated that their shipments of waste or research material could be handled in the same way in the accordance with Department of Transportation regulations, provided that the limits in 10 CFR 37 were not reached.

Session 5. Future Harvesting Program Planning

Session 5 focused on the information needed for informed harvesting decision-making and harvesting program planning. This session featured a presentation by Pradeep Ramuhalli from PNNL, followed by a discussion period covering harvesting program planning and reflection on the 2-day workshop.

Presentation Summary

PNNL presented its perspective on the information needed for informed harvesting decision-making. First, the purpose of the harvesting effort needs to be defined by identifying the technical knowledge gaps to be addressed. Next, a research plan should be developed demonstrating how the harvested material will be used to address the identified gaps. Finally, the appropriate source of material to address the technical gap must be identified, along with resources to support the effort and plans and timelines to perform the harvesting. The specifics of these plans depend greatly on the source of materials and must be flexible based on changing conditions on the ground.

In assessing the best source of materials, researchers should consider the material, its environment, and its condition. Material information includes fabrication information such as manufacturer, composition, and dimensions as well as information related to installation or construction, such as welding processes and parameters. Environmental information includes temperature, humidity, fluence, flux, stress (service, residual, installation), and coolant chemistry. Component condition information includes inspection history, such as identified flaws or degradation.

Discussion Summary

The discussion in Session 5 focused on the best practical approach to plan future harvesting programs. There was clear agreement that this approach must begin with identifying the data needs best addressed by harvesting, whether from operating or decommissioning plants. Once a specific need is identified, the next step is to find a source to acquire the materials of interest as well as other organizations interested in participating in the harvesting effort.

Key Takeaways from Workshop

Session 1. Motivation for Harvesting

The clear takeaway from the discussion in Session 1 was that harvesting requires significant resources to be done successfully; therefore it is paramount to identify how the planned harvesting will clearly address a significant need to ensure the harvesting project provides strong value. In the context of the need for data, EPRI suggested that the goal of harvesting to support research for operation out to 80 years should not be a comprehensive understanding of all aspects of degradation, but rather a snapshot to confirm other lab results and models. This is an important point for all organizations and researchers to keep in mind before investing significant resources in harvesting.

Session 2. Technical Data Needs for Harvesting

The criteria proposed by PNNL are a good starting point for prioritizing issues to address by harvesting. Three additional important criteria would be:

- Fleet-wide vs. plant-specific applicability of data,
- Ease of harvesting (in terms of cost and project risk), and
- Timeliness of the expected research results relative to the objective.

Once a potential harvesting project has reached the point of looking at different sources of materials, the availability of material pedigree information, such as composition, processing, environmental conditions (temperature, humidity, fluence, etc.) is very important to the overall value of harvesting from that particular plant.

Based on the presentations and discussion in Session 2, there appeared to be two areas where participants had broad interest in pursuing further harvesting: high fluence reactor internals and irradiated concrete. The common drivers for the interest in these issues is a lack of representative data at the fluences of interest and significant challenges with acquiring representative data through other means. High fluence reactor internals have been addressed somewhat by ZIRP, but stainless steel materials exposed to higher fluence levels at higher temperatures, where void swelling may become significant, could help validate DOE and EPRI models and provide further technical basis for PWR internals aging management. Irradiated concrete harvesting is currently being pursued from the Zorita reactor in Spain, with international collaboration and potential testing at the Halden Reactor Project.

Other areas with some, but less widespread, interest expressed from workshop participants for new harvesting efforts included RPV materials and electrical cables and components. SCK-CEN and NRC expressed interest in RPV harvesting, and NRC expressed interest in electrical component harvesting.

Session 3. Sources of Materials

To capture the key takeaways from Session 3 focused on sources of materials, two tables of potential sources of materials are presented below. Table 1 covers recent or ongoing harvesting programs, while Table 2 details potential future harvesting opportunities.

Table 1 Ongoing Harvesting Programs

Country	Plant	Design	Size (MWe)	Years in operation	Components	Organization(s)
Canada	NPD	CANDU	20	25	Concrete	AECL
	Gentilly-2	CANDU-6	675	29	Cables	
Japan	Hamaoka 1	BWR-4	540	33	RPV, concrete	CRIEPI, Chubu
Spain	Zorita	W 1-loop	160	37	Internals, concrete	EPRI, NRC
Sweden	Barseback	ABB-II	615	28	RPV	Vattenfall
U.S.	Zion ½	W – 4 loop	1040	24/25	RPV, cables, neutron absorbers	DOE, EPRI, NRC
	Crystal River 3	B&W	860	36	Cables	EPRI
	(b)(4)					

Table 2 Potential Future Sources for Harvesting

Country	Plant	Design	Size (MWe)	Years in operation	Potential Components	Notes
Canada	NRU	Test reactor	135 MWt	61	TBD	AECL; SD: 2018
Germany	Numerous plants either in decommissioning or shutting down soon. See Appendix III.					
Japan	Mihama	W 2-loop	320	40	Concrete	Kansai, Westinghouse
Korea	Kori 1	W 2-loop	576	40	RPV, internals, SGs, pressurizer, welds, CASS,	KHNP, EPRI
Sweden	Ringhals 1	BWR	883	44	RPV, internals SGs, pressurizer, concrete	Vattenfall; SD: 2020 / 2019
	Ringhals 2	W 3-loop	900	44		
U.S.	Kewaunee	W 2-loop	566	39	TBD	SD: 2013
	SONGS 2/3	CE 2-loop	1070	31/30	TBD	SD: 2013
	Crystal River 3	B&W	860	36	TBD	SD: 2013
	Vermont Yankee	BWR-4/Mk-1	605	42	TBD	SD: 2015
	Fort Calhoun	CE 2-loop	482	43	TBD	SD: 2016
	Palisades	CE 2-loop	805	47	TBD	SD: 2018
	Pilgrim	BWR-3/Mk-1	677	47	TBD	SD: 2019
	Oyster Creek	BWR-2/Mk-1	619	50	TBD	SD: 2019

	Indian Point 2/3	W 4-loop	1020 / 1040	48/46	TBD	SD: 2021
	Diablo Canyon ½	W 4-loop	1138 / 1118	40	TBD	SD: 2024-5
	Advanced Test Reactor	Test reactor	250 MWt	50	Core internals	Non-commercial; internals replaced every 10 years

In addition to the potential sources of materials presented and discussed in Session 3, another takeaway was the suggestion of developing a database for previously harvested materials or those available for future harvesting. The NSUF sample library may be a good starting point for such a database, with appropriate modifications for the purposes of harvesting efforts.

Session 4. Harvesting Experience: Lessons Learned and Practical Aspects

There were several important takeaways from Session 4 that were touched on in multiple presentations and the following discussions. One key takeaway is that researchers should identify a clear purpose and scope for harvesting. Having a clear purpose for harvesting helps to guide later decisions that must be made to adjust course when the inevitable changes in schedule or unexpected realities at the plant arise. A related note is that harvesting is not the top priority for decommissioning. Therefore, researchers must have clear objectives and scope for harvesting that can be communicated to the site. This understanding should shape assumptions and interactions with the plant owner or decommissioning company as well as planning for costs and schedule.

Another takeaway was the value of strong site coordination, including site visits. Multiple presenters touched on the value of being on-site to talk to staff and see the components to be harvested. Mockups and 3-D simulations can be valuable to ensure success of the approach or technique used to acquire the specimen. A related point is working with reactor operators at the plant. Several harvesting efforts worked with former reactor operators and benefited greatly from their experience to find records or determine the best method to harvest the desired component. This is a valuable insight that could be effective in future harvesting efforts.

A third key takeaway is early engagement with the plant personnel to express interest in harvesting. This serves to make the plant aware of interest in harvesting and get their support to work with the harvesting process. The other important benefit of early engagement is to gain as much information as possible about the available materials and components, including the associated records and material pedigree information.

Session 5. Future Harvesting Program Planning

The key takeaway in Session 5 was to gather as much information as possible in advance of committing to a specific harvesting project. Ideally, there would be a strong understanding that the material and its aging conditions clearly align with an identified technical data need before committing significant resources to a harvesting effort.

Action Items and Next Steps

The following is a summary of the action items discussed at the end of the workshop:

1. Sharing workshop slides
    - NRC emailed attendees to ask their comfort with sharing their workshop slides with other organizations and received no objection from any presenters.
    - The presentations can be accessed here: https://drive.google.com/open?id=0B5DWMLch5YSXcnpZZ0JOS055QUU .

Commented [FI3]: As commented above, should the slides be included in this report under new appendix?

I will leave out for now and see if there is broader interest. If we do 2 slides per page, that would a >100 page appendix, which is not ideal to me.

2. EPRI indicated that MRP-320 (Product ID: 1022866) on knowledge gaps for irradiated austenitic stainless steel for potential harvesting from MRP-227 inspections is publicly available for a fee.

3. Cable surveillance programs in Germany
    - GRS to inquire with cable colleagues and share any insights.

4. Sources of materials database
    - Potential sources of materials presented in this workshop are summarized in Session 3 summary above and Appendix III below.
    - NRC will be reaching out to PNNL, INL NSUF, CNSC, AECL, and any other organizations interested in database development.

5. Prioritized data needs
    - Suggestion to continue discussions on prioritized data needs within technical areas (RPV, internals, electrical, concrete) through existing coordination groups if possible
        - Focus on identifying specific material / aging conditions of interest and purpose / intended outcome of harvesting
    - Idea to survey participants at the Environmental Degradation conference
        - John Jackson (INL) is on planning committee

6. EPRI report on spent fuel liner boric acid transport through concrete
    - NRC will contact EPRI for report if needed.

7. Harvested Materials Research Results
    - Section of workshop summary report (below) devoted to references from harvested materials research.

References to Previous Harvested Materials Research

This section of the workshop summary addresses a question that was raised during the discussion at the workshop regarding what the outcome or benefit of past harvesting efforts have been. Below is a list of references to research results generated from testing of harvested materials:

1. J.R. Hawthorne and A.L. Hiser, *Experimental Assessments of Gundremmingen RPV Archive Material for Fluence Rate Effects Studies*, NUREG/CR-5201 (MEA-2286), U.S. Nuclear Regulatory Commission, October 1988.

2. O.K. Chopra, and W.J. Shack, *Mechanical Properties of Thermally Aged Cast Stainless Steels from Shippingport Reactor Components,* NUREG/CR-6275 (ANL-94/37), U.S. Nuclear Regulatory Commission, April 1995.

3. G. J. Schuster, S. R. Doctor, S.L. Crawford, and A. F. Pardini, *Characterization of Flaws in U.S. Reactor Pressure Vessels: Density and Distribution of Flaw Indications in the Shoreham Vessel*, NUREG/CR-6471 Volume 3, U.S. Nuclear Regulatory Commission, November 1999.

4. G. J. Schuster, S. R. Doctor, A.F. Pardini, and S.L. Crawford, *Characterization of Flaws in U.S. Reactor Pressure Vessels: Validation of Flaw Density and Distribution in the Weld Metal of the PVRUF Vessel*, NUREG/CR-6471 Volume 2, U.S. Nuclear Regulatory Commission, August 2000.

5. D.E. McCabe, et al. *Evaluation of WF-70 Weld Metal From the Midland Unit 1 Reactor Vessel*, NUREG/CR-5736 (ORNL/TM-13748), U.S. Nuclear Regulatory Commission, November 2000.

6. B. Alexandreanu, O.K. Chopra, and W.J. Shack, *Crack Growth Rates in a PWR Environment of Nickel Alloys from the Davis-Besse and V.C. Summer Power Plants,* NUREG/CR-6921 (ANL-05/55), U.S. Nuclear Regulatory Commission, November 2006.

7. S.E. Cumblidge, et al. *Nondestructive and Destructive Examination Studies on Removed-from-Service Control Rod Drive Mechanism Penetrations*, NUREG/CR-6996, U.S. Nuclear Regulatory Commission, July 2009.

8. S.E. Cumblidge, et al. *Evaluation of Ultrasonic Time-of-Flight Diffraction Data for Selected Control Rod Drive Nozzles from Davis Besse Nuclear Power Plant*, PNNL-19362, Pacific Northwest National Laboratory, April 2011.

9. S.L. Crawford, et al. *Ultrasonic Phased Array Assessment of the Interference Fit and Leak Path of the North Anna Unit 2 Control Rod Drive Mechanism Nozzle 63 with Destructive Validation*, NUREG/CR-7142 (PNNL-21547), U.S. Nuclear Regulatory Commission, August 2012.

Appendix I Workshop Participants

	Name	Organization	Email
Japan	Taku Arai	CRIEPI	arait@criepi.denken.or.jp
	Sadao Higuchi	CRIEPI	higuchi@criepi.denken.or.jp
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	Mita Sircar	NRC	Madhumita.Sircar@nrc.gov
	Tom Koshy	NRC	Thomas.Koshy@nrc.gov
	Jeff Poehler	NRC	Jeffrey.Poehler@nrc.gov
	Allen Hiser	NRC	Allen.Hiser@nrc.gov
	Angela Buford	NRC	Angela.Buford@nrc.gov
	Mark Kirk	NRC	Mark.Kirk@nrc.gov
	Amy Hull	NRC	Amy.Hull@nrc.gov
	Pete Ricardella	NRC/ACRS	Priccardella@Structint.com

Appendix II Workshop Agenda

Tuesday, March 7

Session	Time	Organization	Speaker	Presentation Title
Intro	8:00	NRC	Michael Weber Robert Tregoning	Welcome and Introduction to Workshop
1	8:15 – 8:45	DOE	Rich Reister	DOE Perspectives on Material Harvesting
		EPRI	Sherry Bernhoft	EPRI Perspective on Harvesting Projects
		NRC	Robert Tregoning	NRC Perspective on Motivation for Harvesting
		GRS	Uwe Jendrich	Role of GRS in Decommissioning and LTO
		CRIEPI	Taku Arai	CRIEPI Motivations for Harvested Material
	8:45 – 9:45	DISCUSSION		
9:45-10:00		**BREAK**		
2	10:00 – 10:20	PNNL (for NRC)	Pradeep Ramuhalli	Data Needs Best Addressed By Harvesting
	10:20 – 10:30	NRC	Matthew Hiser	High-Priority Data Needs for Harvesting
	10:30 – 10:55	DOE	Keith Leonard	LWRS Program Perspective on the Technical Needs for Harvesting
	10:55 – 11:20	SCK-CEN	Rachid Chaouadi	Review of past RPV sampling test programs and perspective for long term operation
	11:20 – 11:45	Westinghouse	Arzu Alpan	Importance of Harvesting to Evaluate Radiation Effects on Concrete Properties
	11:45 – 12:30	DISCUSSION		
12:30 – 2:00		**LUNCH**		
3	2:00 – 2:10	NRC	Matthew Hiser	Sources of Materials: Past NRC Harvesting and U.S. Decommissioning Plants
	2:10 – 2:35	EPRI	Al Ahluwalia	Harvesting Plans for Materials Aging Degradation Research in Korea and Sweden
	2:35 – 2:50	DOE/ORNL	Tom Rosseel	Materials Harvested by the LWRS Program
	2:50 – 3:00	DOE/INL	John Jackson	NSUF Material Sample Library
	3:00 – 3:15	Energy Solutions	Gerry van Noordennen	Zion Material Harvesting Program
	3:15 – 3:30	Westinghouse	Arzu Alpan	Potential Harvesting of Concrete from Mihama Unit 1
	3:30 – 3:45	**BREAK**		
	3:45 – 4:00	GRS	Uwe Jendrich	Plants in Decommissioning in Germany
	4:00 – 4:15	CNSC	Daniel Tello	Evaluating Structures, Systems & Components from Decommissioned/Decommissioning Nuclear Facilities in Canada
	4:15 – 5:00	DISCUSSION		

Wednesday, March 8

Session	Time	Organization	Speaker	Presentation Title
4	8:00 – 8:30	EPRI	Jean Smith	Lessons Learned: Harvesting and Shipping of Zorita Materials
	8:30 – 9:00	DOE	Tom Rosseel	LWRS Program: Harvesting Lessons Learned
	9:00 – 9:30	NRC	Matthew Hiser	NRC Perspective on Harvesting Experience and Lessons Learned
	9:30 – 10:00	CRIEPI	Taku Arai	CRIEPI Research Activities with Harvested Materials
	10:00 – 10:15	**BREAK**		
	10:15 - 10:45	Energy Solutions	Gerry van Noordennen	Zion Harvesting Experience and Lessons Learned
	10:45 - 11:15	Dominion	Bill Zipp	Kewaunee Insights on Material Harvesting
	11:15 – 12:00	DISCUSSION		
12:00 – 1:30		**LUNCH**		
5	1:30 – 1:45	PNNL (for NRC)	Pradeep Ramuhalli	Technical Information Needed for Informed Harvesting Decisions
	1:45 – 2:30	DISCUSSION		
	2:30 – 3:00	Action Items and Next Steps		
	3:00 – 4:00	EPRI	Sherry Bernhoft	Closing Thoughts
		DOE	Rich Reister	
		NRC	Robert Tregoning	
		ALL		

Appendix III Harvesting Opportunities in Germany

- Past and current decommissioning projects of **Prototype or Commercial Reactors**

Name	Abbrev.	Reactor type	Power MW_e	Decom. started	Strategy
Rheinsberg	KKR	WWER	70	1995	UC
Compact Natrium Cooled Reactor	KKN	SNR	21	1993	UC
Multipurpose Research R.	MZFR	PWR/D_2O	57	1987	UC
Obrigheim	KWO	PWR	357	2008	UC
Neckarwestheim 1	GKN-1	PWR	840	2017	UC
Isar-1	KKI-1	BWR	912	2017	UC
Gundremmingen-A	KRB-A	BWR	250	1983	RCA KRB-II
Greifswald 1-5	KGR 1-5	WWER	440	1995	UC
Lingen	KWL	BWR	268	1985	UC after SE

UC: unconditional clearance
RCA: radiation controlled area, new license
SE: safe enclosure

NRC Harvesting Workshop, Rockville, March 2017, Decommissioning in Germany 4

- Past and current decommissioning projects of **Prototype or Commercial Reactors**

Name	Abbrev.	Reactor type	Power MW_e	Decom. started	Strategy
Stade	KKS	PWR	672	2005	UC
Research Reactor Jülich	AVR	HTR	15	1994	UC
Thorium High-Temperature-Reaktor	THTR-300	HTR	308	1993	SE since 1997
Würgassen	KWW	BWR	670	1997	UC
Mülheim-Kärlich	KMK	PWR	1302	2004	UC
Hot-Steam Reactor Grosswelzheim	HDR	HDR	25	1983	UC since 1998
Niederaichbach	KKN	DRR/D_2O	106	1975	UC since 1994
Test-Reactor Kahl	VAK	BWR	16	1988	UC since 2010

- **Shut down** Commercial Reactors
  - **that have no decommissioning license granted yet**

Name	Abbrev.	Reactor type	Power MW_e	Date of application
Philippsburg-1	KKP-1	BWR	926	2013 / 2014
Grafenrheinfeld	KKG	PWR	1345	2014
Biblis-A	KWB-A	PWR	1225	2012
Biblis-B	KWB-B	PWR	1300	2012
Unterweser	KKU	BWR	1410	2012 / 2013
Brunsbüttel	KKB	BWR	806	2012 / 2014
Krümmel	KKK	BWR	1402	2015

- Commercial Reactors **in operation**

Name	Abbrev.	Reactor type	Power MW_e	Anticipated date of final shutdown
Gundremmingen-B	KRB-II-B	BWR	1344	31.12.2017
Philippsburg-2	KKP-2	PWR	1468	31.12.2019
Gundremmingen-C	KRB-II-C	BWR	1344	31.12.2021
Grohnde	KWG	PWR	1430	31.12.2021
Brokdorf	KBR	PWR	1480	31.12.2021
Emsland	KKE	PWR	1406	31.12.2022
Isar-2	KKI-2	PWR	1485	31.12.2022
Neckarwestheim-2	GKN-2	PWR	1400	31.12.2022

Note to requester: The attachment is immediately following this email.

From: Purtscher, Patrick
Sent: Fri, 19 May 2017 15:57:20 -0400
To: Hiser, Matthew
Subject: RE: Workshop Summary Report
Attachments: Harvesting Workshop Summary Report draft 5-16-17 PTP comments.docx

My most significant issue was with the Key takeaway section. I think it would be better to move much of it to the original discussion of each session.

Pat

From: Hiser, Matthew
Sent: Tuesday, May 16, 2017 10:43 AM
To: Purtscher, Patrick <Patrick.Purtscher@nrc.gov>; Tregoning, Robert <Robert.Tregoning@nrc.gov>; Ramuhalli, Pradeep (Pradeep.Ramuhalli@pnnl.gov) <Pradeep.Ramuhalli@pnnl.gov>
Subject: RE: Workshop Summary Report

Sending the latest version with a few references to past research on harvested materials…

Matthew Hiser
Materials Engineer
US Nuclear Regulatory Commission | Office of Nuclear Regulatory Research
Division of Engineering | Corrosion and Metallurgy Branch
Phone: 301-415-2454 | Office: TWFN 10D62
Matthew.Hiser@nrc.gov

From: Hiser, Matthew
Sent: Friday, May 12, 2017 5:24 PM
To: Purtscher, Patrick <Patrick.Purtscher@nrc.gov>; Tregoning, Robert <Robert.Tregoning@nrc.gov>; Ramuhalli, Pradeep (Pradeep.Ramuhalli@pnnl.gov) <Pradeep.Ramuhalli@pnnl.gov>
Subject: Workshop Summary Report

Hi Pat, Rob, and Pradeep,

I'd like to share with you a largely complete initial draft of the harvesting workshop summary report. I tried to capture the important points of the presentations and discussion at the workshop and then synthesize that down to "key takeaways" (I am open to a better term, but that's what I came up with). I still need to fill in the section on "References to Past Harvested Materials Research", but otherwise consider this a complete draft.

Please feel free to review and comment the overall organization, level of detail, etc. You can also review the specific wording with edits and tracked changes if you'd like, although I'd suggest not spending too much effort down in the weeds at this point.

My hope is to get some feedback in the next 2 weeks from this group and then share with the broader group of workshop attendees by the end of May for their review and input with a target to finalize this report by the end of June.

Thanks and please let me know if you have any questions!

Matt

Harvesting Workshop Summary Report

Background

On March 7-8, 2017, the Office of Nuclear Regulatory Research of the United States Nuclear Regulatory Commission (NRC) hosted a 2-day workshop on the topic of “Ex-Plant Materials Harvesting.” NRC staff worked in close coordination with staff from the U.S. Department of Energy (DOE) and the Electric Power Research Institute (EPRI) to plan and arrange the workshop.

The decision to organize this workshop was driven by developments in the U.S. and global nuclear industry. In the U.S., there is strong interest in extending plant lifespans through subsequent license renewal (SLR) from 60 to 80 years. Extended plant operation and SLR raise a number of technical issues that may require further research to understand aging mechanisms, which may benefit from harvesting. Meanwhile, in recent years, a number of nuclear plants, both in the U.S. and internationally, have shut down or announced plans to shut down. Unlike in the past when there were very few plants shutting down, these new developments provide opportunities for harvesting components that were aged in representative light water reactor (LWR) environments. In a related development, economic challenges for the nuclear industry and limited government spending have limited the resources available to support new research, including harvesting programs. Given this constrained budget environment, aligning interests and leveraging with other organizations is important to allow maximum benefit and value for future research programs.

Objective and Approach

The objective of the workshop was to generate open discussion of all aspects of ex-plant materials harvesting, including:

1. Deciding whether to harvest,
2. Planning and implementing a harvesting program,
3. Using the harvested materials in research programs.

Through presentations and open discussion, the workshop was organized to allow for all participants to be better informed of the benefits and challenges of harvesting as well as to identify potential areas of common interest for future harvesting programs. Workshop sessions were aligned in broad topics to cover all aspects of harvesting, but allow for participants to drive the discussion.

To help accomplish the workshop objectives, the workshop organizers intentionally sought a diverse group of participants. There are a large number of decommissioning plants and interested researchers outside the U.S., so the organizers focused on outreach to international participants through connections such as IAEA, OECD/NEA, and existing professional contacts. In addition, a key goal for this workshop was to capture the broader practical perspective from plant owners and decommissioning companies, which are vital to any successful harvesting program, but may sometimes be overlooked in researcher-driven discussions. Workshop participants were also diverse in terms of technical area of focus, with metal components such as the reactor pressure vessel (RPV) and internals being discussed along with concrete and electrical components. The final list of workshop participants can be found at the end of this report in Appendix I.

Workshop Organization and Sessions

The workshop was held at NRC headquarters in Rockville, MD. Due to limited space in the meeting room and the need for a limited group size for discussion, a webinar was used to allow remote observers to benefit from the workshop. Workshop sessions were organized topically with about half the time dedicated to presentations and the remaining time set aside for discussion. Presentations were solicited from participants to cover a range of perspectives and technical areas. The final workshop agenda can be found at the end of this summary report in Appendix II.

The workshop was organized into five sessions as follows:

- Session 1 Motivation for Harvesting
- Session 2 Technical Data Needs for Harvesting
- Session 3 Sources of Materials
- Session 4 Harvesting Experience: Lessons Learned and Practical Aspects
- Session 5 Future Harvesting Program Planning

Summary of Workshop Discussion

The subsections below will summarize the presentations and discussion in each session and highlight the key takeaways from the session.

Session 1 Motivation for Harvesting

Session 1 focused on the motivation for harvesting and why workshop participants are interested in harvesting. Presentations were provided in this session by:

- Richard Reister from DOE,
- Sherry Bernhoft from EPRI,
- Robert Tregoning from NRC,
- Uwe Jendrich from the Gesellschaft für Anlagen- und Reaktorsicherheit (GRS) in Germany, and
- Taku Arai from the Central Research Institute of the Electric Power Industry (CRIEPI) in Japan.

<u>Presentation Summaries</u>

DOE described the role of harvesting within the Light Water Reactor Sustainability (LWRS) Program, including the benefits and challenges associated with harvesting. Benefits include the opportunity to fill knowledge gaps where there is limited data or experience and to inform degradation models with data from actual plant components. Challenges include cost, complexity, scheduling, logistics, limited opportunities, acquiring sufficient material pedigree information, and potential negative results impacting operating plants.

EPRI discussed the role of harvesting within the context of aging management for Long-Term Operations (LTO), including their experience from past harvesting programs and criteria for future harvesting. Their experience emphasized the challenges of cost, schedule, logistics, complicated contracting and acquiring material pedigree information. EPRI's criteria for harvesting include value to their members that addresses a prioritized need and knowledge gap that cannot be otherwise filled through other means.

For EPRI, a well-developed project plan that covers funding, risk management, exit ramps, and clear roles and responsibilities is essential.

NRC shared its perspective on the benefits and challenges of harvesting in regulatory research. Harvested materials are valuable due to the representative nature of their aging conditions, which may reduce the uncertainty associated with the applicability of the results to operating plants compared to tests with alternative aging conditions. Harvested materials may be the best option to address technical data needs identified for extended plant operation. Increasing harvesting opportunities from decommissioning plants suggests a proactive approach to harvesting planning may optimize benefits by identifying the appropriate material with the aging conditions of interest for the identified knowledge gap. There are significant challenges associated with harvesting, including cost, schedule, and logistics, but hopefully these can be mitigated or avoided by leveraging with other organizations and learning from past experience.

GRS described its role as the main technical support organization in nuclear safety for the German federal government. GRS provides technical assessment and knowledge transfer for decommissioning activities, aging management, and long-term operation for German federal and international organizations.

CRIEPI discussed its view of how harvested materials and laboratory prepared materials contribute to addressing technical issues. Harvested materials provide exposure to actual plant conditions, but are more limited in availability and the size of the data set that can be generated. Laboratory prepared materials general involve accelerated or simulated aging conditions, but can be used to produce larger data sets and varying parameters can allow understanding of the effect on the mechanism or property of interest. Harvested materials offer fact finding of actual plant conditions as well as confirmation and verification of results from laboratory prepared specimens.

Discussion Summary

The discussion following the presentations in this session focused on clearly identifying the need to be addressed by a harvesting project and the myriad cost, schedule, and logistical challenges associated with harvesting. Leveraging with other organizations to defray costs can also help improve the value of a given program, but also adds complexity as another organization may have a different set of priorities that changes the focus of the harvesting effort.

Session 2 Technical Data Needs for Harvesting

Session 2 focused on discussing the technical data needs for harvesting and what specific knowledge gaps organizations are interested in addressing through harvesting. This discussion included general perspectives on how to determine when harvesting should be pursued rather than other types of research. Presentations were provided in this session by:

- Pradeep Ramuhalli from the Pacific Northwest National Lab (PNNL),
- Matthew Hiser from NRC,
- Keith Leonard from Oak Ridge National Laboratory (ORNL),
- Rachid Chaouadi from SCK-CEN in Belgium, and
- Arzu Alpan from Westinghouse.

Presentation Summaries

PNNL presented their work, under a small NRC contract, to develop a systematic approach to prioritize data needs for harvesting. PNNL proposed five primary criteria for prioritizing harvesting:

- Unique field aspects of degradation
  - For example, unusual operating experience or legacy materials (composition, etc.) that be no longer available
- Ease of laboratory replication of environment-material combination
  - For example, simultaneous thermal and irradiation conditions may be difficult to replicate or mechanism sensitive to dose rate may not be good for accelerated aging
- Applicability of harvested material for addressing critical gaps
  - Prioritize harvesting for critical gaps over less essential data needs
- Availability of reliable in-service inspection (ISI) techniques for the material / component
  - If inspection methods are mature and easy to apply to monitor and track degradation, perhaps the effort of research with harvested materials is not needed.
- Availability of material for harvesting
  - The necessary materials / components must be available to be harvested.

PNNL then presented their application of these criteria to four materials degradation issues as an example: electrical cables, cast austenitic stainless steel (CASS), reactor vessel internals, and dissimilar metal welds. Based on applying these criteria to the examples, PNNL concludes that electrical cables, CASS, and reactor internals are all higher priority for harvesting due to unique aspects of the degradation that are challenging to replicate in the lab. Meanwhile, dissimilar metal welds are of low priority due to the ease of replication in lab aging studies as well as the significant body of knowledge and research on the phenomena.

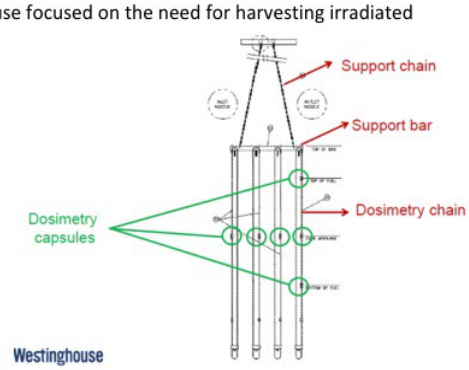
NRC presented a summary of data needs it is interested in pursuing through harvesting. These included RPV materials to validate fluence and attenuation models and to demonstrate the conservatism of regulatory approaches for transition temperature prediction. Other metal components of interest for harvesting would address data gaps in irradiated stainless steels, as well as improve understanding of inspection capabilities and fatigue life calculations. Electrical components of interest include low and medium voltage cables and other electrical components for degradation studies, and electrical enclosures and cables for fire research. Concrete components of interest include irradiated concrete, concrete undergoing alkali-aggregate reactions, post-tensioned structures, reinforcing steel, tendons, and spent fuel pool concrete to assess potential boric acid attack.

DOE/ORNL presented their perspective on data needs for harvesting and its role in providing validation of experimental and theoretical research. DOE performed a significant reactor pressure vessel (RPV) harvesting program at the Zion nuclear power plant to reduce uncertainties in the Master Curve methodology, validate modeling predictions and study flux and fluence attenuation effects. The harvesting is largely complete, but the testing program is currently underway. DOE also indicated interest in using harvested materials to validate its models for swelling and microstructural changes of stainless steel internals under LWR irradiation conditions. Harvesting concrete components would be of interest due to lack of literature data and the multiple dependent variables that may affect concrete

performance. Finally, DOE has been involved in harvesting cables from the Crystal River and Zion plants to address cable aging as a function of material composition and environment.

SCK-CEN presented their interest in a international cooperative program to harvest reactor pressure vessel (RPV) materials. SCK-CEN presented their survey of the literature for past testing programs of harvested RPV materials, and the limitations of these past program. Key limitations include a lack of archive materials, generally lower temperatures, and poor surveillance programs and dosimetry. SCK-CEN then shared some thoughts on their criteria for a new harvesting efforts, including higher fluence levels and temperatures, available archive materials and reliable information on operating history, dosimetry and surveillance program. Other topics relevant to a new RPV harvesting effort include technical issues such as material variability and irradiation conditions as well as logistical and financial considerations.

The final presentation in Session 2 by Westinghouse focused on the need for harvesting irradiated concrete to better understand the threshold radiation level for significant strength reduction. Westinghouse has installed ex-vessel neutron dosimetry (EVND) at a number of plants in the world and proposed to use these dosimetry measurements to validate fluence model calculations to better understand the uncertainty in these calculations. If concrete can be harvested at one of these plants with EVND data, then irradiated concrete properties from testing can be paired with fluence data to improve research benefits.



Discussion Summary

The discussion following Session 2 presentations touched on a number of topics. EPRI shared that they developed a report related to the topics of session 2, but more narrowly focused on PWR internals. MRP-320, “Testing Gap Assessment and Material Identification for PWR Internals,” focuses on prioritizing opportunistic harvesting of stainless steel reactor internals components that may be removed from service following MRP-227 inspections. The methodology and approach in this report may be relevant to the broader harvesting data needs discussion. This report is not publicly available, but is available to EPRI member utilities.

Workshop participants discussed the criteria proposed by PNNL in the first presentation. One additional criteria suggested by EPRI was to consider fleet-wide vs. plant-specific applicability. More broadly applicable materials would be of greater interest for harvesting than those that represent conditions at only a few plants. Another criteria suggested is the availability of material pedigree information, such as composition, processing, environmental conditions (temperature, humidity, fluence, etc.). Another suggested criteria was the ease of harvesting. For example, highly irradiated internals are probably much more difficult and expensive to harvest than electrical cables or unirradiated concrete. This discussion would capture the idea of weighing costs vs. benefits as well as project risk. Further discussion touched on the idea that different organizations may prioritize the various criteria differently, but all will probably at least want to consider the same set of criteria.

Another key theme from this discussion was that a successful program should be guided by a clearly defined objective or problem statement to be addressed. This objective should be well-understood at the initiation of a program and used to guide decision-making through implementation of a harvesting project. This also raises a related point or potential criteria: the timeliness of the expected research results relative to the objective. If the results are needed in the next two years, but a harvesting project will not provide results for at least five years, that should be a strong consideration.

Session 3 Sources of Materials

Session 3 focused on discussing sources of materials for harvesting. This discussion covered previously harvested materials as well as sources for new harvesting programs from operating or decommissioning plants. Both domestic and international sources of materials were discussed in this session.

Presentations were provided in this session by:

- Matthew Hiser from NRC,
- Al Ahluwalia from EPRI,
- Tom Rosseel from DOE/ORNL,
- John Jackson from DOE/Idaho National Laboratory (INL),
- Gerry van Noordennen from EnergySolutions,
- Arzu Alpan from Westinghouse,
- Uwe Jendrich from GRS, and
- Daniel Tello from the Canadian Nuclear Safety Commission (CNSC).

Presentation Summaries

NRC presented their perspective on sources of materials for harvesting. First, NRC shared some of the harvested materials from past research programs that may be available, including irradiated stainless steel internals, RPV materials, nickel alloy welds, neutron absorber material, and electrical components. NRC then summarized the recently and planned shutdown U.S. plants, including their design, thermal output, and years of operation, to provide participants with an idea of the potential sources from decommissioning U.S. plants. Finally, NRC shared a list of information that would be helpful to acquire from decommissioning plants to determine the value of components for harvesting. This information included plant design information (component location and dimensions), environmental conditions (temperature, fluence, humidity, stress, etc.) and operating history, material pedigree information (fabrication records), and inspection records (for interest in components with known flaws).

The next presentation from EPRI covered harvesting opportunities at decommissioning plants in Korea and Sweden. In Korea, Kori-1 is a Westinghouse 2-loop PWR (sister plant is Kewaunee) that will shut down in 2017 after 40 years of operation. Korea Hydro and Nuclear Power Central Research Institute (KHNP-CRI) is planning a comprehensive research program on long-term materials aging based on harvesting from Kori-1 and is seeking international participation in the harvesting effort. KHNP-CRI's plan is focused on metallic components, including RPV, internals, primary system components, steam generator materials. Harvesting is expected to occur in 2024 with testing to follow through 2030.

In Sweden, Vattenfall is currently harvesting in 2017-2018 RPV material from the decommissioning Barseback BWR units. This work is focused on irradiation embrittlement, including comparison of

surveillance data to actual RPV properties, as well as thermal aging embrittlement. In the future, Vattenfall will be shutting down Ringhals 1 and 2 in 2020 and 2019, respectively. Ringhals 1 is a BWR and Ringhals 2 is a Westinghouse 3-loop PWR design. Of particular note, Ringhals 2 has the second oldest replaced Alloy 690 RPV head and steam generators. Other harvesting opportunities at Ringhals include RPV material with a significant surveillance program, thermal aging effects on low alloy steel from the pressurizer, as well as concrete structures. Vattenfall is open to working with partners that are interested in joining them for harvesting at Ringhals.

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The next presentation by DOE/ORNL focused on several harvesting programs that DOE's LWRS program has been involved with. DOE has led the harvesting of components from the Zion [redacted] plant [redacted] in the U.S. From Zion, DOE has harvested electrical cables and components, a large RPV section, and a significant amount of records to provide information on material fabrication, in-service inspection and operating history. Cables from Zion include CRDM, thermocouple, and low and medium voltage cables. DOE indicated some thermocouple cables from Zion may be available for other researchers to use in collaborative studies.

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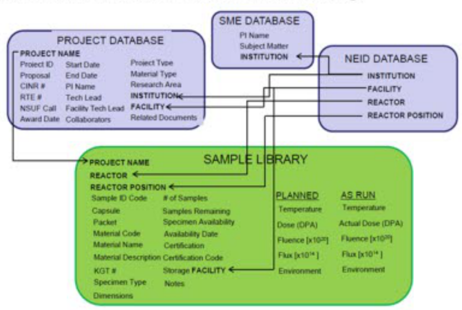
(b)(4) [redacted]

(b)(4) [redacted] DOE is also participating in efforts to harvest cables from Crystal River (led by EPRI) and concrete from the Zorita plant in Spain (led by NRC).

The next presentation by DOE/INL described INL's Nuclear Science User Facilities (NSUF) and the Nuclear Fuels and Materials Library (NFML). NSUF is coordinated by INL and facilitates access to nuclear research facilities around the world, including neutron and ion irradiations, beamlines, hot cell testing, characterization and computing capabilities. NFML is a Web-based searchable database sample library that captures the information from thousands of specimens available to NSUF. NFML is designed to maximize the benefit of previously irradiated materials for future research. Researchers can propose new research projects under NSUF using specimens in NFML using DOE funding. The information captured in NFML aligns well with the goal of this session to potentially develop a database of previously harvested materials.



The next presentation by EnergySolutions offered a more practical perspective on considering sources of materials for harvesting. From the plant owner perspective, in the decommissioning process there is not a financial incentive to support harvesting, therefore researchers need to absorb costs for harvesting and have a clear scope for harvesting. Flexibility in funding for harvesting activities is essential as the decommissioning process and schedule may change quickly.

EnergySolutions provided valuable perspective on the timing in the decommissioning proves for harvesting different components. Harvesting RPV surveillance coupons should take place when the RPV internals are cut and removed. Harvesting RPV materials is only possible from larger RPVs, as smaller RPVs are shipped intact to the disposal facility, rather than cut into pieces. Spent fuel rack neutron absorber coupons must be harvested either before or after dry storage campaign to remove spent fuel from spent fuel pool. Harvesting actual spent fuel rack neutron absorber material must come after pool is completely empty. Electrical cables and other components from mild environments may be harvested at any time (once temporary power is established and plant power is shut off), while electrical components from high rad environments will depend on timing of source term removal schedule. Concrete cores are best harvested when other cores are being taken for site characterization to develop the License Termination Plan. Highly irradiated concrete from biological shield wall would need to come later in decommissioning after RPV is removed.

In terms of upcoming decommissioning plants, EnergySolutions indicated that San Onofre and Vermont Yankee will be entering DECON is 2018 and 2019, respectively. Kewaunee, Crystal River, and Fort Calhoun also may enter DECON in next 2 years. If researchers are interested in harvesting from any of these plants, they should be reaching out to plant owners immediately to begin planning and coordination.

Westinghouse followed their presentation in session 2 by describing an opportunity to harvest concrete from the Mihama 1 plant in Japan. Westinghouse installed and analyzed additional neutron dosimetry in the reactor cavity for one cycle, which were used to validate the radiation transport calculations. Mihama was shutdown in 2015 and is in contact with Westinghouse about the possibility of extracting concrete cores from the biological shield wall. Westinghouse is seeking partners interested in joining this harvesting effort.

The next presentation by GRS covered opportunities for harvesting from German plants. Regulations in Germany require plants to either immediately dismantle or dismantle after a period of safe enclosure, which is largely consistent with options in the U.S. GRS detailed the status of German commercial reactors, which are predominantly BWR and PWR designs. Seventeen reactors are currently undergoing decommissioning, while seven more are currently shutdown and await a decommissioning license. Eight reactors are still operating with scheduled shutdown dates between 2017 and 2022. German RPVs tend to have lower fluence that U.S. designs due to a larger water gap in the downcomer region. Germany has limited experience with harvesting from decommissioning plants. One question that GRS will follow-up on is the "rumored" cable surveillance programs that may be used in Germany and could provide experience and lessons learned for other countries.

The final presentation in Session 3 was by CNSC on harvesting opportunities in Canada. Atomic Energy Canada Limited (AECL) has harvested seven concrete cores from the 20 MW Nuclear Power Demonstration Plant (NPD), which shutdown in 1988 after 25 years of operation. CNSC and AECL are also considering opportunities to harvest concrete from other decommissioned reactors in Canada such as Gentilly-2, Douglas Point, and Whiteshell Reactor 1. In addition to concrete, CNSC and AECL are currently harvesting electrical cables from the 675 MWe CANDU-6 Gentilly-2 reactor, which shutdown in 2012 after 29 years of operation. The purpose of this work is to study cable degradation from thermal aging and radiation damage and validate environmental qualification of the cables. CNSC described some of the challenges with this harvesting effort, such as working with plant owners, records, accessibility and contamination of the materials and budgeting with unexpected delays in harvesting.

A future harvesting opportunity is from the National Research Universal (NRU) reactor at Chalk River, which will shut down in 2018 after operating since 1957. AECL is currently taking an inventory of irradiated materials that can be harvested from NRU in decommissioning. Potential materials for

harvesting include metals (steels, nickel alloys, zirconium, aluminum), concrete, graphite, active equipment (pumps, etc.), graphite seals, electrical cables, and thermocouples.

Discussion Summary

Following the presentations, there was some discussion of lessons from DOE's Zion harvesting effort. DOE worked with a former senior reactor operator at Zion to identify and acquire the appropriate records from Zion for the components being harvested. DOE also described their flexible approach to acquiring RPV samples by sending a large chunk of material (weighing ~90 tons) to EnergySolutions' facility in Tennessee, where smaller pieces (weighing ~500 pounds) were cut to send to ORNL. Most of the decontamination was performed at Zion, with minimal additional cleaning (as well as cladding removal) taking place at EnergySolutions' facility.

