NRC-NIST Cables Project

NRC-NIST Agreement

Assessment of Condition Monitoring Techniques for Electrical Cables

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NRC PM: Darrell Murdock

NIST
National Institute of Standards and Technology
U.S. Department of Commerce

NRC-NIST Cable Project

Objectives

- Evaluate the effectiveness of commonly used cable condition monitoring for specific insulation materials
- Assess qualified life predictions to 50 years, 60 years and 80 years of operation
- Enhance the understanding of condition-based environmental qualification methodology

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NRC-NIST Cable Project

NRC Agreement Tasks

1. Acquisition of materials
2. Develop a test plan
3. Establish baseline values for cable properties using condition monitoring methods, as described in the test plan
4. Simulated operational aging and condition monitoring testing
5. Simulated accident and condition monitoring testing
6. Develop NUREG/CR

Slide 3

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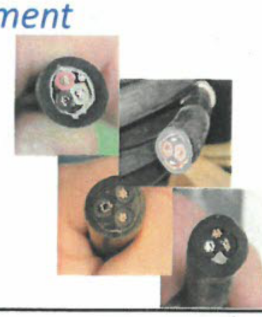
Acquisition of Materials

- Representative polymer insulation and manufacturers
- New cables: current year and vintage
- In-service cables: Zion and Crystal River NPPs
  - Some active and some not active
- *Cables selected for long-term aging experiment*
  - *'Vintage'*
    - *Rockbestos: 1980, XLP/CSPE (3C, 16 AWG)*
    - *Anaconda: ??, EPR/CSPE (2C, 14WG)*
    - *Okonite: 1985, EPR/CPE (3C, 14AWG)*
  - *In-service*
    - *Zion (non-active): BIW, EPR (3C, 16 AWG)*



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Develop a Test Plan

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- Selection of Condition Monitoring Tests
- Simulated Operational Aging Experiment
  - Choice of Radiation Facility
  - Justification of Accelerated Aging Conditions
  - Development of Environmental Chambers
- Choice of Cables to Study
- Loss of Coolant Accident Conditions

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Condition Monitoring Baseline Measurements

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- Mechanical Properties
- Elongation At Break (Tensile)
- Indenter (Modulus)
- Electrical Properties
- Frequency Domain Reflectometry (modification for short cable lengths)
  - Line Resonance Analysis
  - CHAR package
- Tan Delta (Dissipation Factor)
- Insulation Resistance
- Dielectric Spectroscopy (with EPRI)
- Chemical Properties
- Oxidation Induction Time/Temperature
- Thermal Gravimetric Analysis
- Fourier Transform Infrared Spectroscopy
- Raman Spectroscopy

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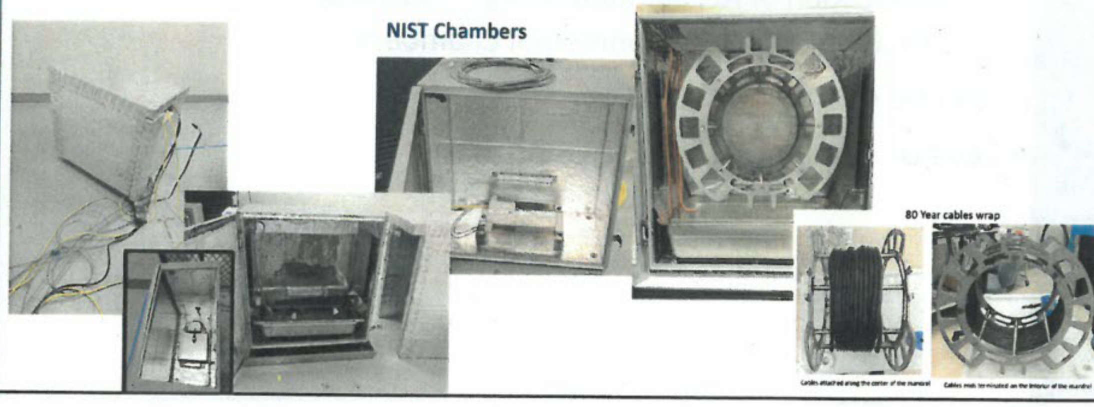
Simulated Operational Aging

- Accelerated aging to simulate normal operational aging in mild and harsh environments
  - Simulate 50, 60 and 80 years of operation
- Perform condition monitoring testing at regular intervals



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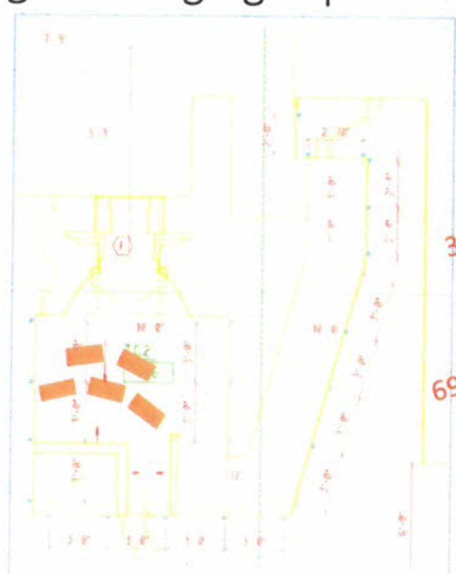
NIST-Sandia Agreement

Long Term Aging Experiment- Sandia



16-month irradiation experiment

22-month total

(GIF maintenance\mandrel shipment)

