

# **Summary Report of the International Concrete Harvesting Workshop**

**Hybrid workshop held on October 4, 2024, NRC headquarters, TWFN  
Auditorium, Rockville MD, US (and video meeting)**

**Organized jointly by the USNRC and OECD/NEA**

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## List of Abbreviations and Acronyms

ACES	Assessment of Safety Performance for Nuclear Civil Engineering Structures
AMP	Aging Management Program
AAR	Alkali-Aggregate Reaction
ASR	Alkali-Silica Reaction
BWR	Boiling Water Reactor
CANDU	CANadian Deuterium Uranium
CBS	Concrete Biological Shield
CEPCO	Chubu Electric Power Company Incorporated
CNL	Canadian Nuclear Laboratories (Canada)
CMs	Components and Materials
CNL	Canadian Nuclear Laboratories (Canada)
CNRA	Committee on Nuclear Regulatory Activities (NEA)
COG	Candu Owners Group (Canada)
CRIEPI	Central Research Institute of Electric Power Industry (Japan)
CSNI	Committee of the Safety of Nuclear Installations (NEA)
CVR	Research Centre Rez (Czechia)
CVUT	Czech Technical University in Prague (Czechia)
DEF	Delayed Ettringite Formation
DOE	Department of Energy (US)
DPA	Displacements Per Atom
EBS	Engineered Barrier System
EDF	Electricité de France (France)
EDS	Energy Dispersive X-Ray Spectroscopy
EPRI	Electric Power Research Institute (US)
FiR 1	Finland Reactor 1
HFR	High Flux Reactor (Netherlands)
IAEA	International Atomic Energy Agency
ICIC	International Committee on Irradiated Concrete
IETcc-CSIC	Eduardo Torroja Institute for Construction Sciences, Spanish National Research Council (Spain)
IGALL	International Generic Aging Lessons Learned (Aging Management for Nuclear Power Plants)
IGRDM	International Group on Radiation Damage Mechanisms
IMAC	Irradiated Minerals, Aggregates and Concrete database (ORNL)
IMTs	Issue Management Tables
INL	Idaho National Laboratory
IRSN	Institut de Radioprotection et de Sûreté Nucléaire (France)
ISI	In-Service Inspections
ISR	Internal Swelling Reaction
JCAMP	Japan Concrete Aging Management Program
KHNP	Korea Hydro and Nuclear Power (Korea)

L-ILW	Low and Intermediate-Level Waste
LMNPP	Life Management of Nuclear Power Plants
LWRS	Light Water Reactor Sustainability Program (USA)
LTO	Long-Term Operation
NDC	Nuclear Development Committee, NEA
NEA	Nuclear Energy Agency (Organization for Economic Development and Cooperation)
NFML	Nuclear Fuels and Materials Library
NNR	National Nuclear Regulator (South Africa)
NPP	Nuclear Power Plant
NRA	Nuclear Regulatory Authority (Japan)
NRG	Nuclear Research and Consultancy Group (Netherlands)
NSC	Nuclear Science Committee
NSUF	Nuclear Science User Facilities (US)
ORNL	Oak Ridge National Laboratory (US)
PIE	Post Irradiation Examination
PNNL	Pacific Northwest National Laboratory
PWR	Pressurized Water Reactor
RIVE	Radiation-Induced Volumetric Expansion
RPV	Reactor Pressure Vessel
SEM	Scanning electronic microscopy
SONGS	San Onofre Nuclear Generating Station (US)
SSM	Strålsäkerhetsmyndigheten, the Swedish Radiation Safety Authority.
SUJB	Czech State Office for Nuclear Safety
TEM	Transmission Electron Microscopy
TSO	Technical support organization
USNRC	United States Nuclear Regulatory Commission
VTT	VTT Technical Research Centre (Finland)
VVER	Voda Voda Energo Reactor (Water-water energetic reactor)
WGIAGE	Working Group on Integrity and Aging on Components and Structures, NEA
XRD	X-Ray Diffraction
XRF	X-Ray Fluorescence

## Executive Summary

Several nuclear power plants (NPPs) have recently been shut down worldwide and are being decommissioned, and with time there will be possibility of shutting down and decommissioning more NPPs, offering new, unique opportunities for harvesting concrete and civil structural components aged under actual operating conditions.

In this context, the International Concrete Harvesting Workshop, jointly organized by the US NRC and the OECD/NEA was held at the US NRC Headquarter in the US on October 4, 2024. It was an occasion to review the status of aged concrete harvesting worldwide and to discuss priorities and opportunities for international collaborative research on harvested concrete.

During the workshop, participating experts noted that it is becoming urgent not to miss concrete harvesting opportunities during decommissioning of nuclear power plants and to organize international collaborative research before loss of relevant technical information about the plants and before their dismantling proceeds. Results of harvesting research can be significant for LTO of operating fleets to beyond 60 or 80 years, as well as for deployment of advanced designs with planned 80 or 100 years of operation as they may be considered in the future.

Harvesting offers a unique opportunity to examine and test concrete aged under real operating conditions and alleviate reserves and uncertainties related to the use of accelerated aging tests results or of results obtained from concrete irradiated under high irradiation flux in research reactors to assess concrete durability.

As a result of their complexity and cost, concrete harvesting efforts have been limited so far, and although plans and opportunities for further harvesting concrete in decommissioned plants have been discussed, their realization remains uncertain. Several challenging aspects exist, including complex and delicate onsite retrieval operations in parallel with fast-track decommissioning schedules, transporting harvested radiological materials to external research laboratories, and marshaling the resources needed to assemble detailed information on the harvested concrete. Recognizing the challenges and cost, harvesting requires strong involvement and close cooperation of governments, regulators, researchers, utilities and decommissioning companies.

Participants have highlighted that all parties engaged in the development of the nuclear sector should be made more aware of the potential benefits from harvesting and related research both for operating and advanced reactors and funding would be needed from a wide range of stakeholders for international harvesting programs.

The limited availability of decommissioned plants for which harvesting may be feasible and the complexity and cost of concrete harvesting and related research, especially for irradiated concrete, makes concrete harvesting and especially harvesting of irradiated concrete, prime candidates for collaboration and cost sharing. Benefits of collaborative research associated with harvesting are numerous. Some of the high-level benefits include sharing (1) information, (2) harvesting and research costs, (3) material sources, and (4) best practices in samples preparation, testing and characterization. Also significant are establishing a commonly shared knowledge base for characterization of the ageing effects, and development of models and their validation and reducing uncertainties.

Workshop participants highlighted that the NEA is well-placed to coordinate, with the support of interested organizations, the implementation of an international research framework on concrete harvesting involving all stakeholders, and using the experience gained from the NEA/SMILE project which addresses collaborative research on metal components harvested in decommissioned Swedish plants.

Participants also agreed that prioritizing concrete harvesting and research for maximizing benefits and addressing the widest range of interest is required. They recommended that a comprehensive prioritization process should be developed based on the information shared at the workshop. As harvesting and collecting information and data from utilities or licensees can be time-consuming and resource intensive, it is crucial to prioritize harvesting and clearly identify samples and structural components expected to provide the most valuable data.

It has also been proposed that efforts should be undertaken to develop a library and database of physically harvested concrete samples and components of interest and make them available for possible collaborative research. Such a database would be useful to prioritize research on physically available samples and components.

The information sharing related to ongoing and planned concrete harvesting research activities and opportunities at international level should be continued and a further step could be to identify the concrete material and components with the highest potential benefits for future harvesting plans and opportunities.

## Introduction

Research supporting the long-term operation (LTO) of nuclear power plants has been critical in ensuring the continued safe operation of the nuclear fleet. LTO research aims at providing understanding of how long-term nuclear power plant operation may affect safety and supports the development of adequate LTO management plans and measures. Though challenging to achieve from economic, technological and human resource standpoints, research on material and components harvested on site and aged under real long-term operation conditions is a highly valuable component of LTO research as it provides fully prototypical information and data. International efforts to conduct collaborative research on material and components harvested in plants are, for example, currently conducted in the NEA/SMILE project focusing on metal material and components harvested in Swedish plants.<sup>(1)</sup> The international community has at several occasions expressed the wish to extend the scope of collaborative research on material harvested from plants to several categories of materials (e.g., concrete and polymer materials) whose aging may have safety implications as well as collaborative networks, involving all countries with LTO programs and a wider number of utilities and decommissioning operators. Following the international metal harvesting workshop which was jointly organized by the USNRC and the NEA in 2022,<sup>(2)</sup> it was recommended to organize a workshop dedicated to concrete harvesting, in response to needs expressed by the international community. The workshop was jointly organized by the USNRC and NEA and focused on discussing the potential benefits of harvesting aged concrete from decommissioned reactors. Research on harvested concrete can help assess in-service degradation factors such as temperature, radiation, and chemical exposure, providing realistic data to guide future licensing and LTO management plans.

## Objective and scope of the workshop

There are increasing opportunities to harvest aged components and materials (CMs) from decommissioning NPPs worldwide.<sup>(3)</sup> Harvested CMs are valuable because, unlike most accelerated-aged laboratory test samples, they have been exposed to actual in-service plant operating conditions, combining temperature, irradiation, chemical environment, mechanical stress effects. Data from NPPs will improve understanding of concrete degradation associated with extended operation of nuclear power plants from relevant aging conditions.

Global harvesting efforts on metals components have progressed since the USNRC-NEA international harvesting workshops in 2020 and 2022.<sup>(2)</sup> Participants from those workshops have highlighted that a similar International Concrete Harvesting Workshop would be beneficial to establish the status of concrete harvesting research and explore opportunities for further information sharing and for organizing collaborative research. The international nuclear community realizes the necessity to work together to optimize concrete harvesting efforts and maximize research value.

### *Participation and organization of sessions*

The International Concrete Harvesting Workshop was held at the USNRC Headquarter in Rockville, Maryland on October 4, 2024. The hybrid workshop was jointly organized by the US NRC and the OECD/NEA and was held in conjunction with the “NRC Hybrid Workshop on Structural Materials: What Research for Beyond 80 Years?” The International Concrete Harvesting Workshop was attended by 102 experts from 12 countries and two international organizations (EPRI, NEA). The detailed workshop agenda and the list of participants can be found at the end of this summary report in Appendix A and Appendix B, respectively.

### **Summary of Workshop Presentations**

The following subsections summarize the presentations.