There was also discussion of acquiring materials from sources other than commercial nuclear facilities. DOE has considered harvesting concrete from other DOE nuclear facilities, but determined that there were compositional differences between the DOE facilities and commercial that would make them not useful. DOE/INL mentioned that the Advanced Test Reactor (ATR) replaces their core internals every ten years. The ATR internals are composed primarily of 347 stainless steel and achieve very high fluence levels after ten years of service.

Another key discussion topic was the possibility of developing a database for previously harvested materials or those available for future harvesting. DOE/INL indicated that their NSUF sample library may be a good starting point for such a database, although any materials in that library should be freely available for use in the research community. CNSC and NRC also expressed interested in working to develop a harvesting database.

Session 4 Harvesting Experience: Lessons Learned and Practical Aspects

Session 4 focused on lessons learned and practical aspects of harvesting. Presenters shared their experience with past harvesting programs, particularly common pitfalls to avoid and successful strategies to overcome them. Presentations also covered the practical aspects of harvesting from the plant owner and decommissioning company perspective.

Presentations were provided in this session by:

- Jean Smith from EPRI,
- Tom Rosseel from DOE/ORNL,
- Matthew Hiser from NRC,
- Taku Arai from CRIEPI,
- Gerry van Noordennen from EnergySolutions, and
- Bill Zipp from Dominion.

Presentation Summaries

EPRI presented their experience and lessons learned from past harvesting programs, particularly harvesting reactor internals and concrete from Zorita and electrical cables from Crystal River. From the Zorita reactor internals experience, EPRI emphasized that harvesting projects take significant time, encounter material retrieval and on-site challenges, and shipping issues. In terms of time, ZIRP took

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about 10 years to go from initial planning to final results, which included about 5 years of project planning, 2 years for material extraction (on-site logistics and shipping), and 3-4 years for testing. EPRI's experience was decommissioning activities were the top priority and harvesting were subject to schedule and logistical challenges based on the changing decommissioning schedule. Shipping issues were also challenging due to sending activated materials (which were classified as "waste") across international borders, from the reactor in Spain to testing facility in Sweden. Further planned shipments of the Zorita materials beyond the initial program continue to be impact by export license challenges in Sweden. More positively, EPRI emphasized that the Zorita reactor internals materials harvesting showed excellent cooperation among many organizations and are providing valuable technical information to numerous research projects.

Lessons learned from the Zorita concrete harvesting focused on the challenges with core sample drilling and handling contaminated concrete. Ultimately, an effective core drilling procedure was identified, but required some trial and error.

Lessons learned from the Crystal River cable harvesting included material concerns, the need for on-site support, and cost. In terms of material concerns, radiation and asbestos contamination created additional challenges for harvesting. On-site support and the ability to visit the site are extremely valuable to ensure clear communication, retrieval or records for material pedigree information, and awareness of on-site developments in the decommissioning process. Cable harvesting at Crystal River was more expensive than anticipated, particularly in terms of EPRI project management time to coordinate the harvesting activities and engineering support at the plant.

DOE presented lessons learned primarily from the experience harvesting RPV materials and electrical cables and components from the Zion plant. In terms of planning and decision-making, DOE had several lessons learned. DOE hosted a workshop at Zion in 2011 to discuss long-term goals and objectives, which proved very helpful in setting priorities and developing partnerships with other organizations. Partnerships were very valuable to DOE's harvesting efforts, allowing for leveraging resources and collaboration and sharing results. There are limited opportunities for harvesting key components, so take full advantage of the opportunities that arise, understanding that there is a necessary compromise between the materials available and their value in terms of fluence or exposure to aging conditions. Another consideration is the quantity of material harvested, which should be sufficient for the objectives of the planned research as well as any collaborations or partnerships, but limited to control costs.

For implementing the harvesting program, DOE found that flexibility was paramount to be able adjust scope and plans in response to schedule changes and other developments, while remaining within cost constraints. Working with a former reactor operator was extremely valuable to benefit from their in-depth knowledge of all parts of the plant, in particular the records for materials pedigree information. Regular site visits and contacts were also essential to stay aware of the latest developments in the harvesting planning and decommissioning process, with the understanding that harvesting is not the top priority for decommissioning company. Other important considerations were hazardous materials handling, transportation, and disposal and logistics, including contracts, liability, shipping and disposal. Finally, DOE's experience is that the total costs of a harvesting program from planning to execution to testing are very high, so they should be carefully weighed against the value of the expected data to be generated.

NRC presented their experience, including benefits from previous harvesting programs, and technical and logistical lessons learned from harvesting. As an organization, NRC has extensive experience with testing harvested materials, including RPV, primary system components, reactor internals, neutron absorbers, concrete and electrical components. NRC's experience is more limited than DOE or EPRI in terms of managing the logistics of a harvesting effort from a decommissioning plant. NRC has generally participated in a secondary role in cooperative efforts or received failed components from operating plants for research. NRC has found that previous harvesting efforts have been effective in reducing unnecessary conservatism, understanding in-service flaws more realistically for NDE and leak rate methodologies, as well as identifying and better understanding safety issues.

For technical lessons learned, NRC's perspective is that harvesting can provide highly representative aged materials for research, which may be the only practical source of such materials. Harvested materials can be effectively used to validate models or a larger data set from accelerated aging tests. It is important understand as much as possible about the materials and their environment in service and how this compares with the operating fleet of reactors before committing to a specific harvesting project. For logistical lessons learned, harvesting is expensive and time-consuming, so a high technical benefit is ne+eded to ensure the program provides values. Leveraging with other organizations can help minimize costs, but can also introduce challenges for aligning priorities and interests of multiple organizations. Finally, transporting irradiated materials, particularly between countries, challenging and time-consuming and should be avoided if at all possible.

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CRIEPI presented their research experience with harvested materials as well as ongoing harvesting from the Hamaoka 1 plant. The first research program involved atom probe tomography (APT) on RPV surveillance materials. CRIEPI found a correlation between the volume fraction of Ni-Si-Mn clusters and the change in nil-ductility temperature. In the second research project, CRIEPI characterized the weld and base materials harvested from Greifswald Unit 4 RPV with small-angle neutron scattering, APT, and hardness testing. In the third research project, CRIEPI performed APT on 304L stainless steel reactor internals harvested from control rod and top guide components from 3-13 dpa. Results showed a strong increase in Ni-Si clusters with increasing fluence, but little variation in Al enriched clusters with increasing fluence.

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For future work, CRIEPI is collaborating with DOE LWRS to investigate RPV materials harvested from Zion

(b)(4) [redacted] CRIEPI also presented activities underway by Chubu Electric Power to harvest RPV and concrete samples from the Hamaoka 1 plant. Hamaoka 1 is a 540 MW BWR-4 that operated for 33 years. Harvesting began in 2015 and will continue through 2018.

The final two presentations of Session 4 provided the non-researcher perspective from a decommissioning company and plant owner. EnergySolutions, which is decommissioning the Zion nuclear plant among other facilities, presented the decommissioning process and their experience and lessons learned from harvesting at Zion. As mentioned previously, surgical harvesting is not the top priority for decommissioning, so researchers must recognize this and coordinate close with the decommissioning company. EnergySolutions emphasized the need to gain senior management support at the plant as well as to expect that there may be staff turnover during a multi-year harvesting effort. Changes in scope and schedule (originating from both sides) can cause frustration on both sides. Early planning and delays with contracting are important to avoid lost opportunities. Being on-site during harvesting is essential to a good outcome.

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At Zion, EnergySolutions worked with DOE to harvest RPV materials, cables, electrical components, and spent fuel storage racks. DOE hoped to harvest a particular RPV surveillance capsule, but was unable to due to the inability identify the correct capsule. There were also challenges with harvesting RPV materials. The cut line on the Unit 2 RPV was too close to the weld to be used for research; fortunately, a successful specimen was harvested from Unit 1. For cabling, the initial plan was to harvest from 11 different locations, but ultimately due to unforeseen challenges and poor communication and coordination, only 4 different cable locations were harvested. Harvesting the desired cable length (30 feet) also proved challenging, with only shorter sections recovered. Plant records searches were largely effective at providing material pedigree information for cables. Concrete coring was initially planned to take place at Zion, but not performed due to lack of research interest. The spent fuel storage rack harvesting went smoothly, which was assisted by efforts over the weekend when decommissioning activities were not occurring.

The next presentation from Dominion provided its perspective on harvesting from decommissioning plants, focused on the experience at Kewaunee Power Station. The top priority (beyond safety) in decommissioning is the preservation and good stewardship of the decommissioning trust fund. Staffing is the largest drain on the trust fund, so at Kewaunee staff was halved within a few months of shutdown and then halved again about 16 months after permanent shutdown once offsite emergency response requirements were eliminated. Dominion described the example of harvesting the RPV surveillance capsules at this point at Kewaunee and the significant challenges that would exist. Given the reduced staffing and the current plant state (reactor coolant system drained, pumps retired, crane and radiation monitoring not maintained), it would be much more difficult now than immediately after shutdown. Kewaunee considered harvesting the surveillance specimens and estimated a cost of six to seven figures based on all the activities required to enable it at this point post-shutdown compared to a much lower cost just after shutdown. Dominion observed that some components, such as cables or electrical components, may be available and relatively easy to harvest at almost any time during decommissioning. However, other components such as highly irradiated internals or RPV may be best harvested either shortly after shutdown when staffing and capabilities on-site are high or wait until active demolition of the reactor, which may be years or decades later.

Dominion also touched on the discussion of records for plant components. Records requirements are limited to those needed for safety. Once the plant shuts down and the range of potential safety concerns decreases, systems are downgraded to non-safety and the associated records are no longer required to be maintained. For perspective, Kewaunee still has all its records four years since shutdown, but will likely not continue this much longer. Dominion closed its presentation with a broader perspective on harvesting, emphasizing the need to clearly define a problem statement and understand what technical and regulatory purpose this harvesting will serve. Early planning focused on achieving the clear objective of the work including scope, schedule, budget and contact with plant is essential to a successful harvesting effort.

Discussion Summary

The discussion touched on the top lessons learned from past harvesting efforts, which included a clear objective and purpose for harvesting, early engagement with the plant, and site coordination during harvesting.

Another suggestion was to get utility management buy-in for the harvesting project by identifying a benefit to the utility. EPRI mentioned that cable harvesting at Crystal River went much more successfully once the utility recognized the potential benefits for subsequent license renewal. Similarly, when harvesting from an operating plant, you need to recognize and work through the challenges the plant may encounter when restarting operations.

During discussion, the question was raised regarding how it is determined whether harvested materials are waste. The discussion concluded that in the U.S. 10 CFR 37 is the important consideration. 10 CFR 37 defines when additional security requirements are imposed, based on the quantity and activity of materials to be transported. The definition of material as waste versus research materials is not as critical in the U.S. EnergySolutions indicated that their shipments of waste or research material could be handled in the same way in the accordance with Department of Transportation regulations, provided that the limits in 10 CFR 37 were not reached.

Session 5 Future Harvesting Program Planning

Session 5 focused on the information needed for informed harvesting decision-making and harvesting program planning. This session featured a presentation by Pradeep Ramuhalli from PNNL, followed by a discussion period covering harvesting program planning and reflection on the 2-day workshop.

Presentation Summary

PNNL presented its perspective on the information needed for informed harvesting decision-making. First, the purpose of the harvesting effort needs to be defined by identify the technical knowledge gaps to be addressed. Next, a research plan should be developed demonstrating how the harvested material will be used to address the identified gaps. Finally, the appropriate source of material to address the technical gap must be identified, along with resources to support the effort and plans and timelines to perform the harvesting. The specifics of these plans depend greatly on the source of materials and must be flexible based on changing conditions on the ground.

In assessing the best source of materials, researchers should consider the material, its environment, and its condition. Material information includes fabrication information such as manufacturer, composition, and dimensions as well as information related to installation or construction, such as welding processes and parameters. Environmental information includes temperature, humidity, fluence, flux, stress (service, residual, installation), and coolant chemistry. Component condition information includes inspection history, such as identified flaws or degradation.

Discussion Summary

The discussion in Session 5 focused on the best practical approach to plan future harvesting programs. There was clear agreement that this approach must begin with identifying the data needs best addressed by harvesting, whether from operating or decommissioning plants. Once a specific need is identified, the next step is to find a source to acquire the materials of interest as well as other organizations interested in participating in the harvesting effort.

Key Takeaways from Workshop

Commented [PP5]: I think some of the information would be better in the previous sections for sessions - 1-5. We may not really need this, think about it.c

Session 1

The clear takeaway from the discussion in session 1 was that harvesting requires significant resources to be done successfully; therefore it is paramount to identify how the planned harvesting will clearly address a significant need to ensure the harvesting project provides strong value. In the context of need for data, EPRI suggested the goal of harvesting to support research for operation out to 80 years is not a full comprehensive understanding of all aspects of the degradation, but rather a snapshot to confirm other lab results and models. This is an important point for all organizations and researchers to keep in mind before investing significant resources in harvesting.

Session 2

The criteria proposed by PNNL are a good starting point for prioritizing issues to address by harvesting. Three additional important criteria would be:

- Fleet-wide vs. plant-specific applicability of data,
- Ease of harvesting (in terms of cost and project risk), and
- Timeliness of the expected research results relative to the objective.

Once a potential harvesting project has reached the point of looking at different sources of materials, the availability of material pedigree information, such as composition, processing, environmental conditions (temperature, humidity, fluence, etc.) is very important to the overall value of harvesting from that particular plant.

Based on the presentations and discussion in Session 2, there appeared to be two areas with broad interest in pursuing further harvesting: high fluence reactor internals and irradiated concrete. The common drivers for the interest in these issues is a lack of representative data at the fluences of interest and significant challenges with acquiring representative data through other means. High fluence reactor internals has been addressed somewhat by the Zorita Internals Research Project (ZIRP), but stainless steel materials exposed to higher fluence levels at higher temperatures, where void swelling may become significant, could help validate DOE and EPRI models and provide further technical basis for PWR internals aging management. Irradiated concrete harvesting is currently being pursued from the Zorita reactor in Spain, with international collaboration and potential testing at the Halden Reactor Project.

Other areas with some, but less widespread, interest expressed from workshop participants for new harvesting efforts included RPV materials and electrical cables and components. SCK-CEN and NRC expressed interest in RPV harvesting, and NRC expressed interest in electrical component harvesting.

Session 3

To capture the key takeaways from Session 3 focused on sources of materials, two tables of potential sources of materials are presented below. The first table covers recent or ongoing harvesting programs, while the second details potential future harvesting opportunities.

Ongoing Harvesting Programs

Country	Plant	Design	Size (MWe)	Years in operation	Components	Organization(s)
Canada	NPD	CANDU	20	25	Concrete	AECL
	Gentilly-2	CANDU-6	675	29	Cables	
Japan	Hamaoka 1	BWR-4	540	33	RPV, concrete	CRIEPI/Chubu
Spain	Zorita	W 1-loop	160	37	Internals, concrete	EPRI, NRC
Sweden	Barseback	ABB-II	615	28	RPV	Vattenfall
U.S.	Zion 1/2	W – 4 loop	1040	24/25	RPV, cables, neutron absorbers	DOE, EPRI, NRC
	Crystal River 3	B&W	860	36	Cables	EPRI
	(b)(4)					

Potential Future Sources for Harvesting

Country	Plant	Design	Size (MWe)	Years in operation	Potential Components	Notes
Canada	NRU	Test reactor	135 MWt	61	TBD	AECL; SD: 2018
Germany	Numerous plants either in decommissioning or shutting down soon. See Appendix III.					
Japan	Mihama	W 2-loop	320	40	Concrete	Kansai, Westinghouse
Korea	Kori 1	W 2-loop	576	40	RPV, internals, SGs, pressurizer, welds, CASS,	KHNP, EPRI
Sweden	Ringhals 1	BWR	883	44	RPV, internals SGs, pressurizer, concrete	Vattenfall; SD: 2020 / 2019
	Ringhals 2	W 3-loop	900	44		
U.S.	Kewaunee	W 2-loop	566	39	TBD	SD: 2013
	SONGS 2/3	CE 2-loop	1070	31/30	TBD	SD: 2013
	Crystal River 3	B&W	860	36	TBD	SD: 2013
	Vermont Yankee	BWR-4/Mk-1	605	42	TBD	SD: 2015
	Fort Calhoun	CE 2-loop	482	43	TBD	SD: 2016
	Palisades	CE 2-loop	805	47	TBD	SD: 2018
	Pilgrim	BWR-3/Mk-1	677	47	TBD	SD: 2019
	Oyster Creek	BWR-2/Mk-1	619	50	TBD	SD: 2019
	Indian Point 2/3	W 4-loop	1020 / 1040	48/46	TBD	SD: 2021
	Diablo Canyon 1/2	W 4-loop	1138 / 1118	40	TBD	SD: 2024-5

	Advanced Test Reactor	Test reactor	250 MWt	50	Core internals	Non-commercial; internals replaced every 10 years

In addition to the potential sources of materials presented and discussed in Session 3, another takeaway was the suggestion of developing a database for previously harvested materials or those available for future harvesting. The NSUF sample library may be a good starting point for such a database, with appropriate modifications for the purposes of harvesting efforts.

Session 4

There were several important takeaways from Session 4 that were touched on in multiple presentations and the discussion. One key takeaway is that researchers should identify a clear purpose and scope for harvesting. Having a clear purpose for harvesting helps to guide later decisions that must be made to adjust course when the inevitable changes in schedule or unexpected realities at the plant arise. A related note is that harvesting is not the top priority for decommissioning. Therefore, researchers must have clear objectives and scope for harvesting that can be communicated to the site. This understanding should shape assumptions and interactions with the plant owner or decommissioning company as well as planning for costs and schedule.

Another takeaway was the value of strong site coordination, including site visits. Multiple presenters touched on the value of being on-site to talk to staff and see the components to be harvested. Mockups and 3-D simulations can be valuable to ensure success of the approach or technique used to acquire the specimen. A related point is working with reactor operators at the plant. Several harvesting efforts worked with former reactor operators and benefited greatly from their experience to find records or determine the best method to harvest the desired component. This is a valuable insight that could be effective in future harvesting efforts.

A third key takeaway is early engagement with the plant to express interest in harvesting. This serves to make the plant aware of your interest in harvesting and get their support to work with the harvesting process. The other important benefit of early engagement is to gain as much information as possible about the available materials and components, including the associated records and material pedigree information.

Session 5

The key takeaway in session 5 was to gather as much information as possible in advance of committing to a specific harvesting project. Ideally, there would be a strong understanding that the material and its aging conditions clearly align with an identified technical data need before committing significant resources to a harvesting effort.

Action Items and Next Steps

The following is a summary of the action items discussed at the end of the workshop:

1. Sharing workshop slides

- NRC emailed attendees to ask their comfort with sharing their workshop slides with other organizations and received no objection from any presenters.
- The presentations can be accessed here: https://drive.google.com/open?id=0B5DWMLch5YSXcnpZZ0JOS055QUU .

2. EPRI indicated that MRP-320 (Product ID: 1022866) on knowledge gaps for irradiated austenitic stainless steel for potential harvesting from MRP-227 inspections is publicly available for a fee.
3. Cable surveillance programs in Germany
   - GRS to inquire with cable colleagues and share any insights.
4. Sources of materials database
   - Potential sources of materials presented in this workshop are summarized in Session 3 summary above and Appendix III below.
   - NRC will be reaching out to PNNL, INL NSUF, CNSC, AECL, and any other organizations interested in database development.
5. Prioritized data needs
   - Suggestion to continue discussions on prioritized data needs within technical areas (RPV, internals, electrical, concrete) through existing coordination groups if possible
     - Focus on identifying specific material / aging conditions of interest and purpose / intended outcome of harvesting
   - Idea to survey Env Deg participants
     - John Jackson (INL) is on planning committee
6. EPRI report on spent fuel liner boric acid transport through concrete
   - NRC will contact EPRI for report if needed.
7. Harvested Materials Research Results
   - Section of workshop summary report (below) devoted to references from harvested materials research.

References to Previous Harvested Materials Research

This section of the workshop summary addresses a question that was raised during the discussion at the workshop regarding what the outcome or benefit of past harvesting efforts have been. Below is a list of references to research results generated from testing of harvested materials:

J.R. Hawthorne and A.L. Hiser, *Experimental Assessments of Gundremmingen RPV Archive Material for Fluence Rate Effects Studies*, NUREG/CR-5201 (MEA-2286), U.S. Nuclear Regulatory Commission, October 1988.

G. J. Schuster, S. R. Doctor, A.F. Pardini, and S.L. Crawford, *Characterization of Flaws in U.S. Reactor Pressure Vessels: Validation of Flaw Density and Distribution in the Weld Metal of the PVRUF Vessel*, NUREG/CR-6471 Volume 2, U.S. Nuclear Regulatory Commission, August 2000.

G. J. Schuster, S. R. Doctor, S.L. Crawford, and A. F. Pardini, *Characterization of Flaws in U.S. Reactor Pressure Vessels: Density and Distribution of Flaw Indications in the Shoreham Vessel*, NUREG/CR-6471 Volume 3, U.S. Nuclear Regulatory Commission, November 1999.

D.E. McCabe, et al. *Evaluation of WF-70 Weld Metal From the Midland Unit 1 Reactor Vessel*, NUREG/CR-5736 (ORNL/TM-13748), U.S. Nuclear Regulatory Commission, November 2000.

B. Alexandreanu, O.K. Chopra, and W.J. Shack, *Crack Growth Rates in a PWR Environment of Nickel Alloys from the Davis-Besse and V.C. Summer Power Plants,* NUREG/CR-6921 (ANL-05/55), U.S. Nuclear Regulatory Commission, November 2006.

S.E. Cumblidge, et al. *Nondestructive and Destructive Examination Studies on Removed-from-Service Control Rod Drive Mechanism Penetrations*, NUREG/CR-6996, U.S. Nuclear Regulatory Commission, July 2009.

S.E. Cumblidge, et al. *Evaluation of Ultrasonic Time-of-Flight Diffraction Data for Selected Control Rod Drive Nozzles from Davis Besse Nuclear Power Plant*, PNNL-19362, Pacific Northwest National Laboratory, April 2011.

S.L. Crawford, et al. *Ultrasonic Phased Array Assessment of the Interference Fit and Leak Path of the North Anna Unit 2 Control Rod Drive Mechanism Nozzle 63 with Destructive Validation*, NUREG/CR-7142 (PNNL-21547), U.S. Nuclear Regulatory Commission, August 2012.

Appendix I Workshop Participants

	Name	Organization	Email
Japan	Taku Arai	CRIEPI	arait@criepi.denken.or.jp
	Sadao Higuchi	CRIEPI	higuchi@criepi.denken.or.jp
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	Pradeep Ramuhalli	PNNL	Pradeep.Ramuhalli@pnnl.gov
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	Rob Tregoning	NRC	Robert.Tregoning@nrc.gov
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	Tom Koshy	NRC	Thomas.Koshy@nrc.gov
	Jeff Poehler	NRC	Jeffrey.Poehler@nrc.gov
	Allen Hiser	NRC	Allen.Hiser@nrc.gov
	Angela Buford	NRC	Angela.Buford@nrc.gov
	Mark Kirk	NRC	Mark.Kirk@nrc.gov
	Amy Hull	NRC	Amy.Hull@nrc.gov
	Pete Ricardella	NRC/ACRS	Priccardella@Structint.com

Appendix II Workshop Agenda

Tuesday, March 7

Session	Time	Organization	Speaker	Presentation Title
Intro	8:00	NRC	Michael Weber Robert Tregoning	Welcome and Introduction to Workshop
1	8:15 – 8:45	DOE	Rich Reister	DOE Perspectives on Material Harvesting
		EPRI	Sherry Bernhoft	EPRI Perspective on Harvesting Projects
		NRC	Robert Tregoning	NRC Perspective on Motivation for Harvesting
		GRS	Uwe Jendrich	Role of GRS in Decommissioning and LTO
		CRIEPI	Taku Arai	CRIEPI Motivations for Harvested Material
	8:45 – 9:45	DISCUSSION		
9:45-10:00		**BREAK**		
2	10:00 – 10:20	PNNL (for NRC)	Pradeep Ramuhalli	Data Needs Best Addressed By Harvesting
	10:20 – 10:30	NRC	Matthew Hiser	High-Priority Data Needs for Harvesting
	10:30 – 10:55	DOE	Keith Leonard	LWRS Program Perspective on the Technical Needs for Harvesting
	10:55 – 11:20	SCK-CEN	Rachid Chaouadi	Review of past RPV sampling test programs and perspective for long term operation
	11:20 – 11:45	Westinghouse	Arzu Alpan	Importance of Harvesting to Evaluate Radiation Effects on Concrete Properties
	11:45 – 12:30	DISCUSSION		
12:30 – 2:00		**LUNCH**		
3	2:00 – 2:10	NRC	Matthew Hiser	Sources of Materials: Past NRC Harvesting and U.S. Decommissioning Plants
	2:10 – 2:35	EPRI	Al Ahluwalia	Harvesting Plans for Materials Aging Degradation Research in Korea and Sweden
	2:35 – 2:50	DOE/ORNL	Tom Rosseel	Materials Harvested by the LWRS Program
	2:50 – 3:00	DOE/INL	John Jackson	NSUF Material Sample Library
	3:00 – 3:15	Energy Solutions	Gerry van Noordennen	Zion Material Harvesting Program
	3:15 – 3:30	Westinghouse	Arzu Alpan	Potential Harvesting of Concrete from Mihama Unit 1
	3:30 – 3:45	**BREAK**		
	3:45 – 4:00	GRS	Uwe Jendrich	Plants in Decommissioning in Germany
	4:00 – 4:15	CNSC	Daniel Tello	Evaluating Structures, Systems & Components from Decommissioned/Decommissioning Nuclear Facilities in Canada
	4:15 – 5:00	DISCUSSION		

Wednesday, March 8

Session	Time	Organization	Speaker	Presentation Title
4	8:00 – 8:30	EPRI	Jean Smith	Lessons Learned: Harvesting and Shipping of Zorita Materials
	8:30 – 9:00	DOE	Tom Rosseel	LWRS Program: Harvesting Lessons Learned
	9:00 – 9:30	NRC	Matthew Hiser	NRC Perspective on Harvesting Experience and Lessons Learned
	9:30 – 10:00	CRIEPI	Taku Arai	CRIEPI Research Activities with Harvested Materials
	10:00 – 10:15	**BREAK**		
	10:15 - 10:45	Energy Solutions	Gerry van Noordennen	Zion Harvesting Experience and Lessons Learned
	10:45 - 11:15	Dominion	Bill Zipp	Kewaunee Insights on Material Harvesting
	11:15 – 12:00	DISCUSSION		
12:00 – 1:30		**LUNCH**		
5	1:30 – 1:45	PNNL (for NRC)	Pradeep Ramuhalli	Technical Information Needed for Informed Harvesting Decisions
	1:45 – 2:30	DISCUSSION		
	2:30 – 3:00	Action Items and Next Steps		
	3:00 – 4:00	EPRI	Sherry Bernhoft	Closing Thoughts
		DOE	Rich Reister	
		NRC	Robert Tregoning	
		ALL		

Appendix III Harvesting Opportunities in Germany

- Past and current decommissioning projects of **Prototype or Commercial Reactors**

Name	Abbrev.	Reactor type	Power MW_e	Decom. started	Strategy
Rheinsberg	KKR	WWER	70	1995	UC
Compact Natrium Cooled Reactor	KKN	SNR	21	1993	UC
Multipurpose Research R.	MZFR	PWR/D_2O	57	1987	UC
Obrigheim	KWO	PWR	357	2008	UC
Neckarwestheim 1	GKN-1	PWR	840	2017	UC
Isar-1	KKI-1	BWR	912	2017	UC
Gundremmingen-A	KRB-A	BWR	250	1983	RCA KRB-II
Greifswald 1-5	KGR 1-5	WWER	440	1995	UC
Lingen	KWL	BWR	268	1985	UC after SE

UC: unconditional clearance
RCA: radiation controlled area, new license
SE: safe enclosure

NRC Harvesting Workshop, Rockville, March 2017, Decommissioning in Germany 4

- Past and current decommissioning projects of **Prototype or Commercial Reactors**

Name	Abbrev.	Reactor type	Power MW_e	Decom. started	Strategy
Stade	KKS	PWR	672	2005	UC
Research Reactor Jülich	AVR	HTR	15	1994	UC
Thorium High-Temperature-Reaktor	THTR-300	HTR	308	1993	SE since 1997
Würgassen	KWW	BWR	670	1997	UC
Mülheim-Kärlich	KMK	PWR	1302	2004	UC
Hot-Steam Reactor Grosswelzheim	HDR	HDR	25	1983	UC since 1998
Niederaichbach	KKN	DRR/D_2O	106	1975	UC since 1994
Test-Reactor Kahl	VAK	BWR	16	1988	UC since 2010

- **Shut down** Commercial Reactors
  - **that have no decommissioning license granted yet**

Name	Abbrev.	Reactor type	Power MW_e	Date of application
Philippsburg-1	KKP-1	BWR	926	2013 / 2014
Grafenrheinfeld	KKG	PWR	1345	2014
Biblis-A	KWB-A	PWR	1225	2012
Biblis-B	KWB-B	PWR	1300	2012
Unterweser	KKU	BWR	1410	2012 / 2013
Brunsbüttel	KKB	BWR	806	2012 / 2014
Krümmel	KKK	BWR	1402	2015

- Commercial Reactors **in operation**

Name	Abbrev.	Reactor type	Power MW_e	Anticipated date of final shutdown
Gundremmingen-B	KRB-II-B	BWR	1344	31.12.2017
Philippsburg-2	KKP-2	PWR	1468	31.12.2019
Gundremmingen-C	KRB-II-C	BWR	1344	31.12.2021
Grohnde	KWG	PWR	1430	31.12.2021
Brokdorf	KBR	PWR	1480	31.12.2021
Emsland	KKE	PWR	1406	31.12.2022
Isar-2	KKI-2	PWR	1485	31.12.2022
Neckarwestheim-2	GKN-2	PWR	1400	31.12.2022

Note to requester: The attachment is immediately following this email.

From: Frankl, Istvan
Sent: Tue, 30 May 2017 17:55:24 -0400
To: Hiser, Matthew
Subject: RE: Workshop Summary Report
Attachments: Harvesting Workshop Summary Report draft 5-26-17 (IF).docx

Thanks Matt.

This is a well-written report. Please see my attached editorial revisions and comments.

Steve

From: Hiser, Matthew
Sent: Friday, May 26, 2017 9:18 AM
To: Purtscher, Patrick <Patrick.Purtscher@nrc.gov>; Tregoning, Robert <Robert.Tregoning@nrc.gov>; Hull, Amy <Amy.Hull@nrc.gov>; Frankl, Istvan <Istvan.Frankl@nrc.gov>
Subject: RE: Workshop Summary Report

I have incorporated significant input from Amy and Pat on the Harvesting Workshop Summary Report. The latest version of the report is attached.

My plan is to send this complete draft to the workshop participants for review and comment by Wednesday, May 31. Please provide any further input or comments by next Wednesday to be incorporated in the draft sent to workshop participants.

I will ask for feedback from workshop participants by the end of June with the intent to finalize this summary report by mid-July.

Please let me know if you have any questions or suggestions on how to best move this effort forward.

Thanks!
Matt

Ex-Plant Materials Harvesting Workshop Summary Report

Workshop held on March 7-8, 2017 at NRC headquarters in Rockville, MD

NRC staff: Matthew Hiser, Patrick Purtscher, Amy Hull, Robert Tregoning

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Background

On March 7-8, 2017, the Office of Nuclear Regulatory Research of the United States Nuclear Regulatory Commission (NRC) hosted a 2-day workshop on the topic of "Ex-Plant Materials Harvesting." NRC staff worked in close coordination with staff from the U.S. Department of Energy (DOE) and the Electric Power Research Institute (EPRI) to plan and arrange the workshop.

The decision to organize this workshop was driven by developments in the U.S. and global nuclear industry. In the U.S., there is strong interest in extending plant lifespans through subsequent license renewal (SLR) from 60 to 80 years. Extended plant operation and SLR raise a number of technical issues that may require further research to understand aging mechanisms, which may benefit from harvesting. Meanwhile, in recent years, a number of nuclear plants, both in the U.S. and internationally, have shut down or announced plans to shut down. Unlike in the past when there were very few plants shutting down, these new developments provide opportunities for harvesting components that were aged in representative light water reactor (LWR) environments. In a related development, economic challenges for the nuclear industry and limited government spending have limited the resources available to support new research, including harvesting programs. Given this constrained budget environment, aligning interests and leveraging with other organizations is important to allow maximum benefit and value for future research programs.

Commented [FI1]: Is there any info from the related PLiM abstract that can be borrowed/ added to this paragraph or other applicable section?

Objective and Approach

The objective of the workshop was to generate open discussion of all aspects of ex-plant materials harvesting, including:

1. Deciding whether to harvest,
2. Planning and implementing a harvesting program,
3. Using the harvested materials in research programs.

Through presentations and open discussion, the workshop was organized to allow for all participants to be better informed of the benefits and challenges of harvesting as well as to identify potential areas of common interest for future harvesting programs. Workshop sessions were aligned in broad topics to cover all aspects of harvesting that~~, but~~ allowed the ~~for~~ participants to drive the discussion.

To help accomplish the workshop objectives, the workshop organizers intentionally sought a diverse group of participants. There are a large number of decommissioning plants and interested researchers outside the U.S., so the organizers focused on outreach to international participants through organizations~~connections~~ such as the International Atomic Energy Agency (IAEA), Organization for Economic Cooperation and Development Nuclear Energy agency (OECD/NEA), and existing professional contacts. In addition, a key goal for this workshop was to capture the broader practical perspective from plant owners and decommissioning companies, which are vital to any successful harvesting program, but may sometimes be overlooked in researcher-driven discussions. Workshop participants were also diverse in terms of technical area of focus, with metal components such as the reactor pressure vessel (RPV) and internals being discussed along with concrete and electrical components. The final list of workshop participants can be found at the end of this report in Appendix I.

Workshop Organization and Sessions

The workshop was held at NRC headquarters in Rockville, MD. Due to limited space in the meeting room and the need for a limited group size for discussion, a webinar was used to allow remote observers to benefit from the workshop. Workshop sessions were organized topically with about half the time dedicated to presentations and the remaining time set aside for discussion. Presentations were solicited from participants to cover a range of perspectives and technical areas. The final workshop agenda can be found at the end of this summary report in Appendix II.

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The workshop was organized into five sessions as follows:

- Session 1. Motivation for Harvesting
- Session 2. Technical Data Needs for Harvesting
- Session 3. Sources of Materials
- Session 4. Harvesting Experience: Lessons Learned and Practical Aspects
- Session 5. Future Harvesting Program Planning

Summary of Workshop Discussion

The subsections below will summarize the presentations and discussion in each session and highlight the key takeaways from the session.

Session 1. Motivation for Harvesting

Session 1 focused on the motivation for harvesting and why workshop participants are interested in harvesting. As shown in Appendix II with presentation titles, speakers for this session included:

- Richard Reister from DOE,
- Sherry Bernhoft from EPRI,
- Robert Tregoning from NRC,
- Uwe Jendrich from the Gesellschaft für Anlagen- und Reaktorsicherheit (GRS) in Germany, and
- Taku Arai from the Central Research Institute of the Electric Power Industry (CRIEPI) in Japan.

Presentation Summaries

DOE described the role of harvesting within the Light Water Reactor Sustainability (LWRS) Program, including the benefits and challenges associated with harvesting. Benefits include the opportunity to fill knowledge gaps where there is limited data or experience and to inform degradation models with data from actual plant components. Challenges include cost, complexity, scheduling, logistics, limited opportunities, acquiring sufficient material pedigree information, and potential negative results impacting operating plants.

EPRI discussed the role of harvesting within the context of aging management for Long-Term Operations (LTO), including their experience from past harvesting programs and criteria for future harvesting. Their experience emphasized the challenges of cost, schedule, logistics, complicated contracting and acquiring material pedigree information. EPRI's criteria for harvesting focus on demonstrating value to their members by addressing a prioritized need that cannot be addressed through other means. For EPRI, a well-developed project plan that covers funding, risk management, exit ramps, and clear roles and responsibilities is essential.

NRC shared its perspective on the benefits and challenges of harvesting in regulatory research. Harvested materials are valuable due to the representative nature of their aging conditions, which may reduce the uncertainty associated with the applicability of the results to operating plants compared to tests with alternative aging conditions. Harvested materials may be the best option to address technical data needs identified for extended plant operation. With increasing harvesting opportunities from decommissioning plants, a proactive approach to harvesting planning can optimize benefits by identifying the right material with the right aging conditions for the identified knowledge gap. There are significant challenges associated with harvesting, including cost, schedule, and logistics, but hopefully these can be mitigated or avoided by leveraging resources with other organizations and learning from past experience.

GRS described its role as the main technical support organization in nuclear safety for the German federal government. GRS provides technical assessment and knowledge transfer for decommissioning activities, aging management, and long-term operation for German federal and international organizations.

CRIEPI discussed its view of how harvested materials and laboratory prepared materials contribute to addressing technical issues. Harvested materials provide exposure to actual plant conditions, but are more limited in availability and the size of the data set that can be generated. Laboratory prepared materials general involve accelerated or simulated aging conditions, but can be used to produce larger data sets and varying parameters can allow understanding of the effect on the mechanism or property of interest. Harvested materials offer fact finding of actual plant conditions as well as confirmation and verification of results from laboratory prepared specimens.

Discussion Summary

The discussion following the presentations in this session focused on clearly identifying the need to be addressed by a harvesting project and the myriad cost, schedule, and logistical challenges associated with harvesting. Leveraging with other organizations to defray costs can also help improve the value of a given program, but also adds complexity as another organization may have a different set of priorities that changes the focus of the harvesting effort.

Session 2. Technical Data Needs for Harvesting

Session 2 focused on discussing the technical data needs for harvesting and what specific knowledge gaps organizations are interested in addressing through harvesting. This discussion included general perspectives on how to determine when harvesting should be pursued rather than other types of research. As shown in Appendix II with presentation titles, speakers for this session included:

- Pradeep Ramuhalli from the Pacific Northwest National Lab (PNNL),
- Matthew Hiser from NRC,
- Keith Leonard from Oak Ridge National Laboratory (ORNL),
- Rachid Chaouadi from the Belgian Nuclear Research Centre (SCK-CEN) in Belgium, and
- Arzu Alpan from Westinghouse.

Presentation Summaries

PNNL presented their work, under a small NRC contract, to develop a systematic approach to prioritize data needs for harvesting. PNNL proposed five primary criteria for prioritizing harvesting:

- Unique field aspects of degradation
    - For example, unusual operating experience or legacy materials (composition, etc.) that may be no longer available
- Ease of laboratory replication of degradation scenario (combination of material and environment)
    - For example, simultaneous thermal and irradiation conditions may be difficult to replicate or mechanism sensitive to dose rate may not be good for accelerated aging
- Applicability of harvested materials for addressing critical gaps
    - Prioritize harvesting for critical gaps over less essential data needs
- Availability of reliable in-service inspection (ISI) techniques for the material / component
    - If inspection methods are mature and easy to apply to monitor and track degradation, perhaps the effort of research with harvested materials is not needed.
- Availability of materials for harvesting
    - The necessary materials / components must be available to be harvested.

PNNL then presented their application of these criteria to four materials degradation issues as an example: electrical cables, cast austenitic stainless steel (CASS), reactor vessel internals, and dissimilar metal welds. Based on applying these criteria to the examples, PNNL concluded that electrical cables, CASS, and reactor internals are all higher priority for harvesting due to unique aspects of the degradation that are challenging to replicate in the lab. Meanwhile, dissimilar metal welds are of low priority due to the ease of replication in lab aging studies as well as the significant body of knowledge and research on the phenomena.

NRC presented a summary of data needs it is interested in pursuing through harvesting. These included RPV materials to validate fluence and attenuation models and to demonstrate the conservatism of regulatory approaches for transition temperature prediction. Other metal components of interest for harvesting would address data gaps in irradiated stainless steels, as well as improve understanding of inspection capabilities and fatigue life calculations. Electrical components of interest include low and medium voltage cables and other electrical components for degradation studies, and electrical enclosures and cables for fire research. Concrete components of interest include irradiated concrete, concrete undergoing alkali-aggregate reactions, post-tensioned structures, reinforcing steel, tendons, and spent fuel pool concrete to assess potential boric acid attack.

DOE/ORNL presented their perspective on data needs for harvesting and its role in providing validation of experimental and theoretical research. DOE/ORNL performed a significant RPV harvesting program at the Zion nuclear power plant to reduce uncertainties in the Master Curve methodology, validate modeling predictions and study flux and fluence attenuation effects. The harvesting is largely complete, but the testing program is currently underway. DOE/ORNL also indicated interest in using harvested materials to validate its models for swelling and microstructural changes of stainless steel internals under LWR irradiation conditions. Harvesting concrete components would be of interest due to lack of literature data and the multiple dependent variables that may affect concrete performance. Finally, DOE/ORNL has been involved in harvesting cables from the Crystal River and Zion plants to address cable aging as a function of material composition and environment.

SCK-CEN presented their interest in an international cooperative program to harvest RPV materials. SCK-CEN presented their survey of the literature for past testing programs of harvested RPV materials, and

the limitations of these past program. Key limitations include a lack of archive materials, generally lower temperatures, and poor surveillance programs and dosimetry. SCK-CEN then shared some thoughts on their criteria for a new harvesting efforts, including higher fluence levels and temperatures, available archive materials and reliable information on operating history, dosimetry and surveillance program. Other topics relevant to a new RPV harvesting effort include technical issues such as material variability and irradiation conditions as well as logistical and financial considerations.

The final presentation in Session 2 by Westinghouse focused on the need for harvesting irradiated concrete to better understand the threshold radiation level for significant strength reduction. Westinghouse has installed ex-vessel neutron dosimetry (EVND) at a number of plants in the world and proposed to use these dosimetry measurements to validate fluence model calculations to better understand the uncertainty in these calculations. Figure 1 shows a schematic of the EVND setup. If concrete can be harvested at one of these plants with EVND data, then irradiated concrete properties from testing can be paired with fluence data to improve research benefits.

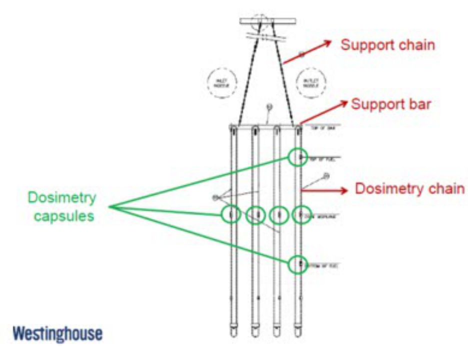

Figure 1 Schematic of Westinghouse ex-vessel neutron dosimetry (EVND)

Discussion Summary

The discussion following Session 2 presentations touched on a number of topics. EPRI shared that they developed a report related to the topics of Session 2, but more narrowly focused on pressurized water reactor (PWR) internals. MRP-320, "Testing Gap Assessment and Material Identification for PWR Internals," focuses on prioritizing opportunistic harvesting of stainless steel reactor internals components that may be removed from service following MRP-227 inspections. The methodology and approach in this report may be relevant to the broader harvesting data needs discussion. This report is not publicly available, but is available to EPRI member utilities.