30 Gray/h: 81 C, 60 % RH; 81 C, 0 % RH

69 Gray/h: 55 C, 0 % RH; 81 C, 60 % RH; 81 C, 0 % RH

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Simulated Accident

- Cables from operational aging experiment exposed to accident conditions
- IEEE 323-1974 (PWR Generic Profile)
  - Cables under accident conditions - temperature, pressure, humidity, radiation, chemical/steam spray
  - Cables connected to power carts and excited with voltage
  - Condition monitoring techniques will be evaluated during and after the accident (post-accident period)
    - Visual inspection, dielectric withstand, and insulation resistance
  - Radiation Dose Rates: 0.5 – 1 MRad/hr
- IEEE 383 (Post-Design Based Event Testing)

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Develop NUREG/CR

- Create a publicly available document delineating the assessment of condition monitoring techniques and confirming the adequacy of tests

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Government of Canada Gouvernement du Canada

Canada

Evaluating Structures, Systems & Components from Decommissioned/Decommissioning Nuclear Facilities in Canada

Presented at the Nuclear Regulatory Commission Harvesting Workshop - March 7-8, 2017

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Désiré Ndomba – CNSC Technical Specialist

Karen Huynh – AECL Federal S&T Manager

e-Docs #5196600

CANADA 150

Outline

- Who we are
  - ➢ Canadian Nuclear Safety Commission (CNSC)
  - ➢ Atomic Energy of Canada Limited (AECL)
- Canadian Harvesting Projects & Sources
  - ➢ Nuclear Power Plants and Research Reactors
    - ✓ Nuclear Power Demonstration (NPD) Generating Station
    - ✓ Gentilly-2 Nuclear Generating Station
    - ✓ Nuclear Research Universal (NRU) Reactor
- Summary

Canadian Nuclear Safety Commission

Canada's nuclear regulator for over 70 years

- Canadian Nuclear Safety Commission (CNSC):
  - Established on May 2000 under the Nuclear Safety Control Act (NSCA);
  - Replaced the Atomic Energy Control Board, which was established in 1946 under the Atomic Energy Control Act;

- CNSC's Mission:
  - Regulate the use of nuclear energy and materials to protect the health, safety and security of Canadians and the environment;
  - Implement Canada's international commitments on the peaceful use of nuclear energy;
  - Disseminate objective scientific, technical and regulatory information to the public;

Atomic Energy of Canada Limited

- AECL is a federal Crown corporation responsible for managing Canada's radioactive waste liabilities and enabling nuclear science and technology
- AECL delivers their mandate through a contractual arrangement with Canadian National Energy Alliance (CNEA) for the management and operation of Canadian Nuclear Laboratories (CNL) under a Government-owned, Contractor-operated (GoCo) model
- AECL oversees the delivery of the Federal Nuclear Science and Technology Work Plan in order to support the Government's priorities and core responsibilities in areas such as nuclear safety, security, energy, health and the environment
- CNL is responsible for the management and operation of the Laboratories, and is the licensee with access rights to AECL's assets and Intellectual Property (IP)

Harvesting Materials in Canada

Why is Harvesting Important?

- The nuclear power plants (NPPs) that are currently in operation were generally designed and built with conservative principles, and in many cases have significant remaining safety margins. Typically, NPPs were designed with the intent of operating for up to 30 years. This is now changing to approximately 60 years.
- Harvesting materials from decommissioned or decommissioning facilities is intended to assess the remaining safety margins for the physical condition of structures, systems and components (SSCs) in NPPs through testing to verify and/or validate the technical feasibility of Long Term Operation (LTO).

Canadian Harvesting Projects

- Canada currently has harvesting projects in 2 areas from different facilities
  - Analysis of Degradation Mechanisms of Cables
  - Understanding Degradation of Concrete

Nuclear Power Demonstration Plant (NPD)

- The 20 MW Nuclear Power Demonstration Plant (NPD) was Canada's first nuclear power reactor to supply electricity to Ontario Hydro's electrical distribution grid
- The reactor permanently shutdown in 1988 after 25 years of service
  - CNSC sponsored a research project with Ontario Hydro in 1991 on: "Cable insulation degradation of the 20 MW Nuclear Power Demonstration Plant"
  - AECL currently has a research project to analyze concrete samples from NPD

Understanding the Degradation of Concrete

Background

- This project will address gaps in the domestic knowledge of concrete degradation in nuclear power plants and will support regulatory decisions for long-term reactor operations of domestic utilities and new reactor technologies, such as SMRs.

Project Objective

- To assess concrete core samples for degradation

Status

- Year one of a three year project
- Received 7 concrete cores from Nuclear Power Demonstration (NPD) reactor
- Identified test techniques to assess for degradation

Other opportunities

- Concrete from other decommissioned reactors in Canada such as Gentilly-2, Douglas Point and AECL's whiteshell reactor in Pinawa, Manitoba

Gentilly-2 Nuclear Power Plant

- Gentilly-2 (G2) Nuclear Power Plant (NPP) is a CANDU-6 675 Mwe nuclear reactor which was permanently shutdown in 2012 after 29 years of service
  - CNSC & AECL/CNL are currently conducting a research project on the Analysis of Degradation Mechanisms of Cable Insulation due to Ageing in a Decommissioned Nuclear Power Plant

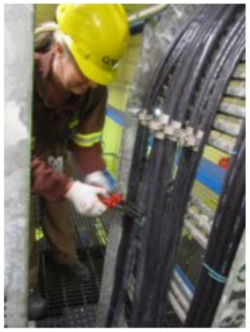
Cable Harvesting Project from G2

Background

- Material properties of cables aged in real time and real operating conditions can be significantly different from the properties received by studying samples aged in laboratory and assumed in codes and standards.