#### *P1: NRC material harvesting activities, Robert Tregoning, USNRC, USA*

Dr. Robert Tregoning described the background of the USNRC’s materials harvesting and the current situation. Historically, the USNRC, industry and others have performed research on materials harvested from a broad range of components.<sup>(4)</sup> Current harvesting objectives focus on materials aging during long-term operation to confirm results from laboratory experiments and analytical simulations, to reduce uncertainties on aging and nondestructive evaluation (NDE) effectiveness and to support continued evolution of effective aging management.

He explained that, as several plants have been shut down and entered decommissioning, there is more “supply” of harvested components than in the past. Further, plants that are shut down have generally operated for longer periods which provides components aged for longer time for harvesting. As harvesting can be complex and costly, it is key to optimize its value. The current situation calls for a more proactive approach. A proactive harvesting strategy could involve elements such as identifying and prioritizing harvesting interests, considering the use of previously harvested materials when possible and the development of a database on harvesting opportunities. The ranking process needs to balance technical interests such as criticalness of the technical issue addressed, the importance of harvested materials over laboratory aging, the applicability to the US operating fleet and regulatory considerations related to inspections and aging management programs (AMPs). Programmatic criteria such as cost, and complexity should be considered as well. The scope of NRC’s harvesting priorities includes metallic components, concrete components, electric cables, electrical equipment and components for fire research. The prioritization done initially in 2019 is being updated and will be completed in 2025. NRC staff have also cataloged previously harvested materials from PNNL, Battelle, ANL and other sources. NRC has worked with EPRI to develop a harvesting opportunities database template. Gathering information has proven challenging.

Harvesting programs need coordination and outreach. Partnering and information sharing is essential to manage harvesting costs and complexity. The USNRC cooperates with DOE, EPRI and international organizations. NRC also holds periodic domestic public meetings on harvesting to solicit feedback from stakeholders and has hosted several international workshops in 2017<sup>(5)</sup>, 2020<sup>(6)</sup> and the last one in 2022.<sup>(2)</sup> Harvesting is an important tool for enhancing the understanding of materials and component aging. As it is resource intensive, it needs to be done in collaboration to get the maximum benefit at the lowest possible cost.

## *P2: Overview of concrete harvesting and research, Madhumita Sircar, USNRC, USA*

Ms. Madhumita Sircar introduced the motivation and vision of the USNRC for the workshop. A desired outcome is to identify ongoing and planned concrete harvesting and research activities or opportunities in several countries that are unique and most valuable to the international community and may be good candidates for information sharing and collaboration. Another outcome would be to identify next steps to pursue information sharing for developing joint harvested concrete research. She talked about the challenges of harvesting:

- Harvesting of irradiated components and materials is expensive, complex and time-consuming even if irradiated concrete has lower dose than some metal components,
- Decommissioning companies are driven by fast-track schedules and have little incentive to support harvesting efforts,
- Acquiring documentation on materials and their service conditions can be problematic once a plant shuts down and staff attrition occurs.

She explained that the USNRC concrete harvesting and research is planned in collaboration with other organizations such as DOE, EPRI and other international organizations. Experience was gained from earlier concrete harvesting attempts from the Zorita plant in Spain, and the San Onofre Nuclear Generating Station (SONGS) in California, USA. From SONGS, available plant documents, reports, drawings and concrete specifications were gathered. Unirradiated concrete was harvested from the back of the steam generator enclosure in October 2021 and ORNL was sponsored to analyze and determine the susceptibility of the harvested concrete to irradiation-induced damage, which is governed by the mineralogy of the concrete's aggregates (presence of high quartz content and chemical heterogeneity of the assemblage) as well as cumulated radiation level, namely high fluence levels. As higher fluences are obtained in PWRs, research has focused on concrete harvested in PWRs. Preliminary harvesting and research plans have been developed based on this experience. Highest priorities for the USNRC are to get a better understanding of:

- evolution of concrete mechanical properties and characteristics under irradiation by collecting real-life data and verifying models,
- embrittlement, fracture toughness and microstructure of reactor supports,
- degradation of post-tensioning systems, considering the coupling with other degradation modes, and the effect on post-tensioned structures.

Of medium-high interest have been the corrosion of rebar and of post-tensioning tendons and embedments, the boric acid attack on the PWR SFP concrete structures and other degradation which may affect containments and other safety-related concrete structures.

On all these topics, the USNRC priority is to seek opportunities for investigations on harvested concrete.

### *P3: Light Water Reactor Sustainability (LWRS) perspectives on Concrete Harvesting Needs and Opportunities, Yann Le Pape, ORNL, USA*

Dr. Yann Le Pape provided insights from the US Department of Energy's LWRS program and presented the motivation for harvesting in-service irradiated concrete. He explained that understanding and physics-based modeling of irradiated concrete rely on observations and post-irradiation analysis of test reactor data obtained under accelerated conditions. However, there is no surveillance program monitoring in-service irradiated concrete in light water reactors (LWRs), and that the in-service conditions are significantly different.

Le Pape noted that high neutron fluxes cause larger radiation-induced volumetric expansion (RIVE), but since in-service fluxes are lower than test reactor fluxes, less RIVE is expected in-service. This can be confirmed by analyzing harvested concrete for RIVE.

Unexpected results were obtained from Hamaoka harvesting by the Japan Concrete Aging Management Program (JCAMP), which showed a strength increase in the cement paste due to the formation of C-A-S-H (calcium-aluminate-silicate-hydrate) and Al-tobermorite phases under specific humidity, temperature, and radiation conditions. These results highlight the possibility of radiochemistry-induced mechanisms that may not have been previously envisioned.

Le Pape emphasized the need for data beyond test reactor data, specifically with exposure to neutron fluence above the "damaging threshold" of  $10^{19}$  n/cm<sup>2</sup> at a depth of 5 cm and with the presence of silicates in concrete aggregates, which are more susceptible to RIVE. He highlighted that a key challenge for harvesting is making it compatible with the decommissioning operations timeline. Successful harvesting requires advanced planning, including simulations, location-specific sampling, and core extraction from various reactor shield locations.

He introduced the approach in RIL 2022-07<sup>(7)</sup> (Assessment of San Onofre (SONGS) Concrete Susceptibility to Irradiation Damage) and the FY24 Concrete Harvesting work package. Unirradiated concrete from the SONGS steam generator room has been cored at three elevations. Unirradiated aggregates from SONGS were characterized using XRD, petrography, micro-XRF, and EDS-SEM. RIVE for the concrete biological shield (CBS) can be estimated for the obtained mineralogical content by comparison with the irradiated minerals, aggregates and concrete (IMAC) database.

The LWRS program continues to engage as part of the FY25 concrete harvesting work package, collaborating with decommissioning companies and plant utilities worldwide to obtain samples that have been exposed to varying irradiation doses, temperatures, and relative humidity within the CBS and other structures.

Le Pape mentioned ongoing projects and collaborations in development for FY25 and further. ORNL is collaborating with various international entities (e.g., Swedish NPP Ringhals, CNL, EDF) to obtain unirradiated and irradiated samples for analysis. These collaborations aim to refine harvesting techniques and collect data on different concrete types and exposure levels. Future directions include developing comprehensive strategies for testing irradiated concrete, understanding material properties at the microstructural level, and addressing variations in irradiated material properties. The program seeks to apply successful methodologies from SONGS to future projects and continue expanding partnerships and support.

#### *P4: EPRI research on concrete harvesting research, Samuel Johnson, EPRI, USA*

Mr. Samuel Johnson presented EPRI's research on harvested concrete. The EPRI concrete research is focused on aging management, inspection and repair of structures as well as developing industry guidance. He said that harvesting is of great interest due to the material being exposed to real operating conditions that may be different than conditions simulated in a laboratory environment.

The primary focus is on studying irradiated concrete from biological shield walls to assess the impacts of lower radiation levels than typically tested in reactors. Harvesting would help EPRI and other stakeholders better understand structural aging and identify degradation processes. However, challenges persist, largely logistic and political, particularly regarding international transfer of irradiated materials for testing. Legal and contractual issues also pose hurdles, along with coordination issues with decommissioning companies, focused on rapid, economical plant closures. Another area of interest involves NDE to examine concrete conditions without removing samples. Integrating NDE with harvesting allows researchers to better simulate and evaluate in situ conditions.

In addition to irradiated concrete, EPRI is studying other degradation mechanisms, including chemical infiltration (e.g., chlorides, carbonation), liner deterioration, and calcium carbonate leaching in areas difficult to inspect traditionally. Harvesting from such inaccessible areas offers insights for managing long-term structural integrity in buried or otherwise hidden concrete components.

He concluded with EPRI's commitment to ongoing collaboration with utilities, regulatory bodies like the USNRC, the DOE, national laboratories, and other interested parties to enhance the understanding and management of concrete aging.

#### *P5: Nuclear materials harvesting and beyond: material acquisition, sample library and concrete related research through NSUF, Rongjie Song, INL, USA*

Dr. Rongjie Song presented activities related to nuclear materials harvesting, acquisition and research through the Nuclear Science User Facilities (NSUF). NSUF was established in 2007 as a United States (US) Department of Energy's Office of Nuclear Energy (DOE-NE) first and only user facility, founded at the Idaho National Laboratory (INL). The INL remains lead and primary institution for the NSUF. The NSUF operates similarly to the other US user facilities (no cost to user, competitive

proposal processes, no travel funding to users, etc.), but also has some unique aspects. The NSUF operates as a consortium of 21 institutions and 65 partner facilities across the United States, providing resources for irradiation studies, post-irradiation examinations, high-performance computing, and more. These resources are available to industry, academia, and laboratories for non-proprietary research, aiming to advance innovation in nuclear energy technologies.

The Nuclear Fuels and Materials Library (NFML), owned by the US DOE-NE and curated by the NSUF, is the largest global open archive of high-value irradiated fuel and material samples and technical information from past and ongoing irradiation test campaigns. The NFML also includes samples from real-world components retrieved from decommissioned power reactors, along with donations from other sources. It houses over 9,000 samples and is increasingly recognized for its role as a repository for a diverse selection of nuclear fuels and materials and is a valuable resource to the nuclear research community. Although the library lacks physical concrete samples, NSUF supports concrete research through awarded projects focused on understanding radiation effects on concrete's microstructure, mechanical properties, and durability.