Workshop participants discussed the criteria proposed by PNNL in the first presentation. One additional criteria suggested by EPRI was to consider fleet-wide vs. plant-specific applicability. More broadly applicable materials would be of greater interest for harvesting than those that represent conditions at only a few plants. Another criteria suggested is the availability of material pedigree information, such as composition, processing, environmental conditions (temperature, humidity, fluence, etc.). Another suggested criteria was the ease of harvesting, which includes the concept of weighing costs vs. benefits as well as project risk. For example, highly irradiated internals are probably much more difficult and expensive to harvest than electrical cables or unirradiated concrete. Further discussion touched on the idea that different organizations may prioritize the various criteria differently, but all will probably at least want to consider the same set of criteria.

Another key theme from this discussion was that a successful program should be guided by a clearly defined objective or problem statement to be addressed. This objective should be well-understood at the initiation of a program and used to guide decision-making through implementation of a harvesting

project. This also raises a related point or potential criteria: the timeliness of the expected research results relative to the objective. If the results are needed in the next two years, but a harvesting project will not provide results for at least five years, that should be a strong consideration.

Session 3. Sources of Materials

Session 3 focused on discussing sources of materials for harvesting. This discussion covered previously harvested materials as well as sources for new harvesting programs from operating or decommissioning plants. Both domestic and international sources of materials were discussed in this session. As shown in Appendix II with presentation titles, speakers for this session included:

- Matthew Hiser from NRC,
- Al Ahluwalia from EPRI,
- Tom Rosseel from DOE/ORNL,
- John Jackson from DOE/Idaho National Laboratory (INL),
- Gerry van Noordennen from EnergySolutions,
- Arzu Alpan from Westinghouse,
- Uwe Jendrich from GRS, and
- Daniel Tello from the Canadian Nuclear Safety Commission (CNSC).

Presentation Summaries

NRC presented their perspective on sources of materials for harvesting. First, NRC shared information on some of the harvested materials from past research programs that may be available, including irradiated stainless steel internals, RPV materials, nickel alloy welds, neutron absorber material, and electrical components. NRC then summarized the recently and planned shutdown U.S. plants, including their design, thermal output, and years of operation, to provide participants with an idea of the potential sources from decommissioning U.S. plants. Finally, NRC shared a list of information that would be helpful to acquire from decommissioning plants to determine the value of components for harvesting. This information included plant design information (component location and dimensions), environmental conditions (temperature, fluence, humidity, stress, etc.) and operating history, material pedigree information (fabrication records), and inspection records (for interest in components with known flaws).

The next presentation from EPRI covered harvesting opportunities at decommissioning plants in Korea and Sweden. In Korea, Kori-1 is a Westinghouse 2-loop PWR (sister plant is Kewaunee) that will shut down in 2017 after 40 years of operation. Korea Hydro and Nuclear Power Central Research Institute (KHNP-CRI) is planning a comprehensive research program on long-term materials aging based on harvesting from Kori-1 and is seeking international participation in the harvesting effort. KHNP-CRI's plan is focused on metallic components, including RPV, internals, primary system components, steam generator materials. Harvesting is expected to occur in 2024 with testing to follow through 2030.

In Sweden, Vattenfall is currently harvesting in 2017-2018 RPV material from the decommissioning Barseback boiling water reactor (BWR) units. This work is focused on irradiation embrittlement, including comparison of surveillance data to actual RPV properties, as well as thermal aging embrittlement. In the future, Vattenfall will be shutting down Ringhals 1 and 2 in 2020 and 2019, respectively. Ringhals 1 is a BWR and Ringhals 2 is a Westinghouse 3-loop PWR design. Of particular note, Ringhals 2 has the second oldest replaced Alloy 690 RPV head and steam generators. Other harvesting opportunities at Ringhals include RPV material with a significant surveillance program, thermal aging effects on low alloy steel from the pressurizer, as well as concrete structures. Vattenfall is open to working with partners that are interested in joining them for harvesting at Ringhals.

The next presentation by DOE/ORNL focused on several harvesting programs that DOE's LWRS program has been involved with. DOE/ORNL has led the harvesting of components from the Zion [redacted] (b)(4) plant[redacted] (b)(4) in the U.S. From Zion, DOE/ORNL has harvested electrical cables and components, a large RPV section, and a significant number of records to provide information on material fabrication, in-service inspection and operating history. Cables from Zion include CRDM, thermocouple, and low and medium voltage cables. DOE/ORNL indicated some thermocouple cables from Zion may be available for other researchers to use in collaborative studies. [redacted] (b)(4) (b)(4) (b)(4) DOE/ORNL is also participating in efforts to harvest cables from Crystal River (led by EPRI) and concrete from the Zorita plant in Spain (led by NRC).

The next presentation by DOE/INL described INL's Nuclear Science User Facilities (NSUF) and the Nuclear Fuels and Materials Library (NFML). NSUF is coordinated by INL and facilitates access to nuclear research facilities around the world, including neutron and ion irradiations, beamlines, hot cell testing, characterization and computing capabilities. NFML is a Web-based searchable database sample library that captures the information from thousands of specimens available to NSUF. NFML is designed to maximize the benefit of previously irradiated materials for future research. Researchers can propose new research projects under NSUF using specimens in NFML using DOE funding. As seen in Figure 2, the information captured in NFML aligns well with the goal of this session to potentially develop a database of previously harvested materials.

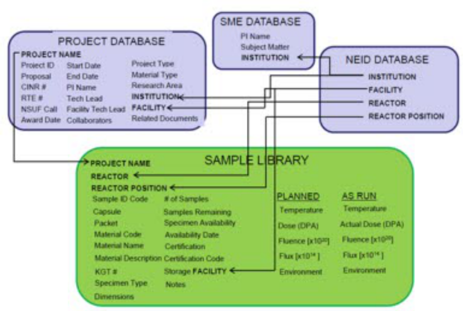

Figure 2 Nuclear Fuels and Materials Library (NFML) Database Design

The next presentation by EnergySolutions offered a more practical perspective on considering sources of materials for harvesting. From the plant owner perspective, ~~in the decommissioning process~~ there is no~~not a~~ financial incentive to support harvesting during decommissioning, therefore researchers need to absorb the costs of~~for~~ harvesting and have a clear scope for harvesting. Flexibility in funding for harvesting activities is essential as the decommissioning process and schedule may change quickly.

EnergySolutions provided valuable perspective on the timing in the decommissioning process for harvesting different components. For instance, the h~~H~~arvesting of RPV surveillance coupons should take place when the RPV internals are cut and removed. Harvesting of RPV materials is only possible from larger RPVs, as smaller RPVs are shipped intact to the disposal facility, rather than cut into pieces. Spent fuel rack neutron absorber coupons must be harvested either before or after the dry storage campaign to remove spent fuel from the spent fuel pool. Harvesting actual spent fuel rack neutron absorber material must come after the pool is completely empty. Electrical cables and other components from mild environments may be harvested at any time (once temporary power is established and plant power is shut off), while the harvesting of electrical components from high rad environments will depend on the timing of source-~~-~~term removal schedules. Concrete cores are best harvested when other cores are being taken for site characterization to develop the License Termination Plan. Highly irradiated concrete from the biological shield wall would need to come later in decommissioning after the RPV is removed.

In terms of upcoming decommissioning plants, EnergySolutions indicated that San Onofre and Vermont Yankee will be entering DECON in~~is~~ 2018 and 2019, respectively. Kewaunee, Crystal River, and Fort Calhoun also may enter DECON in the next 2 years. If researchers are interested in harvesting from any of these plants, they should be reaching out to plant owners immediately to begin planning and coordination.

Westinghouse followed up their presentation in Session 2 by describing an opportunity to harvest concrete from the Mihama 1 plant in Japan. Westinghouse installed and analyzed additional neutron dosimetry in the reactor cavity for one cycle, which were used to validate the radiation transport calculations. Mihama was shutdown in 2015 and is in contact with Westinghouse about the possibility of extracting concrete cores from the biological shield wall. Westinghouse is seeking partners interested in joining this harvesting effort.

The next presentation by GRS covered opportunities for harvesting from German plants. Regulations in Germany require plants to either immediately dismantle or dismantle after a period of safe enclosure, which is largely consistent with options in the U.S. GRS detailed the status of German commercial reactors, which are predominantly BWR and PWR designs. Seventeen reactors are currently undergoing decommissioning, while seven more are currently shutdown and await a decommissioning license. Eight reactors are still operating with scheduled shutdown dates between 2017 and 2022. German RPVs tend to have lower fluence than U.S. designs due to a larger water gap in the downcomer region. Germany has limited experience with harvesting from decommissioning plants. One question that GRS will follow-up on is the "rumored" cable surveillance programs that may be used in Germany and could provide experience and lessons learned for other countries.

The final presentation in Session 3 was by CNSC on harvesting opportunities in Canada. Atomic Energy Canada Limited (AECL) has harvested seven concrete cores from the 20 megawatt electric (MWe) Nuclear Power Demonstration Plant (NPD), which shutdown in 1988 after 25 years of operation. CNSC and AECL are also considering opportunities to harvest concrete from other decommissioned reactors in Canada such as Gentilly-2, Douglas Point, and Whiteshell Reactor 1. In addition to concrete, CNSC and AECL are currently harvesting electrical cables from the 675 MWe CANDU-6 Gentilly-2 reactor, which shutdown in 2012 after 29 years of operation. The purpose of this work is to study cable degradation from thermal aging and radiation damage and validate environmental qualification of the cables. CNSC described some of the challenges with this harvesting effort, such as working with plant owners, records, accessibility and contamination of the materials and budgeting with unexpected delays in harvesting.

A future harvesting opportunity is from the National Research Universal (NRU) reactor at Chalk River, which will shut down in 2018 after operating since 1957. AECL is currently taking an inventory of irradiated materials that can be harvested from NRU in decommissioning. Potential materials for

harvesting include metals (steels, nickel alloys, zirconium, aluminum), concrete, graphite, active equipment (pumps, etc.), graphite seals, electrical cables, and thermocouples.

Discussion Summary

Following the presentations, there was some discussion of lessons learned from DOE's Zion harvesting effort. DOE worked with a former senior reactor operator at Zion to identify and acquire the appropriate records from Zion for the components being harvested. DOE also described their flexible approach to acquiring RPV samples by sending a large chunk of material (weighing ~90 tons) to EnergySolutions' facility in Tennessee, where smaller pieces (weighing ~500 pounds) were cut to send to ORNL. Most of the decontamination was performed at Zion, with minimal additional cleaning (as well as cladding removal) taking place at EnergySolutions' facility.

There was also discussion of acquiring materials from sources other than commercial nuclear facilities. DOE has considered harvesting concrete from other DOE nuclear facilities, but determined that there were compositional differences between the DOE facilities and commercial facilities that would make the concrete from DOE facilities not useful. DOE/INL mentioned that the Advanced Test Reactor (ATR) replaces their core internals every ten years. The ATR internals are composed primarily of 347 stainless steel and achieve very high fluence levels after ten years of service.

Another key discussion topic was the possibility of developing a database for previously harvested materials or those available for future harvesting. DOE/INL indicated that their NSUF sample library may be a good starting point for such a database, although any materials in that library should be freely available for use in the research community. CNSC, NRC, and PNNL also expressed interested in working to develop a harvesting database.

Session 4. Harvesting Experience: Lessons Learned and Practical Aspects

Session 4 focused on lessons learned and practical aspects of harvesting. Presenters shared their experience with past harvesting programs, particularly common pitfalls to avoid and successful strategies to overcome them. Presentations also covered the practical aspects of harvesting from the plant owner and decommissioning company perspective. As shown in Appendix II with presentation titles, speakers for this session included:

- Jean Smith from EPRI,
- Tom Rosseel from DOE/ORNL,
- Matthew Hiser from NRC,
- Taku Arai from CRIEPI,
- Gerry van Noordennen from EnergySolutions, and
- Bill Zipp from Dominion.

Presentation Summaries

EPRI presented their experience and lessons learned from past harvesting programs, particularly harvesting reactor internals and concrete from Zorita and electrical cables from Crystal River. From the Zorita reactor internals experience, EPRI emphasized that harvesting projects take significant time, encounter both material retrieval and on-site challenges, and shipping issues. As shown in Figure 3, the Zorita Internals Research Project (ZIRP) took about 10 years to go from initial planning to final results, which included about 5 years of project planning, 2 years for material extraction (on-site logistics and shipping), and 3-4 years for testing. EPRI's experience was that decommissioning activities were the top priority and that harvesting was secondary, subject to schedule and logistical challenges based on the changing decommissioning schedule. Shipping issues were also challenging due to sending activated materials (which were classified as "waste") across international borders, from the reactor in Spain to the testing facility in Sweden. Currently, further planned shipments of the Zorita materials beyond the initial program continue to be impacted by export license challenges in Sweden. More positively, EPRI emphasized that the Zorita reactor internals materials harvesting showed excellent cooperation among many organizations and are now providing valuable technical information to numerous research projects.

Figure 3 Zorita Internals Research Project (ZIRP) Timeline

Lessons learned from the Zorita concrete harvesting focused on the challenges with core sample drilling and handling contaminated concrete. Ultimately, an effective core drilling procedure was identified, but required some trial and error. Lessons learned from the Crystal River cable harvesting included material concerns, the need for on-site support, and cost. In terms of material concerns, radiation and asbestos contamination created additional challenges for harvesting. On-site support and the ability to visit the site are extremely valuable to ensure clear communication, retrieval or records for material pedigree information, and awareness of on-site developments in the decommissioning process. Cable harvesting at Crystal River was more expensive than anticipated, particularly in terms of EPRI project management time to coordinate the harvesting activities and engineering support at the plant.

DOE/ORNL presented lessons learned primarily from the experience harvesting RPV materials and electrical cables and components from the Zion plant. In terms of planning and decision-making, DOE/ORNL had several lessons learned. DOE/ORNL hosted a workshop at Zion in 2011 to discuss long-term goals and objectives, which proved very helpful in setting priorities and developing partnerships with other organizations. Partnerships were very valuable to DOE/ORNL's harvesting efforts, allowing for leveraging resources and collaboration and sharing results. There are limited opportunities for harvesting key components, so DOE/ORNL emphasized that participants should take full advantage of the opportunities that arise, understanding that there is a necessary compromise between the materials available and their value in terms of fluence or exposure to aging conditions. Another consideration is the quantity of material harvested, which should be sufficient for the objectives of the planned research as well as any collaborations or partnerships, but limited to control costs.

For implementing the harvesting program, DOE/ORNL found that flexibility was paramount to be able to adjust scope and plans in response to schedule changes and other developments, while remaining within cost constraints. Working with a former reactor operator was extremely valuable to benefit from

their in-depth knowledge of all parts of the plant, in particular the records for materials pedigree information. Regular site visits and contacts were also essential to stay aware of the latest developments in the harvesting planning and decommissioning process, with the understanding that harvesting is not the top priority for the decommissioning company. Other important considerations were hazardous materials handling, transportation, and disposal and logistics, including contracts, liability, shipping and disposal. Finally, DOE/ORNL's experience is that the total costs of a harvesting program from planning to execution to testing are very high, so they should be carefully weighed against the value of the expected data to be generated.

NRC presented their experience, including benefits from previous harvesting programs, and technical and logistical lessons learned from harvesting. As an organization, NRC has extensive experience with testing harvested materials, including RPV, primary system components, reactor internals, neutron absorbers, concrete and electrical components. NRC's experience is more limited than DOE or EPRI in terms of managing the logistics of a harvesting effort from a decommissioning plant. NRC has generally participated in a secondary role in cooperative efforts or received failed components from operating plants for research. NRC has found that previous harvesting efforts have been effective in reducing unnecessary conservatism, understanding in-service flaws more realistically for NDE and leak rate methodologies, as well as identifying and better understanding safety issues.

For technical lessons learned, NRC's perspective is that harvesting can provide highly representative aged materials for research, which may be the only practical source of such materials. Harvested materials can be effectively used to validate models or a larger data set from accelerated aging tests. It is important to understand as much as possible about the materials and their in-service environment and how this compares with the operating fleet of reactors before committing to a specific harvesting project. For logistical lessons learned, harvesting is expensive and time-consuming, so a significant technical benefit is needed to ensure the program provides value. Leveraging resources with other organizations can help minimize costs, but can also introduce challenges for aligning priorities and interests of multiple organizations. Finally, transporting irradiated materials, particularly between countries, is challenging and time-consuming and should be avoided if at all possible.

CRIEPI presented their research experience with harvested materials as well as ongoing harvesting from the Hamaoka 1 plant. The first research program involved atom probe tomography (APT) on RPV surveillance materials. CRIEPI found a correlation between the volume fraction of Ni-Si-Mn clusters and the change in nil-ductility temperature. In the second research project, CRIEPI characterized the weld and base materials harvested from Greifswald Unit 4 RPV with small-angle neutron scattering, APT, and hardness testing. In the third research project, CRIEPI performed APT on 304L stainless steel reactor internals harvested from control rod and top guide components from 3-13 dpa. Results showed a strong increase in Ni-Si clusters with increasing fluence, but little variation in Al enriched clusters with increasing fluence.

Commented [FI3]: Was this a VVER-440 in the former GDR?

For future work, CRIEPI is collaborating with the DOE LWRS program to investigate RPV materials harvested from Zion [redacted] CRIEPI also presented activities underway by Chubu Electric Power to harvest RPV and concrete samples from the Hamaoka 1 plant. Hamaoka 1 is a 540 MWe BWR-4 that operated for 33 years. Harvesting began in 2015 and will continue through 2018.

(b)(4)

The final two presentations of Session 4 provided the non-researcher's perspective from a decommissioning company and plant owner. EnergySolutions, which is decommissioning the Zion nuclear plant among other facilities, presented on the decommissioning process and their experience and lessons learned from harvesting at Zion. As mentioned previously, surgical harvesting is not the top priority for decommissioning, so researchers must recognize this and coordinate closely with the decommissioning company. EnergySolutions emphasized the need to gain senior management support at the plant as well as to expect that there may be staff turnover during a multi-year harvesting effort. Changes in scope and schedule (originating from either side) can cause frustration on both sides. Early planning, efficient contracting, and frequent site visits are important to avoid lost opportunities and achieve a successful outcome.

At Zion, EnergySolutions worked with DOE to harvest RPV materials, cables, electrical components, and spent fuel storage racks. DOE hoped to harvest a particular RPV surveillance capsule, but was unable to do so due to the inability to identify the correct capsule. There were also challenges with harvesting RPV materials. The cut line on the Unit 2 RPV was too close to the weld to be used for research; fortunately, a successful specimen was harvested from Unit 1. For cabling, the initial plan was to harvest from 11 different locations, but ultimately, due to unforeseen challenges,~~ and~~ poor communication and coordination, only 4 different cable locations were harvested. Harvesting the desired cable length (30 feet) also proved challenging, with only shorter sections recovered. Searches of plant records were largely effective at providing material pedigree information for cables. Concrete coring was initially planned to take place at Zion, but not performed due to lack of research interest. The spent fuel storage rack harvesting went smoothly, which was assisted by weekend efforts when decommissioning activities were not occurring.

The next presentation from Dominion provided its perspective on harvesting from decommissioning plants, focused on the experience at Kewaunee Power Station. The top priority (beyond safety) in decommissioning is the preservation and good stewardship of the decommissioning trust fund. Staffing is the largest drain on the trust fund, so at Kewaunee, staff was halved within a few months of shutdown and then halved again, about 16 months after permanent shutdown once offsite emergency response requirements were eliminated. Dominion described the example of harvesting the RPV surveillance capsules at this point at Kewaunee and the significant challenges that would exist. Given the reduced staffing and the current plant state (reactor coolant system drained, pumps retired, crane and radiation monitoring not maintained), it would be much more difficult than immediately after shutdown. Kewaunee considered harvesting the RPV surveillance specimens and estimated a cost of six to seven figures based on all the activities required to enable it at this point, post-shutdown, compared to a much lower cost just after shutdown. Dominion observed that some components, such as cables or electrical components, may be available and relatively easy to harvest at almost any time during decommissioning. However, other components such as highly irradiated internals or RPV may be best harvested either shortly after shutdown when staffing and capabilities on-site are high or wait until active demolition of the reactor, which may be years or decades later.

Dominion also touched on the discussion of records for plant components. Records requirements are limited to those needed for safety. Once the plant shuts down and the range of potential safety concerns decreases, systems are downgraded to non-safety and the associated records are no longer required to be maintained. For perspective, Kewaunee still has all its records four years since shutdown, but will likely not continue this much longer. Dominion closed its presentation with a broader

perspective on harvesting, emphasizing the need to clearly define a problem statement and understand what technical and regulatory purpose this harvesting will serve. Early planning focused on achieving the clear objective of the work including scope, schedule, budget and contact with plant is essential to a successful harvesting effort.

Discussion Summary

The discussion touched on the top lessons learned from past harvesting efforts, which included defining a clear objective and purpose for harvesting, early engagement with the plant, and site coordination during harvesting.

Another suggestion was to get utility management buy-in for the harvesting project by identifying a benefit to the utility. EPRI mentioned that cable harvesting at Crystal River went much more successfully once the utility recognized the potential benefits for SLR. Similarly, when harvesting from an operating plant, one must recognize and work through the challenges the plant may encounter when restarting operations.

During discussion, the question was raised regarding how it is determined whether harvested materials are waste. The discussion concluded that in the U.S. 10 Code of Federal Regulations (CFR) 37 is the important consideration. 10 CFR 37 defines when additional security requirements are imposed, based on the quantity and activity of materials to be transported. The definition of material as waste versus research materials is not as critical in the U.S. EnergySolutions indicated that their shipments of waste or research material could be handled in the same way in the accordance with Department of Transportation regulations, provided that the limits in 10 CFR 37 were not reached.

Session 5. Future Harvesting Program Planning

Session 5 focused on the information needed for informed harvesting decision-making and harvesting program planning. This session featured a presentation by Pradeep Ramuhalli from PNNL, followed by a discussion period covering harvesting program planning and reflection on the 2-day workshop.

Presentation Summary

PNNL presented its perspective on the information needed for informed harvesting decision-making. First, the purpose of the harvesting effort needs to be defined by identifying the technical knowledge gaps to be addressed. Next, a research plan should be developed demonstrating how the harvested material will be used to address the identified gaps. Finally, the appropriate source of material to address the technical gap must be identified, along with resources to support the effort and plans and timelines to perform the harvesting. The specifics of these plans depend greatly on the source of materials and must be flexible based on changing conditions on the ground.

In assessing the best source of materials, researchers should consider the material, its environment, and its condition. Material information includes fabrication information such as manufacturer, composition, and dimensions as well as information related to installation or construction, such as welding processes and parameters. Environmental information includes temperature, humidity, fluence, flux, stress (service, residual, installation), and coolant chemistry. Component condition information includes inspection history, such as identified flaws or degradation.

Discussion Summary

The discussion in Session 5 focused on the best practical approach to plan future harvesting programs. There was clear agreement that this approach must begin with identifying the data needs best addressed by harvesting, whether from operating or decommissioning plants. Once a specific need is identified, the next step is to find a source to acquire the materials of interest as well as other organizations interested in participating in the harvesting effort.

Key Takeaways from Workshop

Session 1. Motivation for Harvesting

The clear takeaway from the discussion in Session 1 was that harvesting requires significant resources to be done successfully; therefore it is paramount to identify how the planned harvesting will clearly address a significant need to ensure the harvesting project provides strong value. In the context of the need for data, EPRI suggested that the goal of harvesting to support research for operation out to 80 years should ~~is~~ not be a ~~full~~ comprehensive understanding of all aspects of ~~the~~ degradation, but rather a snapshot to confirm other lab results and models. This is an important point for all organizations and researchers to keep in mind before investing significant resources in harvesting.

Session 2. Technical Data Needs for Harvesting

The criteria proposed by PNNL are a good starting point for prioritizing issues to address by harvesting. Three additional important criteria would be:

- Fleet-wide vs. plant-specific applicability of data,
- Ease of harvesting (in terms of cost and project risk), and
- Timeliness of the expected research results relative to the objective.

Once a potential harvesting project has reached the point of looking at different sources of materials, the availability of material pedigree information, such as composition, processing, environmental conditions (temperature, humidity, fluence, etc.) is very important to the overall value of harvesting from that particular plant.

Based on the presentations and discussion in Session 2, there appeared to be two areas where participants had broad interest in pursuing further harvesting: high fluence reactor internals and irradiated concrete. The common drivers for the interest in these issues is a lack of representative data at the fluences of interest and significant challenges with acquiring representative data through other means. High fluence reactor internals have been addressed somewhat by ZIRP, but stainless steel materials exposed to higher fluence levels at higher temperatures, where void swelling may become significant, could help validate DOE and EPRI models and provide further technical basis for PWR internals aging management. Irradiated concrete harvesting is currently being pursued from the Zorita reactor in Spain, with international collaboration and potential testing at the Halden Reactor Project.

Other areas with some, but less widespread, interest expressed from workshop participants for new harvesting efforts included RPV materials and electrical cables and components. SCK-CEN and NRC expressed interest in RPV harvesting, and NRC expressed interest in electrical component harvesting.

Session 3. Sources of Materials

To capture the key takeaways from Session 3 focused on sources of materials, two tables of potential sources of materials are presented below. Table 1 covers recent or ongoing harvesting programs, while Table 2 details potential future harvesting opportunities.

Table 1 Ongoing Harvesting Programs

Country	Plant	Design	Size (MWe)	Years in operation	Components	Organization(s)
Canada	NPD	CANDU	20	25	Concrete	AECL
	Gentilly-2	CANDU-6	675	29	Cables	
Japan	Hamaoka 1	BWR-4	540	33	RPV, concrete	CRIEPI, Chubu
Spain	Zorita	W 1-loop	160	37	Internals, concrete	EPRI, NRC
Sweden	Barseback	ABB-II	615	28	RPV	Vattenfall
U.S.	Zion ½	W – 4 loop	1040	24/25	RPV, cables, neutron absorbers	DOE, EPRI, NRC
	Crystal River 3	B&W	860	36	Cables	EPRI
	(b)(4)					

Table 2 Potential Future Sources for Harvesting

Country	Plant	Design	Size (MWe)	Years in operation	Potential Components	Notes
Canada	NRU	Test reactor	135 MWt	61	TBD	AECL; SD: 2018
Germany	Numerous plants either in decommissioning or shutting down soon. See Appendix III.					
Japan	Mihama	W 2-loop	320	40	Concrete	Kansai, Westinghouse
Korea	Kori 1	W 2-loop	576	40	RPV, internals, SGs, pressurizer, welds, CASS,	KHNP, EPRI
Sweden	Ringhals 1	BWR	883	44	RPV, internals SGs, pressurizer, concrete	Vattenfall; SD: 2020 / 2019
	Ringhals 2	W 3-loop	900	44		
U.S.	Kewaunee	W 2-loop	566	39	TBD	SD: 2013
	SONGS 2/3	CE 2-loop	1070	31/30	TBD	SD: 2013
	Crystal River 3	B&W	860	36	TBD	SD: 2013
	Vermont Yankee	BWR-4/Mk-1	605	42	TBD	SD: 2015
	Fort Calhoun	CE 2-loop	482	43	TBD	SD: 2016
	Palisades	CE 2-loop	805	47	TBD	SD: 2018
	Pilgrim	BWR-3/Mk-1	677	47	TBD	SD: 2019
	Oyster Creek	BWR-2/Mk-1	619	50	TBD	SD: 2019

	Indian Point 2/3	W 4-loop	1020 / 1040	48/46	TBD	SD: 2021
	Diablo Canyon ½	W 4-loop	1138 / 1118	40	TBD	SD: 2024-5
	Advanced Test Reactor	Test reactor	250 MWt	50	Core internals	Non-commercial; internals replaced every 10 years

In addition to the potential sources of materials presented and discussed in Session 3, another takeaway was the suggestion of developing a database for previously harvested materials or those available for future harvesting. The NSUF sample library may be a good starting point for such a database, with appropriate modifications for the purposes of harvesting efforts.

Session 4. Harvesting Experience: Lessons Learned and Practical Aspects

There were several important takeaways from Session 4 that were touched on in multiple presentations and the following discussions. One key takeaway is that researchers should identify a clear purpose and scope for harvesting. Having a clear purpose for harvesting helps to guide later decisions that must be made to adjust course when the inevitable changes in schedule or unexpected realities at the plant arise. A related note is that harvesting is not the top priority for decommissioning. Therefore, researchers must have clear objectives and scope for harvesting that can be communicated to the site. This understanding should shape assumptions and interactions with the plant owner or decommissioning company as well as planning for costs and schedule.

Another takeaway was the value of strong site coordination, including site visits. Multiple presenters touched on the value of being on-site to talk to staff and see the components to be harvested. Mockups and 3-D simulations can be valuable to ensure success of the approach or technique used to acquire the specimen. A related point is working with reactor operators at the plant. Several harvesting efforts worked with former reactor operators and benefited greatly from their experience to find records or determine the best method to harvest the desired component. This is a valuable insight that could be effective in future harvesting efforts.

A third key takeaway is early engagement with the plant personnel to express interest in harvesting. This serves to make the plant aware of interest in harvesting and get their support to work with the harvesting process. The other important benefit of early engagement is to gain as much information as possible about the available materials and components, including the associated records and material pedigree information.

Session 5. Future Harvesting Program Planning

The key takeaway in Session 5 was to gather as much information as possible in advance of committing to a specific harvesting project. Ideally, there would be a strong understanding that the material and its aging conditions clearly align with an identified technical data need before committing significant resources to a harvesting effort.

Action Items and Next Steps

The following is a summary of the action items discussed at the end of the workshop:

1. Sharing workshop slides
    - NRC emailed attendees to ask their comfort with sharing their workshop slides with other organizations and received no objection from any presenters.
    - The presentations can be accessed here: https://drive.google.com/open?id=0B5DWMLch5YSXcnpZZ0JOS055QUU .
2. EPRI indicated that MRP-320 (Product ID: 1022866) on knowledge gaps for irradiated austenitic stainless steel for potential harvesting from MRP-227 inspections is publicly available for a fee.
3. Cable surveillance programs in Germany
    - GRS to inquire with cable colleagues and share any insights.
4. Sources of materials database
    - Potential sources of materials presented in this workshop are summarized in Session 3 summary above and Appendix III below.
    - NRC will be reaching out to PNNL, INL NSUF, CNSC, AECL, and any other organizations interested in database development.
5. Prioritized data needs
    - Suggestion to continue discussions on prioritized data needs within technical areas (RPV, internals, electrical, concrete) through existing coordination groups if possible
        - Focus on identifying specific material / aging conditions of interest and purpose / intended outcome of harvesting
    - Idea to survey Env Deg participants
        - John Jackson (INL) is on planning committee
6. EPRI report on spent fuel liner boric acid transport through concrete
    - NRC will contact EPRI for report if needed.
7. Harvested Materials Research Results
    - Section of workshop summary report (below) devoted to references from harvested materials research.

Commented [FI4]: As commented above, should the slides be included in this report under new appendix?

Commented [FI5]: Conference? Please spell out the name.

References to Previous Harvested Materials Research

This section of the workshop summary addresses a question that was raised during the discussion at the workshop regarding what the outcome or benefit of past harvesting efforts have been. Below is a list of references to research results generated from testing of harvested materials:

Commented [FI6]: Please number the list of references.

J.R. Hawthorne and A.L. Hiser, *Experimental Assessments of Gundremmingen RPV Archive Material for Fluence Rate Effects Studies*, NUREG/CR-5201 (MEA-2286), U.S. Nuclear Regulatory Commission, October 1988.

O.K. Chopra, and W.J. Shack, *Mechanical Properties of Thermally Aged Cast Stainless Steels from Shippingport Reactor Components,* NUREG/CR-6275 (ANL-94/37), U.S. Nuclear Regulatory Commission, April 1995.

G. J. Schuster, S. R. Doctor, S.L. Crawford, and A. F. Pardini, *Characterization of Flaws in U.S. Reactor Pressure Vessels: Density and Distribution of Flaw Indications in the Shoreham Vessel*, NUREG/CR-6471 Volume 3, U.S. Nuclear Regulatory Commission, November 1999.

G. J. Schuster, S. R. Doctor, A.F. Pardini, and S.L. Crawford, *Characterization of Flaws in U.S. Reactor Pressure Vessels: Validation of Flaw Density and Distribution in the Weld Metal of the PVRUF Vessel*, NUREG/CR-6471 Volume 2, U.S. Nuclear Regulatory Commission, August 2000.

D.E. McCabe, et al. *Evaluation of WF-70 Weld Metal From the Midland Unit 1 Reactor Vessel*, NUREG/CR-5736 (ORNL/TM-13748), U.S. Nuclear Regulatory Commission, November 2000.

B. Alexandreanu, O.K. Chopra, and W.J. Shack, *Crack Growth Rates in a PWR Environment of Nickel Alloys from the Davis-Besse and V.C. Summer Power Plants,* NUREG/CR-6921 (ANL-05/55), U.S. Nuclear Regulatory Commission, November 2006.

S.E. Cumblidge, et al. *Nondestructive and Destructive Examination Studies on Removed-from-Service Control Rod Drive Mechanism Penetrations*, NUREG/CR-6996, U.S. Nuclear Regulatory Commission, July 2009.

S.E. Cumblidge, et al. *Evaluation of Ultrasonic Time-of-Flight Diffraction Data for Selected Control Rod Drive Nozzles from Davis Besse Nuclear Power Plant*, PNNL-19362, Pacific Northwest National Laboratory, April 2011.

S.L. Crawford, et al. *Ultrasonic Phased Array Assessment of the Interference Fit and Leak Path of the North Anna Unit 2 Control Rod Drive Mechanism Nozzle 63 with Destructive Validation*, NUREG/CR-7142 (PNNL-21547), U.S. Nuclear Regulatory Commission, August 2012.

Appendix I Workshop Participants

	Name	Organization	Email
Japan	Taku Arai	CRIEPI	arait@criepi.denken.or.jp
	Sadao Higuchi	CRIEPI	higuchi@criepi.denken.or.jp
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	Allen Hiser	NRC	Allen.Hiser@nrc.gov
	Angela Buford	NRC	Angela.Buford@nrc.gov
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	Amy Hull	NRC	Amy.Hull@nrc.gov
	Pete Ricardella	NRC/ACRS	Priccardella@Structint.com

Appendix II Workshop Agenda

Tuesday, March 7

Session	Time	Organization	Speaker	Presentation Title
Intro	8:00	NRC	Michael Weber Robert Tregoning	Welcome and Introduction to Workshop
1	8:15 – 8:45	DOE	Rich Reister	DOE Perspectives on Material Harvesting
		EPRI	Sherry Bernhoft	EPRI Perspective on Harvesting Projects
		NRC	Robert Tregoning	NRC Perspective on Motivation for Harvesting
		GRS	Uwe Jendrich	Role of GRS in Decommissioning and LTO
		CRIEPI	Taku Arai	CRIEPI Motivations for Harvested Material
	8:45 – 9:45	DISCUSSION		
9:45-10:00		**BREAK**		
2	10:00 – 10:20	PNNL (for NRC)	Pradeep Ramuhalli	Data Needs Best Addressed By Harvesting
	10:20 – 10:30	NRC	Matthew Hiser	High-Priority Data Needs for Harvesting
	10:30 – 10:55	DOE	Keith Leonard	LWRS Program Perspective on the Technical Needs for Harvesting
	10:55 – 11:20	SCK-CEN	Rachid Chaouadi	Review of past RPV sampling test programs and perspective for long term operation
	11:20 – 11:45	Westinghouse	Arzu Alpan	Importance of Harvesting to Evaluate Radiation Effects on Concrete Properties
	11:45 – 12:30	DISCUSSION		
12:30 – 2:00		**LUNCH**		
3	2:00 – 2:10	NRC	Matthew Hiser	Sources of Materials: Past NRC Harvesting and U.S. Decommissioning Plants
	2:10 – 2:35	EPRI	Al Ahluwalia	Harvesting Plans for Materials Aging Degradation Research in Korea and Sweden
	2:35 – 2:50	DOE/ORNL	Tom Rosseel	Materials Harvested by the LWRS Program
	2:50 – 3:00	DOE/INL	John Jackson	NSUF Material Sample Library
	3:00 – 3:15	Energy Solutions	Gerry van Noordennen	Zion Material Harvesting Program
	3:15 – 3:30	Westinghouse	Arzu Alpan	Potential Harvesting of Concrete from Mihama Unit 1
	3:30 – 3:45	**BREAK**		
	3:45 – 4:00	GRS	Uwe Jendrich	Plants in Decommissioning in Germany
	4:00 – 4:15	CNSC	Daniel Tello	Evaluating Structures, Systems & Components from Decommissioned/Decommissioning Nuclear Facilities in Canada
	4:15 – 5:00	DISCUSSION		

Wednesday, March 8

Session	Time	Organization	Speaker	Presentation Title
4	8:00 – 8:30	EPRI	Jean Smith	Lessons Learned: Harvesting and Shipping of Zorita Materials
	8:30 – 9:00	DOE	Tom Rosseel	LWRS Program: Harvesting Lessons Learned
	9:00 – 9:30	NRC	Matthew Hiser	NRC Perspective on Harvesting Experience and Lessons Learned
	9:30 – 10:00	CRIEPI	Taku Arai	CRIEPI Research Activities with Harvested Materials
	10:00 – 10:15	**BREAK**		
	10:15 - 10:45	Energy Solutions	Gerry van Noordennen	Zion Harvesting Experience and Lessons Learned
	10:45 - 11:15	Dominion	Bill Zipp	Kewaunee Insights on Material Harvesting
	11:15 – 12:00	DISCUSSION		
12:00 – 1:30		**LUNCH**		
5	1:30 – 1:45	PNNL (for NRC)	Pradeep Ramuhalli	Technical Information Needed for Informed Harvesting Decisions
	1:45 – 2:30	DISCUSSION		
	2:30 – 3:00	Action Items and Next Steps		
	3:00 – 4:00	EPRI	Sherry Bernhoft	Closing Thoughts
		DOE	Rich Reister	
		NRC	Robert Tregoning	
		ALL		

Appendix III Harvesting Opportunities in Germany

- Past and current decommissioning projects of **Prototype or Commercial Reactors**

Name	Abbrev.	Reactor type	Power MW_e	Decom. started	Strategy
Rheinsberg	KKR	WWER	70	1995	UC
Compact Natrium Cooled Reactor	KKN	SNR	21	1993	UC
Multipurpose Research R.	MZFR	PWR/D_2O	57	1987	UC
Obrigheim	KWO	PWR	357	2008	UC
Neckarwestheim 1	GKN-1	PWR	840	2017	UC
Isar-1	KKI-1	BWR	912	2017	UC
Gundremmingen-A	KRB-A	BWR	250	1983	RCA KRB-II
Greifswald 1-5	KGR 1-5	WWER	440	1995	UC
Lingen	KWL	BWR	268	1985	UC after SE

UC: unconditional clearance
RCA: radiation controlled area, new license
SE: safe enclosure

NRC Harvesting Workshop, Rockville, March 2017, Decommissioning in Germany 4

- Past and current decommissioning projects of **Prototype or Commercial Reactors**

Name	Abbrev.	Reactor type	Power MW_e	Decom. started	Strategy
Stade	KKS	PWR	672	2005	UC
Research Reactor Jülich	AVR	HTR	15	1994	UC
Thorium High-Temperature-Reaktor	THTR-300	HTR	308	1993	SE since 1997
Würgassen	KWW	BWR	670	1997	UC
Mülheim-Kärlich	KMK	PWR	1302	2004	UC
Hot-Steam Reactor Grosswelzheim	HDR	HDR	25	1983	UC since 1998
Niederaichbach	KKN	DRR/D_2O	106	1975	UC since 1994
Test-Reactor Kahl	VAK	BWR	16	1988	UC since 2010

- **Shut down Commercial Reactors**
  - **that have no decommissioning license granted yet**

Name	Abbrev.	Reactor type	Power MW_e	Date of application
Philippsburg-1	KKP-1	BWR	926	2013 / 2014
Grafenrheinfeld	KKG	PWR	1345	2014
Biblis-A	KWB-A	PWR	1225	2012
Biblis-B	KWB-B	PWR	1300	2012
Unterweser	KKU	BWR	1410	2012 / 2013
Brunsbüttel	KKB	BWR	806	2012 / 2014
Krümmel	KKK	BWR	1402	2015

- **Commercial Reactors in operation**

Name	Abbrev.	Reactor type	Power MW_e	Anticipated date of final shutdown
Gundremmingen-B	KRB-II-B	BWR	1344	31.12.2017
Philippsburg-2	KKP-2	PWR	1468	31.12.2019
Gundremmingen-C	KRB-II-C	BWR	1344	31.12.2021
Grohnde	KWG	PWR	1430	31.12.2021
Brokdorf	KBR	PWR	1480	31.12.2021
Emsland	KKE	PWR	1406	31.12.2022
Isar-2	KKI-2	PWR	1485	31.12.2022
Neckarwestheim-2	GKN-2	PWR	1400	31.12.2022

Note to requester: The attachment is immediately following this email.

From: Hiser, Matthew
Sent: Fri, 26 May 2017 13:18:00 +0000
To: Purtscher, Patrick;Tregoning, Robert;Hull, Amy;Frankl, Istvan
Subject: RE: Workshop Summary Report
Attachments: Harvesting Workshop Summary Report draft 5-26-17.docx

I have incorporated significant input from Amy and Pat on the Harvesting Workshop Summary Report. The latest version of the report is attached.

My plan is to send this complete draft to the workshop participants for review and comment by Wednesday, May 31. Please provide any further input or comments by next Wednesday to be incorporated in the draft sent to workshop participants.

I will ask for feedback from workshop participants by the end of June with the intent to finalize this summary report by mid-July.

Please let me know if you have any questions or suggestions on how to best move this effort forward.

Thanks!
Matt

Ex-Plant Materials Harvesting Workshop
Summary Report

Workshop held on March 7-8, 2017 at NRC headquarters in Rockville, MD

NRC staff: Matthew Hiser, Patrick Purtscher, Amy Hull, Robert Tregoning

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Background

On March 7-8, 2017, the Office of Nuclear Regulatory Research of the United States Nuclear Regulatory Commission (NRC) hosted a 2-day workshop on the topic of "Ex-Plant Materials Harvesting." NRC staff worked in close coordination with staff from the U.S. Department of Energy (DOE) and the Electric Power Research Institute (EPRI) to plan and arrange the workshop.

The decision to organize this workshop was driven by developments in the U.S. and global nuclear industry. In the U.S., there is strong interest in extending plant lifespans through subsequent license renewal (SLR) from 60 to 80 years. Extended plant operation and SLR raise a number of technical issues that may require further research to understand aging mechanisms, which may benefit from harvesting. Meanwhile, in recent years, a number of nuclear plants, both in the U.S. and internationally, have shut down or announced plans to shut down. Unlike in the past when there were very few plants shutting down, these new developments provide opportunities for harvesting components that were aged in representative light water reactor (LWR) environments. In a related development, economic challenges for the nuclear industry and limited government spending have limited the resources available to support new research, including harvesting programs. Given this constrained budget environment, aligning interests and leveraging with other organizations is important to allow maximum benefit and value for future research programs.