Project Objective

- Assess current cable degradation resulting from thermal and radiation ageing
- Validate environmental qualification work



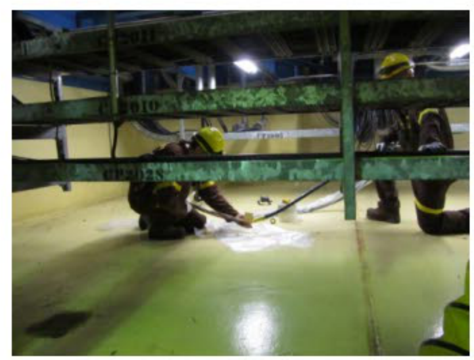
Status

- Reviewed environmental conditions and selected cables to be harvested from Hydro Quebec/Gentilly-2 reactor
- CNSC & AECL/CNL staff have recently witnessed the removal of cable samples from the G-2 NPP
- Samples will be retrieved and tested to improve cable ageing test parameters used to assess cable condition

Cable Harvesting Project from G2 (cont'd)

Challenges

- There were several challenges associated with the cable harvesting project at G2:
  - removal of material samples from a decommissioned NPP is neither a compliance nor licensing activity for licensees;
  - accessibility of analysis and testing records (data, samples, etc.)
  - inaccessibility or contamination of materials to be removed
  - cost related to carry out research activity on these materials.



National Research Universal (NRU) Reactor

- NRU is a 135MWt nuclear research reactor built in the Chalk River Laboratories, Ontario with first criticality achieved on November 3, 1957.
- The NRU reactor has three purposes
  - Supplier of industrial and medical radioisotopes used for the diagnosis and treatment of life-threatening diseases;
  - A major Canadian facility for neutron physics research; and
  - Research and development support for CANDU® power reactors.
- After 5 decades of service, the NRU reactor will shut down permanently in March 2018, after ~270k hours operation.
- The NRU reactor contains a vast array of materials and components including
  - structural materials (such as steels and other nickel bearing alloys, zirconium alloys, aluminum, concrete) and welded joints
  - a thermal graphite column
  - equipment (including pumps)
  - graphite seals
  - electrical cables
  - thermocouples

304 SS, ~1.6 dpa, 35 ^{o}C, ~3.4x10^{26} n/m^2 (E<0.625 eV)

Harvest Material from National Research Universal (NRU) Reactor

Project Objective

- Create an inventory of irradiated materials which can be harvested from the decommissioned NRU reactor
- The inventory will be used to assess irradiation damage on the performance of in-core materials and components

Advantages of Harvesting Materials from NRU

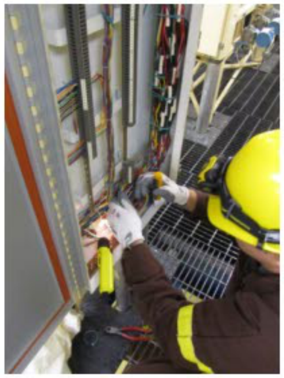
- Assess the effects of irradiation on the performance and degradation of a variety of materials;
  - wide range of temperature, flux and neutron spectrum
  - irradiation times on the order of power reactor lifetimes
  - the combination of operating conditions and exposure is not always easily or economically obtainable in test programs
- Collaborate with various partners throughout the international nuclear industry who also wish to characterize the effects of irradiation on materials
- Provide information to decommissioning groups interested in the radionuclide inventory of the decommissioned reactor.

Status

- One year project that will start on April 1, 2017

Summary

- Understanding ageing degradation is an important aspect to ensure nuclear safety as nuclear power plants age
- R&D behind SSC material life management is needed to ensure the safe and reliable operation of NPPs
- Several nuclear facilities in Canada exist for potential harvesting of Structures, Systems & Components. Examples include:
  - Nuclear Power Demonstration (NPD) Facility
  - Gentilly-2 (G2)
  - National Research Universal Reactor (NRU)
  - Douglas Point
  - AECL's Whiteshell Reactor



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Questions

Thank you!

Review of Past Reactor Pressure Vessels Test Programs and Perspective for Long Term Operation

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Ex-Plant Materials Harvesting Workshop
USNRC, Washington, March 7–8, 2017

Outline

Part I : Past test programs analysis

- Focus on RPV materials (excl. stainless steel cladding, internals, vessel concrete containment, …)
- Literature survey of test programs on decommissioned RPVs
  - 2 PWRs + 2 VVER-440 + 1 PWR and 1 Magnox gas-cooled reactor
  - Brief description of main outcome and limitations

Part II : Discussion (assuming that we are convinced of the benefits of such a test program via vessel sampling)

- Approach / criteria for selection
- Potential issues of interest
- Organizational and financial aspects
- Perspective for the future

Overview of Investigated RPVs

reactor	location	type (electrical power)	start	shutdown	sampling/ testing
BR3 (YR)	Belgium	PWR (11 MWe)	1963	1987	~1995–1999
Chooz-A	France	PWR (305 MWe)	1967	1991	~1995–1999
Greifswald-1 to 4	Germany	VVER-440 (408 MWe)	1974 -1979	1990	~2004–2012
Novovoronesh-1	Russia	VVER-440 (408 MWe)	1964	1984	~1993–2000
Gundremmingen-A	Germany	BWR (237 MWe)	1966	1977	~1988–1992
Trawsfynydd	UK	Magnox (195 MWe)	1965	1991	~1996–2002

- **PWR** (BR3 and Chooz-A)
- **VVER-440** (Greifswald and Novovoronesh)
- **BWR** (Gundremmingen)
- **Magnox gas-cooled** (Trawsfynydd)