Key NSUF-supported concrete research uses various analytical methods, such as microstructure/composition examination, mechanical testing, porosity testing, acoustic exams and permeation tests, to assess radiation effects. Studies on aggregates and other concrete components help to inform maintenance and safety guidelines for nuclear facilities. The NSUF provides state-of-the-art capabilities, unmatched resources and world class expertise to support innovative research projects, taking concrete as an example. The NSUF is experienced in irradiated nuclear materials acquisition using different routes (awarded projects, domestic international collaboration, harvesting, partner facilities, etc.). The NSUF library has a large sample inventory that allows convenient access to samples (especially irradiated materials) for research.

#### *P6: Concrete harvesting activities, plans and related priority research topics in Japan, Masayoshi Kojima, NRA, Japan*

Dr. Masayoshi Kojima presented the status of PWR and BWR reactors in Japan as of October 2024 with 16 operating PWR units, 17 operating BWR units, and 23 units under decommissioning. For the operating reactors, five units have more than 40 years operation, 18 units more than 30 years, and 10 units less than 30 years. Plants that operate or plan to operate beyond 30 years should develop a long-term facility management plan which is reviewed and approved by the NRA. The plan is approved for a period not exceeding 10 years and should therefore be renewed every 10 years for operation up to 60 years. Special inspections related to LTO shall be conducted for plants that are planned to operate beyond 40 years. Such inspections are conducted after 35 years from the date of the start of operation and are considered for the long-term facility management plan developed for operation beyond 40 years. In principle, the special inspections are conducted with the taking of core concrete samples for testing.

The focus of special inspections for both BWRs and PWRs is on the potential decrease with aging in strength and shielding capacities of concrete structures with safety functions including structures involved in severe accident response, with pre-stressed concrete containment and concrete structures supporting safety systems and equipment. Potential degradation phenomena

investigated on harvested concrete samples are carbonation, chloride penetration, and the alkaline aggregate reaction. Concrete samples from the reactor building, auxiliary building, turbine building, and water intake tank must be harvested for inspections. As of October 2024, 7 PWR units between 38 and 49 years of operation and one BWR unit with 45 years of operation have undergone special inspections. Inspection methods involve tests for measuring the compressive strength of concrete, for measuring the dry density of concrete, the carbonation depth of concrete, the chloride ion content in hardened concrete, and methods to diagnose the extent of alkali-aggregate reaction (AAR).

He presented results of inspections obtained for Sendai unit-1 (40 years operation) which showed a higher average concrete structures compressive strength compared to design standard strength, a slightly higher average density compared to design value, carbonation depth between 2 and about 40 mm depending on the investigated concrete structure and chloride content as a function of depth showing chloride penetration is just below the distance for rusting rebars. Regarding AAR, reaction rim formation and gel seepage were observed at most of the inspected locations, but the alkali-aggregate reaction extent was minor. In some concrete samples of the water intake structure, delayed dilatant reactive minerals (cryptocrystalline quartz and microcrystalline quartz) were observed in the part of the marine sand, the rhyolite. Accelerated expansion test showed that the possibility of delayed expansion was low. Other than in the rhyolite, no retarded expansion reactive minerals were observed.

Dr. Kojima also presented the Chubu Electric Power Company (CEPCO) research on the Hamaoka Unit-1 which is under decommissioning by the CEPCO with the objective of developing a new evaluation method of the integrity of concrete structures, making full use of nondestructive testing methods and analytical evaluation methods. The work involves the development of a concrete database collecting data on strength, specific gravity, static and dynamic elasticity modulus, moisture content, formulation estimation, carbonation depth, alkali-aggregate reaction, etc. of aged concrete. The applicability of nondestructive testing and analytical methods to evaluate concrete strength without the need to harvest concrete samples will be assessed.

Results show that in the concrete wall (1.5 m thick) in the general area away from the reactor containment vessel, the interior was about 1.5 times stronger than the outer part. In the biological shielding wall exposed to high temperatures and radiation, the interior was about twice as strong as the outer part. The strength increase was shown to be related to the distribution of moisture in the concrete. Microstructural observations using an electron microscope revealed that calcium hydroxide produced by the hydration reaction of cement reacts with minerals (alkali feldspars) present in the sand in the concrete to form calcium aluminosilicate hydrate. Analysis of biological shielding walls and pedestals (the lower part of the reactor pressure vessel), which are exposed to relatively high temperatures during power plant operation, revealed the formation of tobermorite, a type of rock mineral, which increases chemical stability and strength.<sup>(8)(9)</sup>

The NRA regularly publishes results and details of special inspections on its website. CEPCO presented its research results at the International Committee on Irradiated Concrete (ICIC). In the future, the results of inspections can be presented and discussed at the CSNI WGIAGE.

*P7: Concrete harvesting activities, plans and related priority research topics in Czechia, Petr Stemberk, Czech Technical University, Czechia*

Dr. Petr Stemberk presented ongoing and planned research on concrete harvested in nuclear power plants in Czechia, led by the Research Center Rez (CVR) and the Czech Technical University (CTU). He explained that Czechia is planning to extend the operational plant life of its existing nuclear power plants, Temelin (2 VVER 1000/320 units) and Dukovany I (4 VVER 440/213 units) to 60 years and beyond. Plans to build up to four new 1200 MWe nuclear units at Dukovany (Dukovany II project) and Temelin, two at each site, designed by Korea Hydro and Nuclear Power (KHNP) are well advanced. Dry cooling may be used to expand cooling capacities as water resources may not be sufficient for two additional units at Dukovany when operational plant life of Dukovany I units will be extended beyond 60 years. Plans are that Dukovany II will start to be built in 2029 with one water-cooled unit first and expectations are that this new unit will be commissioned by 2036. For this new generation of plants, it is expected that operation will last up to 80 years. Czechia also plans to build a Small Modular Reactor (SMR) at Temelin. The Rolls Royce concept was selected but Czech SMR designs are also under development.

Czech researchers, particularly at the CTU, are developing advanced numerical tools for material simulations, specifically for nuclear concrete structures, and are heavily involved in interpreting irradiation data. The collaboration between CTU and CVR aims to generate findings to inform the Czech utility CEZ and the national regulatory commission SUJB for future life-extension decisions.

Czech nuclear research programs integrate high school and university students, who contribute to research projects and learn technical skills for potential careers in the nuclear industry. These initiatives aim to meet workforce demands projected for new reactor units. Key research includes testing irradiated concrete samples, designing spent fuel containers, and examining structural integrity of irradiated concrete structures. CTU and CVR contribute to projects like the Horizon 2020-Euratom ACES project with a focus on modeling radiation effects on concrete and their physical validation.

Concerning the international collaborations, Czechia collaborates with neighboring countries and institutions across Europe and Asia, Korea and Japan as well as with Vattenfall in Sweden. A notable project involves retrieving concrete samples from decommissioned plants in Germany and Slovakia for analysis. Czechia plans to create a "Czech CAMP" (Concrete Aging Management Program) funded by a government grant to support local nuclear power infrastructure with Czech-designed solutions.

*P8: Concrete harvesting and related research at CNL, Shahzma Jaffer, CNL, Canada*

Ms. Shahzma Jaffer introduced the nuclear scene in Canada with operating nuclear power reactors at Point Lepreau, Pickering A units 1 and 4, Pickering B, Darlington and Bruce A and B. Pickering A units 2 and 3 and Gentilly 2 have permanently shut down, as well as prototype power reactors (Nuclear Power Demonstration (NPD), Douglas Point, and Gentilly 1). Pickering A units 1 and 4 are planned to be shut down and Pickering B units 5 to 8 are planned to undergo refurbishment. The oldest Canadian power reactor (Pickering A unit 1) has been operating for 53 years. Regarding research reactors, the

McMaster Nuclear Reactor, the SLOWPOKE-2 reactor and the Zero Energy Deuterium reactor (ZED-2) are operating while the national research experimental (NRX), National Research Universal (NRU) and Whiteshell reactor-1 are permanently shut down. The potential for new reactors include new large-scale nuclear builds at Bruce and small modular reactors, e.g. the Darlington new nuclear project. CANDU utilities perform joint research through the CANDU Owners Group (COG).

She explained why harvesting concrete from nuclear facilities would be beneficial. Firstly, it is expected to support continued operation of existing reactors. Concrete structures in nuclear facilities continue to operate over the life of the reactors (including life-extension), and these concrete structures are not replaced like some other components during refurbishments. Concrete structures are exposed to various conditions (e.g., changing seasons, varying loads, vibrations, cyclic and elevated temperatures due to reactor operations, and radiation from the reactor) and questions are asked about the structures' integrity as they continue to operate. Examination of harvested concrete would provide valuable information on structures' integrity.

Secondly, it is expected to support the decommissioning of shutdown reactors. Large amounts of concrete are used in nuclear facilities. No permanent disposal facility exists in Canada for radioactive waste. The near surface disposal facility (NSDF) for low-level waste has yet to be built at Chalk River. There is a need-to-know concrete volumes that meet clearable, low-level, or intermediate-level waste categories and types of radionuclides present. Stakeholders can plan to establish processing facilities to reduce or remove the contamination and change waste classification (where possible). Accurate information on volumes of radioactive waste, radionuclides present and their concentrations are required to plan for safe temporary and permanent disposal facilities. Characterization of harvested concrete would allow planning for decommissioning.

Thirdly, it is expected to provide input to new reactor builds and SMRs. Lessons learned from the operation and decommissioning of nuclear facilities can lead to improvements in the structures for future builds. For example, selected types of aggregates could be used for shielding concrete, "replaceable" structures could be developed that could be upgraded during refurbishments, and activation and contamination of concrete during operation could be reduced to lessen radioactive waste during decommissioning. Studying harvested concrete will allow determination of improvements to be made to future structures.

Ms. Jaffer talked about the challenges on research and development perspectives. The R&D budgets are typically small and not sufficient to cover the costs involved with all the work that is required to harvest concrete cores from a nuclear facility. Stakeholders are concerned about potential effects on structures' functions. Facility/station staff have their own priorities and deadlines to meet. Requests from R&D staff to harvest may be seen as intrusive and more work on the part of facility/station staff. Facilities staff and stakeholders are worried about issues being found that would have consequences for their facilities. She emphasized the importance of focusing concrete harvesting on samples expected to provide long-term benefits and creating a library of harvested material.