Objective and Approach

The objective of the workshop was to generate open discussion of all aspects of ex-plant materials harvesting, including:

1. Deciding whether to harvest,
2. Planning and implementing a harvesting program,
3. Using the harvested materials in research programs.

Through presentations and open discussion, the workshop was organized to allow for all participants to be better informed of the benefits and challenges of harvesting as well as to identify potential areas of common interest for future harvesting programs. Workshop sessions were aligned in broad topics to cover all aspects of harvesting, but allow for participants to drive the discussion.

To help accomplish the workshop objectives, the workshop organizers intentionally sought a diverse group of participants. There are a large number of decommissioning plants and interested researchers outside the U.S., so the organizers focused on outreach to international participants through connections such as the International Atomic Energy Agency (IAEA), Organization for Economic Cooperation and Development Nuclear Energy agency (OECD/NEA), and existing professional contacts. In addition, a key goal for this workshop was to capture the broader practical perspective from plant owners and decommissioning companies, which are vital to any successful harvesting program, but may sometimes be overlooked in researcher-driven discussions. Workshop participants were also diverse in terms of technical area of focus, with metal components such as the reactor pressure vessel (RPV) and internals being discussed along with concrete and electrical components. The final list of workshop participants can be found at the end of this report in Appendix I.

Workshop Organization and Sessions

The workshop was held at NRC headquarters in Rockville, MD. Due to limited space in the meeting room and the need for a limited group size for discussion, a webinar was used to allow remote observers to benefit from the workshop. Workshop sessions were organized topically with about half the time dedicated to presentations and the remaining time set aside for discussion. Presentations were solicited from participants to cover a range of perspectives and technical areas. The final workshop agenda can be found at the end of this summary report in Appendix II.

The workshop was organized into five sessions as follows:

- Session 1. Motivation for Harvesting
- Session 2. Technical Data Needs for Harvesting
- Session 3. Sources of Materials
- Session 4. Harvesting Experience: Lessons Learned and Practical Aspects
- Session 5. Future Harvesting Program Planning

Summary of Workshop Discussion

The subsections below will summarize the presentations and discussion in each session and highlight the key takeaways from the session.

Session 1. Motivation for Harvesting

Session 1 focused on the motivation for harvesting and why workshop participants are interested in harvesting. As shown in Appendix II with presentation titles, speakers for this session included:

- Richard Reister from DOE,
- Sherry Bernhoft from EPRI,
- Robert Tregoning from NRC,
- Uwe Jendrich from the Gesellschaft für Anlagen- und Reaktorsicherheit (GRS) in Germany, and
- Taku Arai from the Central Research Institute of the Electric Power Industry (CRIEPI) in Japan.

<u>Presentation Summaries</u>

DOE described the role of harvesting within the Light Water Reactor Sustainability (LWRS) Program, including the benefits and challenges associated with harvesting. Benefits include the opportunity to fill knowledge gaps where there is limited data or experience and to inform degradation models with data from actual plant components. Challenges include cost, complexity, scheduling, logistics, limited opportunities, acquiring sufficient material pedigree information, and potential negative results impacting operating plants.

EPRI discussed the role of harvesting within the context of aging management for Long-Term Operations (LTO), including their experience from past harvesting programs and criteria for future harvesting. Their experience emphasized the challenges of cost, schedule, logistics, complicated contracting and acquiring material pedigree information. EPRI’s criteria for harvesting focus on demonstrating value to their members by addressing a prioritized need that cannot be addressed through other means. For EPRI, a well-developed project plan that covers funding, risk management, exit ramps, and clear roles and responsibilities is essential.

NRC shared its perspective on the benefits and challenges of harvesting in regulatory research. Harvested materials are valuable due to the representative nature of their aging conditions, which may reduce the uncertainty associated with the applicability of the results to operating plants compared to tests with alternative aging conditions. Harvested materials may be the best option to address technical data needs identified for extended plant operation. With increasing harvesting opportunities from decommissioning plants, a proactive approach to harvesting planning can optimize benefits by identifying the right material with the right aging conditions for the identified knowledge gap. There are significant challenges associated with harvesting, including cost, schedule, and logistics, but hopefully these can be mitigated or avoided by leveraging resources with other organizations and learning from past experience.

GRS described its role as the main technical support organization in nuclear safety for the German federal government. GRS provides technical assessment and knowledge transfer for decommissioning activities, aging management, and long-term operation for German federal and international organizations.

CRIEPI discussed its view of how harvested materials and laboratory prepared materials contribute to addressing technical issues. Harvested materials provide exposure to actual plant conditions, but are more limited in availability and the size of the data set that can be generated. Laboratory prepared materials general involve accelerated or simulated aging conditions, but can be used to produce larger data sets and varying parameters can allow understanding of the effect on the mechanism or property of interest. Harvested materials offer fact finding of actual plant conditions as well as confirmation and verification of results from laboratory prepared specimens.

Discussion Summary

The discussion following the presentations in this session focused on clearly identifying the need to be addressed by a harvesting project and the myriad cost, schedule, and logistical challenges associated with harvesting. Leveraging with other organizations to defray costs can also help improve the value of a given program, but also adds complexity as another organization may have a different set of priorities that changes the focus of the harvesting effort.

Session 2. Technical Data Needs for Harvesting

Session 2 focused on discussing the technical data needs for harvesting and what specific knowledge gaps organizations are interested in addressing through harvesting. This discussion included general perspectives on how to determine when harvesting should be pursued rather than other types of research. As shown in Appendix II with presentation titles, speakers for this session included:

- Pradeep Ramuhalli from the Pacific Northwest National Lab (PNNL),
- Matthew Hiser from NRC,
- Keith Leonard from Oak Ridge National Laboratory (ORNL),
- Rachid Chaouadi from the Belgian Nuclear Research Centre (SCK-CEN) in Belgium, and
- Arzu Alpan from Westinghouse.

Presentation Summaries

PNNL presented their work, under a small NRC contract, to develop a systematic approach to prioritize data needs for harvesting. PNNL proposed five primary criteria for prioritizing harvesting:

- Unique field aspects of degradation
    - For example, unusual operating experience or legacy materials (composition, etc.) that may be no longer available
- Ease of laboratory replication of degradation scenario (combination of material and environment)
    - For example, simultaneous thermal and irradiation conditions may be difficult to replicate or mechanism sensitive to dose rate may not be good for accelerated aging
- Applicability of harvested material for addressing critical gaps
    - Prioritize harvesting for critical gaps over less essential data needs
- Availability of reliable in-service inspection (ISI) techniques for the material / component
    - If inspection methods are mature and easy to apply to monitor and track degradation, perhaps the effort of research with harvested materials is not needed.
- Availability of material for harvesting
    - The necessary materials / components must be available to be harvested.

PNNL then presented their application of these criteria to four materials degradation issues as an example: electrical cables, cast austenitic stainless steel (CASS), reactor vessel internals, and dissimilar metal welds. Based on applying these criteria to the examples, PNNL concluded that electrical cables, CASS, and reactor internals are all higher priority for harvesting due to unique aspects of the degradation that are challenging to replicate in the lab. Meanwhile, dissimilar metal welds are of low priority due to the ease of replication in lab aging studies as well as the significant body of knowledge and research on the phenomena.

NRC presented a summary of data needs it is interested in pursuing through harvesting. These included RPV materials to validate fluence and attenuation models and to demonstrate the conservatism of regulatory approaches for transition temperature prediction. Other metal components of interest for harvesting would address data gaps in irradiated stainless steels, as well as improve understanding of inspection capabilities and fatigue life calculations. Electrical components of interest include low and medium voltage cables and other electrical components for degradation studies, and electrical enclosures and cables for fire research. Concrete components of interest include irradiated concrete, concrete undergoing alkali-aggregate reactions, post-tensioned structures, reinforcing steel, tendons, and spent fuel pool concrete to assess potential boric acid attack.

DOE/ORNL presented their perspective on data needs for harvesting and its role in providing validation of experimental and theoretical research. DOE/ORNL performed a significant RPV harvesting program at the Zion nuclear power plant to reduce uncertainties in the Master Curve methodology, validate modeling predictions and study flux and fluence attenuation effects. The harvesting is largely complete, but the testing program is currently underway. DOE/ORNL also indicated interest in using harvested materials to validate its models for swelling and microstructural changes of stainless steel internals under LWR irradiation conditions. Harvesting concrete components would be of interest due to lack of literature data and the multiple dependent variables that may affect concrete performance. Finally, DOE/ORNL has been involved in harvesting cables from the Crystal River and Zion plants to address cable aging as a function of material composition and environment.

SCK-CEN presented their interest in an international cooperative program to harvest RPV materials. SCK-CEN presented their survey of the literature for past testing programs of harvested RPV materials, and

the limitations of these past program. Key limitations include a lack of archive materials, generally lower temperatures, and poor surveillance programs and dosimetry. SCK-CEN then shared some thoughts on their criteria for a new harvesting efforts, including higher fluence levels and temperatures, available archive materials and reliable information on operating history, dosimetry and surveillance program. Other topics relevant to a new RPV harvesting effort include technical issues such as material variability and irradiation conditions as well as logistical and financial considerations.

The final presentation in Session 2 by Westinghouse focused on the need for harvesting irradiated concrete to better understand the threshold radiation level for significant strength reduction. Westinghouse has installed ex-vessel neutron dosimetry (EVND) at a number of plants in the world and proposed to use these dosimetry measurements to validate fluence model calculations to better understand the uncertainty in these calculations. Figure 1 shows a schematic of the EVND setup. If concrete can be harvested at one of these plants with EVND data, then irradiated concrete properties from testing can be paired with fluence data to improve research benefits.

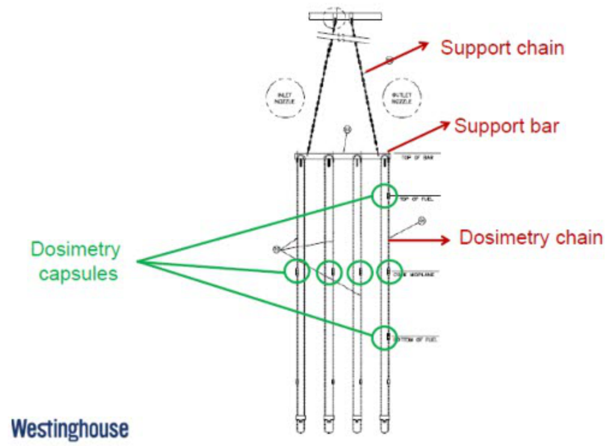

Figure 1 Schematic of Westinghouse ex-vessel neutron dosimetry (EVND)

Discussion Summary

The discussion following Session 2 presentations touched on a number of topics. EPRI shared that they developed a report related to the topics of Session 2, but more narrowly focused on pressurized water reactor (PWR) internals. MRP-320, “Testing Gap Assessment and Material Identification for PWR Internals,” focuses on prioritizing opportunistic harvesting of stainless steel reactor internals components that may be removed from service following MRP-227 inspections. The methodology and approach in this report may be relevant to the broader harvesting data needs discussion. This report is not publicly available, but is available to EPRI member utilities.

Workshop participants discussed the criteria proposed by PNNL in the first presentation. One additional criteria suggested by EPRI was to consider fleet-wide vs. plant-specific applicability. More broadly applicable materials would be of greater interest for harvesting than those that represent conditions at only a few plants. Another criteria suggested is the availability of material pedigree information, such as composition, processing, environmental conditions (temperature, humidity, fluence, etc.). Another suggested criteria was the ease of harvesting, which includes the concept of weighing costs vs. benefits as well as project risk. For example, highly irradiated internals are probably much more difficult and expensive to harvest than electrical cables or unirradiated concrete. Further discussion touched on the idea that different organizations may prioritize the various criteria differently, but all will probably at least want to consider the same set of criteria.

Another key theme from this discussion was that a successful program should be guided by a clearly defined objective or problem statement to be addressed. This objective should be well-understood at the initiation of a program and used to guide decision-making through implementation of a harvesting

project. This also raises a related point or potential criteria: the timeliness of the expected research results relative to the objective. If the results are needed in the next two years, but a harvesting project will not provide results for at least five years, that should be a strong consideration.

Session 3. Sources of Materials

Session 3 focused on discussing sources of materials for harvesting. This discussion covered previously harvested materials as well as sources for new harvesting programs from operating or decommissioning plants. Both domestic and international sources of materials were discussed in this session. As shown in Appendix II with presentation titles, speakers for this session included:

- Matthew Hiser from NRC,
- Al Ahluwalia from EPRI,
- Tom Rosseel from DOE/ORNL,
- John Jackson from DOE/Idaho National Laboratory (INL),
- Gerry van Noordennen from EnergySolutions,
- Arzu Alpan from Westinghouse,
- Uwe Jendrich from GRS, and
- Daniel Tello from the Canadian Nuclear Safety Commission (CNSC).

Presentation Summaries

NRC presented their perspective on sources of materials for harvesting. First, NRC shared some of the harvested materials from past research programs that may be available, including irradiated stainless steel internals, RPV materials, nickel alloy welds, neutron absorber material, and electrical components. NRC then summarized the recently and planned shutdown U.S. plants, including their design, thermal output, and years of operation, to provide participants with an idea of the potential sources from decommissioning U.S. plants. Finally, NRC shared a list of information that would be helpful to acquire from decommissioning plants to determine the value of components for harvesting. This information included plant design information (component location and dimensions), environmental conditions (temperature, fluence, humidity, stress, etc.) and operating history, material pedigree information (fabrication records), and inspection records (for interest in components with known flaws).

The next presentation from EPRI covered harvesting opportunities at decommissioning plants in Korea and Sweden. In Korea, Kori-1 is a Westinghouse 2-loop PWR (sister plant is Kewaunee) that will shut down in 2017 after 40 years of operation. Korea Hydro and Nuclear Power Central Research Institute (KHNP-CRI) is planning a comprehensive research program on long-term materials aging based on harvesting from Kori-1 and is seeking international participation in the harvesting effort. KHNP-CRI's plan is focused on metallic components, including RPV, internals, primary system components, steam generator materials. Harvesting is expected to occur in 2024 with testing to follow through 2030.

In Sweden, Vattenfall is currently harvesting in 2017-2018 RPV material from the decommissioning Barseback boiling water reactor (BWR) units. This work is focused on irradiation embrittlement, including comparison of surveillance data to actual RPV properties, as well as thermal aging embrittlement. In the future, Vattenfall will be shutting down Ringhals 1 and 2 in 2020 and 2019, respectively. Ringhals 1 is a BWR and Ringhals 2 is a Westinghouse 3-loop PWR design. Of particular note, Ringhals 2 has the second oldest replaced Alloy 690 RPV head and steam generators. Other harvesting opportunities at Ringhals include RPV material with a significant surveillance program, thermal aging effects on low alloy steel from the pressurizer, as well as concrete structures. Vattenfall is open to working with partners that are interested in joining them for harvesting at Ringhals.

The next presentation by DOE/ORNL focused on several harvesting programs that DOE's LWRS program has been involved with. DOE/ORNL has led the harvesting of components from the Zion [redacted] (b)(4)
(b)(4) plant [redacted] in the U.S. From Zion, DOE/ORNL has harvested electrical cables and components, a large RPV section, and a significant number of records to provide information on material fabrication, in-service inspection and operating history. Cables from Zion include CRDM, thermocouple, and low and medium voltage cables. DOE/ORNL indicated some thermocouple cables from Zion may be available for other researchers to use in collaborative studies. [redacted] (b)(4)
(b)(4)
(b)(4) DOE/ORNL is also participating in efforts to harvest cables from Crystal River (led by EPRI) and concrete from the Zorita plant in Spain (led by NRC).

The next presentation by DOE/INL described INL's Nuclear Science User Facilities (NSUF) and the Nuclear Fuels and Materials Library (NFML). NSUF is coordinated by INL and facilitates access to nuclear research facilities around the world, including neutron and ion irradiations, beamlines, hot cell testing, characterization and computing capabilities. NFML is a Web-based searchable database sample library that captures the information from thousands of specimens available to NSUF. NFML is designed to maximize the benefit of previously irradiated materials for future research. Researchers can propose new research projects under NSUF using specimens in NFML using DOE funding. As seen in Figure 2, the information captured in NFML aligns well with the goal of this session to potentially develop a database of previously harvested materials.

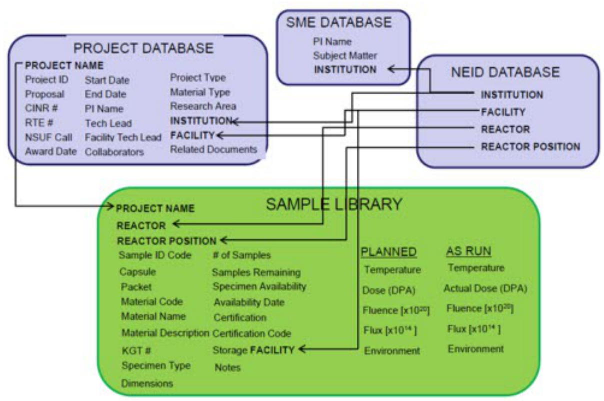

Figure 2 Nuclear Fuels and Materials Library (NFML) Database Design

The next presentation by EnergySolutions offered a more practical perspective on considering sources of materials for harvesting. From the plant owner perspective, in the decommissioning process there is not a financial incentive to support harvesting, therefore researchers need to absorb costs for harvesting and have a clear scope for harvesting. Flexibility in funding for harvesting activities is essential as the decommissioning process and schedule may change quickly.

EnergySolutions provided valuable perspective on the timing in the decommissioning process for harvesting different components. Harvesting RPV surveillance coupons should take place when the RPV internals are cut and removed. Harvesting RPV materials is only possible from larger RPVs, as smaller RPVs are shipped intact to the disposal facility, rather than cut into pieces. Spent fuel rack neutron absorber coupons must be harvested either before or after dry storage campaign to remove spent fuel from the spent fuel pool. Harvesting actual spent fuel rack neutron absorber material must come after the pool is completely empty. Electrical cables and other components from mild environments may be harvested at any time (once temporary power is established and plant power is shut off), while electrical components from high rad environments will depend on timing of source term removal schedule. Concrete cores are best harvested when other cores are being taken for site characterization to develop the License Termination Plan. Highly irradiated concrete from biological shield wall would need to come later in decommissioning after RPV is removed.

In terms of upcoming decommissioning plants, EnergySolutions indicated that San Onofre and Vermont Yankee will be entering DECON is 2018 and 2019, respectively. Kewaunee, Crystal River, and Fort Calhoun also may enter DECON in next 2 years. If researchers are interested in harvesting from any of these plants, they should be reaching out to plant owners immediately to begin planning and coordination.

Westinghouse followed their presentation in Session 2 by describing an opportunity to harvest concrete from the Mihama 1 plant in Japan. Westinghouse installed and analyzed additional neutron dosimetry in the reactor cavity for one cycle, which were used to validate the radiation transport calculations. Mihama was shutdown in 2015 and is in contact with Westinghouse about the possibility of extracting concrete cores from the biological shield wall. Westinghouse is seeking partners interested in joining this harvesting effort.

The next presentation by GRS covered opportunities for harvesting from German plants. Regulations in Germany require plants to either immediately dismantle or dismantle after a period of safe enclosure, which is largely consistent with options in the U.S. GRS detailed the status of German commercial reactors, which are predominantly BWR and PWR designs. Seventeen reactors are currently undergoing decommissioning, while seven more are currently shutdown and await a decommissioning license. Eight reactors are still operating with scheduled shutdown dates between 2017 and 2022. German RPVs tend to have lower fluence than U.S. designs due to a larger water gap in the downcomer region. Germany has limited experience with harvesting from decommissioning plants. One question that GRS will follow-up on is the “rumored” cable surveillance programs that may be used in Germany and could provide experience and lessons learned for other countries.

The final presentation in Session 3 was by CNSC on harvesting opportunities in Canada. Atomic Energy Canada Limited (AECL) has harvested seven concrete cores from the 20 megawatt electric (MWe) Nuclear Power Demonstration Plant (NPD), which shutdown in 1988 after 25 years of operation. CNSC and AECL are also considering opportunities to harvest concrete from other decommissioned reactors in Canada such as Gentilly-2, Douglas Point, and Whiteshell Reactor 1. In addition to concrete, CNSC and AECL are currently harvesting electrical cables from the 675 MWe CANDU-6 Gentilly-2 reactor, which shutdown in 2012 after 29 years of operation. The purpose of this work is to study cable degradation from thermal aging and radiation damage and validate environmental qualification of the cables. CNSC described some of the challenges with this harvesting effort, such as working with plant owners, records, accessibility and contamination of the materials and budgeting with unexpected delays in harvesting.

A future harvesting opportunity is from the National Research Universal (NRU) reactor at Chalk River, which will shut down in 2018 after operating since 1957. AECL is currently taking an inventory of irradiated materials that can be harvested from NRU in decommissioning. Potential materials for harvesting include metals (steels, nickel alloys, zirconium, aluminum), concrete, graphite, active equipment (pumps, etc.), graphite seals, electrical cables, and thermocouples.

Discussion Summary

Following the presentations, there was some discussion of lessons learned from DOE's Zion harvesting effort. DOE worked with a former senior reactor operator at Zion to identify and acquire the appropriate records from Zion for the components being harvested. DOE also described their flexible approach to acquiring RPV samples by sending a large chunk of material (weighing ~90 tons) to EnergySolutions' facility in Tennessee, where smaller pieces (weighing ~500 pounds) were cut to send to ORNL. Most of the decontamination was performed at Zion, with minimal additional cleaning (as well as cladding removal) taking place at EnergySolutions' facility.

There was also discussion of acquiring materials from sources other than commercial nuclear facilities. DOE has considered harvesting concrete from other DOE nuclear facilities, but determined that there were compositional differences between the DOE facilities and commercial facilities that would make the concrete from DOE facilities not useful. DOE/INL mentioned that the Advanced Test Reactor (ATR) replaces their core internals every ten years. The ATR internals are composed primarily of 347 stainless steel and achieve very high fluence levels after ten years of service.

Another key discussion topic was the possibility of developing a database for previously harvested materials or those available for future harvesting. DOE/INL indicated that their NSUF sample library may be a good starting point for such a database, although any materials in that library should be freely available for use in the research community. CNSC, NRC, and PNNL also expressed interested in working to develop a harvesting database.

Session 4. Harvesting Experience: Lessons Learned and Practical Aspects

Session 4 focused on lessons learned and practical aspects of harvesting. Presenters shared their experience with past harvesting programs, particularly common pitfalls to avoid and successful strategies to overcome them. Presentations also covered the practical aspects of harvesting from the plant owner and decommissioning company perspective. As shown in Appendix II with presentation titles, speakers for this session included:

- Jean Smith from EPRI,
- Tom Rosseel from DOE/ORNL,
- Matthew Hiser from NRC,
- Taku Arai from CRIEPI,
- Gerry van Noordennen from EnergySolutions, and
- Bill Zipp from Dominion.

Presentation Summaries

EPRI presented their experience and lessons learned from past harvesting programs, particularly harvesting reactor internals and concrete from Zorita and electrical cables from Crystal River. From the Zorita reactor internals experience, EPRI emphasized that harvesting projects take significant time, encounter both material retrieval and on-site challenges, and shipping issues. As shown in Figure 3, the Zorita Internals Research Project (ZIRP) took about 10 years to go from initial planning to final results, which included about 5 years of project planning, 2 years for material extraction (on-site logistics and shipping), and 3-4 years for testing. EPRI's experience was that decommissioning activities were the top priority and that harvesting was secondary, subject to schedule and logistical challenges based on the changing decommissioning schedule. Shipping issues were also challenging due to sending activated materials (which were classified as "waste") across international borders, from the reactor in Spain to the testing facility in Sweden. Currently, further planned shipments of the Zorita materials beyond the initial program continue to be impacted by export license challenges in Sweden. More positively, EPRI emphasized that the Zorita reactor internals materials harvesting showed excellent cooperation among many organizations and are now providing valuable technical information to numerous research projects.

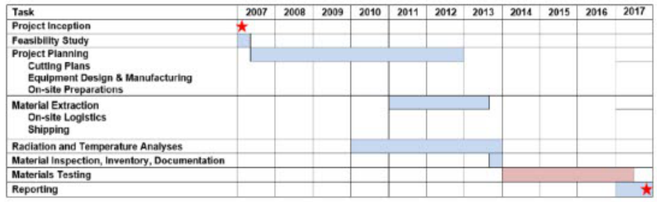

Figure 3 Zorita Internals Research Project (ZIRP) Timeline

Lessons learned from the Zorita concrete harvesting focused on the challenges with core sample drilling and handling contaminated concrete. Ultimately, an effective core drilling procedure was identified, but required some trial and error. Lessons learned from the Crystal River cable harvesting included material concerns, the need for on-site support, and cost. In terms of material concerns, radiation and asbestos contamination created additional challenges for harvesting. On-site support and the ability to visit the site are extremely valuable to ensure clear communication, retrieval or records for material pedigree information, and awareness of on-site developments in the decommissioning process. Cable harvesting at Crystal River was more expensive than anticipated, particularly in terms of EPRI project management time to coordinate the harvesting activities and engineering support at the plant.

DOE/ORNL presented lessons learned primarily from the experience harvesting RPV materials and electrical cables and components from the Zion plant. In terms of planning and decision-making, DOE/ORNL had several lessons learned. DOE/ORNL hosted a workshop at Zion in 2011 to discuss long-term goals and objectives, which proved very helpful in setting priorities and developing partnerships with other organizations. Partnerships were very valuable to DOE/ORNL's harvesting efforts, allowing for leveraging resources and collaboration and sharing results. There are limited opportunities for harvesting key components, so DOE/ORNL emphasized that participants should take full advantage of the opportunities that arise, understanding that there is a necessary compromise between the materials available and their value in terms of fluence or exposure to aging conditions. Another consideration is the quantity of material harvested, which should be sufficient for the objectives of the planned research as well as any collaborations or partnerships, but limited to control costs.

For implementing the harvesting program, DOE/ORNL found that flexibility was paramount to be able to adjust scope and plans in response to schedule changes and other developments, while remaining within cost constraints. Working with a former reactor operator was extremely valuable to benefit from

their in-depth knowledge of all parts of the plant, in particular the records for materials pedigree information. Regular site visits and contacts were also essential to stay aware of the latest developments in the harvesting planning and decommissioning process, with the understanding that harvesting is not the top priority for the decommissioning company. Other important considerations were hazardous materials handling, transportation, and disposal and logistics, including contracts, liability, shipping and disposal. Finally, DOE/ORNL's experience is that the total costs of a harvesting program from planning to execution to testing are very high, so they should be carefully weighed against the value of the expected data to be generated.

NRC presented their experience, including benefits from previous harvesting programs, and technical and logistical lessons learned from harvesting. As an organization, NRC has extensive experience with testing harvested materials, including RPV, primary system components, reactor internals, neutron absorbers, concrete and electrical components. NRC's experience is more limited than DOE or EPRI in terms of managing the logistics of a harvesting effort from a decommissioning plant. NRC has generally participated in a secondary role in cooperative efforts or received failed components from operating plants for research. NRC has found that previous harvesting efforts have been effective in reducing unnecessary conservatism, understanding in-service flaws more realistically for NDE and leak rate methodologies, as well as identifying and better understanding safety issues.

For technical lessons learned, NRC's perspective is that harvesting can provide highly representative aged materials for research, which may be the only practical source of such materials. Harvested materials can be effectively used to validate models or a larger data set from accelerated aging tests. It is important to understand as much as possible about the materials and their in-service environment and how this compares with the operating fleet of reactors before committing to a specific harvesting project. For logistical lessons learned, harvesting is expensive and time-consuming, so a significant technical benefit is needed to ensure the program provides value. Leveraging resources with other organizations can help minimize costs, but can also introduce challenges for aligning priorities and interests of multiple organizations. Finally, transporting irradiated materials, particularly between countries, is challenging and time-consuming and should be avoided if at all possible.

CRIEPI presented their research experience with harvested materials as well as ongoing harvesting from the Hamaoka 1 plant. The first research program involved atom probe tomography (APT) on RPV surveillance materials. CRIEPI found a correlation between the volume fraction of Ni-Si-Mn clusters and the change in nil-ductility temperature. In the second research project, CRIEPI characterized the weld and base materials harvested from Greifswald Unit 4 RPV with small-angle neutron scattering, APT, and hardness testing. In the third research project, CRIEPI performed APT on 304L stainless steel reactor internals harvested from control rod and top guide components from 3-13 dpa. Results showed a strong increase in Ni-Si clusters with increasing fluence, but little variation in Al enriched clusters with increasing fluence.

For future work, CRIEPI is collaborating with the DOE LWRS program to investigate RPV materials
(b)(4) harvested from Zion [redacted]. CRIEPI also presented activities underway by Chubu Electric Power to harvest RPV and concrete samples from the Hamaoka 1 plant. Hamaoka 1 is a 540 MWe BWR-4 that operated for 33 years. Harvesting began in 2015 and will continue through 2018.

The final two presentations of Session 4 provided the non-researcher perspective from a decommissioning company and plant owner. EnergySolutions, which is decommissioning the Zion nuclear plant among other facilities, presented the decommissioning process and their experience and lessons learned from harvesting at Zion. As mentioned previously, surgical harvesting is not the top priority for decommissioning, so researchers must recognize this and coordinate close with the decommissioning company. EnergySolutions emphasized the need to gain senior management support at the plant as well as to expect that there may be staff turnover during a multi-year harvesting effort. Changes in scope and schedule (originating from either side) can cause frustration on both sides. Early planning, efficient contracting, and frequent site visits are important to avoid lost opportunities and achieve a successful outcome.

At Zion, EnergySolutions worked with DOE to harvest RPV materials, cables, electrical components, and spent fuel storage racks. DOE hoped to harvest a particular RPV surveillance capsule, but was unable to due to the inability to identify the correct capsule. There were also challenges with harvesting RPV materials. The cut line on the Unit 2 RPV was too close to the weld to be used for research; fortunately, a successful specimen was harvested from Unit 1. For cabling, the initial plan was to harvest from 11 different locations, but ultimately due to unforeseen challenges and poor communication and coordination, only 4 different cable locations were harvested. Harvesting the desired cable length (30 feet) also proved challenging, with only shorter sections recovered. Searches of plant records were largely effective at providing material pedigree information for cables. Concrete coring was initially planned to take place at Zion, but not performed due to lack of research interest. The spent fuel storage rack harvesting went smoothly, which was assisted by weekend efforts when decommissioning activities were not occurring.

The next presentation from Dominion provided its perspective on harvesting from decommissioning plants, focused on the experience at Kewaunee Power Station. The top priority (beyond safety) in decommissioning is the preservation and good stewardship of the decommissioning trust fund. Staffing is the largest drain on the trust fund, so at Kewaunee, staff was halved within a few months of shutdown and then halved again, about 16 months after permanent shutdown once offsite emergency response requirements were eliminated. Dominion described the example of harvesting the RPV surveillance capsules at this point at Kewaunee and the significant challenges that would exist. Given the reduced staffing and the current plant state (reactor coolant system drained, pumps retired, crane and radiation monitoring not maintained), it would be much more difficult than immediately after shutdown. Kewaunee considered harvesting the RPV surveillance specimens and estimated a cost of six to seven figures based on all the activities required to enable it at this point, post-shutdown, compared to a much lower cost just after shutdown. Dominion observed that some components, such as cables or electrical components, may be available and relatively easy to harvest at almost any time during decommissioning. However, other components such as highly irradiated internals or RPV may be best harvested either shortly after shutdown when staffing and capabilities on-site are high or wait until active demolition of the reactor, which may be years or decades later.

Dominion also touched on the discussion of records for plant components. Records requirements are limited to those needed for safety. Once the plant shuts down and the range of potential safety concerns decreases, systems are downgraded to non-safety and the associated records are no longer required to be maintained. For perspective, Kewaunee still has all its records four years since shutdown, but will likely not continue this much longer. Dominion closed its presentation with a broader

perspective on harvesting, emphasizing the need to clearly define a problem statement and understand what technical and regulatory purpose this harvesting will serve. Early planning focused on achieving the clear objective of the work including scope, schedule, budget and contact with plant is essential to a successful harvesting effort.

Discussion Summary

The discussion touched on the top lessons learned from past harvesting efforts, which included defining a clear objective and purpose for harvesting, early engagement with the plant, and site coordination during harvesting.

Another suggestion was to get utility management buy-in for the harvesting project by identifying a benefit to the utility. EPRI mentioned that cable harvesting at Crystal River went much more successfully once the utility recognized the potential benefits for SLR. Similarly, when harvesting from an operating plant, one must recognize and work through the challenges the plant may encounter when restarting operations.

During discussion, the question was raised regarding how it is determined whether harvested materials are waste. The discussion concluded that in the U.S. 10 Code of Federal Regulations (CFR) 37 is the important consideration. 10 CFR 37 defines when additional security requirements are imposed, based on the quantity and activity of materials to be transported. The definition of material as waste versus research materials is not as critical in the U.S. EnergySolutions indicated that their shipments of waste or research material could be handled in the same way in the accordance with Department of Transportation regulations, provided that the limits in 10 CFR 37 were not reached.

Session 5. Future Harvesting Program Planning

Session 5 focused on the information needed for informed harvesting decision-making and harvesting program planning. This session featured a presentation by Pradeep Ramuhalli from PNNL, followed by a discussion period covering harvesting program planning and reflection on the 2-day workshop.

Presentation Summary

PNNL presented its perspective on the information needed for informed harvesting decision-making. First, the purpose of the harvesting effort needs to be defined by identifying the technical knowledge gaps to be addressed. Next, a research plan should be developed demonstrating how the harvested material will be used to address the identified gaps. Finally, the appropriate source of material to address the technical gap must be identified, along with resources to support the effort and plans and timelines to perform the harvesting. The specifics of these plans depend greatly on the source of materials and must be flexible based on changing conditions on the ground.

In assessing the best source of materials, researchers should consider the material, its environment, and its condition. Material information includes fabrication information such as manufacturer, composition, and dimensions as well as information related to installation or construction, such as welding processes and parameters. Environmental information includes temperature, humidity, fluence, flux, stress (service, residual, installation), and coolant chemistry. Component condition information includes inspection history, such as identified flaws or degradation.

Discussion Summary

The discussion in Session 5 focused on the best practical approach to plan future harvesting programs. There was clear agreement that this approach must begin with identifying the data needs best addressed by harvesting, whether from operating or decommissioning plants. Once a specific need is identified, the next step is to find a source to acquire the materials of interest as well as other organizations interested in participating in the harvesting effort.

Key Takeaways from Workshop

Session 1. Motivation for Harvesting

The clear takeaway from the discussion in Session 1 was that harvesting requires significant resources to be done successfully; therefore it is paramount to identify how the planned harvesting will clearly address a significant need to ensure the harvesting project provides strong value. In the context of need for data, EPRI suggested the goal of harvesting to support research for operation out to 80 years is not a full comprehensive understanding of all aspects of the degradation, but rather a snapshot to confirm other lab results and models. This is an important point for all organizations and researchers to keep in mind before investing significant resources in harvesting.

Session 2. Technical Data Needs for Harvesting

The criteria proposed by PNNL are a good starting point for prioritizing issues to address by harvesting. Three additional important criteria would be:

- Fleet-wide vs. plant-specific applicability of data,
- Ease of harvesting (in terms of cost and project risk), and
- Timeliness of the expected research results relative to the objective.

Once a potential harvesting project has reached the point of looking at different sources of materials, the availability of material pedigree information, such as composition, processing, environmental conditions (temperature, humidity, fluence, etc.) is very important to the overall value of harvesting from that particular plant.

Based on the presentations and discussion in Session 2, there appeared to be two areas where participants had broad interest in pursuing further harvesting: high fluence reactor internals and irradiated concrete. The common drivers for the interest in these issues is a lack of representative data at the fluences of interest and significant challenges with acquiring representative data through other means. High fluence reactor internals have been addressed somewhat by ZIRP, but stainless steel materials exposed to higher fluence levels at higher temperatures, where void swelling may become significant, could help validate DOE and EPRI models and provide further technical basis for PWR internals aging management. Irradiated concrete harvesting is currently being pursued from the Zorita reactor in Spain, with international collaboration and potential testing at the Halden Reactor Project.

Other areas with some, but less widespread, interest expressed from workshop participants for new harvesting efforts included RPV materials and electrical cables and components. SCK-CEN and NRC expressed interest in RPV harvesting, and NRC expressed interest in electrical component harvesting.

Session 3. Sources of Materials

To capture the key takeaways from Session 3 focused on sources of materials, two tables of potential sources of materials are presented below. Table 1 covers recent or ongoing harvesting programs, while Table 2 details potential future harvesting opportunities.

Table 1 Ongoing Harvesting Programs

Country	Plant	Design	Size (MWe)	Years in operation	Components	Organization(s)
Canada	NPD	CANDU	20	25	Concrete	AECL
	Gentilly-2	CANDU-6	675	29	Cables	
Japan	Hamaoka 1	BWR-4	540	33	RPV, concrete	CRIEPI, Chubu
Spain	Zorita	W 1-loop	160	37	Internals, concrete	EPRI, NRC
Sweden	Barseback	ABB-II	615	28	RPV	Vattenfall
U.S.	Zion ½	W – 4 loop	1040	24/25	RPV, cables, neutron absorbers	DOE, EPRI, NRC
	Crystal River 3	B&W	860	36	Cables	EPRI
	(b)(4)					

Table 2 Potential Future Sources for Harvesting

Country	Plant	Design	Size (MWe)	Years in operation	Potential Components	Notes
Canada	NRU	Test reactor	135 MWt	61	TBD	AECL; SD: 2018
Germany	Numerous plants either in decommissioning or shutting down soon. See Appendix III.					
Japan	Mihama	W 2-loop	320	40	Concrete	Kansai, Westinghouse
Korea	Kori 1	W 2-loop	576	40	RPV, internals, SGs, pressurizer, welds, CASS,	KHNP, EPRI
Sweden	Ringhals 1	BWR	883	44	RPV, internals SGs, pressurizer, concrete	Vattenfall; SD: 2020 / 2019
	Ringhals 2	W 3-loop	900	44		
U.S.	Kewaunee	W 2-loop	566	39	TBD	SD: 2013
	SONGS 2/3	CE 2-loop	1070	31/30	TBD	SD: 2013
	Crystal River 3	B&W	860	36	TBD	SD: 2013
	Vermont Yankee	BWR-4/Mk-1	605	42	TBD	SD: 2015
	Fort Calhoun	CE 2-loop	482	43	TBD	SD: 2016
	Palisades	CE 2-loop	805	47	TBD	SD: 2018
	Pilgrim	BWR-3/Mk-1	677	47	TBD	SD: 2019
	Oyster Creek	BWR-2/Mk-1	619	50	TBD	SD: 2019

	Indian Point 2/3	W 4-loop	1020 / 1040	48/46	TBD	SD: 2021
	Diablo Canyon ½	W 4-loop	1138 / 1118	40	TBD	SD: 2024-5
	Advanced Test Reactor	Test reactor	250 MWt	50	Core internals	Non-commercial; internals replaced every 10 years

In addition to the potential sources of materials presented and discussed in Session 3, another takeaway was the suggestion of developing a database for previously harvested materials or those available for future harvesting. The NSUF sample library may be a good starting point for such a database, with appropriate modifications for the purposes of harvesting efforts.

Session 4. Harvesting Experience: Lessons Learned and Practical Aspects

There were several important takeaways from Session 4 that were touched on in multiple presentations and the following discussions. One key takeaway is that researchers should identify a clear purpose and scope for harvesting. Having a clear purpose for harvesting helps to guide later decisions that must be made to adjust course when the inevitable changes in schedule or unexpected realities at the plant arise. A related note is that harvesting is not the top priority for decommissioning. Therefore, researchers must have clear objectives and scope for harvesting that can be communicated to the site. This understanding should shape assumptions and interactions with the plant owner or decommissioning company as well as planning for costs and schedule.

Another takeaway was the value of strong site coordination, including site visits. Multiple presenters touched on the value of being on-site to talk to staff and see the components to be harvested. Mockups and 3-D simulations can be valuable to ensure success of the approach or technique used to acquire the specimen. A related point is working with reactor operators at the plant. Several harvesting efforts worked with former reactor operators and benefited greatly from their experience to find records or determine the best method to harvest the desired component. This is a valuable insight that could be effective in future harvesting efforts.

A third key takeaway is early engagement with the plant personnel to express interest in harvesting. This serves to make the plant aware of interest in harvesting and get their support to work with the harvesting process. The other important benefit of early engagement is to gain as much information as possible about the available materials and components, including the associated records and material pedigree information.

Session 5. Future Harvesting Program Planning

The key takeaway in Session 5 was to gather as much information as possible in advance of committing to a specific harvesting project. Ideally, there would be a strong understanding that the material and its aging conditions clearly align with an identified technical data need before committing significant resources to a harvesting effort.

Action Items and Next Steps

The following is a summary of the action items discussed at the end of the workshop:

1. Sharing workshop slides
    - NRC emailed attendees to ask their comfort with sharing their workshop slides with other organizations and received no objection from any presenters.
    - The presentations can be accessed here: https://drive.google.com/open?id=0B5DWMLch5YSXcnpZZ0JOS055QUU .
2. EPRI indicated that MRP-320 (Product ID: 1022866) on knowledge gaps for irradiated austenitic stainless steel for potential harvesting from MRP-227 inspections is publicly available for a fee.
3. Cable surveillance programs in Germany
    - GRS to inquire with cable colleagues and share any insights.
4. Sources of materials database
    - Potential sources of materials presented in this workshop are summarized in Session 3 summary above and Appendix III below.
    - NRC will be reaching out to PNNL, INL NSUF, CNSC, AECL, and any other organizations interested in database development.
5. Prioritized data needs
    - Suggestion to continue discussions on prioritized data needs within technical areas (RPV, internals, electrical, concrete) through existing coordination groups if possible
        - Focus on identifying specific material / aging conditions of interest and purpose / intended outcome of harvesting
    - Idea to survey Env Deg participants
        - John Jackson (INL) is on planning committee
6. EPRI report on spent fuel liner boric acid transport through concrete
    - NRC will contact EPRI for report if needed.
7. Harvested Materials Research Results
    - Section of workshop summary report (below) devoted to references from harvested materials research.

References to Previous Harvested Materials Research

This section of the workshop summary addresses a question that was raised during the discussion at the workshop regarding what the outcome or benefit of past harvesting efforts have been. Below is a list of references to research results generated from testing of harvested materials:

J.R. Hawthorne and A.L. Hiser, *Experimental Assessments of Gundremmingen RPV Archive Material for Fluence Rate Effects Studies*, NUREG/CR-5201 (MEA-2286), U.S. Nuclear Regulatory Commission, October 1988.

O.K. Chopra, and W.J. Shack, *Mechanical Properties of Thermally Aged Cast Stainless Steels from Shippingport Reactor Components,* NUREG/CR-6275 (ANL-94/37), U.S. Nuclear Regulatory Commission, April 1995.

G. J. Schuster, S. R. Doctor, S.L. Crawford, and A. F. Pardini, *Characterization of Flaws in U.S. Reactor Pressure Vessels: Density and Distribution of Flaw Indications in the Shoreham Vessel*, NUREG/CR-6471 Volume 3, U.S. Nuclear Regulatory Commission, November 1999.