Overview of Investigated RPVs

reactor	condition	T_{irrad} (°C)	materials	Φ_{max} (10^{19} n/cm^2, E>1MeV)	composition Cu/Ni/P (%)	data sets
BR3 (PWR)	IAR	260	Ni-mod A302B	4	0.2/0.6/0.02	single
Chooz-A (PWR)	I	255-265	1.2MD07 (A336)	2	0.1/0.6/0.02	multiple through thickness
Greifswald-1 to 4* (VVER-440)	I, IA, IAR, IARA	255	10KhMFT	2	0.15/0.3/0.04	multiple through thickness
Novovoronesh-1 (VVER-440)	I, IA	250 (↘228)	15Kh2MFA	1.4	0.15/0.1/0.03	single
Gundremmingen-A (BWR)	I	284-288	20NiMoCr26 (A 336)	0.3	0.2/0.5/0.01	multiple through thickness
Trawsfynydd (Magnox–gas cooled)	I	190	manual SA weld	0.2	0.26/0.1/0.04	mixture

Legend : I = as-irradiated ; IA = I + annealing ; IAR = IA + re-irradiation ; IARA = IAR + annealing
** No relation between units 1 to 4 and I, IA, IAR, IARA*

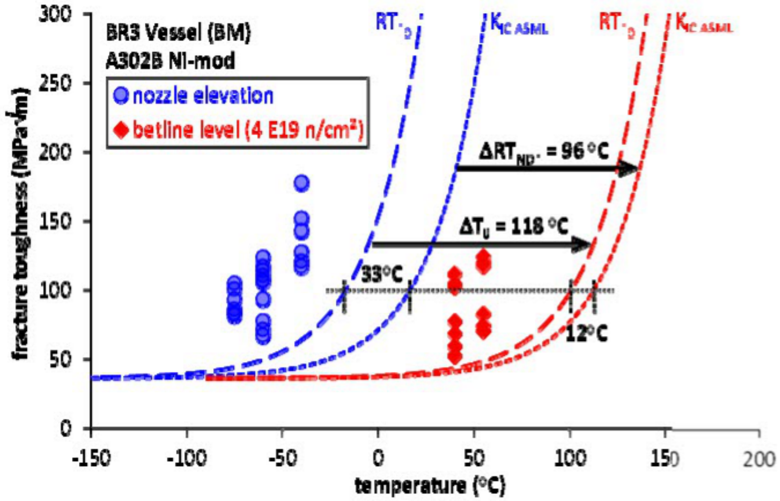
Overview of Investigated RPVs

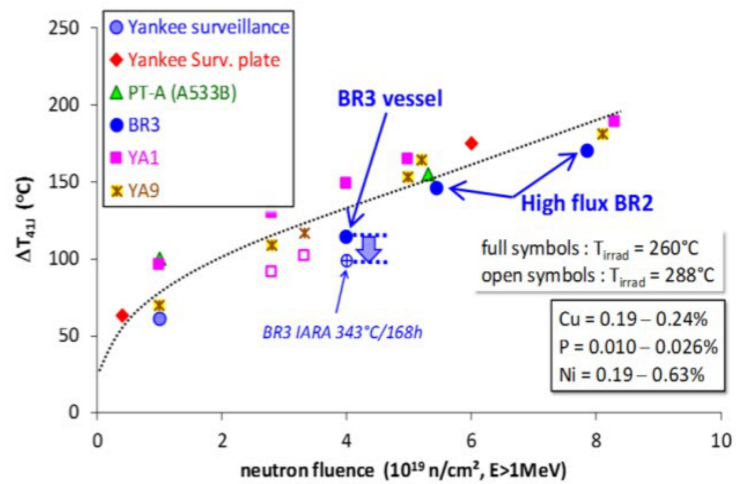
reactor		Cu	Ni	P	test (T, CVN, FT)
BR3 (YR)	BM	0.19	0.56	0.02	T, CVN, FT
	Weld	--	--	--	--
Chooz-A	BM	0.08–0.10	0.59–0.61	0.010–0.015	T, CVN, FT
	Weld	0.08–0.09	0.13–0.21	0.010–0.016	FT
Greifswald-1 to 4	BM	0.13	0.18	0.01	CVN, FT
	Weld	0.12–0.18	0.19–0.29	0.032–0.036	CVN, FT
Novovoronesh-1	BM	0.15	0.13	0.015	--
	Weld	0.12	0.12	0.033	CVN
Gundremmingen-A	BM	0.16	0.74	0.013	T, CVN
	Weld	0.24	0.11	0.009	CVN
Trawsfynydd	BM	--	--	--	--
	Weld	0.24–0.27	0.10–0.11	0.034–0.038	FT