She presented past work done on concrete harvested from the NPD reactor vault and the Gentilly-1 concrete containment building.<sup>(10)</sup> For Gentilly-1, the investigations included visual observations, field testing and laboratory testing. The field testing indicated that reinforcing bars in the wall and dome and P-T wires in the dome had no signs of corrosion. Some corrosion was seen in the wall P-T

wires which was attributed to them being left un-grouted during construction. Reinforcing bars were in tension instead of compression likely due to AAR. Laboratory testing evidenced cracks parallel to the perimeter wall surface, a carbonation depth of only 6 mm and showed that chloride contamination was not an issue.

She concluded by saying that there are potential opportunities to harvest in the future in Canada with several reactors under decommissioning or that will be decommissioned soon. There are opportunities for cost efficiencies through harvesting samples during decommissioning characterization campaigns. There is a need to work further with the involved stakeholders to determine the harvesting opportunities that are available.

#### *P9: Concrete harvesting plans for EDF in France, Benoit Masson, EDF, France*

Mr. Benoît Masson said that currently harvesting at EDF is done if there are opportunities (repairs, modifications, etc.) on the operating plants. There are also plans under discussion for harvesting at the Fessenheim NPP, the only PWR plant under decommissioning in France after 43 years of operation. Possible harvesting in the next years would mostly concern anchorages, anchors, concrete from containment building, concrete from biological shield and water-stop seal with an interest on ASR and delayed ettringite formation (DEF) topics.

Some samples of concrete have already been harvested, including a water-stop seal, and modulus, strength and composition were evaluated. The presence of gels revealing ASR or DEF was analyzed by scanning electron microscopy (SEM). There are plans to harvest another water-stop seal, a pressurizer pre-stressed anchorage, anchors, concrete behind the steel liner and biological shield concrete at Fessenheim. Feasibility analyses are ongoing. It is expected that analyzing the capacity of aged anchors will be very challenging as information on environmental conditions during the years of operation is limited. Another issue is that the anchor type is specific to Fessenheim, and lessons learned may not be widely applicable. Concrete behind the steel liner will be harvested to check the electrochemical properties and the state of corrosion of the concrete. These properties must be well understood to be able to perform accurate measurements. Harvesting biological shield concrete present challenges and limitations. Irradiation and space between the vessel and the wall do not permit harvesting from the vessel side. The harvesting will be possible after removing the vessel which will not occur before 2032. If the fluence level is below  $10^{19}$  n/cm<sup>2</sup>, no irradiation effect is expected. Calculations are ongoing to evaluate the fluence level and the concrete thickness of interest.

Regarding the ASR and DEF topics, no decision has been taken for the moment to perform related harvesting at EDF, but when a repair or modification will be done, potentials for harvesting and analysis will be considered.<sup>(11)</sup> Further, large concrete mockups are periodically investigated in France by IRSN in the observatory of the durability of reinforced concrete structures (ODOBA) project, and in the recently launched European research program ACES (characterization, prediction, and monitoring of internal swelling reactions in concrete).

*P10: IRSN views on concrete harvesting, Christophe Marquie, IRSN, France*

Mr. Christophe Marquie presented IRSN's view regarding concrete harvesting. As the French operator, EDF, plans to extend the operation of its NPPs beyond 60 years and as concrete structures are non-replaceable components, IRSN, as a TSO, needs to assess how aging could affect the safety of concrete structures (leak tightness and structural strength) under normal and accidental conditions. IRSN has identified two priorities: the mechanical stability of the RPV support structures considering the effect of irradiation on concrete and the behavior of the containment building considering creeping and shrinkage (effect on prestress) and internal swelling reactions (ISR). IRSN is leading an international project on ISR (ODOBA Project with USNRC, CNSC, VTT and Bel-V) and is participating in the European ACES Project which is a comprehensive project on concrete aging).

IRSN has a strong interest in harvesting activities to have access to real material aged in real conditions to be able to compare the data obtained with experimental laboratory work, analyzing effects as those of accelerated aging protocols and of scaling from laboratory tests to real structures (partially addressed in the ODOBA project). IRSN is in relation with EDF regarding potential for harvesting from Fessenheim NPP but is also willing to have international collaboration on concrete harvesting and related research.

In the past, IRSN had supported the Canadian initiative of the OECD/NEA HARVEST Project that was unfortunately not launched. IRSN can propose in conjunction with harvesting initiatives to build ODOBA-like experimentation on "twin structures" involving large metric concrete structures submitted to accelerated aging (as well as some smaller scale laboratory cylinders) with feasibility to be assessed (availability of concrete pouring data, aggregates, cements, etc.).

Regarding irradiation effects, previous studies showed a cliff-edge effect for irradiation of about  $10^{19}$  n/cm<sup>2</sup>. IRSN is making neutronic evaluation of neutron and gamma dose on the RPV support structures. This threshold might be passed in PWRs after 60 years of operation. One of the main issues is the representativity of high fluence rate to simulate long operation time on RIVE formation. Data from Fessenheim harvesting may only arrive in a few years (expected by EDF in 2032), and IRSN is ready to support initiatives on this topic.

*P11: Ringhals nuclear power plant (NPP) potential harvesting of irradiated concrete, Johanna Spals, Vattenfall/Ringhals, Sweden*

Ms. Johanna Spals presented potential for concrete harvesting at the Ringhals NPP. Ringhals NPP has four units with one BWR unit and 3 PWRs units. Units 1 (BWR) and 2 (PWR) have been in operation since 1975. Unit 1 was shut down in 2020 and Unit 2 in 2019. Units 3 and 4 have entered in operation in 1981 and 1983 and plans are to extend service life to 60 years for both units and to prepare to go to 80 years. Plans for extended operation of Unit 3 and 4 motivate Ringhals to do investigations on concrete components harvested in Unit 2 under decommissioning, as Unit 2 is very similar to Unit 3 and Unit 4.

The decommissioning of Unit 2 has started, and some preparatory work has been performed. Some of the tendons are de-tensioned. A hole is done through the wall between the containment and the fuel building. A hole between the containment and the outdoor is being prepared.

Unit 2 is a 3 loop PWR which operated for 43 years. 50 mm cores have been drilled in the biological shield concrete to measure contamination levels. Calculation of biological shield fluence shows that the radiation level is above the “damaging threshold” level for the inner 50 mm of the concrete structure. The next step is the material characterization of the concrete. It is planned to extract concrete samples for characterization during the fall of 2024. Unirradiated concrete with the same material properties as the biological shield will be retrieved and analyzed. Plans are to do testing on the samples in collaboration with ORNL.

#### *P12: Concrete harvesting plans in Finland, Miguel Ferreira, VTT, Finland*

Mr. Miguel Ferreira started his talk saying that there is currently no explicit concrete harvesting plan in Finland. He presented two items related to research on harvested concrete: VTT’s investigations on concrete cores harvested in the Finland Reactor 1 (FiR 1) research reactor and Fortum activities and interest for the Loviisa NPP. The FiR 1 research reactor (Triga Mark II, 250 kW reactor) was shut down in 2015 and the decommissioning license was obtained in 2021. The largest volume of material that needs to be decommissioned is concrete. A preliminary study was done to assess activity level in the concrete, first numerically, and then in the later stage, by harvesting three core samples from the concrete biological shield at different locations. The samples are currently being analyzed by ultrasonic pulse velocity, SEM/EDS and chemically (dissolution and leaching tests). Preliminary results show that though ASR gel formation was observed in the innermost segment of a concrete core taken close to an opening, no residual expansion was measured. Minimal differences were seen between dissolution of calcium-containing phases between low and more highly irradiated areas. Taken together, these results suggest that there is no significant effect of the low dose of radiation ( $5.57 \cdot 10^{16} \text{ n/cm}^2$ ) on FiR 1 concrete chemical and mechanical stability.

Mr. Ferreira then introduced activities and interests for the Loviisa NPP (2 VVER-440 units operating since 1977 and 1980) and onsite low and intermediate-level waste (L/ILW) repository with an engineered barrier system (EBS) based on concrete). New operating licenses were issued in 2023 for power production until 2050, for preparing the NPP decommissioning by 2055 and for operating the onsite waste facilities until 2090. Related to the long-term life cycle management of the plant, various modernization programs and projects were conducted, and a new long-term operation program will be conducted until 2050, including upgrades/replacements of structures, systems and components. All relevant aging phenomena over a period exceeding 70 years are to be addressed with concrete sampling considered in accessible locations. Of specific interest are concrete chemical damage mechanisms (effects of sulfates), effects of neutron irradiation, increase of compressive strength, diffusivity, porosity, ASR and post-closure long-term performance of EBS structures in the repository.

#### *P13: Concrete harvesting plans in Spain, ZORITA NPP concrete project, Javier Sanchez, IETcc-CSIC, Spain*

Mr. Javier Sanchez presented the concrete harvesting plans in Spain with the Zorita NPP plant concrete project. He started with a description of the Zorita NPP and of the concrete harvesting

objectives. The Zorita NPP is a 160 MWe 1-loop PWR reactor of a Westinghouse design. It was commissioned in 1968 and operated until 2006, corresponding to 38 years of operation (26.36 Effective Full Power Years). In 2010, ENRESA took responsibility for the plant decommissioning. The decommissioning was seen as an opportunity to investigate the effects of high irradiation on the reactor's biological shielding, of high temperatures at the hot leg locations, aggressive chemicals in the spent fuel pool and of the outdoor environment on the exterior of the concrete building. This is done with in situ investigations of durability (measurements of corrosion potential, resistivity and corrosion rate) and with harvesting concrete cores at different locations for analysis.<sup>(12)(13)</sup> The samples extraction plan include 24 samples from the biological shielding with samples extracted at different locations according to the map of maximum neutron fluence, four samples from the spent fuel pool nearest to the pool sump to investigate effect of boric acid, two samples from the hot leg that have seen high temperatures and four samples from the exterior of the containment building (2 below and two above ground level). Further, 59 specimens of non-irradiated concrete have also been extracted at different locations (cubicle CH1-level 611, exterior of containment building, mobile parts of the transfer channel, middle and exterior of the biological shielding) to serve as reference specimens for comparison with irradiated concrete. 20 of these non-irradiated samples have been selected for various analyses (porosity, microscopy, carbonation depth, ATD, DRX, tomography, petrography, water porosity, resistivity, ultrasonic velocity, Schmidt hammer).