G. J. Schuster, S. R. Doctor, A.F. Pardini, and S.L. Crawford, *Characterization of Flaws in U.S. Reactor Pressure Vessels: Validation of Flaw Density and Distribution in the Weld Metal of the PVRUF Vessel*, NUREG/CR-6471 Volume 2, U.S. Nuclear Regulatory Commission, August 2000.

D.E. McCabe, et al. *Evaluation of WF-70 Weld Metal From the Midland Unit 1 Reactor Vessel*, NUREG/CR-5736 (ORNL/TM-13748), U.S. Nuclear Regulatory Commission, November 2000.

B. Alexandreanu, O.K. Chopra, and W.J. Shack, *Crack Growth Rates in a PWR Environment of Nickel Alloys from the Davis-Besse and V.C. Summer Power Plants,* NUREG/CR-6921 (ANL-05/55), U.S. Nuclear Regulatory Commission, November 2006.

S.E. Cumblidge, et al. *Nondestructive and Destructive Examination Studies on Removed-from-Service Control Rod Drive Mechanism Penetrations*, NUREG/CR-6996, U.S. Nuclear Regulatory Commission, July 2009.

S.E. Cumblidge, et al. *Evaluation of Ultrasonic Time-of-Flight Diffraction Data for Selected Control Rod Drive Nozzles from Davis Besse Nuclear Power Plant*, PNNL-19362, Pacific Northwest National Laboratory, April 2011.

S.L. Crawford, et al. *Ultrasonic Phased Array Assessment of the Interference Fit and Leak Path of the North Anna Unit 2 Control Rod Drive Mechanism Nozzle 63 with Destructive Validation*, NUREG/CR-7142 (PNNL-21547), U.S. Nuclear Regulatory Commission, August 2012.

Appendix I Workshop Participants

	Name	Organization	Email
Japan	Taku Arai	CRIEPI	arait@criepi.denken.or.jp
	Sadao Higuchi	CRIEPI	higuchi@criepi.denken.or.jp
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Europe	Uwe Jendrich	GRS	Uwe.Jendrich@grs.de
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Canada	Daniel Tello	CNSC	daniel.tello@canada.ca
	Désiré Ndomba	CNSC	desire.ndomba@canada.ca
	Karen Huynh	AECL	khuynh@aecl.ca
US industry	Gerry van Noordennen	Energy Solutions	gpvannoordennen@energysolutions.com
	Bill Zipp	Dominion	william.f.zipp@dom.com
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	Arzu Alpan	Westinghouse	alpanfa@westinghouse.com
EPRI	Sherry Bernhoft	EPRI	sbernhoft@epri.com
	Robin Dyle	EPRI	rdyle@epri.com
	Jean Smith	EPRI	jmsmith@epri.com
	Al Ahluwalia	EPRI	kahluwal@epri.com
DOE	Tom Rosseel	ORNL	rosseeltm@ornl.gov
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	Keith Leonard	ORNL	leonardk@ornl.gov
	Mikhail A. Sokolov	ORNL	sokolovm@ornl.gov
	John Wagner	INL	john.wagner@inl.gov
	John Jackson	INL	john.jackson@inl.gov
	Pradeep Ramuhalli	PNNL	Pradeep.Ramuhalli@pnnl.gov
NRC	Pat Purtscher	NRC	Patrick.Purtscher@nrc.gov
	Rob Tregoning	NRC	Robert.Tregoning@nrc.gov
	Matt Hiser	NRC	Matthew.Hiser@nrc.gov
	Mita Sircar	NRC	Madhumita.Sircar@nrc.gov
	Tom Koshy	NRC	Thomas.Koshy@nrc.gov
	Jeff Poehler	NRC	Jeffrey.Poehler@nrc.gov
	Allen Hiser	NRC	Allen.Hiser@nrc.gov
	Angela Buford	NRC	Angela.Buford@nrc.gov
	Mark Kirk	NRC	Mark.Kirk@nrc.gov
	Amy Hull	NRC	Amy.Hull@nrc.gov
	Pete Ricardella	NRC/ACRS	Priccardella@Structint.com

Appendix II Workshop Agenda

Tuesday, March 7

Session	Time	Organization	Speaker	Presentation Title
Intro	8:00	NRC	Michael Weber Robert Tregoning	Welcome and Introduction to Workshop
1	8:15 – 8:45	DOE	Rich Reister	DOE Perspectives on Material Harvesting
		EPRI	Sherry Bernhoft	EPRI Perspective on Harvesting Projects
		NRC	Robert Tregoning	NRC Perspective on Motivation for Harvesting
		GRS	Uwe Jendrich	Role of GRS in Decommissioning and LTO
		CRIEPI	Taku Arai	CRIEPI Motivations for Harvested Material
	8:45 – 9:45	DISCUSSION		
9:45-10:00		**BREAK**		
2	10:00 – 10:20	PNNL (for NRC)	Pradeep Ramuhalli	Data Needs Best Addressed By Harvesting
	10:20 – 10:30	NRC	Matthew Hiser	High-Priority Data Needs for Harvesting
	10:30 – 10:55	DOE	Keith Leonard	LWRS Program Perspective on the Technical Needs for Harvesting
	10:55 – 11:20	SCK-CEN	Rachid Chaouadi	Review of past RPV sampling test programs and perspective for long term operation
	11:20 – 11:45	Westinghouse	Arzu Alpan	Importance of Harvesting to Evaluate Radiation Effects on Concrete Properties
	11:45 – 12:30	DISCUSSION		
12:30 – 2:00		**LUNCH**		
3	2:00 – 2:10	NRC	Matthew Hiser	Sources of Materials: Past NRC Harvesting and U.S. Decommissioning Plants
	2:10 – 2:35	EPRI	Al Ahluwalia	Harvesting Plans for Materials Aging Degradation Research in Korea and Sweden
	2:35 – 2:50	DOE/ORNL	Tom Rosseel	Materials Harvested by the LWRS Program
	2:50 – 3:00	DOE/INL	John Jackson	NSUF Material Sample Library
	3:00 – 3:15	Energy Solutions	Gerry van Noordennen	Zion Material Harvesting Program
	3:15 – 3:30	Westinghouse	Arzu Alpan	Potential Harvesting of Concrete from Mihama Unit 1
	3:30 – 3:45	**BREAK**		
	3:45 – 4:00	GRS	Uwe Jendrich	Plants in Decommissioning in Germany
	4:00 – 4:15	CNSC	Daniel Tello	Evaluating Structures, Systems & Components from Decommissioned/Decommissioning Nuclear Facilities in Canada
	4:15 – 5:00	DISCUSSION		

Wednesday, March 8

Session	Time	Organization	Speaker	Presentation Title
4	8:00 – 8:30	EPRI	Jean Smith	Lessons Learned: Harvesting and Shipping of Zorita Materials
	8:30 – 9:00	DOE	Tom Rosseel	LWRS Program: Harvesting Lessons Learned
	9:00 – 9:30	NRC	Matthew Hiser	NRC Perspective on Harvesting Experience and Lessons Learned
	9:30 – 10:00	CRIEPI	Taku Arai	CRIEPI Research Activities with Harvested Materials
	10:00 – 10:15	**BREAK**		
	10:15 - 10:45	Energy Solutions	Gerry van Noordennen	Zion Harvesting Experience and Lessons Learned
	10:45 - 11:15	Dominion	Bill Zipp	Kewaunee Insights on Material Harvesting
	11:15 – 12:00	DISCUSSION		
12:00 – 1:30		**LUNCH**		
5	1:30 – 1:45	PNNL (for NRC)	Pradeep Ramuhalli	Technical Information Needed for Informed Harvesting Decisions
	1:45 – 2:30	DISCUSSION		
	2:30 – 3:00	Action Items and Next Steps		
	3:00 – 4:00	EPRI	Sherry Bernhoft	Closing Thoughts
		DOE	Rich Reister	
		NRC	Robert Tregoning	
		ALL		

Appendix III Harvesting Opportunities in Germany

- Past and current decommissioning projects of **Prototype or Commercial Reactors**

Name	Abbrev.	Reactor type	Power MW_e	Decom. started	Strategy
Rheinsberg	KKR	WWER	70	1995	UC
Compact Natrium Cooled Reactor	KKN	SNR	21	1993	UC
Multipurpose Research R.	MZFR	PWR/D_2O	57	1987	UC
Obrigheim	KWO	PWR	357	2008	UC
Neckarwestheim 1	GKN-1	PWR	840	2017	UC
Isar-1	KKI-1	BWR	912	2017	UC
Gundremmingen-A	KRB-A	BWR	250	1983	RCA KRB-II
Greifswald 1-5	KGR 1-5	WWER	440	1995	UC
Lingen	KWL	BWR	268	1985	UC after SE

UC: unconditional clearance
RCA: radiation controlled area, new license
SE: safe enclosure

NRC Harvesting Workshop, Rockville, March 2017, Decommissioning in Germany 4

- Past and current decommissioning projects of **Prototype or Commercial Reactors**

Name	Abbrev.	Reactor type	Power MW_e	Decom. started	Strategy
Stade	KKS	PWR	672	2005	UC
Research Reactor Jülich	AVR	HTR	15	1994	UC
Thorium High-Temperature-Reaktor	THTR-300	HTR	308	1993	SE since 1997
Würgassen	KWW	BWR	670	1997	UC
Mülheim-Kärlich	KMK	PWR	1302	2004	UC
Hot-Steam Reactor Grosswelzheim	HDR	HDR	25	1983	UC since 1998
Niederaichbach	KKN	DRR/D_2O	106	1975	UC since 1994
Test-Reactor Kahl	VAK	BWR	16	1988	UC since 2010

- **Shut down Commercial Reactors**
  - **that have no decommissioning license granted yet**

Name	Abbrev.	Reactor type	Power MW_e	Date of application
Philippsburg-1	KKP-1	BWR	926	2013 / 2014
Grafenrheinfeld	KKG	PWR	1345	2014
Biblis-A	KWB-A	PWR	1225	2012
Biblis-B	KWB-B	PWR	1300	2012
Unterweser	KKU	BWR	1410	2012 / 2013
Brunsbüttel	KKB	BWR	806	2012 / 2014
Krümmel	KKK	BWR	1402	2015

- **Commercial Reactors in operation**

Name	Abbrev.	Reactor type	Power MW_e	Anticipated date of final shutdown
Gundremmingen-B	KRB-II-B	BWR	1344	31.12.2017
Philippsburg-2	KKP-2	PWR	1468	31.12.2019
Gundremmingen-C	KRB-II-C	BWR	1344	31.12.2021
Grohnde	KWG	PWR	1430	31.12.2021
Brokdorf	KBR	PWR	1480	31.12.2021
Emsland	KKE	PWR	1406	31.12.2022
Isar-2	KKI-2	PWR	1485	31.12.2022
Neckarwestheim-2	GKN-2	PWR	1400	31.12.2022

Note to requester: The attachment is immediately following this email.

From: Hiser, Matthew
Sent: Tue, 16 May 2017 14:42:30 +0000
To: Purtscher, Patrick;Tregoning, Robert;Ramuhalli, Pradeep (Pradeep.Ramuhalli@pnnl.gov)
Subject: RE: Workshop Summary Report
Attachments: Harvesting Workshop Summary Report draft 5-16-17.docx

Sending the latest version with a few references to past research on harvested materials…

Matthew Hiser
Materials Engineer
US Nuclear Regulatory Commission | Office of Nuclear Regulatory Research
Division of Engineering | Corrosion and Metallurgy Branch
Phone: 301-415-2454 | Office: TWFN 10D62
Matthew.Hiser@nrc.gov

From: Hiser, Matthew
Sent: Friday, May 12, 2017 5:24 PM
To: Purtscher, Patrick ; Tregoning, Robert ; Ramuhalli, Pradeep (Pradeep.Ramuhalli@pnnl.gov)
Subject: Workshop Summary Report

Hi Pat, Rob, and Pradeep,

I'd like to share with you a largely complete initial draft of the harvesting workshop summary report. I tried to capture the important points of the presentations and discussion at the workshop and then synthesize that down to "key takeaways" (I am open to a better term, but that's what I came up with). I still need to fill in the section on "References to Past Harvested Materials Research", but otherwise consider this a complete draft.

Please feel free to review and comment the overall organization, level of detail, etc. You can also review the specific wording with edits and tracked changes if you'd like, although I'd suggest not spending too much effort down in the weeds at this point.

My hope is to get some feedback in the next 2 weeks from this group and then share with the broader group of workshop attendees by the end of May for their review and input with a target to finalize this report by the end of June.

Thanks and please let me know if you have any questions!

Matt

Harvesting Workshop Summary Report

Background

On March 7-8, 2017, the Office of Nuclear Regulatory Research of the United States Nuclear Regulatory Commission (NRC) hosted a 2-day workshop on the topic of "Ex-Plant Materials Harvesting." NRC staff worked in close coordination with staff from the U.S. Department of Energy (DOE) and the Electric Power Research Institute (EPRI) to plan and arrange the workshop.

The decision to organize this workshop was driven by developments in the U.S. and global nuclear industry. In the U.S., there is strong interest in extending plant lifespans through subsequent license renewal (SLR) from 60 to 80 years. Extended plant operation and SLR raise a number of technical issues that may require further research to understand aging mechanisms, which may benefit from harvesting. Meanwhile, in recent years, a number of nuclear plants, both in the U.S. and internationally, have shut down or announced plans to shut down. Unlike in the past when there were very few plants shutting down, these new developments provide opportunities for harvesting components that were aged in representative light water reactor (LWR) environments. In a related development, economic challenges for the nuclear industry and limited government spending have limited the resources available to support new research, including harvesting programs. Given this constrained budget environment, aligning interests and leveraging with other organizations is important to allow maximum benefit and value for future research programs.

Objective and Approach

The objective of the workshop was to generate open discussion of all aspects of ex-plant materials harvesting, including:

1. Deciding whether to harvest,
2. Planning and implementing a harvesting program,
3. Using the harvested materials in research programs.

Through presentations and open discussion, the workshop was organized to allow for all participants to be better informed of the benefits and challenges of harvesting as well as to identify potential areas of common interest for future harvesting programs. Workshop sessions were aligned in broad topics to cover all aspects of harvesting, but allow for participants to drive the discussion.

To help accomplish the workshop objectives, the workshop organizers intentionally sought a diverse group of participants. There are a large number of decommissioning plants and interested researchers outside the U.S., so the organizers focused on outreach to international participants through connections such as IAEA, OECD/NEA, and existing professional contacts. In addition, a key goal for this workshop was to capture the broader practical perspective from plant owners and decommissioning companies, which are vital to any successful harvesting program, but may sometimes be overlooked in researcher-driven discussions. Workshop participants were also diverse in terms of technical area of focus, with metal components such as the reactor pressure vessel (RPV) and internals being discussed along with concrete and electrical components. The final list of workshop participants can be found at the end of this report in Appendix I.

Workshop Organization and Sessions

The workshop was held at NRC headquarters in Rockville, MD. Due to limited space in the meeting room and the need for a limited group size for discussion, a webinar was used to allow remote observers to benefit from the workshop. Workshop sessions were organized topically with about half the time dedicated to presentations and the remaining time set aside for discussion. Presentations were solicited from participants to cover a range of perspectives and technical areas. The final workshop agenda can be found at the end of this summary report in Appendix II.

The workshop was organized into five sessions as follows:

- Session 1 Motivation for Harvesting
- Session 2 Technical Data Needs for Harvesting
- Session 3 Sources of Materials
- Session 4 Harvesting Experience: Lessons Learned and Practical Aspects
- Session 5 Future Harvesting Program Planning

Summary of Workshop Discussion

The subsections below will summarize the presentations and discussion in each session and highlight the key takeaways from the session.

Session 1 Motivation for Harvesting

Session 1 focused on the motivation for harvesting and why workshop participants are interested in harvesting. Presentations were provided in this session by:

- Richard Reister from DOE,
- Sherry Bernhoft from EPRI,
- Robert Tregoning from NRC,
- Uwe Jendrich from the Gesellschaft für Anlagen- und Reaktorsicherheit (GRS) in Germany, and
- Taku Arai from the Central Research Institute of the Electric Power Industry (CRIEPI) in Japan.

<u>Presentation Summaries</u>

DOE described the role of harvesting within the Light Water Reactor Sustainability (LWRS) Program, including the benefits and challenges associated with harvesting. Benefits include the opportunity to fill knowledge gaps where there is limited data or experience and to inform degradation models with data from actual plant components. Challenges include cost, complexity, scheduling, logistics, limited opportunities, acquiring sufficient material pedigree information, and potential negative results impacting operating plants.

EPRI discussed the role of harvesting within the context of aging management for Long-Term Operations (LTO), including their experience from past harvesting programs and criteria for future harvesting. Their experience emphasized the challenges of cost, schedule, logistics, complicated contracting and acquiring material pedigree information. EPRI's criteria for harvesting include value to their members that addresses a prioritized need and knowledge gap that cannot be otherwise filled through other means.

For EPRI, a well-developed project plan that covers funding, risk management, exit ramps, and clear roles and responsibilities is essential.

NRC shared its perspective on the benefits and challenges of harvesting in regulatory research. Harvested materials are valuable due to the representative nature of their aging conditions, which may reduce the uncertainty associated with the applicability of the results to operating plants compared to tests with alternative aging conditions. Harvested materials may be the best option to address technical data needs identified for extended plant operation. Increasing harvesting opportunities from decommissioning plants suggests a proactive approach to harvesting planning may optimize benefits by identifying the appropriate material with the aging conditions of interest for the identified knowledge gap. There are significant challenges associated with harvesting, including cost, schedule, and logistics, but hopefully these can be mitigated or avoided by leveraging with other organizations and learning from past experience.

GRS described its role as the main technical support organization in nuclear safety for the German federal government. GRS provides technical assessment and knowledge transfer for decommissioning activities, aging management, and long-term operation for German federal and international organizations.

CRIEPI discussed its view of how harvested materials and laboratory prepared materials contribute to addressing technical issues. Harvested materials provide exposure to actual plant conditions, but are more limited in availability and the size of the data set that can be generated. Laboratory prepared materials general involve accelerated or simulated aging conditions, but can be used to produce larger data sets and varying parameters can allow understanding of the effect on the mechanism or property of interest. Harvested materials offer fact finding of actual plant conditions as well as confirmation and verification of results from laboratory prepared specimens.

Discussion Summary

The discussion following the presentations in this session focused on clearly identifying the need to be addressed by a harvesting project and the myriad cost, schedule, and logistical challenges associated with harvesting. Leveraging with other organizations to defray costs can also help improve the value of a given program, but also adds complexity as another organization may have a different set of priorities that changes the focus of the harvesting effort.

Session 2 Technical Data Needs for Harvesting

Session 2 focused on discussing the technical data needs for harvesting and what specific knowledge gaps organizations are interested in addressing through harvesting. This discussion included general perspectives on how to determine when harvesting should be pursued rather than other types of research. Presentations were provided in this session by:

- Pradeep Ramuhalli from the Pacific Northwest National Lab (PNNL),
- Matthew Hiser from NRC,
- Keith Leonard from Oak Ridge National Laboratory (ORNL),
- Rachid Chaouadi from SCK-CEN in Belgium, and
- Arzu Alpan from Westinghouse.

Presentation Summaries

PNNL presented their work, under a small NRC contract, to develop a systematic approach to prioritize data needs for harvesting. PNNL proposed five primary criteria for prioritizing harvesting:

- Unique field aspects of degradation
  - For example, unusual operating experience or legacy materials (composition, etc.) that be no longer available
- Ease of laboratory replication of environment-material combination
  - For example, simultaneous thermal and irradiation conditions may be difficult to replicate or mechanism sensitive to dose rate may not be good for accelerated aging
- Applicability of harvested material for addressing critical gaps
  - Prioritize harvesting for critical gaps over less essential data needs
- Availability of reliable in-service inspection (ISI) techniques for the material / component
  - If inspection methods are mature and easy to apply to monitor and track degradation, perhaps the effort of research with harvested materials is not needed.
- Availability of material for harvesting
  - The necessary materials / components must be available to be harvested.

PNNL then presented their application of these criteria to four materials degradation issues as an example: electrical cables, cast austenitic stainless steel (CASS), reactor vessel internals, and dissimilar metal welds. Based on applying these criteria to the examples, PNNL concludes that electrical cables, CASS, and reactor internals are all higher priority for harvesting due to unique aspects of the degradation that are challenging to replicate in the lab. Meanwhile, dissimilar metal welds are of low priority due to the ease of replication in lab aging studies as well as the significant body of knowledge and research on the phenomena.

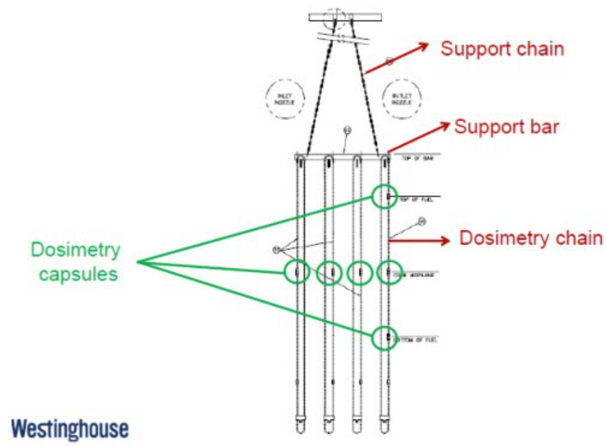
NRC presented a summary of data needs it is interested in pursuing through harvesting. These included RPV materials to validate fluence and attenuation models and to demonstrate the conservatism of regulatory approaches for transition temperature prediction. Other metal components of interest for harvesting would address data gaps in irradiated stainless steels, as well as improve understanding of inspection capabilities and fatigue life calculations. Electrical components of interest include low and medium voltage cables and other electrical components for degradation studies, and electrical enclosures and cables for fire research. Concrete components of interest include irradiated concrete, concrete undergoing alkali-aggregate reactions, post-tensioned structures, reinforcing steel, tendons, and spent fuel pool concrete to assess potential boric acid attack.

DOE/ORNL presented their perspective on data needs for harvesting and its role in providing validation of experimental and theoretical research. DOE performed a significant reactor pressure vessel (RPV) harvesting program at the Zion nuclear power plant to reduce uncertainties in the Master Curve methodology, validate modeling predictions and study flux and fluence attenuation effects. The harvesting is largely complete, but the testing program is currently underway. DOE also indicated interest in using harvested materials to validate its models for swelling and microstructural changes of stainless steel internals under LWR irradiation conditions. Harvesting concrete components would be of interest due to lack of literature data and the multiple dependent variables that may affect concrete

performance. Finally, DOE has been involved in harvesting cables from the Crystal River and Zion plants to address cable aging as a function of material composition and environment.

SCK-CEN presented their interest in a international cooperative program to harvest reactor pressure vessel (RPV) materials. SCK-CEN presented their survey of the literature for past testing programs of harvested RPV materials, and the limitations of these past program. Key limitations include a lack of archive materials, generally lower temperatures, and poor surveillance programs and dosimetry. SCK-CEN then shared some thoughts on their criteria for a new harvesting efforts, including higher fluence levels and temperatures, available archive materials and reliable information on operating history, dosimetry and surveillance program. Other topics relevant to a new RPV harvesting effort include technical issues such as material variability and irradiation conditions as well as logistical and financial considerations.

The final presentation in Session 2 by Westinghouse focused on the need for harvesting irradiated concrete to better understand the threshold radiation level for significant strength reduction. Westinghouse has installed ex-vessel neutron dosimetry (EVND) at a number of plants in the world and proposed to use these dosimetry measurements to validate fluence model calculations to better understand the uncertainty in these calculations. If concrete can be harvested at one of these plants with EVND data, then irradiated concrete properties from testing can be paired with fluence data to improve research benefits.



Discussion Summary

The discussion following Session 2 presentations touched on a number of topics. EPRI shared that they developed a report related to the topics of session 2, but more narrowly focused on PWR internals. MRP-320, "Testing Gap Assessment and Material Identification for PWR Internals," focuses on prioritizing opportunistic harvesting of stainless steel reactor internals components that may be removed from service following MRP-227 inspections. The methodology and approach in this report may be relevant to the broader harvesting data needs discussion. This report is not publicly available, but is available to EPRI member utilities.

Workshop participants discussed the criteria proposed by PNNL in the first presentation. One additional criteria suggested by EPRI was to consider fleet-wide vs. plant-specific applicability. More broadly applicable materials would be of greater interest for harvesting than those that represent conditions at only a few plants. Another criteria suggested is the availability of material pedigree information, such as composition, processing, environmental conditions (temperature, humidity, fluence, etc.). Another suggested criteria was the ease of harvesting. For example, highly irradiated internals are probably much more difficult and expensive to harvest than electrical cables or unirradiated concrete. This discussion would capture the idea of weighing costs vs. benefits as well as project risk. Further discussion touched on the idea that different organizations may prioritize the various criteria differently, but all will probably at least want to consider the same set of criteria.

Another key theme from this discussion was that a successful program should be guided by a clearly defined objective or problem statement to be addressed. This objective should be well-understood at the initiation of a program and used to guide decision-making through implementation of a harvesting project. This also raises a related point or potential criteria: the timeliness of the expected research results relative to the objective. If the results are needed in the next two years, but a harvesting project will not provide results for at least five years, that should be a strong consideration.

Session 3 Sources of Materials

Session 3 focused on discussing sources of materials for harvesting. This discussion covered previously harvested materials as well as sources for new harvesting programs from operating or decommissioning plants. Both domestic and international sources of materials were discussed in this session.

Presentations were provided in this session by:

- Matthew Hiser from NRC,
- Al Ahluwalia from EPRI,
- Tom Rosseel from DOE/ORNL,
- John Jackson from DOE/Idaho National Laboratory (INL),
- Gerry van Noordennen from EnergySolutions,
- Arzu Alpan from Westinghouse,
- Uwe Jendrich from GRS, and
- Daniel Tello from the Canadian Nuclear Safety Commission (CNSC).

Presentation Summaries

NRC presented their perspective on sources of materials for harvesting. First, NRC shared some of the harvested materials from past research programs that may be available, including irradiated stainless steel internals, RPV materials, nickel alloy welds, neutron absorber material, and electrical components. NRC then summarized the recently and planned shutdown U.S. plants, including their design, thermal output, and years of operation, to provide participants with an idea of the potential sources from decommissioning U.S. plants. Finally, NRC shared a list of information that would be helpful to acquire from decommissioning plants to determine the value of components for harvesting. This information included plant design information (component location and dimensions), environmental conditions (temperature, fluence, humidity, stress, etc.) and operating history, material pedigree information (fabrication records), and inspection records (for interest in components with known flaws).

The next presentation from EPRI covered harvesting opportunities at decommissioning plants in Korea and Sweden. In Korea, Kori-1 is a Westinghouse 2-loop PWR (sister plant is Kewaunee) that will shut down in 2017 after 40 years of operation. Korea Hydro and Nuclear Power Central Research Institute (KHNP-CRI) is planning a comprehensive research program on long-term materials aging based on harvesting from Kori-1 and is seeking international participation in the harvesting effort. KHNP-CRI's plan is focused on metallic components, including RPV, internals, primary system components, steam generator materials. Harvesting is expected to occur in 2024 with testing to follow through 2030.

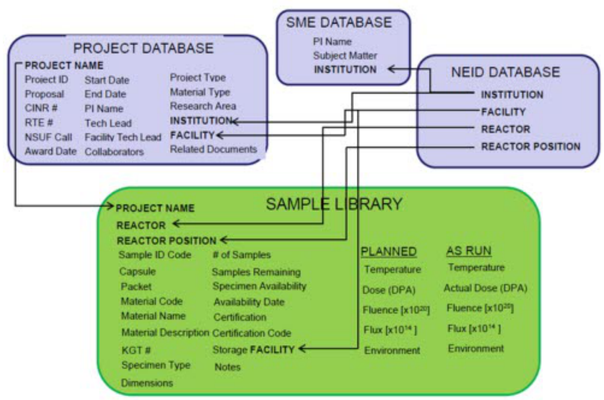
In Sweden, Vattenfall is currently harvesting in 2017-2018 RPV material from the decommissioning Barseback BWR units. This work is focused on irradiation embrittlement, including comparison of

surveillance data to actual RPV properties, as well as thermal aging embrittlement. In the future, Vattenfall will be shutting down Ringhals 1 and 2 in 2020 and 2019, respectively. Ringhals 1 is a BWR and Ringhals 2 is a Westinghouse 3-loop PWR design. Of particular note, Ringhals 2 has the second oldest replaced Alloy 690 RPV head and steam generators. Other harvesting opportunities at Ringhals include RPV material with a significant surveillance program, thermal aging effects on low alloy steel from the pressurizer, as well as concrete structures. Vattenfall is open to working with partners that are interested in joining them for harvesting at Ringhals.

(b)(4)

The next presentation by DOE/ORNL focused on several harvesting programs that DOE's LWRS program has been involved with. DOE has led the harvesting of components from the Zion [redacted] plant [redacted] in (b)(4) the U.S. From Zion, DOE has harvested electrical cables and components, a large RPV section, and a significant amount of records to provide information on material fabrication, in-service inspection and operating history. Cables from Zion include CRDM, thermocouple, and low and medium voltage cables. DOE indicated some thermocouple cables from Zion may be available for other researchers to use in collaborative studies. [redacted] (b)(4)
(b)(4)
(b)(4)
DOE is also participating in efforts to harvest cables from Crystal River (led by EPRI) and concrete from the Zorita plant in Spain (led by NRC).

The next presentation by DOE/INL described INL's Nuclear Science User Facilities (NSUF) and the Nuclear Fuels and Materials Library (NFML). NSUF is coordinated by INL and facilitates access to nuclear research facilities around the world, including neutron and ion irradiations, beamlines, hot cell testing, characterization and computing capabilities. NFML is a Web-based searchable database sample library that captures the information from thousands of specimens available to NSUF. NFML is designed to maximize the benefit of previously irradiated materials for future research. Researchers can propose new research projects under NSUF using specimens in NFML using DOE funding. The information captured in NFML aligns well with the goal of this session to potentially develop a database of previously harvested materials.



The next presentation by EnergySolutions offered a more practical perspective on considering sources of materials for harvesting. From the plant owner perspective, in the decommissioning process there is not a financial incentive to support harvesting, therefore researchers need to absorb costs for harvesting and have a clear scope for harvesting. Flexibility in funding for harvesting activities is essential as the decommissioning process and schedule may change quickly.

EnergySolutions provided valuable perspective on the timing in the decommissioning proves for harvesting different components. Harvesting RPV surveillance coupons should take place when the RPV internals are cut and removed. Harvesting RPV materials is only possible from larger RPVs, as smaller RPVs are shipped intact to the disposal facility, rather than cut into pieces. Spent fuel rack neutron absorber coupons must be harvested either before or after dry storage campaign to remove spent fuel from spent fuel pool. Harvesting actual spent fuel rack neutron absorber material must come after pool is completely empty. Electrical cables and other components from mild environments may be harvested at any time (once temporary power is established and plant power is shut off), while electrical components from high rad environments will depend on timing of source term removal schedule. Concrete cores are best harvested when other cores are being taken for site characterization to develop the License Termination Plan. Highly irradiated concrete from biological shield wall would need to come later in decommissioning after RPV is removed.

In terms of upcoming decommissioning plants, EnergySolutions indicated that San Onofre and Vermont Yankee will be entering DECON is 2018 and 2019, respectively. Kewaunee, Crystal River, and Fort Calhoun also may enter DECON in next 2 years. If researchers are interested in harvesting from any of these plants, they should be reaching out to plant owners immediately to begin planning and coordination.

Westinghouse followed their presentation in session 2 by describing an opportunity to harvest concrete from the Mihama 1 plant in Japan. Westinghouse installed and analyzed additional neutron dosimetry in the reactor cavity for one cycle, which were used to validate the radiation transport calculations. Mihama was shutdown in 2015 and is in contact with Westinghouse about the possibility of extracting concrete cores from the biological shield wall. Westinghouse is seeking partners interested in joining this harvesting effort.

The next presentation by GRS covered opportunities for harvesting from German plants. Regulations in Germany require plants to either immediately dismantle or dismantle after a period of safe enclosure, which is largely consistent with options in the U.S. GRS detailed the status of German commercial reactors, which are predominantly BWR and PWR designs. Seventeen reactors are currently undergoing decommissioning, while seven more are currently shutdown and await a decommissioning license. Eight reactors are still operating with scheduled shutdown dates between 2017 and 2022. German RPVs tend to have lower fluence that U.S. designs due to a larger water gap in the downcomer region. Germany has limited experience with harvesting from decommissioning plants. One question that GRS will follow-up on is the “rumored” cable surveillance programs that may be used in Germany and could provide experience and lessons learned for other countries.

The final presentation in Session 3 was by CNSC on harvesting opportunities in Canada. Atomic Energy Canada Limited (AECL) has harvested seven concrete cores from the 20 MW Nuclear Power Demonstration Plant (NPD), which shutdown in 1988 after 25 years of operation. CNSC and AECL are also considering opportunities to harvest concrete from other decommissioned reactors in Canada such as Gentilly-2, Douglas Point, and Whiteshell Reactor 1. In addition to concrete, CNSC and AECL are currently harvesting electrical cables from the 675 MWe CANDU-6 Gentilly-2 reactor, which shutdown in 2012 after 29 years of operation. The purpose of this work is to study cable degradation from thermal aging and radiation damage and validate environmental qualification of the cables. CNSC described some of the challenges with this harvesting effort, such as working with plant owners, records, accessibility and contamination of the materials and budgeting with unexpected delays in harvesting.

A future harvesting opportunity is from the National Research Universal (NRU) reactor at Chalk River, which will shut down in 2018 after operating since 1957. AECL is currently taking an inventory of irradiated materials that can be harvested from NRU in decommissioning. Potential materials for

harvesting include metals (steels, nickel alloys, zirconium, aluminum), concrete, graphite, active equipment (pumps, etc.), graphite seals, electrical cables, and thermocouples.

Discussion Summary

Following the presentations, there was some discussion of lessons from DOE's Zion harvesting effort. DOE worked with a former senior reactor operator at Zion to identify and acquire the appropriate records from Zion for the components being harvested. DOE also described their flexible approach to acquiring RPV samples by sending a large chunk of material (weighing ~90 tons) to EnergySolutions' facility in Tennessee, where smaller pieces (weighing ~500 pounds) were cut to send to ORNL. Most of the decontamination was performed at Zion, with minimal additional cleaning (as well as cladding removal) taking place at EnergySolutions' facility.

There was also discussion of acquiring materials from sources other than commercial nuclear facilities. DOE has considered harvesting concrete from other DOE nuclear facilities, but determined that there were compositional differences between the DOE facilities and commercial that would make them not useful. DOE/INL mentioned that the Advanced Test Reactor (ATR) replaces their core internals every ten years. The ATR internals are composed primarily of 347 stainless steel and achieve very high fluence levels after ten years of service.

Another key discussion topic was the possibility of developing a database for previously harvested materials or those available for future harvesting. DOE/INL indicated that their NSUF sample library may be a good starting point for such a database, although any materials in that library should be freely available for use in the research community. CNSC and NRC also expressed interested in working to develop a harvesting database.

Session 4 Harvesting Experience: Lessons Learned and Practical Aspects

Session 4 focused on lessons learned and practical aspects of harvesting. Presenters shared their experience with past harvesting programs, particularly common pitfalls to avoid and successful strategies to overcome them. Presentations also covered the practical aspects of harvesting from the plant owner and decommissioning company perspective.

Presentations were provided in this session by:

- Jean Smith from EPRI,
- Tom Rosseel from DOE/ORNL,
- Matthew Hiser from NRC,
- Taku Arai from CRIEPI,
- Gerry van Noordennen from EnergySolutions, and
- Bill Zipp from Dominion.

Presentation Summaries

EPRI presented their experience and lessons learned from past harvesting programs, particularly harvesting reactor internals and concrete from Zorita and electrical cables from Crystal River. From the Zorita reactor internals experience, EPRI emphasized that harvesting projects take significant time, encounter material retrieval and on-site challenges, and shipping issues. In terms of time, ZIRP took

about 10 years to go from initial planning to final results, which included about 5 years of project planning, 2 years for material extraction (on-site logistics and shipping), and 3-4 years for testing. EPRI's experience was decommissioning activities were the top priority and harvesting were subject to schedule and logistical challenges based on the changing decommissioning schedule. Shipping issues were also challenging due to sending activated materials (which were classified as "waste") across international borders, from the reactor in Spain to testing facility in Sweden. Further planned shipments of the Zorita materials beyond the initial program continue to be impact by export license challenges in Sweden. More positively, EPRI emphasized that the Zorita reactor internals materials harvesting showed excellent cooperation among many organizations and are providing valuable technical information to numerous research projects.

Lessons learned from the Zorita concrete harvesting focused on the challenges with core sample drilling and handling contaminated concrete. Ultimately, an effective core drilling procedure was identified, but required some trial and error. Lessons learned from the Crystal River cable harvesting included material concerns, the need for on-site support, and cost. In terms of material concerns, radiation and asbestos contamination created additional challenges for harvesting. On-site support and the ability to visit the site are extremely valuable to ensure clear communication, retrieval or records for material pedigree information, and awareness of on-site developments in the decommissioning process. Cable harvesting at Crystal River was more expensive than anticipated, particularly in terms of EPRI project management time to coordinate the harvesting activities and engineering support at the plant.

DOE presented lessons learned primarily from the experience harvesting RPV materials and electrical cables and components from the Zion plant. In terms of planning and decision-making, DOE had several lessons learned. DOE hosted a workshop at Zion in 2011 to discuss long-term goals and objectives, which proved very helpful in setting priorities and developing partnerships with other organizations. Partnerships were very valuable to DOE's harvesting efforts, allowing for leveraging resources and collaboration and sharing results. There are limited opportunities for harvesting key components, so take full advantage of the opportunities that arise, understanding that there is a necessary compromise between the materials available and their value in terms of fluence or exposure to aging conditions. Another consideration is the quantity of material harvested, which should be sufficient for the objectives of the planned research as well as any collaborations or partnerships, but limited to control costs.

For implementing the harvesting program, DOE found that flexibility was paramount to be able adjust scope and plans in response to schedule changes and other developments, while remaining within cost constraints. Working with a former reactor operator was extremely valuable to benefit from their in-depth knowledge of all parts of the plant, in particular the records for materials pedigree information. Regular site visits and contacts were also essential to stay aware of the latest developments in the harvesting planning and decommissioning process, with the understanding that harvesting is not the top priority for decommissioning company. Other important considerations were hazardous materials handling, transportation, and disposal and logistics, including contracts, liability, shipping and disposal. Finally, DOE's experience is that the total costs of a harvesting program from planning to execution to testing are very high, so they should be carefully weighed against the value of the expected data to be generated.

NRC presented their experience, including benefits from previous harvesting programs, and technical and logistical lessons learned from harvesting. As an organization, NRC has extensive experience with testing harvested materials, including RPV, primary system components, reactor internals, neutron absorbers, concrete and electrical components. NRC's experience is more limited than DOE or EPRI in terms of managing the logistics of a harvesting effort from a decommissioning plant. NRC has generally participated in a secondary role in cooperative efforts or received failed components from operating plants for research. NRC has found that previous harvesting efforts have been effective in reducing unnecessary conservatism, understanding in-service flaws more realistically for NDE and leak rate methodologies, as well as identifying and better understanding safety issues.

For technical lessons learned, NRC's perspective is that harvesting can provide highly representative aged materials for research, which may be the only practical source of such materials. Harvested materials can be effectively used to validate models or a larger data set from accelerated aging tests. It is important understand as much as possible about the materials and their environment in service and how this compares with the operating fleet of reactors before committing to a specific harvesting project. For logistical lessons learned, harvesting is expensive and time-consuming, so a high technical benefit is needed to ensure the program provides values. Leveraging with other organizations can help minimize costs, but can also introduce challenges for aligning priorities and interests of multiple organizations. Finally, transporting irradiated materials, particularly between countries, challenging and time-consuming and should be avoided if at all possible.

CRIEPI presented their research experience with harvested materials as well as ongoing harvesting from the Hamaoka 1 plant. The first research program involved atom probe tomography (APT) on RPV surveillance materials. CRIEPI found a correlation between the volume fraction of Ni-Si-Mn clusters and the change in nil-ductility temperature. In the second research project, CRIEPI characterized the weld and base materials harvested from Greifswald Unit 4 RPV with small-angle neutron scattering, APT, and hardness testing. In the third research project, CRIEPI performed APT on 304L stainless steel reactor internals harvested from control rod and top guide components from 3-13 dpa. Results showed a strong increase in Ni-Si clusters with increasing fluence, but little variation in Al enriched clusters with increasing fluence.

For future work, CRIEPI is collaborating with DOE LWRS to investigate RPV materials harvested from Zion (b)(4) [redacted] CRIEPI also presented activities underway by Chubu Electric Power to harvest RPV and concrete samples from the Hamaoka 1 plant. Hamaoka 1 is a 540 MW BWR-4 that operated for 33 years. Harvesting began in 2015 and will continue through 2018.

The final two presentations of Session 4 provided the non-researcher perspective from a decommissioning company and plant owner. EnergySolutions, which is decommissioning the Zion nuclear plant among other facilities, presented the decommissioning process and their experience and lessons learned from harvesting at Zion. As mentioned previously, surgical harvesting is not the top priority for decommissioning, so researchers must recognize this and coordinate close with the decommissioning company. EnergySolutions emphasized the need to gain senior management support at the plant as well as to expect that there may be staff turnover during a multi-year harvesting effort. Changes in scope and schedule (originating from both sides) can cause frustration on both sides. Early planning and delays with contracting are important to avoid lost opportunities. Being on-site during harvesting is essential to a good outcome.

At Zion, EnergySolutions worked with DOE to harvest RPV materials, cables, electrical components, and spent fuel storage racks. DOE hoped to harvest a particular RPV surveillance capsule, but was unable to due to the inability identify the correct capsule. There were also challenges with harvesting RPV materials. The cut line on the Unit 2 RPV was too close to the weld to be used for research; fortunately, a successful specimen was harvested from Unit 1. For cabling, the initial plan was to harvest from 11 different locations, but ultimately due to unforeseen challenges and poor communication and coordination, only 4 different cable locations were harvested. Harvesting the desired cable length (30 feet) also proved challenging, with only shorter sections recovered. Plant records searches were largely effective at providing material pedigree information for cables. Concrete coring was initially planned to take place at Zion, but not performed due to lack of research interest. The spent fuel storage rack harvesting went smoothly, which was assisted by efforts over the weekend when decommissioning activities were not occurring.

The next presentation from Dominion provided its perspective on harvesting from decommissioning plants, focused on the experience at Kewaunee Power Station. The top priority (beyond safety) in decommissioning is the preservation and good stewardship of the decommissioning trust fund. Staffing is the largest drain on the trust fund, so at Kewaunee staff was halved within a few months of shutdown and then halved again about 16 months after permanent shutdown once offsite emergency response requirements were eliminated. Dominion described the example of harvesting the RPV surveillance capsules at this point at Kewaunee and the significant challenges that would exist. Given the reduced staffing and the current plant state (reactor coolant system drained, pumps retired, crane and radiation monitoring not maintained), it would be much more difficult now than immediately after shutdown. Kewaunee considered harvesting the surveillance specimens and estimated a cost of six to seven figures based on all the activities required to enable it at this point post-shutdown compared to a much lower cost just after shutdown. Dominion observed that some components, such as cables or electrical components, may be available and relatively easy to harvest at almost any time during decommissioning. However, other components such as highly irradiated internals or RPV may be best harvested either shortly after shutdown when staffing and capabilities on-site are high or wait until active demolition of the reactor, which may be years or decades later.