T = tensile
CVN = Charpy impact
FT = fracture toughness

- All low Ni / medium Cu / medium to high P
- Modern steels : low Cu and low P

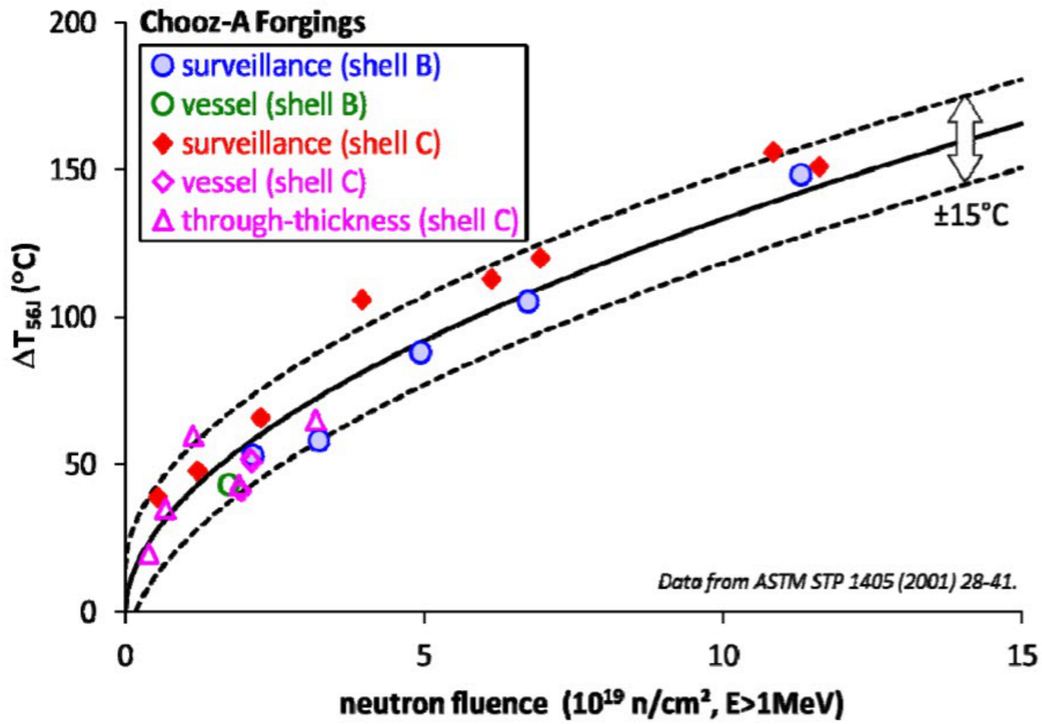
BR3 (PWR)

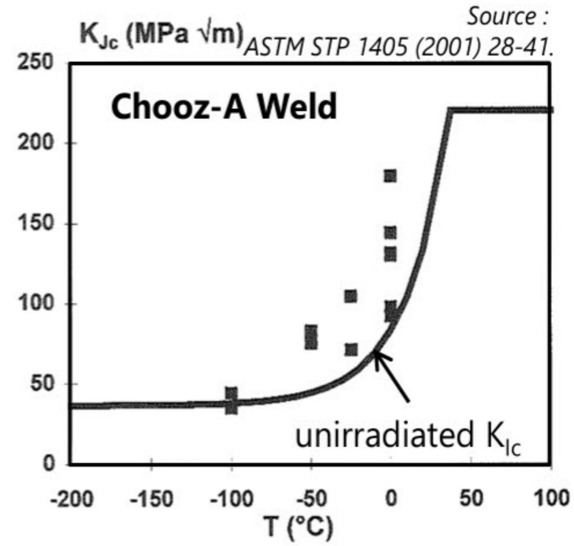




- Conservative regulatory RPV integrity assessment due to Ni-content, temperature and grain size.
- Actual embrittlement conditions are less than predicted after comparison with other surrogate materials and direct measurements of fracture toughness on the vessel material.

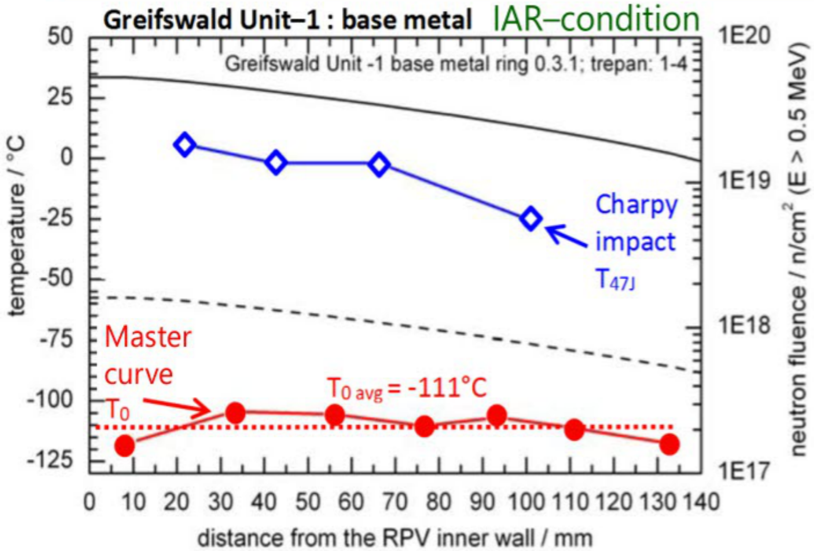
Chooz-A (PWR)