The Zorita NPP concrete harvesting and research project is done in collaboration with several stakeholders in Spain (CEIDEN, CSIC, CSN, Endesa Generacion, Enresa, Iberdrola, Naturgy) and is expected to provide a significant database on concrete aging under real conditions.

#### *P14: Concrete harvesting activities in the Netherlands, Srijan Kumar, NRG, Netherlands*

Mr. Srijan Kumar presented tests (mainly mechanical) performed on concrete cores taken from structures of the high flux reactor (HFR) at Petten, Netherlands. He provided background information regarding the HFR which is a light water cooled and moderated tank-in-pool reactor which has operated for 63 years since 1961. The reactor pool and storage pools-1 & 2 are housed inside the reactor containment building. Heavy density concrete (3500 kg/m<sup>3</sup>) and very heavy density concrete (4200 kg/m<sup>3</sup>) are used for the basins. An aluminum liner is used for leak tightness. Outside the basins, normal density concrete was used. The concrete class is C20/25 (20.7 N/mm<sup>2</sup>).

A concrete core was drilled out from the underside on the basin in 1985 and compressive strength, density and porosity of the concrete have been determined. In 2009, two concrete cores were drilled out from the ceiling of the sub-pile room to do similar measurements. Based on its mass, appearance and magnetism, it was suspected that the aggregate was greigite and not barite, magnetite and hematite as were previously assumed.

In 2010, a vertical drilling was carried out over approximately 1.9 m of the total 2.235 m thickness of the reactor floor. The floor was drilled from the bottom in four steps (cores). Ten cylinders were sawn off from the four drilled cores from the reactor floor. Six cylinders were used to determine the tensile strength. Four cylinders were used to determine the compressive strength and volumetric weight. The large range of compressive strength is given by the voids present in the concrete.

Finally in 2017, six cores were extracted from the pipe corridor (two from walls and four from ceilings) to measure concrete mechanical properties. There is a visible difference between concretes of different strength class.

A chlorine ingress model has been developed based on in situ properties of concrete. The model has been calibrated using data from chimney's concrete cores.

Future works include determination of the in situ material properties of the very high-density concrete of the real nature of the aggregates (magnetite or barite or greigite) and the enhancement of the chlorine ingress model based on more data from the reactor pool structure. Reinforcement coupons may be extracted to determine the properties of rebars. The effect of the alkali-silica reaction (ASR) on the reactor pool structure needs to be investigated.<sup>(14)(15)</sup>

*P15: Vision for participating in concrete harvesting initiative to support independent research on qualification of concrete for long-term operation of nuclear facilities in South Africa, Sifiso Nhleko, NNR, South Africa*

First, Dr. Sifiso Nhleko introduced the background in South Africa and explained that his presentation is not representing the position of NNR. He presented nuclear sites in South Africa with the Koeberg site with two 900 MWe units, with Unit 1 operating since 1984 and Unit 2 since 1985, the Vaalputs radioactive waste disposal site, and the Safari research reactor site at Necsa, operating since 1965. He highlighted that research should investigate changes in material properties due to aging/time, ambient temperature, irradiation damage, chloride-induced concrete corrosion, carbonation, ASR, implementation of mitigation measures such as “impressed current cathodic protection,” and other effects such as biological attack, boron effects, stress, etc.

He then provided a few considerations. Visual inspections conducted over the years show that there are significant differences in the durability performance of concrete between structures located at coastal nuclear sites and inland nuclear sites. The differences have never been investigated and expressed in quantitative terms through the conduct of rigorous and high-quality “nuclear research.” Differences may be due to different exposure conditions, the design of the concrete itself, implementation of maintenance/mitigation measures and or unknown aging phenomena. It is necessary to conduct research to understand the durability performance of concrete considering planned extensions of operation to 60 or 80 years. Participating in international concrete harvesting initiatives will allow South Africa to benefit from information sharing or joint harvested concrete research among interested countries and organizations.

A way forward in South Africa could be to identify national needs/site-specific research issues, to define a national position on participation (regulator and operators), to implement a plan, to define funding requirements, to collaborate with qualifying academic research institutions and national laboratories and to develop and agree on protocols for information sharing.

## Discussion on Priorities and Opportunities for Collaboration and Information Sharing

Two panel sessions were held following the information presentations. The first session was intended to be a technical discussion on concrete harvesting research priorities. It was moderated by Madumitha Sircar (USNRC) and Jose Pires (USNRC) and involved five panelists: Yann La Pape (ORNL, US), Christophe Marquie (IRSN, France), Ipppei Maruyama (University of Tokyo, Japan), Julia Tchnerer (AtkinsRéalis, Canada) and Petr Stemberk (CVUT, Czechia). The second session was intended to be a strategic discussion on potential for future international cooperation. It was moderated by Keiko Chitose (NEA) and involved seven panelists: Jeff Poehler (USNRC, US), Elena Tajuelo-Rodriguez (ORNL, US), Sam Johnson (EPRI, US), Takashi Osaki (Chubu Electric, Japan), Ipppei Maruyama (University of Tokyo, Japan), Fabienne Ribeiro (IRSN, France) and Didier Jacquemain (NEA). Main points of the discussion are summarized in the following paragraphs.

### Research priorities and prioritization process

- Prioritizing harvesting and research on harvested concrete and civil structural components is challenging but essential because there are potentially several aging issues to investigate with several potential degradation mechanisms that can affect concrete durability. Sometimes more than one degradation mode may occur simultaneously. Inspection, monitoring, operating experience and characterization of real-life aged material is key in helping to identify aging processes to consider in priority in the assessment of concrete durability. The incremental knowledge gained on aged concrete from onsite monitoring (e.g., as implemented at Zorita) or characterization of harvested concrete at different plants, though limited at this stage, should be regularly shared and reviewed, as was initiated with this workshop, to prioritize research work.
- Other factors make this research prioritization complex. Concrete aging is complex due to concrete composite nature, with various aggregates and paste components undergoing different chemical reactions in different environments. This variability means aging mechanisms may differ from one plant to another depending on concrete type and depending on factors like pouring conditions and initial cooling and shrinkage, rebar positioning and initial mechanical load, loading conditions during operation (e.g. irradiation, thermal, chemical and mechanical), delamination, cracking, and corrosion, etc. To address this variability, modeling based approaches are needed to determine the remaining capacity of concrete structures for long-term safety. Further, modeling approaches are required to scale results obtained from harvested small concrete samples (or samples tested in laboratories) to the full concrete structure. These considerations highlight that:
  - Prioritization of which concrete samples to harvest should be accompanied with a reliable level of information and data on their initial characteristics and on their environmental and loading conditions during operation. Information and data on the whole concrete structure should also be available for analysis purposes.
  - Prioritization of which concrete samples to harvest should, as possible, account for information and data of common interest, i.e., be representative of a class of concrete and from locations that are more susceptible to degradation.

- Prioritization of harvesting should consider the research plan for the harvested material which should identify the specific mechanisms to be investigated in order to reduce uncertainties that may remain from, for example, laboratory testing.
  - Prioritization of harvesting and concrete characterization should consider the validation of modeling and simulation for the assessment of structural performance.
- Despite differences in concrete at each power plant, there is significant knowledge to share, including on effects of concrete aging on structures, on approaches to mitigate detrimental effects, on onsite measurement and characterization methods, on methods to harvest concrete, where applicable, etc. Such knowledge sharing should also help prioritizing research in the interest of optimizing concrete aging management.
- In prioritizing, it is essential to continue after this workshop to have open discussions at the international level to identify shared issues related to concrete aging.
- Collecting information and data from utilities or licensees can be time-consuming and resource intensive, so it is crucial to prioritize these efforts and clearly identify samples expected to provide the most valuable data.
- In prioritizing concrete and civil structural components harvesting, only concrete cores and specimens for which one expects a high cost/benefits ratio and for which harvesting is feasible should be considered.
  - Harvesting irradiated concrete could be considered in priority, as durability of irradiated concrete can potentially be an issue and not accessible for inspection and monitoring. It will also be a more challenging and more costly effort than harvesting non-irradiated concrete. Thus, if a large collaborative framework is developed, it needs to be focused on that effort. Harvesting non-irradiated concrete to investigate other types of degradation than those induced by irradiation, is expected to be simpler and could be accomplished more on an individual basis with organizing information sharing with the research community.
- Data on aged concrete sometimes show similar trend, e.g. increase of compressive strength in structures. The number of samples to be analyzed may be optimized based on similar observations made for similar types of concrete.
- It would be highly valuable to develop a library/database of physically harvested concrete and civil structural components samples of interest, available for collaborative research. Samples of interest should have sufficient information on history of in-service conditions they were exposed to. The library could also include reference samples for comparison (e.g., non-irradiated samples to compare to irradiated samples). Samples collected during repair or modification operations in operating plants could also be considered for addition in the database, if relevant. Such a database would be useful to prioritize research on physically available samples.
- The information related to ongoing/planned concrete harvesting research opportunities and activities exchanged at the workshop could be collected in a table (see Appendix C, containing the table established after the workshop). The information contained in the table should be periodically updated.
- A prioritization effort should be continued, informed by the material and views collected at this workshop. Participants are expected to provide updated information on concrete harvesting activities in their countries/organizations. Support from organizations like EPRI or

the USNRC in the prioritization would be valuable. A further step could be to identify from harvesting opportunities/plans concrete material with the highest potential benefits.

## Potential actions/recommendations

**NEA/USNRC to continue collecting information on ongoing, planned or potential concrete and civil structural components harvesting activities (updates to Appendix C table) with the support of interested organizations and initiate discussions regarding how to conduct a prioritization process with a core group of organizations interested in this exercise, with considering the workshop guidance.**

**NEA/USNRC to manage discussions with interested organizations about the development of a database of physically available harvested concrete samples that can be considered for collaborative research.**

Note: these actions could be followed by a core group which will further discuss the development of an international research framework on concrete harvesting research (see next section).