Dominion also touched on the discussion of records for plant components. Records requirements are limited to those needed for safety. Once the plant shuts down and the range of potential safety concerns decreases, systems are downgraded to non-safety and the associated records are no longer required to be maintained. For perspective, Kewaunee still has all its records four years since shutdown, but will likely not continue this much longer. Dominion closed its presentation with a broader perspective on harvesting, emphasizing the need to clearly define a problem statement and understand what technical and regulatory purpose this harvesting will serve. Early planning focused on achieving the clear objective of the work including scope, schedule, budget and contact with plant is essential to a successful harvesting effort.

Discussion Summary

The discussion touched on the top lessons learned from past harvesting efforts, which included a clear objective and purpose for harvesting, early engagement with the plant, and site coordination during harvesting.

Another suggestion was to get utility management buy-in for the harvesting project by identifying a benefit to the utility. EPRI mentioned that cable harvesting at Crystal River went much more successfully once the utility recognized the potential benefits for subsequent license renewal. Similarly, when harvesting from an operating plant, you need to recognize and work through the challenges the plant may encounter when restarting operations.

During discussion, the question was raised regarding how it is determined whether harvested materials are waste. The discussion concluded that in the U.S. 10 CFR 37 is the important consideration. 10 CFR 37 defines when additional security requirements are imposed, based on the quantity and activity of materials to be transported. The definition of material as waste versus research materials is not as critical in the U.S. EnergySolutions indicated that their shipments of waste or research material could be handled in the same way in the accordance with Department of Transportation regulations, provided that the limits in 10 CFR 37 were not reached.

Session 5 Future Harvesting Program Planning

Session 5 focused on the information needed for informed harvesting decision-making and harvesting program planning. This session featured a presentation by Pradeep Ramuhalli from PNNL, followed by a discussion period covering harvesting program planning and reflection on the 2-day workshop.

Presentation Summary

PNNL presented its perspective on the information needed for informed harvesting decision-making. First, the purpose of the harvesting effort needs to be defined by identify the technical knowledge gaps to be addressed. Next, a research plan should be developed demonstrating how the harvested material will be used to address the identified gaps. Finally, the appropriate source of material to address the technical gap must be identified, along with resources to support the effort and plans and timelines to perform the harvesting. The specifics of these plans depend greatly on the source of materials and must be flexible based on changing conditions on the ground.

In assessing the best source of materials, researchers should consider the material, its environment, and its condition. Material information includes fabrication information such as manufacturer, composition, and dimensions as well as information related to installation or construction, such as welding processes and parameters. Environmental information includes temperature, humidity, fluence, flux, stress (service, residual, installation), and coolant chemistry. Component condition information includes inspection history, such as identified flaws or degradation.

Discussion Summary

The discussion in Session 5 focused on the best practical approach to plan future harvesting programs. There was clear agreement that this approach must begin with identifying the data needs best addressed by harvesting, whether from operating or decommissioning plants. Once a specific need is identified, the next step is to find a source to acquire the materials of interest as well as other organizations interested in participating in the harvesting effort.

Key Takeaways from Workshop

Session 1

The clear takeaway from the discussion in session 1 was that harvesting requires significant resources to be done successfully; therefore it is paramount to identify how the planned harvesting will clearly address a significant need to ensure the harvesting project provides strong value. In the context of need for data, EPRI suggested the goal of harvesting to support research for operation out to 80 years is not a full comprehensive understanding of all aspects of the degradation, but rather a snapshot to confirm other lab results and models. This is an important point for all organizations and researchers to keep in mind before investing significant resources in harvesting.

Session 2

The criteria proposed by PNNL are a good starting point for prioritizing issues to address by harvesting. Three additional important criteria would be:

- Fleet-wide vs. plant-specific applicability of data,
- Ease of harvesting (in terms of cost and project risk), and
- Timeliness of the expected research results relative to the objective.

Once a potential harvesting project has reached the point of looking at different sources of materials, the availability of material pedigree information, such as composition, processing, environmental conditions (temperature, humidity, fluence, etc.) is very important to the overall value of harvesting from that particular plant.

Based on the presentations and discussion in Session 2, there appeared to be two areas with broad interest in pursuing further harvesting: high fluence reactor internals and irradiated concrete. The common drivers for the interest in these issues is a lack of representative data at the fluences of interest and significant challenges with acquiring representative data through other means. High fluence reactor internals has been addressed somewhat by the Zorita Internals Research Project (ZIRP), but stainless steel materials exposed to higher fluence levels at higher temperatures, where void swelling may become significant, could help validate DOE and EPRI models and provide further technical basis for PWR internals aging management. Irradiated concrete harvesting is currently being pursued from the Zorita reactor in Spain, with international collaboration and potential testing at the Halden Reactor Project.

Other areas with some, but less widespread, interest expressed from workshop participants for new harvesting efforts included RPV materials and electrical cables and components. SCK-CEN and NRC expressed interest in RPV harvesting, and NRC expressed interest in electrical component harvesting.

Session 3

To capture the key takeaways from Session 3 focused on sources of materials, two tables of potential sources of materials are presented below. The first table covers recent or ongoing harvesting programs, while the second details potential future harvesting opportunities.

Ongoing Harvesting Programs

Country	Plant	Design	Size (MWe)	Years in operation	Components	Organization(s)
Canada	NPD	CANDU	20	25	Concrete	AECL
	Gentilly-2	CANDU-6	675	29	Cables	
Japan	Hamaoka 1	BWR-4	540	33	RPV, concrete	CRIEPI/Chubu
Spain	Zorita	W 1-loop	160	37	Internals, concrete	EPRI, NRC
Sweden	Barseback	ABB-II	615	28	RPV	Vattenfall
U.S.	Zion 1/2	W – 4 loop	1040	24/25	RPV, cables, neutron absorbers	DOE, EPRI, NRC
	Crystal River 3	B&W	860	36	Cables	EPRI
	(b)(4)					

Potential Future Sources for Harvesting

Country	Plant	Design	Size (MWe)	Years in operation	Potential Components	Notes
Canada	NRU	Test reactor	135 MWt	61	TBD	AECL; SD: 2018
Germany	Numerous plants either in decommissioning or shutting down soon. See Appendix III.					
Japan	Mihama	W 2-loop	320	40	Concrete	Kansai, Westinghouse
Korea	Kori 1	W 2-loop	576	40	RPV, internals, SGs, pressurizer, welds, CASS,	KHNP, EPRI
Sweden	Ringhals 1	BWR	883	44	RPV, internals SGs, pressurizer, concrete	Vattenfall; SD: 2020 / 2019
	Ringhals 2	W 3-loop	900	44		
U.S.	Kewaunee	W 2-loop	566	39	TBD	SD: 2013
	SONGS 2/3	CE 2-loop	1070	31/30	TBD	SD: 2013
	Crystal River 3	B&W	860	36	TBD	SD: 2013
	Vermont Yankee	BWR-4/Mk-1	605	42	TBD	SD: 2015
	Fort Calhoun	CE 2-loop	482	43	TBD	SD: 2016
	Palisades	CE 2-loop	805	47	TBD	SD: 2018
	Pilgrim	BWR-3/Mk-1	677	47	TBD	SD: 2019
	Oyster Creek	BWR-2/Mk-1	619	50	TBD	SD: 2019
	Indian Point 2/3	W 4-loop	1020 / 1040	48/46	TBD	SD: 2021
	Diablo Canyon 1/2	W 4-loop	1138 / 1118	40	TBD	SD: 2024-5
	Advanced Test Reactor	Test reactor	250 MWt	50	Core internals	Non-commercial; internals replaced every 10 years

In addition to the potential sources of materials presented and discussed in Session 3, another takeaway was the suggestion of developing a database for previously harvested materials or those available for future harvesting. The NSUF sample library may be a good starting point for such a database, with appropriate modifications for the purposes of harvesting efforts.

Session 4

There were several important takeaways from Session 4 that were touched on in multiple presentations and the discussion. One key takeaway is that researchers should identify a clear purpose and scope for harvesting. Having a clear purpose for harvesting helps to guide later decisions that must be made to adjust course when the inevitable changes in schedule or unexpected realities at the plant arise. A related note is that harvesting is not the top priority for decommissioning. Therefore, researchers must have clear objectives and scope for harvesting that can be communicated to the site. This understanding should shape assumptions and interactions with the plant owner or decommissioning company as well as planning for costs and schedule.

Another takeaway was the value of strong site coordination, including site visits. Multiple presenters touched on the value of being on-site to talk to staff and see the components to be harvested. Mockups and 3-D simulations can be valuable to ensure success of the approach or technique used to acquire the specimen. A related point is working with reactor operators at the plant. Several harvesting efforts worked with former reactor operators and benefited greatly from their experience to find records or determine the best method to harvest the desired component. This is a valuable insight that could be effective in future harvesting efforts.

A third key takeaway is early engagement with the plant to express interest in harvesting. This serves to make the plant aware of your interest in harvesting and get their support to work with the harvesting process. The other important benefit of early engagement is to gain as much information as possible about the available materials and components, including the associated records and material pedigree information.

Session 5

The key takeaway in session 5 was to gather as much information as possible in advance of committing to a specific harvesting project. Ideally, there would be a strong understanding that the material and its aging conditions clearly align with an identified technical data need before committing significant resources to a harvesting effort.

Action Items and Next Steps

The following is a summary of the action items discussed at the end of the workshop:

1. Sharing workshop slides
    - NRC emailed attendees to ask their comfort with sharing their workshop slides with other organizations and received no objection from any presenters.
    - The presentations can be accessed here: https://drive.google.com/open?id=0B5DWMLch5YSXcnpZZ0JOS055QUU .

2. EPRI indicated that MRP-320 (Product ID: 1022866) on knowledge gaps for irradiated austenitic stainless steel for potential harvesting from MRP-227 inspections is publicly available for a fee.

3. Cable surveillance programs in Germany
   - GRS to inquire with cable colleagues and share any insights.

4. Sources of materials database
   - Potential sources of materials presented in this workshop are summarized in Session 3 summary above and Appendix III below.
   - NRC will be reaching out to PNNL, INL NSUF, CNSC, AECL, and any other organizations interested in database development.

5. Prioritized data needs
   - Suggestion to continue discussions on prioritized data needs within technical areas (RPV, internals, electrical, concrete) through existing coordination groups if possible
     - Focus on identifying specific material / aging conditions of interest and purpose / intended outcome of harvesting
   - Idea to survey Env Deg participants
     - John Jackson (INL) is on planning committee

6. EPRI report on spent fuel liner boric acid transport through concrete
   - NRC will contact EPRI for report if needed.

7. Harvested Materials Research Results
   - Section of workshop summary report (below) devoted to references from harvested materials research.

References to Previous Harvested Materials Research

This section of the workshop summary addresses a question that was raised during the discussion at the workshop regarding what the outcome or benefit of past harvesting efforts have been. Below is a list of references to research results generated from testing of harvested materials:

J.R. Hawthorne and A.L. Hiser, *Experimental Assessments of Gundremmingen RPV Archive Material for Fluence Rate Effects Studies*, NUREG/CR-5201 (MEA-2286), U.S. Nuclear Regulatory Commission, October 1988.

G. J. Schuster, S. R. Doctor, A.F. Pardini, and S.L. Crawford, *Characterization of Flaws in U.S. Reactor Pressure Vessels: Validation of Flaw Density and Distribution in the Weld Metal of the PVRUF Vessel*, NUREG/CR-6471 Volume 2, U.S. Nuclear Regulatory Commission, August 2000.

G. J. Schuster, S. R. Doctor, S.L. Crawford, and A. F. Pardini, *Characterization of Flaws in U.S. Reactor Pressure Vessels: Density and Distribution of Flaw Indications in the Shoreham Vessel*, NUREG/CR-6471 Volume 3, U.S. Nuclear Regulatory Commission, November 1999.

D.E. McCabe, et al. *Evaluation of WF-70 Weld Metal From the Midland Unit 1 Reactor Vessel*, NUREG/CR-5736 (ORNL/TM-13748), U.S. Nuclear Regulatory Commission, November 2000.

B. Alexandreanu, O.K. Chopra, and W.J. Shack, *Crack Growth Rates in a PWR Environment of Nickel Alloys from the Davis-Besse and V.C. Summer Power Plants,* NUREG/CR-6921 (ANL-05/55), U.S. Nuclear Regulatory Commission, November 2006.

S.E. Cumblidge, et al. *Nondestructive and Destructive Examination Studies on Removed-from-Service Control Rod Drive Mechanism Penetrations*, NUREG/CR-6996, U.S. Nuclear Regulatory Commission, July 2009.

S.E. Cumblidge, et al. *Evaluation of Ultrasonic Time-of-Flight Diffraction Data for Selected Control Rod Drive Nozzles from Davis Besse Nuclear Power Plant*, PNNL-19362, Pacific Northwest National Laboratory, April 2011.

S.L. Crawford, et al. *Ultrasonic Phased Array Assessment of the Interference Fit and Leak Path of the North Anna Unit 2 Control Rod Drive Mechanism Nozzle 63 with Destructive Validation*, NUREG/CR-7142 (PNNL-21547), U.S. Nuclear Regulatory Commission, August 2012.

Appendix I Workshop Participants

	Name	Organization	Email
Japan	Taku Arai	CRIEPI	arait@criepi.denken.or.jp
	Sadao Higuchi	CRIEPI	higuchi@criepi.denken.or.jp
	Kazunobu Sakamoto	JNRA	kazunobu_sakamoto@nsr.go.jp
	Yasuhiro Chimi	JAEA	chimi.yasuhiro@jaea.go.jp
Europe	Uwe Jendrich	GRS	Uwe.Jendrich@grs.de
	Rachid Chaouadi	SCK-CEN	rachid.chaouadi@sckcen.be
	Guy Roussel	Bel V	guy.roussel@Belv.be
Canada	Daniel Tello	CNSC	daniel.tello@canada.ca
	Désiré Ndomba	CNSC	desire.ndomba@canada.ca
	Karen Huynh	AECL	khuynh@aecl.ca
US industry	Gerry van Noordennen	Energy Solutions	gpvannoordennen@energysolutions.com
	Bill Zipp	Dominion	william.f.zipp@dom.com
	Mark Richter	NEI	mar@nei.org
	Arzu Alpan	Westinghouse	alpanfa@westinghouse.com
EPRI	Sherry Bernhoft	EPRI	sbernhoft@epri.com
	Robin Dyle	EPRI	rdyle@epri.com
	Jean Smith	EPRI	jmsmith@epri.com
	Al Ahluwalia	EPRI	kahluwal@epri.com
DOE	Tom Rosseel	ORNL	rosseeltm@ornl.gov
	Rich Reister	DOE	Richard.Reister@nuclear.energy.gov
	Keith Leonard	ORNL	leonardk@ornl.gov
	Mikhail A. Sokolov	ORNL	sokolovm@ornl.gov
	John Wagner	INL	john.wagner@inl.gov
	John Jackson	INL	john.jackson@inl.gov
	Pradeep Ramuhalli	PNNL	Pradeep.Ramuhalli@pnnl.gov
NRC	Pat Purtscher	NRC	Patrick.Purtscher@nrc.gov
	Rob Tregoning	NRC	Robert.Tregoning@nrc.gov
	Matt Hiser	NRC	Matthew.Hiser@nrc.gov
	Mita Sircar	NRC	Madhumita.Sircar@nrc.gov
	Tom Koshy	NRC	Thomas.Koshy@nrc.gov
	Jeff Poehler	NRC	Jeffrey.Poehler@nrc.gov
	Allen Hiser	NRC	Allen.Hiser@nrc.gov
	Angela Buford	NRC	Angela.Buford@nrc.gov
	Mark Kirk	NRC	Mark.Kirk@nrc.gov
	Amy Hull	NRC	Amy.Hull@nrc.gov
	Pete Ricardella	NRC/ACRS	Priccardella@Structint.com

Appendix II Workshop Agenda

Tuesday, March 7

Session	Time	Organization	Speaker	Presentation Title
Intro	8:00	NRC	Michael Weber Robert Tregoning	Welcome and Introduction to Workshop
1	8:15 – 8:45	DOE	Rich Reister	DOE Perspectives on Material Harvesting
		EPRI	Sherry Bernhoft	EPRI Perspective on Harvesting Projects
		NRC	Robert Tregoning	NRC Perspective on Motivation for Harvesting
		GRS	Uwe Jendrich	Role of GRS in Decommissioning and LTO
		CRIEPI	Taku Arai	CRIEPI Motivations for Harvested Material
	8:45 – 9:45	DISCUSSION		
9:45-10:00		**BREAK**		
2	10:00 – 10:20	PNNL (for NRC)	Pradeep Ramuhalli	Data Needs Best Addressed By Harvesting
	10:20 – 10:30	NRC	Matthew Hiser	High-Priority Data Needs for Harvesting
	10:30 – 10:55	DOE	Keith Leonard	LWRS Program Perspective on the Technical Needs for Harvesting
	10:55 – 11:20	SCK-CEN	Rachid Chaouadi	Review of past RPV sampling test programs and perspective for long term operation
	11:20 – 11:45	Westinghouse	Arzu Alpan	Importance of Harvesting to Evaluate Radiation Effects on Concrete Properties
	11:45 – 12:30	DISCUSSION		
12:30 – 2:00		**LUNCH**		
3	2:00 – 2:10	NRC	Matthew Hiser	Sources of Materials: Past NRC Harvesting and U.S. Decommissioning Plants
	2:10 – 2:35	EPRI	Al Ahluwalia	Harvesting Plans for Materials Aging Degradation Research in Korea and Sweden
	2:35 – 2:50	DOE/ORNL	Tom Rosseel	Materials Harvested by the LWRS Program
	2:50 – 3:00	DOE/INL	John Jackson	NSUF Material Sample Library
	3:00 – 3:15	Energy Solutions	Gerry van Noordennen	Zion Material Harvesting Program
	3:15 – 3:30	Westinghouse	Arzu Alpan	Potential Harvesting of Concrete from Mihama Unit 1
	3:30 – 3:45	**BREAK**		
	3:45 – 4:00	GRS	Uwe Jendrich	Plants in Decommissioning in Germany
	4:00 – 4:15	CNSC	Daniel Tello	Evaluating Structures, Systems & Components from Decommissioned/Decommissioning Nuclear Facilities in Canada
	4:15 – 5:00	DISCUSSION		

Wednesday, March 8

Session	Time	Organization	Speaker	Presentation Title
4	8:00 – 8:30	EPRI	Jean Smith	Lessons Learned: Harvesting and Shipping of Zorita Materials
	8:30 – 9:00	DOE	Tom Rosseel	LWRS Program: Harvesting Lessons Learned
	9:00 – 9:30	NRC	Matthew Hiser	NRC Perspective on Harvesting Experience and Lessons Learned
	9:30 – 10:00	CRIEPI	Taku Arai	CRIEPI Research Activities with Harvested Materials
	10:00 – 10:15	**BREAK**		
	10:15 - 10:45	Energy Solutions	Gerry van Noordennen	Zion Harvesting Experience and Lessons Learned
	10:45 - 11:15	Dominion	Bill Zipp	Kewaunee Insights on Material Harvesting
	11:15 – 12:00	DISCUSSION		
12:00 – 1:30		**LUNCH**		
5	1:30 – 1:45	PNNL (for NRC)	Pradeep Ramuhalli	Technical Information Needed for Informed Harvesting Decisions
	1:45 – 2:30	DISCUSSION		
	2:30 – 3:00	Action Items and Next Steps		
	3:00 – 4:00	EPRI	Sherry Bernhoft	Closing Thoughts
		DOE	Rich Reister	
		NRC	Robert Tregoning	
		ALL		

Appendix III Harvesting Opportunities in Germany

- Past and current decommissioning projects of **Prototype or Commercial Reactors**

Name	Abbrev.	Reactor type	Power MW_e	Decom. started	Strategy
Rheinsberg	KKR	WWER	70	1995	UC
Compact Natrium Cooled Reactor	KKN	SNR	21	1993	UC
Multipurpose Research R.	MZFR	PWR/D_2O	57	1987	UC
Obrigheim	KWO	PWR	357	2008	UC
Neckarwestheim 1	GKN-1	PWR	840	2017	UC
Isar-1	KKI-1	BWR	912	2017	UC
Gundremmingen-A	KRB-A	BWR	250	1983	RCA KRB-II
Greifswald 1-5	KGR 1-5	WWER	440	1995	UC
Lingen	KWL	BWR	268	1985	UC after SE

UC: unconditional clearance
RCA: radiation controlled area, new license
SE: safe enclosure

NRC Harvesting Workshop, Rockville, March 2017, Decommissioning in Germany 4

- Past and current decommissioning projects of **Prototype or Commercial Reactors**

Name	Abbrev.	Reactor type	Power MW_e	Decom. started	Strategy
Stade	KKS	PWR	672	2005	UC
Research Reactor Jülich	AVR	HTR	15	1994	UC
Thorium High-Temperature-Reaktor	THTR-300	HTR	308	1993	SE since 1997
Würgassen	KWW	BWR	670	1997	UC
Mülheim-Kärlich	KMK	PWR	1302	2004	UC
Hot-Steam Reactor Grosswelzheim	HDR	HDR	25	1983	UC since 1998
Niederaichbach	KKN	DRR/D_2O	106	1975	UC since 1994
Test-Reactor Kahl	VAK	BWR	16	1988	UC since 2010

- **Shut down Commercial Reactors**
  - **that have no decommissioning license granted yet**

Name	Abbrev.	Reactor type	Power MW_e	Date of application
Philippsburg-1	KKP-1	BWR	926	2013 / 2014
Grafenrheinfeld	KKG	PWR	1345	2014
Biblis-A	KWB-A	PWR	1225	2012
Biblis-B	KWB-B	PWR	1300	2012
Unterweser	KKU	BWR	1410	2012 / 2013
Brunsbüttel	KKB	BWR	806	2012 / 2014
Krümmel	KKK	BWR	1402	2015

- **Commercial Reactors in operation**

Name	Abbrev.	Reactor type	Power MW_e	Anticipated date of final shutdown
Gundremmingen-B	KRB-II-B	BWR	1344	31.12.2017
Philippsburg-2	KKP-2	PWR	1468	31.12.2019
Gundremmingen-C	KRB-II-C	BWR	1344	31.12.2021
Grohnde	KWG	PWR	1430	31.12.2021
Brokdorf	KBR	PWR	1480	31.12.2021
Emsland	KKE	PWR	1406	31.12.2022
Isar-2	KKI-2	PWR	1485	31.12.2022
Neckarwestheim-2	GKN-2	PWR	1400	31.12.2022

Note to requester: The attachment is immediately following this email.

From: Hull, Amy
Sent: Fri, 19 May 2017 13:47:31 -0400
To: Hiser, Matthew
Subject: Reviewed with comments -- Harvesting Workshop summary Report draft abh 5-19-17-1pm
Attachments: Harvesting Workshop summary Report draft abh 5-19-17-1pm.docx

Hi Matt,

This is lovely work and it was a very productive workshop.

I have another suggestion for you --- I think it would be a great idea to also have this as a presentation for IAEA PLiM this Fall. At the last SMIRT, there were summary papers of workshops like this that were very valuable. Condensing wisdom of many people into a short presentation – but you get a refereed article out of it. I think the short abstracts have to be done soon (today?) so you might want to check with Rob or Carol about this.

Harvesting Workshop
USNRC HQ * March 7-8, 2017
Summary Report

Commented [HA1]: This document is long enough and complicated enough and valuable enough, please think about adding linked table of contents so reader can go directly to a section.

Background

On March 7-8, 2017, the Office of Nuclear Regulatory Research of the United States Nuclear Regulatory Commission (NRC) hosted a 2-day workshop on the topic of "Ex-Plant Materials Harvesting." NRC staff worked in close coordination with staff from the U.S. Department of Energy (DOE) and the Electric Power Research Institute (EPRI) to plan and arrange the workshop.

Commented [HA2]: If this included PNNL folks on contract, then you should call out PNNL, since they are not DOE staff—National Lab scientists are not federal employees.

The decision to organize this workshop was driven by developments in the U.S. and global nuclear industry. In the U.S., there is strong interest in extending plant lifespans through subsequent license renewal (SLR) from 60 to 80 years. Extended plant operation and SLR raise a number of technical issues that may require further research to understand aging mechanisms, which may benefit from harvesting. Meanwhile, in recent years, a number of nuclear plants, both in the U.S. and internationally, have shut down or announced plans to shut down. Unlike in the past when there were very few plants shutting down, these new developments provide opportunities for harvesting components that were aged in representative light water reactor (LWR) environments. In a related development, economic challenges for the nuclear industry and limited government spending have limited the resources available to support new research, including harvesting programs. Given this constrained budget environment, aligning interests and leveraging with other organizations is important to allow maximum benefit and value for future research programs.

Commented [HA3]: Global comment – I think documents are easier to read when there are 2 spaces between sentences, but that is elective and optional.

Commented [HA4]: Maybe restate the first sentence in this paragraph, lifespans extended through proactive management of materials degradation and SLR research, etc – operating time extended through SLR.

Objective and Approach

The objective of the workshop was to generate open discussion of all aspects of ex-plant materials harvesting, including:

1. Deciding whether to harvest,
2. Planning and implementing a harvesting program,
3. Using the harvested materials in research programs.

Through presentations and open discussion, the workshop was organized to allow for all participants to be better informed of the benefits and challenges of harvesting as well as to identify potential areas of common interest for future harvesting programs. Workshop sessions were aligned in broad topics to cover all aspects of harvesting, but allow for participants to drive the discussion.

To help accomplish the workshop objectives, the workshop organizers intentionally sought a diverse group of participants. There are a large number of decommissioning plants and interested researchers outside the U.S., so the organizers focused on outreach to international participants through connections such as IAEA, OECD/NEA, and existing professional contacts. In addition, a key goal for this workshop was to capture the broader practical perspective from plant owners and decommissioning companies, which are vital to any successful harvesting program, but may sometimes be overlooked in

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researcher-driven discussions. Workshop participants were also diverse in terms of technical area of focus, with metal components such as the reactor pressure vessel (RPV) and internals being discussed along with concrete and electrical components. The final list of workshop participants can be found at the end of this report in Appendix I.

Workshop Organization and Sessions

The workshop was held at NRC headquarters in Rockville, MD. Due to limited space in the meeting room and the need for a limited group size for discussion, a webinar was used to allow remote observers to benefit from the workshop. Workshop sessions were organized topically with about half the time dedicated to presentations and the remaining time set aside for discussion. Presentations were solicited from participants to cover a range of perspectives and technical areas. The final workshop agenda can be found at the end of this summary report in Appendix II.

The workshop was organized into five sessions as follows:

- Session 1. Motivation for Harvesting
- Session 2. Technical Data Needs for Harvesting
- Session 3. Sources of Materials
- Session 4. Harvesting Experience: Lessons Learned and Practical Aspects
- Session 5. Future Harvesting Program Planning

Summary of Workshop Discussion

The subsections below will summarize the presentations and discussion in each session and highlight the key takeaways from the session.

Session 1. Motivation for Harvesting

Session 1 focused on the motivation for harvesting and why workshop participants are interested in harvesting. As shown in Appendix II~~2~~, providing presentation titles, speakers for~~presentations were provided in~~ this session included~~by~~:

- Richard Reister from DOE,
- Sherry Bernhoft from EPRI,
- Robert Tregoning from NRC,
- Uwe Jendrich from the Gesellschaft für Anlagen- und Reaktorsicherheit (GRS) in Germany, and
- Taku Arai from the Central Research Institute of the Electric Power Industry (CRIEPI) in Japan.

Presentation Summaries

DOE described the role of harvesting within the Light Water Reactor Sustainability (LWRS) Program, including the benefits and challenges associated with harvesting. Benefits include the opportunity to fill knowledge gaps where there is limited data or experience and to inform degradation models with data from actual plant components. Challenges include cost, complexity, scheduling, logistics, limited opportunities, acquiring sufficient material pedigree information, and potential negative results impacting operating plants.

EPRI discussed the role of harvesting within the context of aging management for Long-Term Operations (LTO), including their experience from past harvesting programs and criteria for future harvesting. Their experience emphasized the challenges of cost, schedule, logistics, complicated contracting and acquiring material pedigree information. EPRI's criteria for harvesting include value to their members that addresses a prioritized need and knowledge gap that cannot be otherwise filled through other means. For EPRI members, a well-developed project plan that covers funding, risk management, exit ramps, and clear roles and responsibilities is considered essential.

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NRC shared its perspective on the benefits and challenges of harvesting in regulatory research. Harvested materials are valuable due to the real-world nature of their aging conditions, which may reduce the uncertainty associated with the applicability of the results to operating plants compared to tests with alternative aging conditions. Harvested materials may be the best option to address technical data needs identified for extended plant operation. Increasing harvesting opportunities from decommissioning plants suggests a proactive approach to harvesting planning which may optimize benefits by identifying the appropriate material with the aging conditions of interest for the identified knowledge gap. There are significant challenges associated with harvesting, including cost, schedule, and logistics, but hopefully these can be mitigated or avoided by leveraging coordination with other organizations and learning from past experience.

Commented [HA7]: Too much, rewrite for clarity.

Commented [HA8]: There should be a noun following this verb form. Leveraging what – insight, collaboration, coordination?

GRS described its role as the main technical support organization in nuclear safety for the German federal government. GRS provides technical assessment and knowledge transfer for reactor decommissioning activities, aging management, and long-term operation for German federal and international organizations.

CRIEPI discussed its view of how harvested materials and laboratory prepared materials contribute to addressing technical issues. Harvested materials provide exposure to actual plant conditions, but are more limited in availability and the size of the data set that can be generated. Laboratory prepared materials general involve accelerated or simulated aging conditions, but can be used to produce larger data sets and varying parameters can allow understanding of the effect on the mechanism or property of interest. Harvested materials offer fact finding of actual plant conditions as well as confirmation and verification of results from laboratory prepared specimens.

Discussion Summary

The discussion following the presentations in this session focused on clearly identifying the need to be addressed by a harvesting project and the myriad cost, schedule, and logistical challenges associated with harvesting. Sharing projects with other organizations to defray costs can also help improve the value of a given program, but also adds complexity as another organization may have a different set of priorities that changes the focus of the harvesting effort.

Session 2. Technical Data Needs for Harvesting

Session 2 focused on discussing the technical data needs for harvesting and what specific knowledge gaps organizations are interested in addressing through harvesting. This discussion included general perspectives on how to determine when harvesting should be pursued rather than other types of research. As shown~~Presentations were provided~~ in Appendix II, providing presentation titles, speakers for this session included~~by~~:

- Pradeep Ramuhalli from the Pacific Northwest National Lab (PNNL),
- Matthew Hiser from NRC,
- Keith Leonard from Oak Ridge National Laboratory (ORNL),
- Rachid Chaouadi from SCK-CEN in Belgium, and
- Arzu Alpan from Westinghouse.

Presentation Summaries

PNNL presented their work, under a small NRC contract, to develop a systematic approach to prioritize data needs for harvesting. PNNL proposed five primary criteria for prioritizing harvesting:

- Unique field aspects of degradation
  - For example, unusual operating experience or legacy materials (composition, etc.) that may be no longer available
- Ease of laboratory replication of environment-material combination (degradation scenario)
  - For example, simultaneous thermal and irradiation conditions may be difficult to replicate or mechanism sensitive to dose rate may not be good for accelerated aging
- Applicability of harvested material for addressing critical gaps
  - Prioritize harvesting for critical gaps over less essential data needs
- Availability of reliable in-service inspection (ISI) techniques for the material / component
  - If inspection methods are mature and easy to apply to monitor and track degradation, perhaps the effort of research with harvested materials is not needed.
- Availability of material for harvesting
  - The necessary materials / components must be available to be harvested.

PNNL then presented their application of these criteria to four materials degradation issues as an example: electrical cables, cast austenitic stainless steel (CASS), reactor vessel internals, and dissimilar metal welds. Based on applying these criteria to the examples, PNNL concludeds~~s~~ that electrical cables, CASS, and reactor internals are all higher priority for harvesting due to unique aspects of the degradation that are challenging to replicate in the lab. Meanwhile, dissimilar metal welds are of low priority due to the ease of replication in lab aging studies as well as the significant body of knowledge and research on the phenomena.

NRC presented a summary of data needs it is interested in pursuing through harvesting. These included RPV materials to validate fluence and attenuation models and to demonstrate the conservatism of regulatory approaches for transition temperature prediction. Other metal components of interest for harvesting would address data gaps in irradiated stainless steels, as well as improve understanding of inspection capabilities and fatigue life calculations. Electrical components of interest include low and medium voltage cables and other electrical components for degradation studies, and electrical enclosures and cables for fire research. Concrete components of interest include irradiated concrete, concrete undergoing alkali-aggregate reactions, post-tensioned structures, reinforcing steel, tendons, and spent fuel pool concrete to assess potential boric acid attack.

DOE/ORNL presented their perspective on data needs for harvesting and its role in providing validation of experimental and theoretical research. DOE performed a significant ~~reactor pressure vessel (~~RPV~~)~~ harvesting program at the Zion nuclear power plant to reduce uncertainties in the Master Curve methodology, validate modeling predictions and study flux and fluence attenuation effects. The

Commented [HA9]: pls define SCK-CEN in line above, since this is the first time the acronym is used.

Commented [HA10]: Global comment, are you sure that you want to refer to organization in these sections, since the speaker may represent only themselves --- certainly Pradeep does not speak for PNNL.

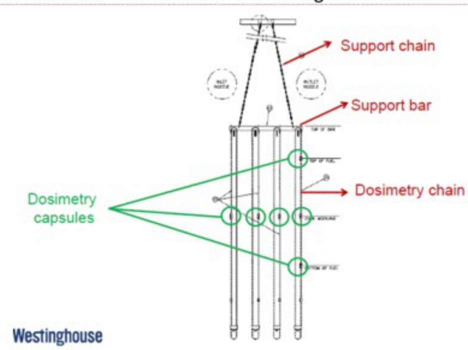
Commented [HA11]: Do you want to continue to use the term DOE/ORNL? If ORNL actually did the work, I think you should.

Commented [HA12]: Global comment – you only need to define acronym 1X, the first time used --- RPV was defined on pg. 1

harvesting is largely complete, but the testing program is currently underway. DOE also indicated interest in using harvested materials to validate its models for swelling and microstructural changes of stainless steel internals under LWR irradiation conditions. Harvesting concrete components would be of interest due to lack of literature data and the multiple dependent variables that may affect concrete performance. Finally, DOE has been involved in harvesting cables from the Crystal River and Zion plants to address cable aging as a function of material composition and environment.

SCK-CEN presented their interest in an international cooperative program to harvest ~~reactor pressure vessel (~~RPV~~)~~ materials. SCK-CEN presented their survey of the literature for past testing programs of harvested RPV materials, and the limitations of these past programs. Key limitations included a lack of archive materials, generally lower temperatures, and poor surveillance programs and dosimetry. SCK-CEN then shared some thoughts on their criteria for a new harvesting efforts, including higher fluence levels and temperatures, available archive materials and reliable information on operating history, dosimetry and surveillance program. Other topics discussed, relevant to a new RPV harvesting effort, included technical issues such as material variability and irradiation conditions as well as logistical and financial considerations.

The final presentation in Session 2 by Westinghouse focused on the need for harvesting irradiated concrete to better understand the threshold radiation level for significant strength reduction. Westinghouse has installed ex-vessel neutron dosimetry (EVND) at a number of plants in the world and proposed to use these dosimetry measurements to validate fluence model calculations to better understand the uncertainty in these calculations. If concrete can be harvested at one of these plants with EVND data, then irradiated concrete properties from testing can be paired with fluence data to improve research benefits.



Commented [HA13]: Nice illustration, do you want to call it Figure 1 with a cross-referencw with the narrative?

Discussion Summary

The discussion following Session 2 presentations touched on a number of topics. EPRI shared that they developed a report related to the topics of S~~s~~ession 2, but more narrowly focused on PWR internals. MRP-320, "Testing Gap Assessment and Material Identification for PWR Internals," focuses on prioritizing opportunistic harvesting of stainless steel reactor internals components that may be removed from service following MRP-227 inspections. The methodology and approach in this report may be relevant to the broader harvesting data needs discussion. This report is not publicly available, but is available to EPRI member utilities.

Commented [HA14]: Just wondering…are you able to see this through MOU?

Workshop participants discussed the criteria proposed by PNNL in the first presentation. One additional criteria suggested by EPRI was to consider fleet-wide vs. plant-specific applicability. More broadly applicable materials would be of greater interest for harvesting than those that represent conditions at only a few plants. Another criteria suggested is the availability of material pedigree information, such as composition, processing, environmental conditions (temperature, humidity, fluence, etc.). Another suggested criteria was the ease of harvesting. For example, highly irradiated internals are probably much more difficult and expensive to harvest than electrical cables or unirradiated concrete. This discussion would capture the idea of weighing costs vs. benefits as well as project risk. Further discussion touched on the idea that different organizations may prioritize the various criteria differently, but all will probably at least want to consider the same set of criteria.

Commented [HA15]: Not clear if you are talking about future or past discussion. Please correct verb tense.

Another key theme from this discussion was that a successful program should be guided by a clearly defined objective or problem statement to be addressed. This objective should be well-understood at the initiation of a program and used to guide decision-making through implementation of a harvesting project. This also raises a related point or potential criteria: the timeliness of the expected research results relative to the objective. If the results are needed in the next two years, but a harvesting project will not provide results for at least five years, that should be a strong consideration.

Session 3. Sources of Materials

Session 3 focused on discussing sources of materials for harvesting. This discussion covered previously harvested materials as well as sources for new harvesting programs from operating or decommissioning plants. Both domestic and international sources of materials were discussed in this session.

As shown~~Presentations were provided~~ in Appendix II, providing presentation titles, speakers for this session included~~by~~:

- Matthew Hiser from NRC,
- Al Ahluwalia from EPRI,
- Tom Rosseel from DOE/ORNL,
- John Jackson from DOE/Idaho National Laboratory (INL),
- Gerry van Noordennen from EnergySolutions,
- Arzu Alpan from Westinghouse,
- Uwe Jendrich from GRS, and
- Daniel Tello from the Canadian Nuclear Safety Commission (CNSC).

Presentation Summaries

NRC presented their perspective on sources of materials for harvesting. First, NRC shared some of the harvested materials from past research programs that may be available, including irradiated stainless steel internals, RPV materials, nickel alloy welds, neutron absorber material, and electrical components. NRC then summarized the recently and planned shutdown U.S. plants, including their design, thermal output, and years of operation, to provide participants with an idea of the potential sources from decommissioning U.S. plants. Finally, NRC shared a list of information that would be helpful to acquire from decommissioning plants to determine the value of components for harvesting. This information included plant design information (component location and dimensions), environmental conditions (temperature, fluence, humidity, stress, etc.) and operating history, material pedigree information (fabrication records), and inspection records (for interest in components with known flaws).

The next presentation from EPRI covered harvesting opportunities at decommissioning plants in Korea and Sweden. In Korea, Kori-1 is a Westinghouse 2-loop PWR (sister plant is Kewaunee) that will shut down in 2017 after 40 years of operation. Korea Hydro and Nuclear Power Central Research Institute (KHNP-CRI) is planning a comprehensive research program on long-term materials aging based on harvesting from Kori-1 and is seeking international participation in the harvesting effort. KHNP-CRI's plan is focused on metallic components, including RPV, internals, primary system components, steam generator materials. Harvesting is expected to occur in 2024 with testing to follow through 2030.

In Sweden, Vattenfall is currently harvesting in 2017-2018 RPV material from the decommissioning Barseback BWR units. This work is focused on irradiation embrittlement, including comparison of surveillance data to actual RPV properties, as well as thermal aging embrittlement. In the future, Vattenfall will be shutting down Ringhals 1 and 2 in 2020 and 2019, respectively. Ringhals 1 is a BWR and Ringhals 2 is a Westinghouse 3-loop PWR design. Of particular note, Ringhals 2 has the second oldest replaced Alloy 690 RPV head and steam generators. Other harvesting opportunities at Ringhals include RPV material with a significant surveillance program, thermal aging effects on low alloy steel from the pressurizer, as well as concrete structures. Vattenfall is open to working with partners that are interested in joining them for harvesting at Ringhals.

(b)(4)

The next presentation by DOE/ORNL focused on several harvesting programs that DOE's LWRS program has been involved with. DOE has led the harvesting of components from the Zion [redacted] plant [redacted] in the U.S. From Zion, DOE has harvested electrical cables and components, a large RPV section, and a significant number~~amount~~ of records to provide information on material fabrication, in-service inspection and operating history. Cables from Zion include CRDM, thermocouple, and low and medium voltage cables. DOE indicated some thermocouple cables from Zion may be available for other researchers to use in collaborative studies. [redacted] DOE is also participating in efforts to harvest cables from Crystal River (led by EPRI) and concrete from the Zorita plant in Spain (led by NRC).

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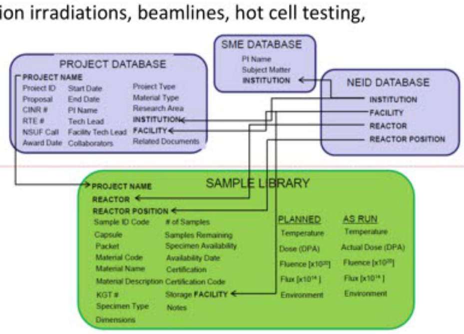
The next presentation by DOE/INL described INL's Nuclear Science User Facilities (NSUF) and the Nuclear Fuels and Materials Library (NFML). NSUF is coordinated by INL and facilitates access to nuclear research facilities around the world, including neutron and ion irradiations, beamlines, hot cell testing, characterization, and computing capabilities. NFML is a Web-based searchable database sample library that captures the information from thousands of specimens available to NSUF. NFML is designed to maximize the benefit of previously irradiated materials for future research. Researchers can propose new research projects under NSUF using specimens in NFML using DOE funding. The information captured in NFML aligns well with the goal of this session to potentially develop a database of previously harvested materials.



Commented [HA16]: Nice illustration, maybe cross-reference as Figure 2 with caption and call-out in text.

The next presentation by EnergySolutions offered a more practical perspective on considering sources of materials for harvesting. From the plant owner perspective, in the decommissioning process there is not a financial incentive to support harvesting, therefore researchers need to absorb costs for harvesting and have a clear scope for harvesting. Flexibility in funding for harvesting activities is essential as the decommissioning process and schedule may change quickly.

EnergySolutions provided valuable perspective on the timing in the decommissioning process~~ves~~ for harvesting different components. Harvesting RPV surveillance coupons should take place when the RPV internals are cut and removed. Harvesting RPV materials is only possible from larger RPVs, as smaller RPVs are shipped intact to the disposal facility, rather than cut into pieces. Spent fuel rack neutron absorber coupons must be harvested either before or after dry storage campaign to remove spent fuel from the spent fuel pool. Harvesting actual spent fuel rack neutron absorber material must come after the pool is completely empty. Electrical cables and other components from mild environments may be harvested at any time (once temporary power is established and plant power is shut off), while electrical components from high rad environments will depend on timing of source term removal schedule. Concrete cores are best harvested when other cores are being taken for site characterization to develop the License Termination Plan. Highly irradiated concrete from biological shield wall would need to come later in decommissioning after RPV is removed.