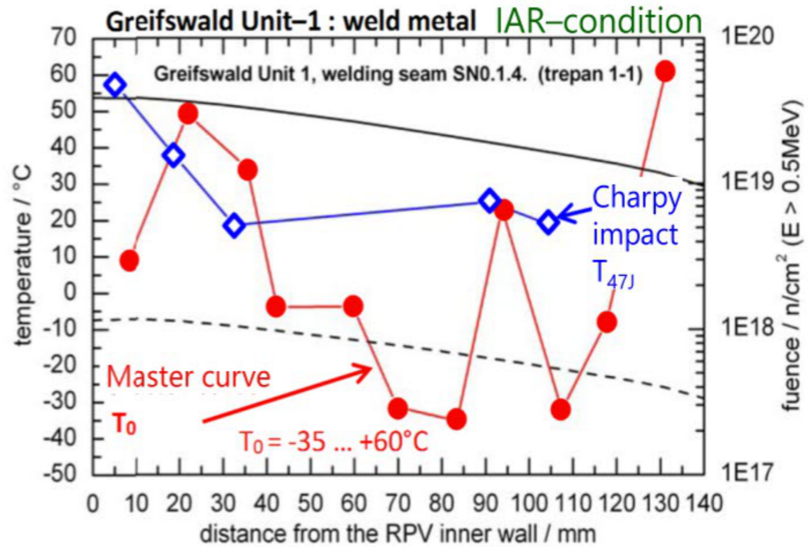


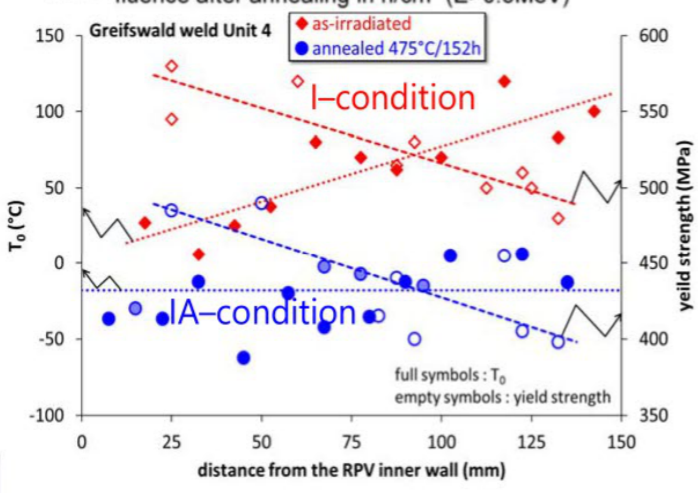


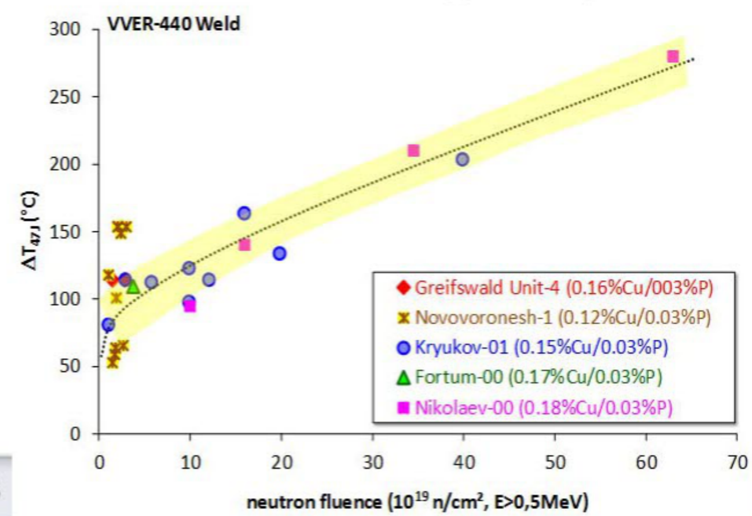
- Demonstration of the validity of the surveillance program for the base metal.
- Fracture toughness data on the weld metal were all well bounded by the fracture toughness lower bound curve established in the unirradiated condition (K_{Ic} based on RT_{NDT}).

Greifswald (VVER-440)