## International collaborative research framework

- It is becoming urgent not to miss increasing unique opportunities to harvest concrete in plants being decommissioned worldwide or in operating plants (e.g., when implementing modifications) and to organize international collaborative research on concrete harvesting when LTO of the operating fleet to beyond 60 or 80 years is considered in several countries. The current context presents a real need and opportunities for examining samples from decommissioning plants. Delaying this examination could prevent getting timely reliable data, as samples cannot be preserved in their original condition. This urgency highlights the importance of leveraging decommissioning opportunities to gather the real-life data.
- Harvesting offers a unique opportunity to examine and test real-aged concrete and alleviate uncertainties related to the use of accelerated aging test results to assess concrete durability and structural performance. Reducing uncertainties on concrete durability analysis would be beneficial for more efficiently demonstrate the safety of LTO. It is also helpful to enhance public confidence that planned LTO of the operating fleet is safe. Given the significance of harvesting research, government funding may be needed for harvesting programs at international level.
- International cooperation and a strong involvement of several stakeholders, including governments, regulators and their technical support organizations, utilities, research organizations and decommissioning operators are vital for successful collaborative concrete harvesting and research. International cooperation shall contribute enhancing knowledge on concrete aging and its management and on concrete structures durability. Involvement of several stakeholders should foster consensus on analysis of concrete durability, assessment of structural performance adequacy and on civil structures aging management. To address

collaboration challenges among regulators, researchers, and operators, a tiered approach to information sharing should be set-up. While it is not practical to initially share broadly all information, establishing specific organizations and protocols for harvesting-related data and creating public layers for broader awareness of existing programs could enhance international collaboration and knowledge sharing.

- Industry, utilities and designers awareness that harvesting research programs, including for concrete, can benefit the industry, e.g. by supporting streamlined LTO management plans for the operating fleet (informing on potential degradations, by the implementation of potential mitigation approaches, by the value and appropriateness of field measurements, including nondestructive techniques, by enhanced concrete durability analysis) and by informing design options for operation to beyond 80 or 100 years for new designs.
- **Utilities' engagement** in concrete and civil structural components harvesting research is essential for several reasons in addition to their own intrinsic expertise:
  - they are the best placed to share field experience on concrete aging and its management to inform on research to conduct in priority and most valuable concrete samples to harvest.
  - they know, can collect and share the status of information and knowledge on the concrete history (initial characteristics and composition and any evolution with time, environment evolution during the years of operation (e.g., irradiation level, temperature, chemical environment, etc.)).
  - they are the best placed, together with decommissioning operators, to inform on feasibility and establish plans for concrete harvesting. Support from decommissioning companies in harvesting is also critical.
- A strategic vision and harvesting research framework should be developed, describing expected benefits to both society and industry, to motivate all stakeholders, including governments and plant operators, to pursue and fund concrete harvesting. This strategic vision should integrate the interests from the industry and propose mechanisms to preserve industry's interests and developed in cooperation with industry research organizations.
- It could be of interest for utilities and decommissioning companies to contribute to international sharing of information on methods for onsite concrete destructive and nondestructive testing, validation of methodologies including advanced ones, and for optimization of harvesting approaches. This could also benefit decommissioning approaches.
- NEA is well-placed to support the implementation of an international research framework on concrete harvesting involving all stakeholders, using the experience gained from more than 65 years of joint nuclear safety research projects and more particularly the experience of the NEA/SMILE project which is a first of a kind successful international collaboration on harvesting research with a focus on metal components.
- NEA joint projects frameworks are internationally recognized as being pragmatic and efficient for managing collaborative research among a range of organizations with different interests. NEA can also seek support from governments and industries with enhancing awareness of these activities and benefits of the NEA projects. A way to proceed could be to organize more discussion forums and progressively start moving forward to real collaborative harvesting and research opportunities.

- The NEA is currently developing a nuclear safety research roadmap in relation with its standing technical committees (CNRA, CSNI, NSC and NDC), reflecting the views of regulators and TSOs on nuclear safety research priorities. One of the key recommendations of the roadmap is to extend, beyond the NEA/SMILE project, international collaborative research on materials harvested from operational and shutdown plants, to include a wider range of utilities, and harvesting concrete and civil structural components. Several regulators consider that information and data from material harvesting research programs could contribute to facilitate licensing for LTO of the operating fleet to beyond 60 and 80 years by strengthening the technical bases for assessing concrete structures durability.
- The panel recommendation emphasizes the need for strong international collaboration and stakeholders support, including industry, to operate material harvesting and research. It suggests developing a dedicated collaborative framework under the NEA to establish research priorities, opportunities, and a library of available materials and research infrastructures. Such a framework would facilitate the development of collaborative programs. Additionally, establishing a research network and research platforms with complementary research capabilities would enhance the effectiveness of research efforts, providing means to establish shared harvesting and analysis approaches and cost sharing. Joint research and shared funding can yield more benefits with less money.
- Early engagement with decommissioning plants, years before they start the process, is the key to success. Collaboration is essential for funding and cooperation among various organizations. Successful examples like the Zorita harvesting effort and the NEA/SMILE project show the value of multi-organization collaboration. Challenges include fitting into decommissioning schedules and incentivizing companies to support harvesting. Promoting the benefits of harvesting to the industry is vital to gain more support, especially by demonstrating its value to the operating fleet.
- Harvesting during decommissioning activities can be challenging as it may be resource intensive e.g., the need to collect samples from areas where accessibility is limited (irradiation, complex retrieval). It may be considered intrusive if it affects decommissioning schedules. There is also the need to collect good information on material initial characteristics (composition, initial characteristics, initial mechanical stresses, presence of rebars, etc.) and on history (temperatures, irradiation, evolution of stresses, environmental conditions, evolution of any degradation, maintenance/repair, etc). Some data may not be easily reachable and sharable, and mechanisms should be developed to protect industry's interests (see the next section).
- Experts from the existing international groups addressing aging of concrete structures, e.g., the ICIC Technical Advisory Group, the NEA/CSNI WGIAGE concrete subgroup and the IAEA IGALL relevant group could be invited to provide insights regarding the definition of an international collaborative research framework and potential research programs on concrete harvesting.
- When developing a collaborative framework, and especially for each specific project, it is crucial to first understand the capabilities of all involved entities. This includes identifying who will handle concrete harvesting, who has facilities for storing materials, including irradiated ones, and who will test and analyze the materials. Additionally, there must be a clear alignment of priorities for harvesting efforts, which should be agreed upon by all parties

involved. **Funding** is another critical aspect, requiring clarity on which entities can provide financial support, and which can contribute through collaborative research. Addressing these administrative and logistic hurdles is key to ensuring the success of such efforts.

## Potential actions/recommendations

**NEA/USNRC to establish a core group to further discuss the development of an international research framework on concrete harvesting research, with considering the workshop guidance.**

The core group would work in relation with the CSNI/WGIAGE and the ICIC to collect insights from these groups.

The core group would be commissioned to develop a strategic plan by the end of 2025 or early 2026 for the framework including high-level research objectives (priority topics to address) and framework objectives (e.g., community building, mechanisms for data and information sharing, etc.) as was done for the NEA Framework for Irradiation Experiments (FIDES-II) and is currently being done for the Framework for Advanced Thermal-Hydraulic Experiment for Nuclear Analysis and safety (ATHENA). The core group would also be commissioned to develop a provisional framework development plan, e.g. number of projects, integration of harvesting operators, of research facilities, etc.

## Data collection, accessibility and information sharing

- Consistency should be searched in information and data collection to build a useful database on aged concrete samples and structural components, e.g. rebar, tendon, reactor support steel. Nature of data/information to collect, e.g., on samples location in civil structures, on characteristics evolution with time, on operational history, surveillance capsule data, drawings and material specifications should be driven by analysis needs. It would be useful to discuss and agree on key data/information needed for generating reliable results for analysis and modeling.
- It could be of interest to consider commonalities between information and data valuable for metal harvesting and for concrete harvesting. For instance, plant operating history and neutronics data would be of common interest for metal and concrete harvesting. There are common challenges in data/information collection for making metal and concrete harvesting valuable.
- Part of the data/information to collect can be widely open while part of it can be sensitive data/information which should be protected to respect the interests of the utility providing them. In the event sensitive data/information is to be shared in a collaborative framework, protection mechanisms should be in place to avoid dissemination beyond group(s) authorized by the information/data provider. Data/information may be classified as public, restricted to members or even to subsets of members in a collaborative framework. For instance, data is restricted to project members in NEA projects during a non-disclosure period set by the members. Following the non-disclosure period, the data can be made

available to NEA members organizations upon request and on a single-user basis. This is discussed and decided by the project members. In the NEA/SMILE project, Ringhals and Oskarshamn utilities do not share data/information they consider sensitive. Dissemination of data/information under export control is made in compliance with export control licenses. The project is currently working out how the data will be stored, maintained and shared in the future once the project is over. The NEA/SMILE project experience can be used for management of data/information in a collaborative framework on concrete harvesting.

- IGRDM and ICIC international groups are other examples having experience in data/information management and sharing. Utilities sensitive data/information are not made public. This is a condition for them making data/information available to the members. Technical presentations and reports are restricted to members as long as data and analysis are not considered fully valid by the group. Publications in journals are only done when data and modeling are considered fully valid by members. If needed and of interest, sensitive data/information can also be anonymous (e.g., not referring to plant name).
- The key point is to find a balance between data sharing opportunities and ensuring utilities agree to provide access to data/information of interest and support harvesting actions. Technically, it is crucial to consider operational history and characteristics of diverse material in durability analyses. Access to materials, historical data, and shared protocols is essential for comprehensive research, requiring detailed discussions and agreements with utilities.

## Potential actions/recommendations

**The core group who will work on the collaborative framework development for concrete harvesting should consider:**

- **leading a task to agree on key data/information/results to collect for comprehensive analysis and modeling of concrete aging, durability, and implications related to structural performance,**
- **developing mechanisms to protect sensitive information/data provided by utilities, using the experience gained from ongoing collaborative initiatives, such as the NEA/SMILE project, the ICIC, and the IGRDM.**

## Key Takeaways

### **Urgency to further consider opportunities for harvesting and performing collaborative research on aged concrete and structural components**

Several NPPs have recently been shut down worldwide (retirement after long-term operation or closure) and are being decommissioned, and some other NPPs are highly likely to be shut down and decommissioned in future, offering new, unique opportunities for harvesting concrete and structural components aged under actual operating conditions, including concrete with long operating histories, corresponding to up to 40 years and beyond of operation, with variable environmental conditions.