Commented [HA17]: "mild environment" above – do you want to say something like "benign" environment or define further?

In terms of upcoming decommissioning plants, EnergySolutions indicated that San Onofre and Vermont Yankee will be entering DECON is 2018 and 2019, respectively. Kewaunee, Crystal River, and Fort Calhoun also may enter DECON in next 2 years. If researchers are interested in harvesting from any of these plants, they should be reaching out to plant owners immediately to begin planning and coordination.

Westinghouse followed their presentation in S~~s~~ession 2 by describing an opportunity to harvest concrete from the Mihama 1 plant in Japan. Westinghouse installed and analyzed additional neutron dosimetry in the reactor cavity for one cycle, which were used to validate the radiation transport calculations. Mihama was shut down in 2015 and is in contact with Westinghouse about the possibility of extracting concrete cores from the biological shield wall. Westinghouse is seeking partners interested in joining this harvesting effort.

The next presentation by GRS covered opportunities for harvesting from German plants. Regulations in Germany require plants to either immediately dismantle or dismantle after a period of safe enclosure, which is largely consistent with options in the U.S. GRS detailed the status of German commercial reactors, which are predominantly BWR and PWR designs. Seventeen reactors are currently undergoing decommissioning, while seven more are currently shutdown and await a decommissioning license. Eight reactors are still operating with scheduled shutdown dates between 2017 and 2022. German RPVs tend to have lower fluence than~~t~~ U.S. designs due to a larger water gap in the downcomer region. Germany has limited experience with harvesting from decommissioning plants. One question that GRS will follow-up on is the "rumored" cable surveillance programs that may be used in Germany and could provide experience and lessons learned for other countries.

The final presentation in Session 3 was by CNSC on harvesting opportunities in Canada. Atomic Energy Canada Limited (AECL) has harvested seven concrete cores from the 20 MW Nuclear Power Demonstration Plant (NPD), which shutdown in 1988 after 25 years of operation. CNSC and AECL are also considering opportunities to harvest concrete from other decommissioned reactors in Canada such as Gentilly-2, Douglas Point, and Whiteshell Reactor 1. In addition to concrete, CNSC and AECL are currently harvesting electrical cables from the 675 MWe CANDU-6 Gentilly-2 reactor, which shutdown in 2012 after 29 years of operation. The purpose of this work is to study cable degradation from thermal aging and radiation damage and validate environmental qualification of the cables. CNSC described some of the challenges with this harvesting effort, such as working with plant owners, records, accessibility and contamination of the materials and budgeting with unexpected delays in harvesting.

A future harvesting opportunity is from the National Research Universal (NRU) reactor at Chalk River, which will shut down in 2018 after operating since 1957. AECL is currently taking an inventory of irradiated materials that can be harvested from NRU in decommissioning. Potential materials for harvesting include metals (steels, nickel alloys, zirconium, aluminum), concrete, graphite, active equipment (pumps, etc.), graphite seals, electrical cables, and thermocouples.

Discussion Summary

Following the presentations, there was some discussion of lessons learned from DOE's Zion harvesting effort. DOE worked with a former senior reactor operator at Zion to identify and acquire the appropriate records from Zion for the components being harvested. DOE also described their flexible approach to acquiring RPV samples by sending a large chunk of material (weighing ~90 tons) to EnergySolutions' facility in Tennessee, where smaller pieces (weighing ~500 pounds) were cut to send to ORNL. Most of the decontamination was performed at Zion, with minimal additional cleaning (as well as cladding removal) taking place at EnergySolutions' facility.

There was also discussion of acquiring materials from sources other than commercial nuclear facilities. DOE has considered harvesting concrete from other DOE nuclear facilities, but determined that there were compositional differences between the DOE facilities and commercial facilities that would make them not useful. DOE/INL mentioned that the Advanced Test Reactor (ATR) replaces their core internals every ten years. The ATR internals are composed primarily of 347 stainless steel and achieve very high fluence levels after ten years of service.

Another key discussion topic was the possibility of developing a database for previously harvested materials or those available for future harvesting. DOE/INL indicated that their NSUF sample library may be a good starting point for such a database, although any materials in that library should be freely available for use in the research community. CNSC and NRC also expressed interested in working to develop a harvesting database.

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Session 4. Harvesting Experience: Lessons Learned and Practical Aspects

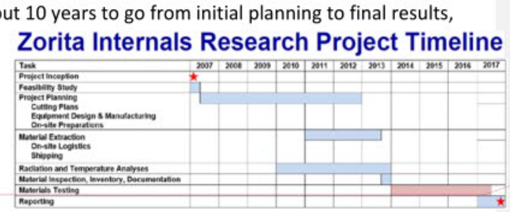
Session 4 focused on lessons learned and practical aspects of harvesting. Presenters shared their experience with past harvesting programs, particularly common pitfalls to avoid and successful strategies to overcome them. Presentations also covered the practical aspects of harvesting from the plant owner and decommissioning company perspective.

As shown~~Presentations were provided~~ in Appendix II, providing presentation titles, speakers for this session included~~by~~:

- Jean Smith from EPRI,
- Tom Rosseel from DOE/ORNL,
- Matthew Hiser from NRC,
- Taku Arai from CRIEPI,
- Gerry van Noordennen from EnergySolutions, and
- Bill Zipp from Dominion.

Presentation Summaries

EPRI presented their experience and lessons learned from past harvesting programs, particularly harvesting reactor internals and concrete from Zorita and electrical cables from Crystal River. From the Zorita reactor internals experience, EPRI emphasized that harvesting projects take significant time, encounter both material retrieval and on-site challenges, and shipping issues. In terms of time, the Zorita Internals Research Project (ZIRP) took about 10 years to go from initial planning to final results, which included about 5 years of project planning, 2 years for material extraction (on-site logistics and shipping), and 3-4 years for testing. EPRI's experience was that decommissioning activities were the top priority and that harvesting as secondary, ~~were~~ subject to schedule and logistical challenges based on the changing decommissioning schedule. Shipping issues were also challenging due to sending activated materials (which were classified as "waste") across international borders, from the reactor in Spain to the testing facility in Sweden. Currently, f~~F~~urther planned shipments of the Zorita materials beyond the initial program continue to be impacted by export license challenges in Sweden. More positively, EPRI emphasized that the Zorita reactor internals materials harvesting showed excellent cooperation among many organizations and are now providing valuable technical information to numerous research projects.



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Lessons learned from the Zorita concrete harvesting focused on the challenges with core sample drilling and handling contaminated concrete. Ultimately, an effective core drilling procedure was identified, but required some trial and error. Lessons learned from the Crystal River cable harvesting included material concerns, the need for on-site support, and cost. In terms of material concerns, radiation and asbestos contamination created additional challenges for harvesting. On-site support and the ability to visit the site are extremely valuable to ensure clear communication, retrieval or records for material pedigree information, and awareness of on-site developments in the decommissioning process. Cable harvesting at Crystal River was more expensive than anticipated, particularly in terms of EPRI project management time to coordinate the harvesting activities and engineering support at the plant.

DOE presented lessons learned primarily from the experience harvesting RPV materials and electrical cables and components from the Zion plant. In terms of planning and decision-making, DOE had several lessons learned. DOE hosted a workshop at Zion in 2011 to discuss long-term goals and objectives, which proved very helpful in setting priorities and developing partnerships with other organizations. Partnerships were very valuable to DOE's harvesting efforts, allowing for leveraging resources and collaboration and sharing results. There are limited opportunities for harvesting key components, so DOE emphasized that participants should take full advantage of the opportunities that arise, understanding that there is a necessary compromise between the materials available and their value in terms of fluence or exposure to aging conditions. Another consideration is the quantity of material harvested, which should be sufficient for the objectives of the planned research as well as any collaborations or partnerships, but limited to control costs.

For implementing the harvesting program, DOE found that flexibility was paramount to be able to adjust scope and plans in response to schedule changes and other developments, while remaining within cost constraints. Working with a former reactor operator was extremely valuable to benefit from their in-depth knowledge of all parts of the plant, in particular the records for materials pedigree information. Regular site visits and contacts were also essential to stay aware of the latest developments in the harvesting planning and decommissioning process, with the understanding that harvesting is not the top priority for the decommissioning company. Other important considerations were hazardous materials handling, transportation, and disposal and logistics, including contracts, liability, shipping and disposal. Finally, DOE's experience is that the total costs of a harvesting program from planning to execution to testing are very high, so they should be carefully weighed against the value of the expected data to be generated.

NRC presented their experience, including benefits from previous harvesting programs, and technical and logistical lessons learned from harvesting. As an organization, NRC has extensive experience with testing harvested materials, including RPV, primary system components, reactor internals, neutron absorbers, concrete and electrical components. NRC's experience is more limited than DOE or EPRI in terms of managing the logistics of a harvesting effort from a decommissioning plant. NRC has generally participated in a secondary role in cooperative efforts or received failed components from operating plants for research. NRC has found that previous harvesting efforts have been effective in reducing unnecessary conservatism, understanding in-service flaws more realistically for NDE and leak rate methodologies, as well as identifying and better understanding safety issues.

For technical lessons learned, NRC's perspective is that harvesting can provide highly representative aged materials for research, which may be the only practical source of such materials. Harvested materials can be effectively used to validate models or a larger data set from accelerated aging tests. It is important to understand as much as possible about the materials and their in-service environment ~~in service~~ and how this compares with the operating fleet of reactors before committing to a specific harvesting project. For logistical lessons learned, harvesting is expensive and time-consuming, so a significant~~high~~ technical benefit is needed to ensure the program provides values. Leveraging resources with other organizations can help minimize costs, but can also introduce challenges for aligning priorities and interests of multiple organizations. Finally, transporting irradiated materials, particularly between countries, is challenging and time-consuming and should be avoided if at all possible.

CRIEPI presented their research experience with harvested materials as well as ongoing harvesting from the Hamaoka 1 plant. The first research program involved atom probe tomography (APT) on RPV surveillance materials. CRIEPI found a correlation between the volume fraction of Ni-Si-Mn clusters and the change in nil-ductility temperature. In the second research project, CRIEPI characterized the weld and base materials harvested from Greifswald Unit 4 RPV with small-angle neutron scattering, APT, and hardness testing. In the third research project, CRIEPI performed APT on 304L stainless steel reactor internals harvested from control rod and top guide components from 3-13 dpa. Results showed a strong increase in Ni-Si clusters with increasing fluence, but little variation in Al enriched clusters with increasing fluence.

For future work, CRIEPI is collaborating with the DOE LWRS to investigate RPV materials harvested from (b)(4) Zion [redacted] CRIEPI also presented activities underway by Chubu Electric Power to harvest RPV and concrete samples from the Hamaoka 1 plant. Hamaoka 1 is a 540 MW BWR-4 that operated for 33 years. Harvesting began in 2015 and will continue through 2018.

The final two presentations of Session 4 provided the non-researcher perspective from a decommissioning company and plant owner. EnergySolutions, which is decommissioning the Zion nuclear plant among other facilities, presented the decommissioning process and their experience and lessons learned from harvesting at Zion. As mentioned previously, surgical harvesting is not the top priority for decommissioning, so researchers must recognize this and coordinate close with the decommissioning company. EnergySolutions emphasized the need to gain senior management support at the plant as well as to expect that there may be staff turnover during a multi-year harvesting effort. Changes in scope and schedule (originating from either side~~both sides~~) can cause frustration on both sides. Early planning and delays with contracting are important to avoid lost opportunities. Being on-site during harvesting is essential to a good outcome.

At Zion, EnergySolutions worked with DOE to harvest RPV materials, cables, electrical components, and spent fuel storage racks. DOE hoped to harvest a particular RPV surveillance capsule, but was unable to, due to the inability to identify the correct capsule. There were also challenges with harvesting RPV materials. The cut line on the Unit 2 RPV was too close to the weld to be used for research; fortunately, a successful specimen was harvested from Unit 1. For cabling, the initial plan was to harvest from 11 different locations, but ultimately due to unforeseen challenges and poor communication and coordination, only 4 different cable locations were harvested. Harvesting the desired cable length (30 feet) also proved challenging, with only shorter sections recovered. ~~Plant records S~~searches of plant records were largely effective at providing material pedigree information for cables. Concrete coring was initially planned to take place at Zion, but not performed due to lack of research interest. The spent fuel storage rack harvesting went smoothly, which was assisted by weekend efforts ~~over the weekend~~ when decommissioning activities were not occurring.

The next presentation from Dominion provided its perspective on harvesting from decommissioning plants, focused on the experience at Kewaunee Power Station. The top priority (beyond safety) in decommissioning is the preservation and good stewardship of the decommissioning trust fund. Staffing is the largest drain on the trust fund, so at Kewaunee, staff was halved within a few months of shutdown and then halved again, about 16 months after permanent shutdown once offsite emergency response requirements were eliminated. Dominion described the example of harvesting the RPV surveillance capsules at this point at Kewaunee and the significant challenges that would exist. Given the reduced staffing and the current plant state (reactor coolant system drained, pumps retired, crane and radiation monitoring not maintained), it would be much more difficult ~~now~~ than immediately after shutdown. Kewaunee considered harvesting the surveillance specimens and estimated a cost of six to seven figures based on all the activities required to enable it at this point, post-shutdown, compared to a much lower cost just after shutdown. Dominion observed that some components, such as cables or electrical components, may be available and relatively easy to harvest at almost any time during decommissioning. However, other components such as highly irradiated internals or RPV may be best harvested either shortly after shutdown when staffing and capabilities on-site are high or wait until active demolition of the reactor, which may be years or decades later.

Dominion also touched on the discussion of records for plant components. Records requirements are limited to those needed for safety. Once the plant shuts down and the range of potential safety concerns decreases, systems are downgraded to non-safety and the associated records are no longer required to be maintained. For perspective, Kewaunee still has all its records four years since shutdown, but will likely not continue this much longer. Dominion closed its presentation with a broader

perspective on harvesting, emphasizing the need to clearly define a problem statement and understand what technical and regulatory purpose this harvesting will serve. Early planning focused on achieving the clear objective of the work including scope, schedule, budget and contact with plant is essential to a successful harvesting effort.

Discussion Summary

The discussion touched on the top lessons learned from past harvesting efforts, which included defining a clear objective and purpose for harvesting, early engagement with the plant, and site coordination during harvesting.

Another suggestion was to get utility management buy-in for the harvesting project by identifying a benefit to the utility. EPRI mentioned that cable harvesting at Crystal River went much more successfully once the utility recognized the potential benefits for SLR~~subsequent license renewal~~. Similarly, when harvesting from an operating plant, one must~~you need to~~ recognize and work through the challenges the plant may encounter when restarting operations.

Commented [HA20]: Global comment – once acronym is defined, use that acronym.

Commented [HA21]: Typically in a technical report, don't use the pronoun 'you'.

During discussion, the question was raised regarding how it is determined whether harvested materials are waste. The discussion concluded that in the U.S. 10 CFR 37 is the important consideration. 10 CFR 37 defines when additional security requirements are imposed, based on the quantity and activity of materials to be transported. The definition of material as waste versus research materials is not as critical in the U.S. EnergySolutions indicated that their shipments of waste or research material could be handled in the same way in the accordance with Department of Transportation regulations, provided that the limits in 10 CFR 37 were not reached.

Session 5. Future Harvesting Program Planning

Session 5 focused on the information needed for informed harvesting decision-making and harvesting program planning. This session featured a presentation by Pradeep Ramuhalli from PNNL, followed by a discussion period covering harvesting program planning and reflection on the 2-day workshop.

Presentation Summary

PNNL presented its perspective on the information needed for informed harvesting decision-making. First, the purpose of the harvesting effort needs to be defined by identifying the technical knowledge gaps to be addressed. Next, a research plan should be developed demonstrating how the harvested material will be used to address the identified gaps. Finally, the appropriate source of material to address the technical gap must be identified, along with resources to support the effort and plans and timelines to perform the harvesting. The specifics of these plans depend greatly on the source of materials and must be flexible based on changing conditions on the ground.

In assessing the best source of materials, researchers should consider the material, its environment, and its condition. Material information includes fabrication information such as manufacturer, composition, and dimensions as well as information related to installation or construction, such as welding processes and parameters. Environmental information includes temperature, humidity, fluence, flux, stress (service, residual, installation), and coolant chemistry. Component condition information includes inspection history, such as identified flaws or degradation.

Discussion Summary

The discussion in Session 5 focused on the best practical approach to plan future harvesting programs. There was clear agreement that this approach must begin with identifying the data needs best addressed by harvesting, whether from operating or decommissioning plants. Once a specific need is identified, the next step is to find a source to acquire the materials of interest as well as other organizations interested in participating in the harvesting effort.

Key Takeaways from Workshop

Session 1

The clear takeaway from the discussion in S~~s~~ession 1 was that harvesting requires significant resources to be done successfully; therefore it is paramount to identify how the planned harvesting will clearly address a significant need to ensure the harvesting project provides strong value. In the context of need for data, EPRI suggested the goal of harvesting to support research for operation out to 80 years is not a full comprehensive understanding of all aspects of the degradation, but rather a snapshot to confirm other lab results and models. This is an important point for all organizations and researchers to keep in mind before investing significant resources in harvesting.

Session 2

The criteria proposed by PNNL are a good starting point for prioritizing issues to address by harvesting. Three additional important criteria would be:

- Fleet-wide vs. plant-specific applicability of data,
- Ease of harvesting (in terms of cost and project risk), and
- Timeliness of the expected research results relative to the objective.

Once a potential harvesting project has reached the point of looking at different sources of materials, the availability of material pedigree information, such as composition, processing, environmental conditions (temperature, humidity, fluence, etc.) is very important to the overall value of harvesting from that particular plant.

Based on the presentations and discussion in Session 2, there appeared to be two areas where participants had~~ith~~ broad interest in pursuing further harvesting: high fluence reactor internals and irradiated concrete. The common drivers for the interest in these issues is a lack of representative data at the fluence of interest and significant challenges with acquiring representative data through other means. High fluence reactor internals have ~~s~~ been addressed somewhat by~~ the Zorita Internals Research Project (~~ZIRP~~)~~, but stainless steel materials exposed to higher fluence levels at higher temperatures, where void swelling may become significant, could help validate DOE and EPRI models and provide further technical basis for PWR internals aging management. Irradiated concrete harvesting is currently being pursued from the Zorita reactor in Spain, with international collaboration and potential testing at the Halden Reactor Project.

Other areas with some, but less widespread, interest expressed from workshop participants for new harvesting efforts included RPV materials and electrical cables and components. SCK-CEN and NRC expressed interest in RPV harvesting, and NRC expressed interest in electrical component harvesting.

Session 3

To capture the key takeaways from Session 3 focused on sources of materials, two tables of potential sources of materials are presented below. T~~he first t~~able 1 covers recent or ongoing harvesting programs, while Table 2 ~~the second~~ details potential future harvesting opportunities.

Table 1. Ongoing Harvesting Programs

Country	Plant	Design	Size (MWe)	Years in operation	Components	Organization(s)
Canada	NPD	CANDU	20	25	Concrete	AECL
	Gentilly-2	CANDU-6	675	29	Cables	
Japan	Hamaoka 1	BWR-4	540	33	RPV, concrete	CRIEPI/Chubu
Spain	Zorita	W 1-loop	160	37	Internals, concrete	EPRI, NRC
Sweden	Barseback	ABB-II	615	28	RPV	Vattenfall
U.S.	Zion 1/2	W – 4 loop	1040	24/25	RPV, cables, neutron absorbers	DOE, EPRI, NRC
	Crystal River 3	B&W	860	36	Cables	EPRI
	(b)(4)					

Table 2. Potential Future Sources for Harvesting

Country	Plant	Design	Size (MWe)	Years in operation	Potential Components	Notes
Canada	NRU	Test reactor	135 MWt	61	TBD	AECL; SD: 2018
Germany	Numerous plants either in decommissioning or shutting down soon. See Appendix III.					
Japan	Mihama	W 2-loop	320	40	Concrete	Kansai, Westinghouse
Korea	Kori 1	W 2-loop	576	40	RPV, internals, SGs, pressurizer, welds, CASS,	KHNP, EPRI
Sweden	Ringhals 1	BWR	883	44	RPV, internals SGs, pressurizer, concrete	Vattenfall; SD: 2020 / 2019
	Ringhals 2	W 3-loop	900	44		
U.S.	Kewaunee	W 2-loop	566	39	TBD	SD: 2013
	SONGS 2/3	CE 2-loop	1070	31/30	TBD	SD: 2013
	Crystal River 3	B&W	860	36	TBD	SD: 2013
	Vermont Yankee	BWR-4/Mk-1	605	42	TBD	SD: 2015
	Fort Calhoun	CE 2-loop	482	43	TBD	SD: 2016
	Palisades	CE 2-loop	805	47	TBD	SD: 2018
	Pilgrim	BWR-3/Mk-1	677	47	TBD	SD: 2019
	Oyster Creek	BWR-2/Mk-1	619	50	TBD	SD: 2019

	Indian Point 2/3	W 4-loop	1020 / 1040	48/46	TBD	SD: 2021
	Diablo Canyon 1/2	W 4-loop	1138 / 1118	40	TBD	SD: 2024-5
	Advanced Test Reactor	Test reactor	250 MWt	50	Core internals	Non-commercial; internals replaced every 10 years

In addition to the potential sources of materials presented and discussed in Session 3, another takeaway was the suggestion of developing a database for previously harvested materials or those available for future harvesting. The NSUF sample library may be a good starting point for such a database, with appropriate modifications for the purposes of harvesting efforts.

Session 4

There were several important takeaways from Session 4 that were touched on in multiple presentations and the following discussions. One key takeaway is that researchers should identify a clear purpose and scope for harvesting. Having a clear purpose for harvesting helps to guide later decisions that must be made to adjust course when the inevitable changes in schedule or unexpected realities at the plant arise. A related note is that harvesting is not the top priority for decommissioning. Therefore, researchers must have clear objectives and scope for harvesting that can be communicated to the site. This understanding should shape assumptions and interactions with the plant owner or decommissioning company as well as planning for costs and schedule.

Another takeaway was the value of strong site coordination, including site visits. Multiple presenters touched on the value of being on-site to talk to staff and see the components to be harvested. Mockups and 3-D simulations can be valuable to ensure success of the approach or technique used to acquire the specimen. A related point is working with reactor operators at the plant. Several harvesting efforts worked with former reactor operators and benefited greatly from their experience to find records or determine the best method to harvest the desired component. This is a valuable insight that could be effective in future harvesting efforts.

A third key takeaway is early engagement with the plant personnel to express interest in harvesting. This serves to make the plant aware of ~~your~~ interest in harvesting and get their support to work with the harvesting process. The other important benefit of early engagement is to gain as much information as possible about the available materials and components, including the associated records and material pedigree information.

Session 5

The key takeaway in S~~s~~ession 5 was to gather as much information as possible in advance of committing to a specific harvesting project. Ideally, there would be a strong understanding that the material and its aging conditions clearly align with an identified technical data need before committing significant resources to a harvesting effort.

Action Items and Next Steps

The following is a summary of the action items discussed at the end of the workshop:

1. Sharing workshop slides
    - NRC emailed attendees to ask their comfort with sharing their workshop slides with other organizations and received no objection from any presenters.
    - The presentations can be accessed here: https://drive.google.com/open?id=0B5DWMLch5YSXcnpZZ0JOS055QUU .
    - For NRC staff, the presentations are archived on the LTO SharePoint site: http://fusion.nrc.gov/res/team/de/cmb/LTO/default.aspx?RootFolder=%2Fres%2Fteam%2Fde%2Fcmb%2FLTO%2FProgram%20Documents%2FStrategic%20Approach%20for%20Obtaining%20Material%20and%20Component%20Aging%20Information&FolderCTID=0x012000A4119D2C08121A4CAE71D67AEB499BF9&View={A08F45B4-F7E9-4960-9890-37F16055A16F}
2. EPRI indicated that MRP-320 (Product ID: 1022866) on knowledge gaps for irradiated austenitic stainless steel for potential harvesting from MRP-227 inspections is publicly available for a fee.
3. Cable surveillance programs in Germany
    - GRS to inquire with cable colleagues and share any insights.
4. Sources of materials database
    - Potential sources of materials presented in this workshop are summarized in Session 3 summary above and Appendix III below.
    - NRC will be reaching out to PNNL, INL NSUF, CNSC, AECL, and any other organizations interested in database development.
5. Prioritized data needs
    - Suggestion to continue discussions on prioritized data needs within technical areas (RPV, internals, electrical, concrete) through existing coordination groups if possible
        - Focus on identifying specific material / aging conditions of interest and purpose / intended outcome of harvesting
    - Idea to survey participants at the 2017 Environmental Degradation conference
        - John Jackson (INL) is on planning committee
6. EPRI report on spent fuel liner boric acid transport through concrete
    - NRC will contact EPRI for report if needed.
7. Harvested Materials Research Results
    - Section of workshop summary report (below) devoted to references from harvested materials research.

References to Previous Harvested Materials Research

This section of the workshop summary addresses a question that was raised during the discussion at the workshop regarding what the outcome or benefit of past harvesting efforts have been. Below is a list of selected, representative references to research results generated from testing of harvested materials:

Commented [HA22]: Should these be in any order? Chronological? Alphabetical?

Commented [HA23]: These words were added because I think your list was not pretending to be comprehensive. There was other earlier work done at ANL from samples harvested from the ShippingPort reactor, for example.

J.R. Hawthorne and A.L. Hiser, *Experimental Assessments of Gundremmingen RPV Archive Material for Fluence Rate Effects Studies*, NUREG/CR-5201 (MEA-2286), U.S. Nuclear Regulatory Commission, October 1988.

G. J. Schuster, S. R. Doctor, A.F. Pardini, and S.L. Crawford, *Characterization of Flaws in U.S. Reactor Pressure Vessels: Validation of Flaw Density and Distribution in the Weld Metal of the PVRUF Vessel*, NUREG/CR-6471 Volume 2, U.S. Nuclear Regulatory Commission, August 2000.

G. J. Schuster, S. R. Doctor, S.L. Crawford, and A. F. Pardini, *Characterization of Flaws in U.S. Reactor Pressure Vessels: Density and Distribution of Flaw Indications in the Shoreham Vessel*, NUREG/CR-6471 Volume 3, U.S. Nuclear Regulatory Commission, November 1999.

D.E. McCabe, et al. *Evaluation of WF-70 Weld Metal From the Midland Unit 1 Reactor Vessel*, NUREG/CR-5736 (ORNL/TM-13748), U.S. Nuclear Regulatory Commission, November 2000.

B. Alexandreanu, O.K. Chopra, and W.J. Shack, *Crack Growth Rates in a PWR Environment of Nickel Alloys from the Davis-Besse and V.C. Summer Power Plants,* NUREG/CR-6921 (ANL-05/55), U.S. Nuclear Regulatory Commission, November 2006.

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Appendix I Workshop Participants

	Name	Organization	Email
Japan	Taku Arai	CRIEPI	arait@criepi.denken.or.jp
	Sadao Higuchi	CRIEPI	higuchi@criepi.denken.or.jp
	Kazunobu Sakamoto	JNRA	kazunobu_sakamoto@nsr.go.jp
	Yasuhiro Chimi	JAEA	chimi.yasuhiro@jaea.go.jp
Europe	Uwe Jendrich	GRS	Uwe.Jendrich@grs.de
	Rachid Chaouadi	SCK-CEN	rachid.chaouadi@sckcen.be
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Canada	Daniel Tello	CNSC	daniel.tello@canada.ca
	Désiré Ndomba	CNSC	desire.ndomba@canada.ca
	Karen Huynh	AECL	khuynh@aecl.ca
US industry	Gerry van Noordennen	Energy Solutions	gpvannoordennen@energysolutions.com
	Bill Zipp	Dominion	william.f.zipp@dom.com
	Mark Richter	NEI	mar@nei.org
	Arzu Alpan	Westinghouse	alpanfa@westinghouse.com
EPRI	Sherry Bernhoft	EPRI	sbernhoft@epri.com
	Robin Dyle	EPRI	rdyle@epri.com
	Jean Smith	EPRI	jmsmith@epri.com
	Al Ahluwalia	EPRI	kahluwal@epri.com
DOE	Tom Rosseel	ORNL	rosseeltm@ornl.gov
	Rich Reister	DOE	Richard.Reister@nuclear.energy.gov
	Keith Leonard	ORNL	leonardk@ornl.gov
	Mikhail A. Sokolov	ORNL	sokolovm@ornl.gov
	John Wagner	INL	john.wagner@inl.gov
	John Jackson	INL	john.jackson@inl.gov
	Pradeep Ramuhalli	PNNL	Pradeep.Ramuhalli@pnnl.gov
NRC	Pat Purtscher	NRC	Patrick.Purtscher@nrc.gov
	Rob Tregoning	NRC	Robert.Tregoning@nrc.gov
	Matt Hiser	NRC	Matthew.Hiser@nrc.gov
	Mita Sircar	NRC	Madhumita.Sircar@nrc.gov
	Tom Koshy	NRC	Thomas.Koshy@nrc.gov
	Jeff Poehler	NRC	Jeffrey.Poehler@nrc.gov
	Allen Hiser	NRC	Allen.Hiser@nrc.gov
	Angela Buford	NRC	Angela.Buford@nrc.gov
	Mark Kirk	NRC	Mark.Kirk@nrc.gov
	Amy Hull	NRC	Amy.Hull@nrc.gov
	Pete Ricardella	NRC/ACRS	Priccardella@Structint.com

Commented [HA24]: Does this include the webinar people? If not, maybe you should clarify that these were In-room Participants or some such word. What order are they in? not alphabetical in any way…

Commented [HA25]: Mike Weber gave the keynote speech. Did Frankl or Brian Thomas attend?

Appendix II Workshop Agenda

Tuesday, March 7

Session	Time	Organization	Speaker	Presentation Title
Intro	8:00	NRC	Michael Weber Robert Tregoning	Welcome and Introduction to Workshop
1	8:15 – 8:45	DOE	Rich Reister	DOE Perspectives on Material Harvesting
		EPRI	Sherry Bernhoft	EPRI Perspective on Harvesting Projects
		NRC	Robert Tregoning	NRC Perspective on Motivation for Harvesting
		GRS	Uwe Jendrich	Role of GRS in Decommissioning and LTO
		CRIEPI	Taku Arai	CRIEPI Motivations for Harvested Material
	8:45 – 9:45	DISCUSSION		
9:45-10:00		**BREAK**		
2	10:00 – 10:20	PNNL (for NRC)	Pradeep Ramuhalli	Data Needs Best Addressed By Harvesting
	10:20 – 10:30	NRC	Matthew Hiser	High-Priority Data Needs for Harvesting
	10:30 – 10:55	DOE	Keith Leonard	LWRS Program Perspective on the Technical Needs for Harvesting
	10:55 – 11:20	SCK-CEN	Rachid Chaouadi	Review of past RPV sampling test programs and perspective for long term operation
	11:20 – 11:45	Westinghouse	Arzu Alpan	Importance of Harvesting to Evaluate Radiation Effects on Concrete Properties
	11:45 – 12:30	DISCUSSION		
12:30 – 2:00		**LUNCH**		
3	2:00 – 2:10	NRC	Matthew Hiser	Sources of Materials: Past NRC Harvesting and U.S. Decommissioning Plants
	2:10 – 2:35	EPRI	Al Ahluwalia	Harvesting Plans for Materials Aging Degradation Research in Korea and Sweden
	2:35 – 2:50	DOE/ORNL	Tom Rosseel	Materials Harvested by the LWRS Program
	2:50 – 3:00	DOE/INL	John Jackson	NSUF Material Sample Library
	3:00 – 3:15	Energy Solutions	Gerry van Noordennen	Zion Material Harvesting Program
	3:15 – 3:30	Westinghouse	Arzu Alpan	Potential Harvesting of Concrete from Mihama Unit 1
	3:30 – 3:45	**BREAK**		
	3:45 – 4:00	GRS	Uwe Jendrich	Plants in Decommissioning in Germany
	4:00 – 4:15	CNSC	Daniel Tello	Evaluating Structures, Systems & Components from Decommissioned/Decommissioning Nuclear Facilities in Canada
	4:15 – 5:00	DISCUSSION		

Wednesday, March 8

Session	Time	Organization	Speaker	Presentation Title
4	8:00 – 8:30	EPRI	Jean Smith	Lessons Learned: Harvesting and Shipping of Zorita Materials
	8:30 – 9:00	DOE	Tom Rosseel	LWRS Program: Harvesting Lessons Learned
	9:00 – 9:30	NRC	Matthew Hiser	NRC Perspective on Harvesting Experience and Lessons Learned
	9:30 – 10:00	CRIEPI	Taku Arai	CRIEPI Research Activities with Harvested Materials
	10:00 – 10:15	**BREAK**		
	10:15 - 10:45	Energy Solutions	Gerry van Noordennen	Zion Harvesting Experience and Lessons Learned
	10:45 - 11:15	Dominion	Bill Zipp	Kewaunee Insights on Material Harvesting
	11:15 – 12:00	DISCUSSION		
12:00 – 1:30		**LUNCH**		
5	1:30 – 1:45	PNNL (for NRC)	Pradeep Ramuhalli	Technical Information Needed for Informed Harvesting Decisions
	1:45 – 2:30	DISCUSSION		
	2:30 – 3:00	Action Items and Next Steps		
	3:00 – 4:00	EPRI	Sherry Bernhoft	Closing Thoughts
		DOE	Rich Reister	
		NRC	Robert Tregoning	
		ALL		

Appendix III Harvesting Opportunities in Germany

- Past and current decommissioning projects of **Prototype or Commercial Reactors**

Name	Abbrev.	Reactor type	Power MW_e	Decom. started	Strategy
Rheinsberg	KKR	WWER	70	1995	UC
Compact Natrium Cooled Reactor	KKN	SNR	21	1993	UC
Multipurpose Research R.	MZFR	PWR/D_2O	57	1987	UC
Obrigheim	KWO	PWR	357	2008	UC
Neckarwestheim 1	GKN-1	PWR	840	2017	UC
Isar-1	KKI-1	BWR	912	2017	UC
Gundremmingen-A	KRB-A	BWR	250	1983	RCA KRB-II
Greifswald 1-5	KGR 1-5	WWER	440	1995	UC
Lingen	KWL	BWR	268	1985	UC after SE

UC: unconditional clearance
RCA: radiation controlled area, new license
SE: safe enclosure

NRC Harvesting Workshop, Rockville, March 2017, Decommissioning in Germany 4

- Past and current decommissioning projects of **Prototype or Commercial Reactors**

Name	Abbrev.	Reactor type	Power MW_e	Decom. started	Strategy
Stade	KKS	PWR	672	2005	UC
Research Reactor Jülich	AVR	HTR	15	1994	UC
Thorium High-Temperature-Reaktor	THTR-300	HTR	308	1993	SE since 1997
Würgassen	KWW	BWR	670	1997	UC
Mülheim-Kärlich	KMK	PWR	1302	2004	UC
Hot-Steam Reactor Grosswelzheim	HDR	HDR	25	1983	UC since 1998
Niederaichbach	KKN	DRR/D_2O	106	1975	UC since 1994
Test-Reactor Kahl	VAK	BWR	16	1988	UC since 2010

- **Shut down** Commercial Reactors
  - **that have no decommissioning license granted yet**

Name	Abbrev.	Reactor type	Power MW_e	Date of application
Philippsburg-1	KKP-1	BWR	926	2013 / 2014
Grafenrheinfeld	KKG	PWR	1345	2014
Biblis-A	KWB-A	PWR	1225	2012
Biblis-B	KWB-B	PWR	1300	2012
Unterweser	KKU	BWR	1410	2012 / 2013
Brunsbüttel	KKB	BWR	806	2012 / 2014
Krümmel	KKK	BWR	1402	2015

- Commercial Reactors **in operation**

Name	Abbrev.	Reactor type	Power MW_e	Anticipated date of final shutdown
Gundremmingen-B	KRB-II-B	BWR	1344	31.12.2017
Philippsburg-2	KKP-2	PWR	1468	31.12.2019
Gundremmingen-C	KRB-II-C	BWR	1344	31.12.2021
Grohnde	KWG	PWR	1430	31.12.2021
Brokdorf	KBR	PWR	1480	31.12.2021
Emsland	KKE	PWR	1406	31.12.2022
Isar-2	KKI-2	PWR	1485	31.12.2022
Neckarwestheim-2	GKN-2	PWR	1400	31.12.2022

Note to requester: The attachment is immediately following this email.

From: Hiser, Matthew
Sent: Fri, 12 May 2017 21:23:49 +0000
To: Purtscher, Patrick;Tregoning, Robert;Ramuhalli, Pradeep (Pradeep.Ramuhalli@pnnl.gov)
Subject: Workshop Summary Report
Attachments: Harvesting Workshop Summary Report draft 5-12-17.docx

Hi Pat, Rob, and Pradeep,

I'd like to share with you a largely complete initial draft of the harvesting workshop summary report. I tried to capture the important points of the presentations and discussion at the workshop and then synthesize that down to "key takeaways" (I am open to a better term, but that's what I came up with). I still need to fill in the section on "References to Past Harvested Materials Research", but otherwise consider this a complete draft.

Please feel free to review and comment the overall organization, level of detail, etc. You can also review the specific wording with edits and tracked changes if you'd like, although I'd suggest not spending too much effort down in the weeds at this point.

My hope is to get some feedback in the next 2 weeks from this group and then share with the broader group of workshop attendees by the end of May for their review and input with a target to finalize this report by the end of June.

Thanks and please let me know if you have any questions!

Matt

Harvesting Workshop Summary Report

Background

On March 7-8, 2017, the Office of Nuclear Regulatory Research of the United States Nuclear Regulatory Commission (NRC) hosted a 2-day workshop on the topic of "Ex-Plant Materials Harvesting." NRC staff worked in close coordination with staff from the U.S. Department of Energy (DOE) and the Electric Power Research Institute (EPRI) to plan and arrange the workshop.

The decision to organize this workshop was driven by developments in the U.S. and global nuclear industry. In the U.S., there is strong interest in extending plant lifespans through subsequent license renewal (SLR) from 60 to 80 years. Extended plant operation and SLR raise a number of technical issues that may require further research to understand aging mechanisms, which may benefit from harvesting. Meanwhile, in recent years, a number of nuclear plants, both in the U.S. and internationally, have shut down or announced plans to shut down. Unlike in the past when there were very few plants shutting down, these new developments provide opportunities for harvesting components that were aged in representative light water reactor (LWR) environments. In a related development, economic challenges for the nuclear industry and limited government spending have limited the resources available to support new research, including harvesting programs. Given this constrained budget environment, aligning interests and leveraging with other organizations is important to allow maximum benefit and value for future research programs.

Objective and Approach

The objective of the workshop was to generate open discussion of all aspects of ex-plant materials harvesting, including:

1. Deciding whether to harvest,
2. Planning and implementing a harvesting program,
3. Using the harvested materials in research programs.

Through presentations and open discussion, the workshop was organized to allow for all participants to be better informed of the benefits and challenges of harvesting as well as to identify potential areas of common interest for future harvesting programs. Workshop sessions were aligned in broad topics to cover all aspects of harvesting, but allow for participants to drive the discussion.

To help accomplish the workshop objectives, the workshop organizers intentionally sought a diverse group of participants. There are a large number of decommissioning plants and interested researchers outside the U.S., so the organizers focused on outreach to international participants through connections such as IAEA, OECD/NEA, and existing professional contacts. In addition, a key goal for this workshop was to capture the broader practical perspective from plant owners and decommissioning companies, which are vital to any successful harvesting program, but may sometimes be overlooked in researcher-driven discussions. Workshop participants were also diverse in terms of technical area of focus, with metal components such as the reactor pressure vessel (RPV) and internals being discussed along with concrete and electrical components. The final list of workshop participants can be found at the end of this report in Appendix I.

Workshop Organization and Sessions

The workshop was held at NRC headquarters in Rockville, MD. Due to limited space in the meeting room and the need for a limited group size for discussion, a webinar was used to allow remote observers to benefit from the workshop. Workshop sessions were organized topically with about half the time dedicated to presentations and the remaining time set aside for discussion. Presentations were solicited from participants to cover a range of perspectives and technical areas. The final workshop agenda can be found at the end of this summary report in Appendix II.

The workshop was organized into five sessions as follows:

- Session 1 Motivation for Harvesting
- Session 2 Technical Data Needs for Harvesting
- Session 3 Sources of Materials
- Session 4 Harvesting Experience: Lessons Learned and Practical Aspects
- Session 5 Future Harvesting Program Planning

Summary of Workshop Discussion

The subsections below will summarize the presentations and discussion in each session and highlight the key takeaways from the session.

Session 1 Motivation for Harvesting

Session 1 focused on the motivation for harvesting and why workshop participants are interested in harvesting. Presentations were provided in this session by:

- Richard Reister from DOE,
- Sherry Bernhoft from EPRI,
- Robert Tregoning from NRC,
- Uwe Jendrich from the Gesellschaft für Anlagen- und Reaktorsicherheit (GRS) in Germany, and
- Taku Arai from the Central Research Institute of the Electric Power Industry (CRIEPI) in Japan.

<u>Presentation Summaries</u>

DOE described the role of harvesting within the Light Water Reactor Sustainability (LWRS) Program, including the benefits and challenges associated with harvesting. Benefits include the opportunity to fill knowledge gaps where there is limited data or experience and to inform degradation models with data from actual plant components. Challenges include cost, complexity, scheduling, logistics, limited opportunities, acquiring sufficient material pedigree information, and potential negative results impacting operating plants.

EPRI discussed the role of harvesting within the context of aging management for Long-Term Operations (LTO), including their experience from past harvesting programs and criteria for future harvesting. Their experience emphasized the challenges of cost, schedule, logistics, complicated contracting and acquiring material pedigree information. EPRI's criteria for harvesting include value to their members that addresses a prioritized need and knowledge gap that cannot be otherwise filled through other means.

For EPRI, a well-developed project plan that covers funding, risk management, exit ramps, and clear roles and responsibilities is essential.

NRC shared its perspective on the benefits and challenges of harvesting in regulatory research. Harvested materials are valuable due to the representative nature of their aging conditions, which may reduce the uncertainty associated with the applicability of the results to operating plants compared to tests with alternative aging conditions. Harvested materials may be the best option to address technical data needs identified for extended plant operation. Increasing harvesting opportunities from decommissioning plants suggests a proactive approach to harvesting planning may optimize benefits by identifying the appropriate material with the aging conditions of interest for the identified knowledge gap. There are significant challenges associated with harvesting, including cost, schedule, and logistics, but hopefully these can be mitigated or avoided by leveraging with other organizations and learning from past experience.

GRS described its role as the main technical support organization in nuclear safety for the German federal government. GRS provides technical assessment and knowledge transfer for decommissioning activities, aging management, and long-term operation for German federal and international organizations.