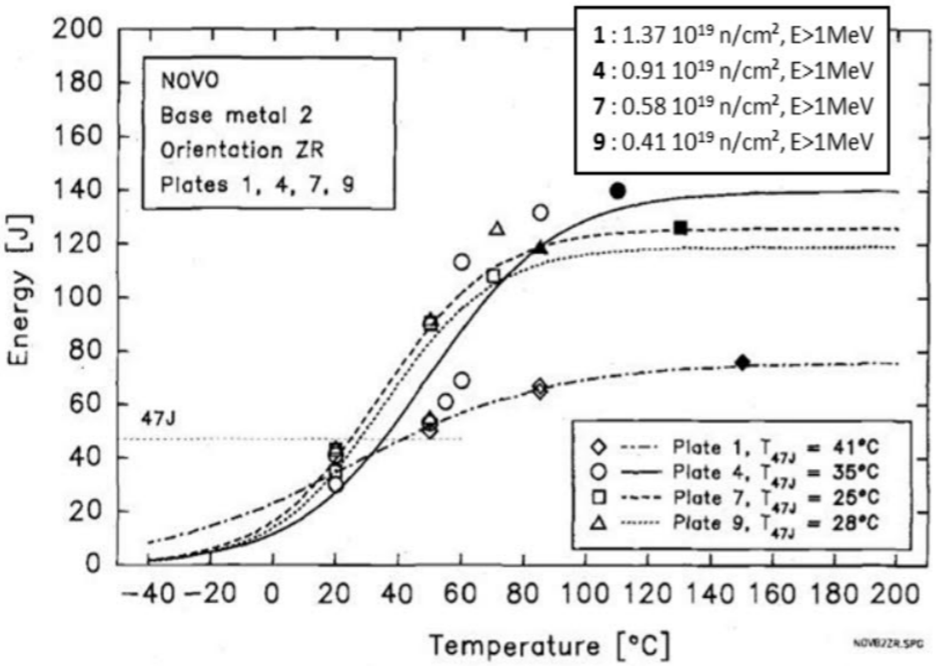


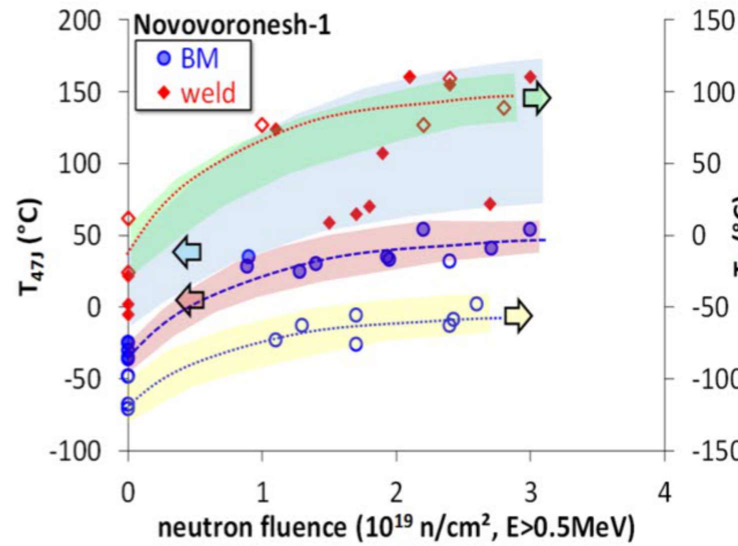






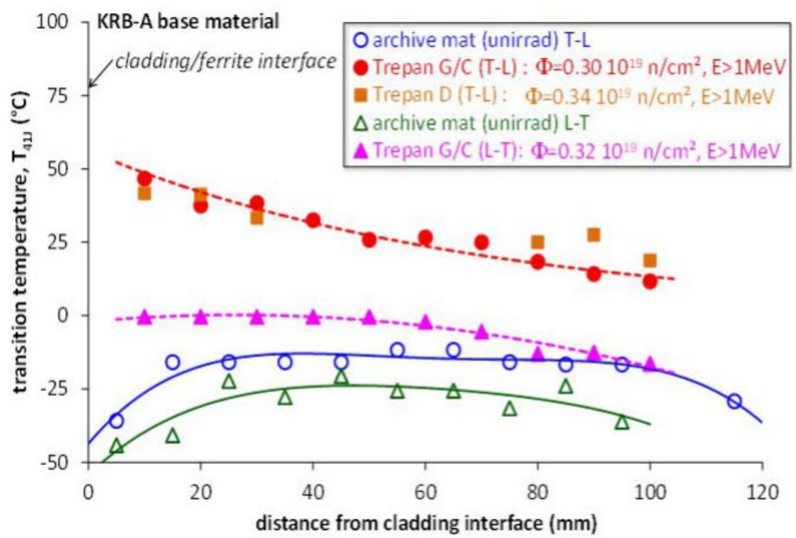
Novovoronech–1 (VVER-440)

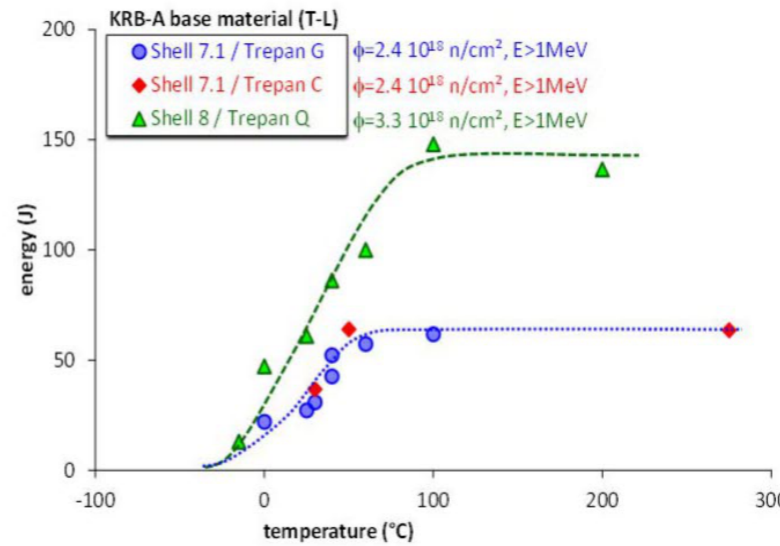


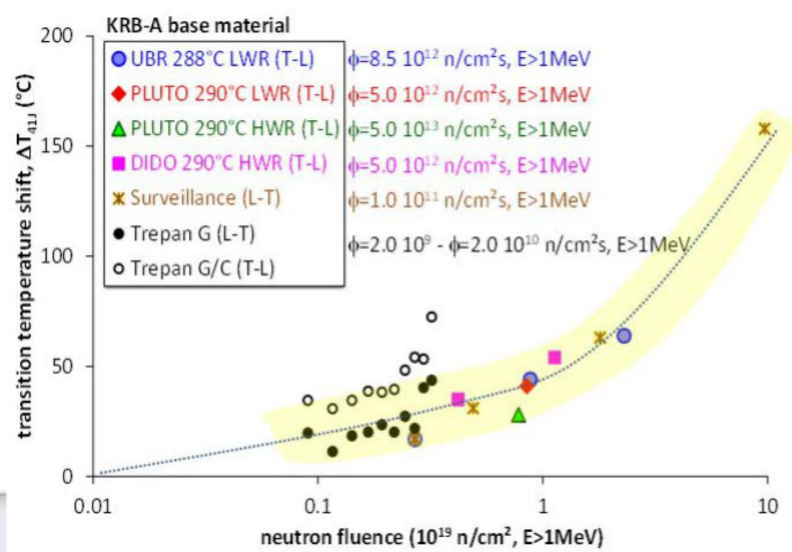


- ➢ Non-uniform through wall distribution of P-content in the weld.
- ➢ Large scatter in embrittlement based on Charpy impact transition temperature T_{47J}.
- ➢ Less scatter when master curve T_0 is used.
- ➢ No comparison to surveillance data.