It is becoming urgent not to miss these opportunities and to organize international collaborative research on concrete harvesting when LTO of the operating fleet to beyond 60 or 80 years, as well as possible deployment of advanced designs with planned 80 or 100 years of operation, are considered in several countries.

Harvesting offers a unique opportunity to examine and test concrete aged under real operating conditions and alleviate reserves and uncertainties related to the use of accelerated aging tests results such as results obtained from concrete irradiated under high irradiation flux in research reactors to assess concrete durability. Reducing uncertainties on concrete durability analysis would certainly be beneficial for demonstrating the safety of LTO to beyond already licensed extensions. It also can enhance public confidence that planned LTO of the operating fleet is safe.

Due to their modest complexity and cost, irradiated concrete harvesting efforts have been limited so far, with some notable exceptions (e.g., at the Zorita NPP, and Hamaoka NPP), and though plans and opportunities for further harvesting concrete in decommissioned plants are being discussed, their issue remain uncertain with reluctance of stakeholders related to their cost and complexity.

### **Harvesting can yield significant safety benefits for the nuclear sector and requires diverse, strong stakeholder involvement**

Harvesting concrete in plants is unparalleled to provide prototypical materials (when compared to artificially aged concrete in laboratories or concrete irradiated in research reactors) for identifying and characterizing aging phenomena which can potentially affect the durability of concrete structures, and which must be considered in priority in durability analysis. It would also provide data to validate computational models developed to assess the durability of concrete structures for different aging mechanisms and their effects under various environmental conditions. It would also contribute to optimizing aging management plans and measures with assessing the efficiency of any surveillance, maintenance, mitigation, reparation operations.

However, several challenging aspects exist, including complex and delicate onsite retrieval operations that can affect decommissioning schedules, transporting harvested radiological materials to external research laboratories, and marshaling the resources needed to assemble detailed information on harvested concrete. Recognizing the challenges and cost, harvesting requires strong involvement and close cooperation of several stakeholders (i.e., governments, regulators, researchers, utilities, decommissioning companies).

The NEA is currently establishing a nuclear safety research roadmap reflecting high-level views of regulators on nuclear safety priority research topics. It is recommended in this roadmap that collaborative efforts should be extended beyond the existing NEA/SMILE joint project to harvest worldwide aged materials, including concrete and structural components (not currently addressed in SMILE), from operational and shutdown nuclear power plants for future research and evaluation and that age-related degradation models be developed that are capable of realistically representing component and structures reliability changes during long-term operation to support safety or risk assessment activities.

Workshop participants highlighted the challenge to get support and involvement from decommissioning companies for harvesting activities, particularly when there is no direct benefit for them. Utilities may be reluctant to share some sensitive information which could challenge their commercial interest. The benefits of harvesting research, including for concrete, should be further considered by utilities from the perspective of prolonged profitability and optimization of NPPs LTO management operations. Mechanisms for protecting sensitive information provided by utilities should be in place, where needed, to fluidify information sharing when needed for efficient collaborative research.

Knowledge gained is also expected to be of value for designers of new and advanced reactors with planned operating lifetime of 80 years and beyond.

All parties engaged in the development of the nuclear sector should be made more aware of the potential benefits from harvesting and related research both for operating and advanced reactors and funding should be sought from a wide range of stakeholders for harvesting programs at international level.

### **The high-complexity and cost of concrete harvesting, and related research activities make them prime candidates for collaboration and cost sharing**

The OECD/NEA SMILE joint project conducted by Studsvik in Sweden provides a first of a kind large collaborative effort around aged metal material harvested in several decommissioning Swedish plants. A similar framework could be established for concrete harvesting research, possibly involving utilities, regulators and research laboratories in several countries. In Sweden, utilities, decommissioning companies, Studsvik as research laboratory and the regulator SSM have all worked jointly for the project development, with the support of organizations from several other countries. This project offers a unique opportunity for cooperation among different stakeholders (e.g., regulators, utilities, research organizations, decommissioning companies) to address challenges related to harvesting material on site, such as performing onsite measurements; collecting historical information and data on harvested material; calculating environmental loads on materials during their service life; and collecting and preparing the most prototypic samples for further characterization and testing. It is also a unique opportunity to share experience and good practices and optimize characterization and testing methods.

Benefits of collaborative research associated with harvesting are numerous with some of the high-level benefits being information sharing, sharing harvesting and research costs, sharing material sources, sharing best practices in samples preparation, testing and characterization, establishing

commonly shared knowledge base for characterization of the aging effects, development of models and their validation.

Workshop participants highlighted that NEA is well-placed to support the implementation of an international research framework on concrete harvesting involving all stakeholders, using the experience gained from the NEA/SMILE project. NEA can also contribute to seek support from governments and industries through its Technical Standing Committees. Participants recommended to continue discussing, under the NEA auspices, potentialities for an international collaborative framework on concrete and structural components harvesting and research in the interest of all stakeholders of the nuclear sector.

**Prioritizing concrete harvesting and research for maximizing benefits and addressing the widest range of interest is required**

Participants agreed on the need to engage further in research prioritization and identification of opportunities for collaborative research on harvested concrete. A first comprehensive prioritization process should be developed based on the shared information and discussions gathered through the workshop. Though prioritizing harvesting and research on harvested concrete may appear challenging, the following should be considered:

- identifying key aging phenomena to address in priority which are likely to affect concrete durability and structural performance, and what uncertainties would be addressed by the harvesting research that supplements laboratory work,
- identifying key modeling and analysis needs,
- identifying concrete samples and structural components which would be beneficial to harvest in priority with consideration of harvesting feasibility and potential to share data, relevance for several concrete structures, feasibility of information collection and sharing on concrete and steel composition, characteristics, history of environmental conditions, location of harvesting samples, on the relevant structures, etc.,
- performing some onsite nondestructive testing without impacting decommissioning activities,
- identifying measurements to perform in priority and developing a research plan to inform concrete durability and structural performance analysis and modeling, monitoring and aging management of structures.

As harvesting and collecting information and data from utilities or licensees can be time-consuming and resource intensive, it is crucial to prioritize harvesting and clearly identify samples expected to provide the most valuable data. The data should be scalable for structure analysis.

Library/Database - Efforts should be undertaken to develop a library and database of physically harvested concrete samples and structural components of interest, available for collaborative research. The library could include irradiated and non-irradiated reference samples/components for comparison. Samples/components collected during repair or modification operations in operating plants could also be considered, if relevant. Such a database would be useful to prioritize research on physically available samples/components.

The information related to ongoing/planned concrete harvesting research activities and opportunities at international level should be collected, periodically updated and shared timely to identify collaborative research potentials. A further step could be to identify harvesting opportunities, develop harvesting and research plans, prioritize of concrete and structural components with the highest potential benefits.

Matching the research priorities to needed material conditions (e.g., concrete types, service temperature, irradiation, environmental conditions) and further to the available components from decommissioning plants should help focus resources on identifying and harvesting those samples with the most value.

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## Appendix A: Workshop Agenda

### Hybrid Workshop on International Concrete Harvesting Agenda

4<sup>th</sup> October 2024, NRC Headquarters, TWFN Auditorium, Rockville MD, US (and video meeting)

8:30-17:00 (times are in EDT (GMT-4.0))

Start	End	Activity / Item	Name
9:00	9:05	Welcome and Introduction	NRC Madhumita Sircar
9:05	9:10	Opening remarks	NRC Michele Sampson
9:10	9:15	Opening remarks	NEA John Nakoski (Remote)
9:15	9:25	<a href="#">P1 Harvesting Strategy, Opportunities and International Collaboration</a>	NRC Rob TREGONING
9:25	9:35	<a href="#">P2 Overview : Concrete Harvesting and Research</a>	NRC Madhumita SIRCAR
9:35	9:55	<a href="#">P3 LWRS Perspective on Concrete Harvesting Needs and Opportunities</a>	ORNL Yann LE PAPE
9:55	10:05	<a href="#">P4 EPRI Research on Concrete Harvesting</a>	EPRI Samuel JOHNSON
10:05	10:25	<a href="#">P5 Nuclear Materials Harvesting and Beyond: Materials Acquisition, Sample Library, and Concrete-Related Research through NSUF</a>	NSUF Rongjie SONG
<b>10:25</b>	<b>10:40</b>	<b>Break</b>	
10:40	11:00	<a href="#">P6 Concrete Harvesting activities/plans and related priority research topics in Japan</a>	NRA Masayoshi Kojima
11:00	11:20	<a href="#">P7 Concrete Harvesting activities/plans and related priority research topics in Czechia</a>	CVUT Petr STEMBERK
11:20	11:40	<a href="#">P8 Concrete Harvesting and Related Research</a>	CNL Shahzma JAFFER

Start	End	Activity / Item	Name
11:40	12:00	P9 Concrete Harvesting plans for EDF in France	EDF Benoit MASSON (Remote)
		<a href="#">P10 IRSN Views on Concrete Harvesting</a>	IRSN Christophe MARQUIE
<b>12:00</b>	<b>13:30</b>	<b>Lunch Break</b>	
13:30	14:00	<b>Short presentations</b>	
		<a href="#">P11 Ringhals NPP Potential harvesting of irradiated concrete</a>	Vattenfall Johanna SPALS (Remote)
		<a href="#">P12 Concrete Harvesting plans in Finland</a>	VTT Miguel FERREIRA(Remote)
		<a href="#">P13 Concrete Harvesting plans in Spain, ZORITA NPP concrete Project</a>	IETcc-CSIC Javier SANCHEZ (Remote)
		<a href="#">P14 Concrete Harvesting activities in the Netherlands</a>	NRG Srijan KUMAR (Remote)
		<a href="#">P15 Vision for participating in concrete harvesting initiative to support independent research on qualification of concrete for long term operation of nuclear facilities in South Africa</a>	NNR Sifiso Nhleko (Remote)
14:00	15:00	Panel1  Technical discussion: priority research topics on harvested concrete, worldwide overview and discussion on priorities for harvesting and research  Moderator NRC Madhumita SIRCAR / Jose PIRES	<ul style="list-style-type: none"> <li>• ORNL Yann LEPAPE</li> <li>• IRSN Christophe MARQUIE</li> <li>• University of Tokyo Ippei MARUYAMA</li> <li>• CVUT Petr STEMBERK</li> <li>• AtkinsRéalis Julia TCHERNER</li> </ul>
<b>15:00</b>	<b>15:30</b>	<b>Break</b>	