CRIEPI discussed its view of how harvested materials and laboratory prepared materials contribute to addressing technical issues. Harvested materials provide exposure to actual plant conditions, but are more limited in availability and the size of the data set that can be generated. Laboratory prepared materials general involve accelerated or simulated aging conditions, but can be used to produce larger data sets and varying parameters can allow understanding of the effect on the mechanism or property of interest. Harvested materials offer fact finding of actual plant conditions as well as confirmation and verification of results from laboratory prepared specimens.

Discussion Summary

The discussion following the presentations in this session focused on clearly identifying the need to be addressed by a harvesting project and the myriad cost, schedule, and logistical challenges associated with harvesting. Leveraging with other organizations to defray costs can also help improve the value of a given program, but also adds complexity as another organization may have a different set of priorities that changes the focus of the harvesting effort.

Session 2 Technical Data Needs for Harvesting

Session 2 focused on discussing the technical data needs for harvesting and what specific knowledge gaps organizations are interested in addressing through harvesting. This discussion included general perspectives on how to determine when harvesting should be pursued rather than other types of research. Presentations were provided in this session by:

- Pradeep Ramuhalli from the Pacific Northwest National Lab (PNNL),
- Matthew Hiser from NRC,
- Keith Leonard from Oak Ridge National Laboratory (ORNL),
- Rachid Chaouadi from SCK-CEN in Belgium, and
- Arzu Alpan from Westinghouse.

Presentation Summaries

PNNL presented their work, under a small NRC contract, to develop a systematic approach to prioritize data needs for harvesting. PNNL proposed five primary criteria for prioritizing harvesting:

- Unique field aspects of degradation
    - For example, unusual operating experience or legacy materials (composition, etc.) that be no longer available
- Ease of laboratory replication of environment-material combination
    - For example, simultaneous thermal and irradiation conditions may be difficult to replicate or mechanism sensitive to dose rate may not be good for accelerated aging
- Applicability of harvested material for addressing critical gaps
    - Prioritize harvesting for critical gaps over less essential data needs
- Availability of reliable in-service inspection (ISI) techniques for the material / component
    - If inspection methods are mature and easy to apply to monitor and track degradation, perhaps the effort of research with harvested materials is not needed.
- Availability of material for harvesting
    - The necessary materials / components must be available to be harvested.

PNNL then presented their application of these criteria to four materials degradation issues as an example: electrical cables, cast austenitic stainless steel (CASS), reactor vessel internals, and dissimilar metal welds. Based on applying these criteria to the examples, PNNL concludes that electrical cables, CASS, and reactor internals are all higher priority for harvesting due to unique aspects of the degradation that are challenging to replicate in the lab. Meanwhile, dissimilar metal welds are of low priority due to the ease of replication in lab aging studies as well as the significant body of knowledge and research on the phenomena.

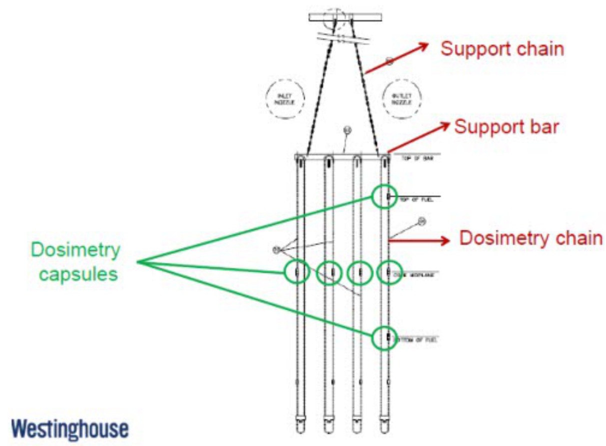
NRC presented a summary of data needs it is interested in pursuing through harvesting. These included RPV materials to validate fluence and attenuation models and to demonstrate the conservatism of regulatory approaches for transition temperature prediction. Other metal components of interest for harvesting would address data gaps in irradiated stainless steels, as well as improve understanding of inspection capabilities and fatigue life calculations. Electrical components of interest include low and medium voltage cables and other electrical components for degradation studies, and electrical enclosures and cables for fire research. Concrete components of interest include irradiated concrete, concrete undergoing alkali-aggregate reactions, post-tensioned structures, reinforcing steel, tendons, and spent fuel pool concrete to assess potential boric acid attack.

DOE/ORNL presented their perspective on data needs for harvesting and its role in providing validation of experimental and theoretical research. DOE performed a significant reactor pressure vessel (RPV) harvesting program at the Zion nuclear power plant to reduce uncertainties in the Master Curve methodology, validate modeling predictions and study flux and fluence attenuation effects. The harvesting is largely complete, but the testing program is currently underway. DOE also indicated interest in using harvested materials to validate its models for swelling and microstructural changes of stainless steel internals under LWR irradiation conditions. Harvesting concrete components would be of interest due to lack of literature data and the multiple dependent variables that may affect concrete

performance. Finally, DOE has been involved in harvesting cables from the Crystal River and Zion plants to address cable aging as a function of material composition and environment.

SCK-CEN presented their interest in a international cooperative program to harvest reactor pressure vessel (RPV) materials. SCK-CEN presented their survey of the literature for past testing programs of harvested RPV materials, and the limitations of these past program. Key limitations include a lack of archive materials, generally lower temperatures, and poor surveillance programs and dosimetry. SCK-CEN then shared some thoughts on their criteria for a new harvesting efforts, including higher fluence levels and temperatures, available archive materials and reliable information on operating history, dosimetry and surveillance program. Other topics relevant to a new RPV harvesting effort include technical issues such as material variability and irradiation conditions as well as logistical and financial considerations.

The final presentation in Session 2 by Westinghouse focused on the need for harvesting irradiated concrete to better understand the threshold radiation level for significant strength reduction. Westinghouse has installed ex-vessel neutron dosimetry (EVND) at a number of plants in the world and proposed to use these dosimetry measurements to validate fluence model calculations to better understand the uncertainty in these calculations. If concrete can be harvested at one of these plants with EVND data, then irradiated concrete properties from testing can be paired with fluence data to improve research benefits.



Discussion Summary

The discussion following Session 2 presentations touched on a number of topics. EPRI shared that they developed a report related to the topics of session 2, but more narrowly focused on PWR internals. MRP-320, “Testing Gap Assessment and Material Identification for PWR Internals,” focuses on prioritizing opportunistic harvesting of stainless steel reactor internals components that may be removed from service following MRP-227 inspections. The methodology and approach in this report may be relevant to the broader harvesting data needs discussion. This report is not publicly available, but is available to EPRI member utilities.

Workshop participants discussed the criteria proposed by PNNL in the first presentation. One additional criteria suggested by EPRI was to consider fleet-wide vs. plant-specific applicability. More broadly applicable materials would be of greater interest for harvesting than those that represent conditions at only a few plants. Another criteria suggested is the availability of material pedigree information, such as composition, processing, environmental conditions (temperature, humidity, fluence, etc.). Another suggested criteria was the ease of harvesting. For example, highly irradiated internals are probably much more difficult and expensive to harvest than electrical cables or unirradiated concrete. This discussion would capture the idea of weighing costs vs. benefits as well as project risk. Further discussion touched on the idea that different organizations may prioritize the various criteria differently, but all will probably at least want to consider the same set of criteria.

Another key theme from this discussion was that a successful program should be guided by a clearly defined objective or problem statement to be addressed. This objective should be well-understood at the initiation of a program and used to guide decision-making through implementation of a harvesting project. This also raises a related point or potential criteria: the timeliness of the expected research results relative to the objective. If the results are needed in the next two years, but a harvesting project will not provide results for at least five years, that should be a strong consideration.

Session 3 Sources of Materials

Session 3 focused on discussing sources of materials for harvesting. This discussion covered previously harvested materials as well as sources for new harvesting programs from operating or decommissioning plants. Both domestic and international sources of materials were discussed in this session.

Presentations were provided in this session by:

- Matthew Hiser from NRC,
- Al Ahluwalia from EPRI,
- Tom Rosseel from DOE/ORNL,
- John Jackson from DOE/Idaho National Laboratory (INL),
- Gerry van Noordennen from EnergySolutions,
- Arzu Alpan from Westinghouse,
- Uwe Jendrich from GRS, and
- Daniel Tello from the Canadian Nuclear Safety Commission (CNSC).

Presentation Summaries

NRC presented their perspective on sources of materials for harvesting. First, NRC shared some of the harvested materials from past research programs that may be available, including irradiated stainless steel internals, RPV materials, nickel alloy welds, neutron absorber material, and electrical components. NRC then summarized the recently and planned shutdown U.S. plants, including their design, thermal output, and years of operation, to provide participants with an idea of the potential sources from decommissioning U.S. plants. Finally, NRC shared a list of information that would be helpful to acquire from decommissioning plants to determine the value of components for harvesting. This information included plant design information (component location and dimensions), environmental conditions (temperature, fluence, humidity, stress, etc.) and operating history, material pedigree information (fabrication records), and inspection records (for interest in components with known flaws).

The next presentation from EPRI covered harvesting opportunities at decommissioning plants in Korea and Sweden. In Korea, Kori-1 is a Westinghouse 2-loop PWR (sister plant is Kewaunee) that will shut down in 2017 after 40 years of operation. Korea Hydro and Nuclear Power Central Research Institute (KHNP-CRI) is planning a comprehensive research program on long-term materials aging based on harvesting from Kori-1 and is seeking international participation in the harvesting effort. KHNP-CRI's plan is focused on metallic components, including RPV, internals, primary system components, steam generator materials. Harvesting is expected to occur in 2024 with testing to follow through 2030.

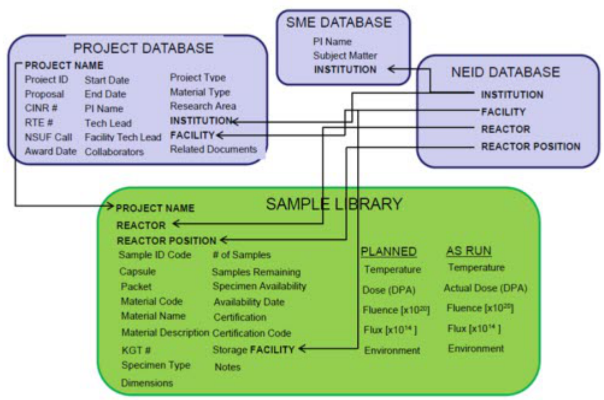
In Sweden, Vattenfall is currently harvesting in 2017-2018 RPV material from the decommissioning Barseback BWR units. This work is focused on irradiation embrittlement, including comparison of

surveillance data to actual RPV properties, as well as thermal aging embrittlement. In the future, Vattenfall will be shutting down Ringhals 1 and 2 in 2020 and 2019, respectively. Ringhals 1 is a BWR and Ringhals 2 is a Westinghouse 3-loop PWR design. Of particular note, Ringhals 2 has the second oldest replaced Alloy 690 RPV head and steam generators. Other harvesting opportunities at Ringhals include RPV material with a significant surveillance program, thermal aging effects on low alloy steel from the pressurizer, as well as concrete structures. Vattenfall is open to working with partners that are interested in joining them for harvesting at Ringhals.

(b)(4)

The next presentation by DOE/ORNL focused on several harvesting programs that DOE's LWRS program has been involved with. DOE has led the harvesting of components from the Zion [redacted] plant [redacted] in (b)(4) the U.S. From Zion, DOE has harvested electrical cables and components, a large RPV section, and a significant amount of records to provide information on material fabrication, in-service inspection and operating history. Cables from Zion include CRDM, thermocouple, and low and medium voltage cables. DOE indicated some thermocouple cables from Zion may be available for other researchers to use in collaborative studies. [redacted] (b)(4) (b)(4) (b)(4) DOE is also participating in efforts to harvest cables from Crystal River (led by EPRI) and concrete from the Zorita plant in Spain (led by NRC).

The next presentation by DOE/INL described INL's Nuclear Science User Facilities (NSUF) and the Nuclear Fuels and Materials Library (NFML). NSUF is coordinated by INL and facilitates access to nuclear research facilities around the world, including neutron and ion irradiations, beamlines, hot cell testing, characterization and computing capabilities. NFML is a Web-based searchable database sample library that captures the information from thousands of specimens available to NSUF. NFML is designed to maximize the benefit of previously irradiated materials for future research. Researchers can propose new research projects under NSUF using specimens in NFML using DOE funding. The information captured in NFML aligns well with the goal of this session to potentially develop a database of previously harvested materials.



The next presentation by EnergySolutions offered a more practical perspective on considering sources of materials for harvesting. From the plant owner perspective, in the decommissioning process there is not a financial incentive to support harvesting, therefore researchers need to absorb costs for harvesting and have a clear scope for harvesting. Flexibility in funding for harvesting activities is essential as the decommissioning process and schedule may change quickly.

EnergySolutions provided valuable perspective on the timing in the decommissioning proves for harvesting different components. Harvesting RPV surveillance coupons should take place when the RPV internals are cut and removed. Harvesting RPV materials is only possible from larger RPVs, as smaller RPVs are shipped intact to the disposal facility, rather than cut into pieces. Spent fuel rack neutron absorber coupons must be harvested either before or after dry storage campaign to remove spent fuel from spent fuel pool. Harvesting actual spent fuel rack neutron absorber material must come after pool is completely empty. Electrical cables and other components from mild environments may be harvested at any time (once temporary power is established and plant power is shut off), while electrical components from high rad environments will depend on timing of source term removal schedule. Concrete cores are best harvested when other cores are being taken for site characterization to develop the License Termination Plan. Highly irradiated concrete from biological shield wall would need to come later in decommissioning after RPV is removed.

In terms of upcoming decommissioning plants, EnergySolutions indicated that San Onofre and Vermont Yankee will be entering DECON is 2018 and 2019, respectively. Kewaunee, Crystal River, and Fort Calhoun also may enter DECON in next 2 years. If researchers are interested in harvesting from any of these plants, they should be reaching out to plant owners immediately to begin planning and coordination.

Westinghouse followed their presentation in session 2 by describing an opportunity to harvest concrete from the Mihama 1 plant in Japan. Westinghouse installed and analyzed additional neutron dosimetry in the reactor cavity for one cycle, which were used to validate the radiation transport calculations. Mihama was shutdown in 2015 and is in contact with Westinghouse about the possibility of extracting concrete cores from the biological shield wall. Westinghouse is seeking partners interested in joining this harvesting effort.

The next presentation by GRS covered opportunities for harvesting from German plants. Regulations in Germany require plants to either immediately dismantle or dismantle after a period of safe enclosure, which is largely consistent with options in the U.S. GRS detailed the status of German commercial reactors, which are predominantly BWR and PWR designs. Seventeen reactors are currently undergoing decommissioning, while seven more are currently shutdown and await a decommissioning license. Eight reactors are still operating with scheduled shutdown dates between 2017 and 2022. German RPVs tend to have lower fluence that U.S. designs due to a larger water gap in the downcomer region. Germany has limited experience with harvesting from decommissioning plants. One question that GRS will follow-up on is the “rumored” cable surveillance programs that may be used in Germany and could provide experience and lessons learned for other countries.

The final presentation in Session 3 was by CNSC on harvesting opportunities in Canada. Atomic Energy Canada Limited (AECL) has harvested seven concrete cores from the 20 MW Nuclear Power Demonstration Plant (NPD), which shutdown in 1988 after 25 years of operation. CNSC and AECL are also considering opportunities to harvest concrete from other decommissioned reactors in Canada such as Gentilly-2, Douglas Point, and Whiteshell Reactor 1. In addition to concrete, CNSC and AECL are currently harvesting electrical cables from the 675 MWe CANDU-6 Gentilly-2 reactor, which shutdown in 2012 after 29 years of operation. The purpose of this work is to study cable degradation from thermal aging and radiation damage and validate environmental qualification of the cables. CNSC described some of the challenges with this harvesting effort, such as working with plant owners, records, accessibility and contamination of the materials and budgeting with unexpected delays in harvesting.

A future harvesting opportunity is from the National Research Universal (NRU) reactor at Chalk River, which will shut down in 2018 after operating since 1957. AECL is currently taking an inventory of irradiated materials that can be harvested from NRU in decommissioning. Potential materials for

harvesting include metals (steels, nickel alloys, zirconium, aluminum), concrete, graphite, active equipment (pumps, etc.), graphite seals, electrical cables, and thermocouples.

Discussion Summary

Following the presentations, there was some discussion of lessons from DOE's Zion harvesting effort. DOE worked with a former senior reactor operator at Zion to identify and acquire the appropriate records from Zion for the components being harvested. DOE also described their flexible approach to acquiring RPV samples by sending a large chunk of material (weighing ~90 tons) to EnergySolutions' facility in Tennessee, where smaller pieces (weighing ~500 pounds) were cut to send to ORNL. Most of the decontamination was performed at Zion, with minimal additional cleaning (as well as cladding removal) taking place at EnergySolutions' facility.

There was also discussion of acquiring materials from sources other than commercial nuclear facilities. DOE has considered harvesting concrete from other DOE nuclear facilities, but determined that there were compositional differences between the DOE facilities and commercial that would make them not useful. DOE/INL mentioned that the Advanced Test Reactor (ATR) replaces their core internals every ten years. The ATR internals are composed primarily of 347 stainless steel and achieve very high fluence levels after ten years of service.

Another key discussion topic was the possibility of developing a database for previously harvested materials or those available for future harvesting. DOE/INL indicated that their NSUF sample library may be a good starting point for such a database, although any materials in that library should be freely available for use in the research community. CNSC and NRC also expressed interested in working to develop a harvesting database.

Session 4 Harvesting Experience: Lessons Learned and Practical Aspects

Session 4 focused on lessons learned and practical aspects of harvesting. Presenters shared their experience with past harvesting programs, particularly common pitfalls to avoid and successful strategies to overcome them. Presentations also covered the practical aspects of harvesting from the plant owner and decommissioning company perspective.

Presentations were provided in this session by:

- Jean Smith from EPRI,
- Tom Rosseel from DOE/ORNL,
- Matthew Hiser from NRC,
- Taku Arai from CRIEPI,
- Gerry van Noordennen from EnergySolutions, and
- Bill Zipp from Dominion.

Presentation Summaries

EPRI presented their experience and lessons learned from past harvesting programs, particularly harvesting reactor internals and concrete from Zorita and electrical cables from Crystal River. From the Zorita reactor internals experience, EPRI emphasized that harvesting projects take significant time, encounter material retrieval and on-site challenges, and shipping issues. In terms of time, ZIRP took

about 10 years to go from initial planning to final results, which included about 5 years of project planning, 2 years for material extraction (on-site logistics and shipping), and 3-4 years for testing. EPRI's experience was decommissioning activities were the top priority and harvesting were subject to schedule and logistical challenges based on the changing decommissioning schedule. Shipping issues were also challenging due to sending activated materials (which were classified as "waste") across international borders, from the reactor in Spain to testing facility in Sweden. Further planned shipments of the Zorita materials beyond the initial program continue to be impact by export license challenges in Sweden. More positively, EPRI emphasized that the Zorita reactor internals materials harvesting showed excellent cooperation among many organizations and are providing valuable technical information to numerous research projects.

Lessons learned from the Zorita concrete harvesting focused on the challenges with core sample drilling and handling contaminated concrete. Ultimately, an effective core drilling procedure was identified, but required some trial and error. Lessons learned from the Crystal River cable harvesting included material concerns, the need for on-site support, and cost. In terms of material concerns, radiation and asbestos contamination created additional challenges for harvesting. On-site support and the ability to visit the site are extremely valuable to ensure clear communication, retrieval or records for material pedigree information, and awareness of on-site developments in the decommissioning process. Cable harvesting at Crystal River was more expensive than anticipated, particularly in terms of EPRI project management time to coordinate the harvesting activities and engineering support at the plant.

DOE presented lessons learned primarily from the experience harvesting RPV materials and electrical cables and components from the Zion plant. In terms of planning and decision-making, DOE had several lessons learned. DOE hosted a workshop at Zion in 2011 to discuss long-term goals and objectives, which proved very helpful in setting priorities and developing partnerships with other organizations. Partnerships were very valuable to DOE's harvesting efforts, allowing for leveraging resources and collaboration and sharing results. There are limited opportunities for harvesting key components, so take full advantage of the opportunities that arise, understanding that there is a necessary compromise between the materials available and their value in terms of fluence or exposure to aging conditions. Another consideration is the quantity of material harvested, which should be sufficient for the objectives of the planned research as well as any collaborations or partnerships, but limited to control costs.

For implementing the harvesting program, DOE found that flexibility was paramount to be able adjust scope and plans in response to schedule changes and other developments, while remaining within cost constraints. Working with a former reactor operator was extremely valuable to benefit from their in-depth knowledge of all parts of the plant, in particular the records for materials pedigree information. Regular site visits and contacts were also essential to stay aware of the latest developments in the harvesting planning and decommissioning process, with the understanding that harvesting is not the top priority for decommissioning company. Other important considerations were hazardous materials handling, transportation, and disposal and logistics, including contracts, liability, shipping and disposal. Finally, DOE's experience is that the total costs of a harvesting program from planning to execution to testing are very high, so they should be carefully weighed against the value of the expected data to be generated.

NRC presented their experience, including benefits from previous harvesting programs, and technical and logistical lessons learned from harvesting. As an organization, NRC has extensive experience with testing harvested materials, including RPV, primary system components, reactor internals, neutron absorbers, concrete and electrical components. NRC's experience is more limited than DOE or EPRI in terms of managing the logistics of a harvesting effort from a decommissioning plant. NRC has generally participated in a secondary role in cooperative efforts or received failed components from operating plants for research. NRC has found that previous harvesting efforts have been effective in reducing unnecessary conservatism, understanding in-service flaws more realistically for NDE and leak rate methodologies, as well as identifying and better understanding safety issues.

For technical lessons learned, NRC's perspective is that harvesting can provide highly representative aged materials for research, which may be the only practical source of such materials. Harvested materials can be effectively used to validate models or a larger data set from accelerated aging tests. It is important understand as much as possible about the materials and their environment in service and how this compares with the operating fleet of reactors before committing to a specific harvesting project. For logistical lessons learned, harvesting is expensive and time-consuming, so a high technical benefit is needed to ensure the program provides values. Leveraging with other organizations can help minimize costs, but can also introduce challenges for aligning priorities and interests of multiple organizations. Finally, transporting irradiated materials, particularly between countries, challenging and time-consuming and should be avoided if at all possible.

CRIEPI presented their research experience with harvested materials as well as ongoing harvesting from the Hamaoka 1 plant. The first research program involved atom probe tomography (APT) on RPV surveillance materials. CRIEPI found a correlation between the volume fraction of Ni-Si-Mn clusters and the change in nil-ductility temperature. In the second research project, CRIEPI characterized the weld and base materials harvested from Greifswald Unit 4 RPV with small-angle neutron scattering, APT, and hardness testing. In the third research project, CRIEPI performed APT on 304L stainless steel reactor internals harvested from control rod and top guide components from 3-13 dpa. Results showed a strong increase in Ni-Si clusters with increasing fluence, but little variation in Al enriched clusters with increasing fluence.

For future work, CRIEPI is collaborating with DOE LWRS to investigate RPV materials harvested from Zion
(b)(4) [redacted] CRIEPI also presented activities underway by Chubu Electric Power to harvest RPV and concrete samples from the Hamaoka 1 plant. Hamaoka 1 is a 540 MW BWR-4 that operated for 33 years. Harvesting began in 2015 and will continue through 2018.

The final two presentations of Session 4 provided the non-researcher perspective from a decommissioning company and plant owner. EnergySolutions, which is decommissioning the Zion nuclear plant among other facilities, presented the decommissioning process and their experience and lessons learned from harvesting at Zion. As mentioned previously, surgical harvesting is not the top priority for decommissioning, so researchers must recognize this and coordinate close with the decommissioning company. EnergySolutions emphasized the need to gain senior management support at the plant as well as to expect that there may be staff turnover during a multi-year harvesting effort. Changes in scope and schedule (originating from both sides) can cause frustration on both sides. Early planning and delays with contracting are important to avoid lost opportunities. Being on-site during harvesting is essential to a good outcome.

At Zion, EnergySolutions worked with DOE to harvest RPV materials, cables, electrical components, and spent fuel storage racks. DOE hoped to harvest a particular RPV surveillance capsule, but was unable to due to the inability identify the correct capsule. There were also challenges with harvesting RPV materials. The cut line on the Unit 2 RPV was too close to the weld to be used for research; fortunately, a successful specimen was harvested from Unit 1. For cabling, the initial plan was to harvest from 11 different locations, but ultimately due to unforeseen challenges and poor communication and coordination, only 4 different cable locations were harvested. Harvesting the desired cable length (30 feet) also proved challenging, with only shorter sections recovered. Plant records searches were largely effective at providing material pedigree information for cables. Concrete coring was initially planned to take place at Zion, but not performed due to lack of research interest. The spent fuel storage rack harvesting went smoothly, which was assisted by efforts over the weekend when decommissioning activities were not occurring.

The next presentation from Dominion provided its perspective on harvesting from decommissioning plants, focused on the experience at Kewaunee Power Station. The top priority (beyond safety) in decommissioning is the preservation and good stewardship of the decommissioning trust fund. Staffing is the largest drain on the trust fund, so at Kewaunee staff was halved within a few months of shutdown and then halved again about 16 months after permanent shutdown once offsite emergency response requirements were eliminated. Dominion described the example of harvesting the RPV surveillance capsules at this point at Kewaunee and the significant challenges that would exist. Given the reduced staffing and the current plant state (reactor coolant system drained, pumps retired, crane and radiation monitoring not maintained), it would be much more difficult now than immediately after shutdown. Kewaunee considered harvesting the surveillance specimens and estimated a cost of six to seven figures based on all the activities required to enable it at this point post-shutdown compared to a much lower cost just after shutdown. Dominion observed that some components, such as cables or electrical components, may be available and relatively easy to harvest at almost any time during decommissioning. However, other components such as highly irradiated internals or RPV may be best harvested either shortly after shutdown when staffing and capabilities on-site are high or wait until active demolition of the reactor, which may be years or decades later.

Dominion also touched on the discussion of records for plant components. Records requirements are limited to those needed for safety. Once the plant shuts down and the range of potential safety concerns decreases, systems are downgraded to non-safety and the associated records are no longer required to be maintained. For perspective, Kewaunee still has all its records four years since shutdown, but will likely not continue this much longer. Dominion closed its presentation with a broader perspective on harvesting, emphasizing the need to clearly define a problem statement and understand what technical and regulatory purpose this harvesting will serve. Early planning focused on achieving the clear objective of the work including scope, schedule, budget and contact with plant is essential to a successful harvesting effort.

Discussion Summary

The discussion touched on the top lessons learned from past harvesting efforts, which included a clear objective and purpose for harvesting, early engagement with the plant, and site coordination during harvesting.

Another suggestion was to get utility management buy-in for the harvesting project by identifying a benefit to the utility. EPRI mentioned that cable harvesting at Crystal River went much more successfully once the utility recognized the potential benefits for subsequent license renewal. Similarly, when harvesting from an operating plant, you need to recognize and work through the challenges the plant may encounter when restarting operations.

During discussion, the question was raised regarding how it is determined whether harvested materials are waste. The discussion concluded that in the U.S. 10 CFR 37 is the important consideration. 10 CFR 37 defines when additional security requirements are imposed, based on the quantity and activity of materials to be transported. The definition of material as waste versus research materials is not as critical in the U.S. EnergySolutions indicated that their shipments of waste or research material could be handled in the same way in the accordance with Department of Transportation regulations, provided that the limits in 10 CFR 37 were not reached.

Session 5 Future Harvesting Program Planning

Session 5 focused on the information needed for informed harvesting decision-making and harvesting program planning. This session featured a presentation by Pradeep Ramuhalli from PNNL, followed by a discussion period covering harvesting program planning and reflection on the 2-day workshop.

Presentation Summary

PNNL presented its perspective on the information needed for informed harvesting decision-making. First, the purpose of the harvesting effort needs to be defined by identify the technical knowledge gaps to be addressed. Next, a research plan should be developed demonstrating how the harvested material will be used to address the identified gaps. Finally, the appropriate source of material to address the technical gap must be identified, along with resources to support the effort and plans and timelines to perform the harvesting. The specifics of these plans depend greatly on the source of materials and must be flexible based on changing conditions on the ground.

In assessing the best source of materials, researchers should consider the material, its environment, and its condition. Material information includes fabrication information such as manufacturer, composition, and dimensions as well as information related to installation or construction, such as welding processes and parameters. Environmental information includes temperature, humidity, fluence, flux, stress (service, residual, installation), and coolant chemistry. Component condition information includes inspection history, such as identified flaws or degradation.

Discussion Summary

The discussion in Session 5 focused on the best practical approach to plan future harvesting programs. There was clear agreement that this approach must begin with identifying the data needs best addressed by harvesting, whether from operating or decommissioning plants. Once a specific need is identified, the next step is to find a source to acquire the materials of interest as well as other organizations interested in participating in the harvesting effort.

Key Takeaways from Workshop

<u>Session 1</u>

The clear takeaway from the discussion in session 1 was that harvesting requires significant resources to be done successfully; therefore it is paramount to identify how the planned harvesting will clearly address a significant need to ensure the harvesting project provides strong value. In the context of need for data, EPRI suggested the goal of harvesting to support research for operation out to 80 years is not a full comprehensive understanding of all aspects of the degradation, but rather a snapshot to confirm other lab results and models. This is an important point for all organizations and researchers to keep in mind before investing significant resources in harvesting.

<u>Session 2</u>

The criteria proposed by PNNL are a good starting point for prioritizing issues to address by harvesting. Three additional important criteria would be:

- Fleet-wide vs. plant-specific applicability of data,
- Ease of harvesting (in terms of cost and project risk), and
- Timeliness of the expected research results relative to the objective.

Once a potential harvesting project has reached the point of looking at different sources of materials, the availability of material pedigree information, such as composition, processing, environmental conditions (temperature, humidity, fluence, etc.) is very important to the overall value of harvesting from that particular plant.

Based on the presentations and discussion in Session 2, there appeared to be two areas with broad interest in pursuing further harvesting: high fluence reactor internals and irradiated concrete. The common drivers for the interest in these issues is a lack of representative data at the fluences of interest and significant challenges with acquiring representative data through other means. High fluence reactor internals has been addressed somewhat by the Zorita Internals Research Project (ZIRP), but stainless steel materials exposed to higher fluence levels at higher temperatures, where void swelling may become significant, could help validate DOE and EPRI models and provide further technical basis for PWR internals aging management. Irradiated concrete harvesting is currently being pursued from the Zorita reactor in Spain, with international collaboration and potential testing at the Halden Reactor Project.

Other areas with some, but less widespread, interest expressed from workshop participants for new harvesting efforts included RPV materials and electrical cables and components. SCK-CEN and NRC expressed interest in RPV harvesting, and NRC expressed interest in electrical component harvesting.

<u>Session 3</u>

To capture the key takeaways from Session 3 focused on sources of materials, two tables of potential sources of materials are presented below. The first table covers recent or ongoing harvesting programs, while the second details potential future harvesting opportunities.

Ongoing Harvesting Programs

Country	Plant	Design	Size (MWe)	Years in operation	Components	Organization(s)
Canada	NPD	CANDU	20	25	Concrete	AECL
	Gentilly-2	CANDU-6	675	29	Cables	
Japan	Hamaoka 1	BWR-4	540	33	RPV, concrete	CRIEPI/Chubu
Spain	Zorita	W 1-loop	160	37	Internals, concrete	EPRI, NRC
Sweden	Barseback	ABB-II	615	28	RPV	Vattenfall
U.S.	Zion 1/2	W – 4 loop	1040	24/25	RPV, cables, neutron absorbers	DOE, EPRI, NRC
	Crystal River 3	B&W	860	36	Cables	EPRI
	(b)(4)					

Potential Future Sources for Harvesting

Country	Plant	Design	Size (MWe)	Years in operation	Potential Components	Notes
Canada	NRU	Test reactor	135 MWt	61	TBD	AECL; SD: 2018
Germany	Numerous plants either in decommissioning or shutting down soon. See Appendix III.					
Japan	Mihama	W 2-loop	320	40	Concrete	Kansai, Westinghouse
Korea	Kori 1	W 2-loop	576	40	RPV, internals, SGs, pressurizer, welds, CASS,	KHNP, EPRI
Sweden	Ringhals 1	BWR	883	44	RPV, internals SGs, pressurizer, concrete	Vattenfall; SD: 2020 / 2019
	Ringhals 2	W 3-loop	900	44		
U.S.	Kewaunee	W 2-loop	566	39	TBD	SD: 2013
	SONGS 2/3	CE 2-loop	1070	31/30	TBD	SD: 2013
	Crystal River 3	B&W	860	36	TBD	SD: 2013
	Vermont Yankee	BWR-4/Mk-1	605	42	TBD	SD: 2015
	Fort Calhoun	CE 2-loop	482	43	TBD	SD: 2016
	Palisades	CE 2-loop	805	47	TBD	SD: 2018
	Pilgrim	BWR-3/Mk-1	677	47	TBD	SD: 2019
	Oyster Creek	BWR-2/Mk-1	619	50	TBD	SD: 2019
	Indian Point 2/3	W 4-loop	1020 / 1040	48/46	TBD	SD: 2021
	Diablo Canyon 1/2	W 4-loop	1138 / 1118	40	TBD	SD: 2024-5
	Advanced Test Reactor	Test reactor	250 MWt	50	Core internals	Non-commercial; internals replaced every 10 years

In addition to the potential sources of materials presented and discussed in Session 3, another takeaway was the suggestion of developing a database for previously harvested materials or those available for future harvesting. The NSUF sample library may be a good starting point for such a database, with appropriate modifications for the purposes of harvesting efforts.

Session 4

There were several important takeaways from Session 4 that were touched on in multiple presentations and the discussion. One key takeaway is that researchers should identify a clear purpose and scope for harvesting. Having a clear purpose for harvesting helps to guide later decisions that must be made to adjust course when the inevitable changes in schedule or unexpected realities at the plant arise. A related note is that harvesting is not the top priority for decommissioning. Therefore, researchers must have clear objectives and scope for harvesting that can be communicated to the site. This understanding should shape assumptions and interactions with the plant owner or decommissioning company as well as planning for costs and schedule.

Another takeaway was the value of strong site coordination, including site visits. Multiple presenters touched on the value of being on-site to talk to staff and see the components to be harvested. Mockups and 3-D simulations can be valuable to ensure success of the approach or technique used to acquire the specimen. A related point is working with reactor operators at the plant. Several harvesting efforts worked with former reactor operators and benefited greatly from their experience to find records or determine the best method to harvest the desired component. This is a valuable insight that could be effective in future harvesting efforts.

A third key takeaway is early engagement with the plant to express interest in harvesting. This serves to make the plant aware of your interest in harvesting and get their support to work with the harvesting process. The other important benefit of early engagement is to gain as much information as possible about the available materials and components, including the associated records and material pedigree information.

Session 5

The key takeaway in session 5 was to gather as much information as possible in advance of committing to a specific harvesting project. Ideally, there would be a strong understanding that the material and its aging conditions clearly align with an identified technical data need before committing significant resources to a harvesting effort.

Action Items and Next Steps

The following is a summary of the action items discussed at the end of the workshop:

1. Sharing workshop slides
    - NRC emailed attendees to ask their comfort with sharing their workshop slides with other organizations and received no objection from any presenters.
    - The presentations can be accessed here: https://drive.google.com/open?id=0B5DWMLch5YSXcnpZZ0JOS055QUU .

2. EPRI indicated that MRP-320 (Product ID: 1022866) on knowledge gaps for irradiated austenitic stainless steel for potential harvesting from MRP-227 inspections is publicly available for a fee.

3. Cable surveillance programs in Germany
    - GRS to inquire with cable colleagues and share any insights.

4. Sources of materials database
    - Potential sources of materials presented in this workshop are summarized in Session 3 summary above and Appendix III below.
    - NRC will be reaching out to PNNL, INL NSUF, CNSC, AECL, and any other organizations interested in database development.

5. Prioritized data needs
    - Suggestion to continue discussions on prioritized data needs within technical areas (RPV, internals, electrical, concrete) through existing coordination groups if possible
        - Focus on identifying specific material / aging conditions of interest and purpose / intended outcome of harvesting
    - Idea to survey Env Deg participants
        - John Jackson (INL) is on planning committee

6. EPRI report on spent fuel liner boric acid transport through concrete
    - NRC will contact EPRI for report if needed.

7. Harvested Materials Research Results
    - Section of workshop summary report (below) devoted to references from harvested materials research.

References to Previous Harvested Materials Research

This section of the workshop summary addresses a question that was raised during the discussion at the workshop regarding what the outcome or benefit of past harvesting efforts have been. Below is a list of references to research results generated from testing of harvested materials:

Appendix I Workshop Participants

	Name	Organization	Email
Japan	Taku Arai	CRIEPI	arait@criepi.denken.or.jp
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Appendix II Workshop Agenda

Tuesday, March 7

Session	Time	Organization	Speaker	Presentation Title
Intro	8:00	NRC	Michael Weber Robert Tregoning	Welcome and Introduction to Workshop
1	8:15 – 8:45	DOE	Rich Reister	DOE Perspectives on Material Harvesting
		EPRI	Sherry Bernhoft	EPRI Perspective on Harvesting Projects
		NRC	Robert Tregoning	NRC Perspective on Motivation for Harvesting
		GRS	Uwe Jendrich	Role of GRS in Decommissioning and LTO
		CRIEPI	Taku Arai	CRIEPI Motivations for Harvested Material
	8:45 – 9:45	DISCUSSION		
9:45-10:00		**BREAK**		
2	10:00 – 10:20	PNNL (for NRC)	Pradeep Ramuhalli	Data Needs Best Addressed By Harvesting
	10:20 – 10:30	NRC	Matthew Hiser	High-Priority Data Needs for Harvesting
	10:30 – 10:55	DOE	Keith Leonard	LWRS Program Perspective on the Technical Needs for Harvesting
	10:55 – 11:20	SCK-CEN	Rachid Chaouadi	Review of past RPV sampling test programs and perspective for long term operation
	11:20 – 11:45	Westinghouse	Arzu Alpan	Importance of Harvesting to Evaluate Radiation Effects on Concrete Properties
	11:45 – 12:30	DISCUSSION		
12:30 – 2:00		**LUNCH**		
3	2:00 – 2:10	NRC	Matthew Hiser	Sources of Materials: Past NRC Harvesting and U.S. Decommissioning Plants
	2:10 – 2:35	EPRI	Al Ahluwalia	Harvesting Plans for Materials Aging Degradation Research in Korea and Sweden
	2:35 – 2:50	DOE/ORNL	Tom Rosseel	Materials Harvested by the LWRS Program
	2:50 – 3:00	DOE/INL	John Jackson	NSUF Material Sample Library
	3:00 – 3:15	Energy Solutions	Gerry van Noordennen	Zion Material Harvesting Program
	3:15 – 3:30	Westinghouse	Arzu Alpan	Potential Harvesting of Concrete from Mihama Unit 1
	3:30 – 3:45	**BREAK**		
	3:45 – 4:00	GRS	Uwe Jendrich	Plants in Decommissioning in Germany
	4:00 – 4:15	CNSC	Daniel Tello	Evaluating Structures, Systems & Components from Decommissioned/Decommissioning Nuclear Facilities in Canada
	4:15 – 5:00	DISCUSSION		

Wednesday, March 8

Session	Time	Organization	Speaker	Presentation Title
4	8:00 – 8:30	EPRI	Jean Smith	Lessons Learned: Harvesting and Shipping of Zorita Materials
	8:30 – 9:00	DOE	Tom Rosseel	LWRS Program: Harvesting Lessons Learned
	9:00 – 9:30	NRC	Matthew Hiser	NRC Perspective on Harvesting Experience and Lessons Learned
	9:30 – 10:00	CRIEPI	Taku Arai	CRIEPI Research Activities with Harvested Materials
	10:00 – 10:15	**BREAK**		
	10:15 - 10:45	Energy Solutions	Gerry van Noordennen	Zion Harvesting Experience and Lessons Learned
	10:45 - 11:15	Dominion	Bill Zipp	Kewaunee Insights on Material Harvesting
	11:15 – 12:00	DISCUSSION		
12:00 – 1:30		**LUNCH**		
5	1:30 – 1:45	PNNL (for NRC)	Pradeep Ramuhalli	Technical Information Needed for Informed Harvesting Decisions
	1:45 – 2:30	DISCUSSION		
	2:30 – 3:00	Action Items and Next Steps		
	3:00 – 4:00	EPRI	Sherry Bernhoft	Closing Thoughts
		DOE	Rich Reister	
		NRC	Robert Tregoning	
		ALL		

Appendix III Harvesting Opportunities in Germany

- Past and current decommissioning projects of **Prototype or Commercial Reactors**

Name	Abbrev.	Reactor type	Power MW_e	Decom. started	Strategy
Rheinsberg	KKR	WWER	70	1995	UC
Compact Natrium Cooled Reactor	KKN	SNR	21	1993	UC
Multipurpose Research R.	MZFR	PWR/D_2O	57	1987	UC
Obrigheim	KWO	PWR	357	2008	UC
Neckarwestheim 1	GKN-1	PWR	840	2017	UC
Isar-1	KKI-1	BWR	912	2017	UC
Gundremmingen-A	KRB-A	BWR	250	1983	RCA KRB-II
Greifswald 1-5	KGR 1-5	WWER	440	1995	UC
Lingen	KWL	BWR	268	1985	UC after SE

UC: unconditional clearance
RCA: radiation controlled area, new license
SE: safe enclosure

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- Past and current decommissioning projects of **Prototype or Commercial Reactors**

Name	Abbrev.	Reactor type	Power MW_e	Decom. started	Strategy
Stade	KKS	PWR	672	2005	UC
Research Reactor Jülich	AVR	HTR	15	1994	UC
Thorium High-Temperature-Reaktor	THTR-300	HTR	308	1993	SE since 1997
Würgassen	KWW	BWR	670	1997	UC
Mülheim-Kärlich	KMK	PWR	1302	2004	UC
Hot-Steam Reactor Grosswelzheim	HDR	HDR	25	1983	UC since 1998
Niederaichbach	KKN	DRR/D_2O	106	1975	UC since 1994
Test-Reactor Kahl	VAK	BWR	16	1988	UC since 2010

- **Shut down Commercial Reactors**
  - **that have no decommissioning license granted yet**

Name	Abbrev.	Reactor type	Power MW_e	Date of application
Philippsburg-1	KKP-1	BWR	926	2013 / 2014
Grafenrheinfeld	KKG	PWR	1345	2014
Biblis-A	KWB-A	PWR	1225	2012
Biblis-B	KWB-B	PWR	1300	2012
Unterweser	KKU	BWR	1410	2012 / 2013
Brunsbüttel	KKB	BWR	806	2012 / 2014
Krümmel	KKK	BWR	1402	2015

- **Commercial Reactors in operation**

Name	Abbrev.	Reactor type	Power MW_e	Anticipated date of final shutdown
Gundremmingen-B	KRB-II-B	BWR	1344	31.12.2017
Philippsburg-2	KKP-2	PWR	1468	31.12.2019
Gundremmingen-C	KRB-II-C	BWR	1344	31.12.2021
Grohnde	KWG	PWR	1430	31.12.2021
Brokdorf	KBR	PWR	1480	31.12.2021
Emsland	KKE	PWR	1406	31.12.2022
Isar-2	KKI-2	PWR	1485	31.12.2022
Neckarwestheim-2	GKN-2	PWR	1400	31.12.2022