Start	End	Activity / Item	Name
15:30	16:30	<p>Panel 2</p> <p>Strategic discussion: potentials for future international cooperation</p> <p>Moderator NEA Keiko CHITOSE</p>	<ul style="list-style-type: none"> <li>• ORNL Elena TAJUELO-RODRIGUEZ</li> <li>• EPRI Samuel JOHNSON</li> <li>• Chubu Takashi OSAKI</li> <li>• University of Tokyo Ippei MARUYAMA</li> <li>• IRSN Fabienne RIBEIRO</li> <li>• NRC Jeff POEHLER</li> <li>• NEA Didier JACQUEMAIN (Remote)</li> </ul>
16:30	16:55	Wrap-up: Key workshop takeaways, Next steps	<p>NRC Jose PIRES</p> <p>NEA Didier JACQUEMAIN(Remote)</p>
16:55	17:00	Closing remarks	NRC

## Appendix B: Workshop Participants

First Name	Last Name	Country	Organization
Maha	ABDALLAH	CANADA	CNSC
Cedric	ANDROUET	CANADA	CNSC
Shahzma	JAFFER	CANADA	Canadian Nuclear Laboratories
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Antonin	KRIZ	CZECHIA	State Office for Nuclear Safety
Kamil	SOBEK	CZECHIA	Research Centre Rez
Petr	STEMBERK	CZECHIA	Czech Technical University in Prague
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David	BOUHJITI	FRANCE	IRSN
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Veronique	DEWYNTER	FRANCE	CEA
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Benoit	MASSON	FRANCE	EDF
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Ippei	MARUYAMA	JAPAN	University of Tokyo, Tokyo
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Takumi	TERACHI	JAPAN	INSS
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Wonderboy	Gubela	SOUTH AFRICA	National Nuclear Regulator
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Dale	Deliste	UNITED STATES	USNRC
Carolyn	Fairbanks	UNITED STATES	USNRC
Amitava	GHOSH	UNITED STATES	USNRC
Frank	Gift	UNITED STATES	EPRI
Amy	HULL	UNITED STATES	USNRC
Samuel	JOHNSON	UNITED STATES	EPRI
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George	WANG	UNITED STATES	USNRC
Zuhan	XI	UNITED STATES	USNRC
Florencia	Renteria		Women in Nuclear Young Generation

## Appendix C: Past, planned and potential concrete harvesting activities

Country	Plant/Research reactor	Utility	Design	Size (MWe)	Years in operation	Shutdown Date	Decommissioning timeline, concrete harvesting plans or opportunities	Involved Organizations	Potential Concrete Components	
									Summary of Components Previously Discussed	Notes
Canada	NRU	CNL (AECL)	Test reactor	135 MWT	61	2018	Potential to harvest shield plugs	CNL, CNSC	Shield plugs	
	NPD	CNL (AECL)	Test reactor	20	25	1987	Cores from the reactor vault available and analyzed	CNL, CNSC	Reactor vault	
	Gentilly-2	Hydro Quebec	CANDU-6	675	30	2012	Concrete containment building harvesting completed on national basis, as well as field and laboratory testing. Larger international collaboration was discussed till 2020 (NEA Harvest project) but was dropped.	Hydro Quebec, CNL, CNSC, COG	Concrete containment building	Field testing on rebars and post-tensioned cables suggest AAR. Laboratory testing on concrete cores suggests carbonation and chloride contamination are not issues.
	Pickering A	Ontario Power Generation	CANDU	550	unit 1: 53 unit 2: 36 unit 3: 36 unit 4: 51	unit 1: 2024 unit 2: 2007 unit 3: 2008 unit 4: 2024	No current plans for concrete harvesting, opportunities to discuss with stakeholders	Ontario Power Generation, CNL, CNSC, COG	Potential components to be discussed	Unit 1 and unit 4 have just been shutdown
	Others								CNL has harvested concrete cores from a dry-fuel storage canister (held fuel for 23 years and was outside for 44 years).	Potential to Harvest in the Future: Several reactors are or will be undergoing decommissioning
France	Fessenheim 1/2	EDF	PWR/CP0	900	43	2020	Harvesting plans under discussion, some harvesting feasibility studies ongoing	EDF	Pressurizer prestressed anchorage, anchors, concrete from containment behind the steel liner, biological shield concrete and water stop seals with interest on ASR and DEF topics	Potential harvesting plans at Fessenheim to be re-discussed in 2025 with results of feasibility studies. EDF also envision to harvest during repairs, modifications in operating plants.
Germany	Numerous plants either in decommissioning or shutting down soon. No known plans for concrete harvesting. Some activities in collaboration with Czechia (see below). Information to be completed later.									
	Greifswald	VE Kombinat Kernkraftwerke "Bruno Leuschner"	VVER 440 (8 units)	440	max. 17	1990	Decommissioning planned to be completed in 2028	CTU, CVR, EWN Entsorgungswerk für Nuklearanlagen GmbH	Large piece of a concrete biological shield transported to CVR (6 tons)	Drilling and analyses plans to be defined
Japan	Numerous plants either in decommissioning or shutting down. No known plans for concrete harvesting. Information to be completed later.									
	Hamaoka 1	Chubu	BWR-4	540	33	2009	Core samples from 11 locations were analysed for a new evaluation method. The core samples collection from other units (Unit 2, 3 and 5) was also conducted for database extension.	CRIEPI, Chubu	Outer wall of containment vessel, RPV pedestal, main steam tunnel, wall, reactor building inner/outer walls, spent fuel pool wall, foundation mat.	Research for 1) development of concrete database, 2) verification of non-destructive testing method, 3) verification of evaluation method by numerical analysis
	Hamaoka 2	Chubu	BWR-4	840	31	2009	Core samples from 4 locations were analysed for a new evaluation method. The core samples collection from other unit (1, 3 and 5) was also conducted for database extension.	CRIEPI, Chubu	Outer wall of containment vessel, RPV pedestal, reactor building inner walls	Research for 1) development of concrete database, 2) verification of non-destructive testing method, 3) verification of evaluation method by numerical analysis
	PWR plants	TBD	TBD	TBD	TBD	TBD	Harvesting including concrete under discussion	TBD	Potential components to be discussed	

Country	Plant/Research reactor	Utility	Design	Size (MWe)	Years in operation	Shutdown Date	Decommissioning timeline, concrete harvesting plans or opportunities	Involved Organizations	Potential Concrete Components		
									Summary of Components Previously Discussed	Notes	
Korea	Kori 1	KHNP	W 2-loop	576	40	2017	Decommissioning plan approved at the end of 2024, dismantling of unirradiated structures will begin in 2025, dismantling of irradiated structures planned in 2030	KHNP, KAERI, EPRI	Bioshield		
The Netherlands	HFR	JRC, NRG	Tank-in-pool research reactor	50 MW	63	Operating	Concrete cores drilled out in 1985, 2009, 2010, 2017	JRC/NRG	Very high-density concrete. Reactor pool structure (to investigate the impact of ASR)		
Slovak Republic	EBO V1 Units 1 and 2	Electrostation Bohunice	VVER 440/230	440	28	unit 1: 2006 unit 2: 2008	Decommissioning till 2027, concrete harvesting opportunities discussed with CVR	CVR and CTU	To be discussed		
South Africa	Koeberg Unit 1 and 2	Eskom	3-loop Westinghouse/Framatome	900	40.5 Unit 1 and 39.5 Unit 2		Currently undergoing licence renewal/LTO for additional operation period of 20 yrs	NNR Centre for Nuclear Safety and Security (CNSS), Eskom and other national laboratories	Containment building walls and dome	The plan is to characterize the long term creep behaviour of the containment concrete	
Spain	Zorita	Union Fenosa	W1-loop	160	38 (26.36 EFPY)	2006	Concrete harvesting planned or on-going	CEIDEN, IETcc-CSIC, CSN, Endesa Geberacion, ENRESA, Iberdrola, Naturgy	Irradiated concrete: biological shielding (24 samples), SFP (4 samples), hot leg (2 samples), exterior of containment building (4 samples) - Unirradiated concrete: 59 samples from the cubicle CH1-level 611, exterior of containment building, mobile parts of the transfer channel, middle and exterior of the biological shielding	Analyses of 20 unirradiated concrete cores on-going (porosity, microscopy, carbonation depth, ATD, XRD, tomography, petrography, water porosity, resistivity, ultrasonic velocity, Schmidt hammer)	
Sweden	Oskarshamn 1	OKG	BWR	473	45 (28.2 EFPY)	2017	Decommissioning and harvesting of metal components on-going, opportunities for concrete harvesting being discussed	OKG, CVR, CTU	To be discussed	Presented by CVR, CTU at the workshop	
	Oskarshamn 2		BWR	638	39 (31.7 EFPY)	2013	Decommissioning and harvesting of metal components on-going, opportunities for concrete harvesting being discussed	OKG, CVR, CTU	To be discussed		
	Ringhals 1	Vattenfall	BWR (ABB-1)	883	44 (31.7 EFPY)	2020	No plans for concrete harvesting				
	Ringhals 2		PWR 3-loop	900	44 (29.7 EFPY)	2019	Decommissioning and harvesting of metal components on-going, concrete core from biological shielding drilled, opportunities for concrete harvesting to be further discussed	Vattenfall/Ringhals, ORNL	Concrete biological shielding	Plans to characterize concrete samples from end 2024. Calculations showed that the exposure to neutron fluence was above the "damaging threshold" of $10^{19}$ n/cm <sup>2</sup> at a depth of 5 cm.	
Switzerland	Muhleberg	BKW Energie	BWR-4/Mk-1	355	47	2019	Decommissioning on-going, planned to be completed by 2030, information on concrete harvesting to be checked	ENSI, BKW Energie			
U.S.	Numerous plants either in decommissioning or shutting down. No known plans for concrete harvesting. Information to be completed later.										
	SONGS 2	Southern California Edison (SCE)	CE 2-loop	1070	31	2013	3 unirradiated concrete specimens drilled from outside of steam generator room in 2021; no future plans for harvesting irradiated concrete	ORNL, SCE, EPRI, USNRC	Unirradiated concrete specimens drilled from outside of steam generator room	Research done to establish methods to harvest and analyse harvested concrete	