Gundremmingen–A (BWR)

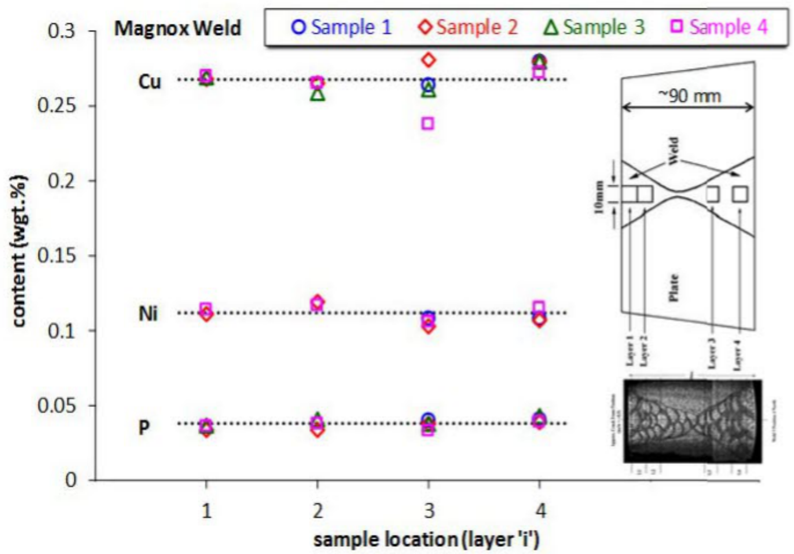


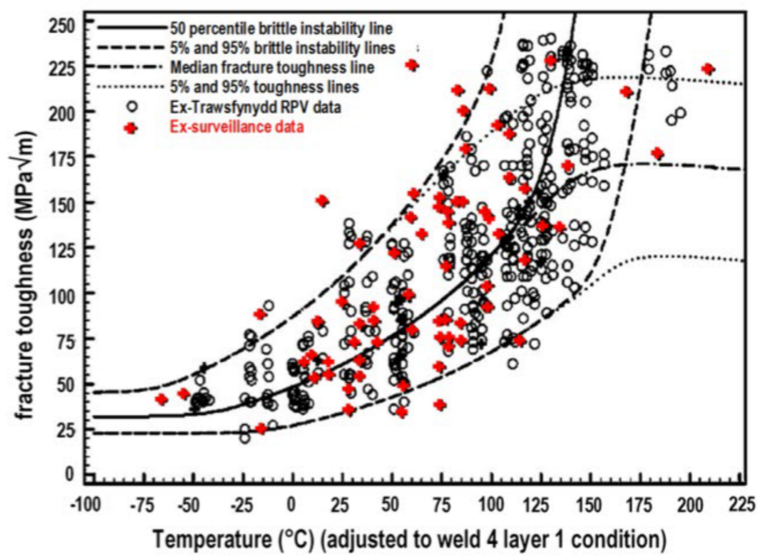




- Significant effect of specimen orientation (T-L versus L-T) on T_{41J} and USE.
- Effect of specimen orientation.
- Significant effect of specimen location in the base metal.
- Uniform through wall chemical composition of the weld.

Trawsfynydd (Magnox)





- Uniform chemical composition (through wall)
- Good agreement with surveillance data
- Allowed the demonstration of the safety integrity approach followed for this type of reactors.

Outcome

reactor	outcome
BR3 (PWR)	Conservative regulatory RPV integrity assessment due to Ni-content, temperature and grain size. Actual embrittlement conditions are less than predicted after comparison with other surrogate materials and measurements of fracture toughness on the vessel material.
Chooz-A (PWR)	Demonstration of the validity of the surveillance program of the base metal. Fracture toughness data on the weld metal were all bounded by the fracture toughness lower bound established in the unirradiated condition.
Greifswald-1 to 4 (VVER-440)	Uniform chemical composition of the weld through the wall thickness except at the weld root but large scatter in the transition temperatures without correlation to the neutron exposure. Scatter attributed to local microstructure (coarse versus fine). Annealing at 475°C/152h allows an effective recovery. No comparison to surveillance data.
Novovoronesh-1 (VVER-440)	Non-uniform through wall distribution of P-content in the weld. Large scatter in embrittlement based on Charpy impact transition temperature T_{47J}. Less scatter when master curve T_0 is used. No comparison to surveillance data. Post-irradiation annealing was also investigated and showed that 600°C/2h leads to an effective recovery.
Gundremmingen-A (BWR)	Significant effect of specimen orientation (T-L versus L-T) on the transition temperature T_{41J} and upper shelf energy. Effect of specimen orientation complicated the comparison to surveillance data. A significant effect of specimen location was observed for the base metal. Uniform through wall chemical composition of the weld.
Trawsfynydd (Magnox–gas cooled)	Good agreement with surveillance data. Allowed the demonstration of the safety integrity approach followed for this type of reactors.

Limitations

- Materials
  - Gen–I materials (BR3 + Chooz-A), VVER-440 welds (high P >0,03%)
  - Limited to small areas of the reactor vessels
  - Many of these vessels were annealed
    - BR3 (ineffective : 343°C/168h),
    - Greifswald–1, –2 and –3 (effective : 475°C/152h)
  - Material variability (VVER-Welds, Gundremmingen base metal)
  - Systematic absence of archive materials (except Gundremmingen)
- Environment
  - Majority irradiated at low temperature : 190 to 265°C except Gundremmingen (~288°C)
  - Change of temperature during operation : Chooz-A (265 ↘ 255°C) and Novovoronesh (250 ↘ 228°C)
- Poor and/or unreliable surveillance program (except Chooz-A)
- Poor and/or unreliable dosimetry

Discussion

Approach

- Vessel selection
  - Do we have a choice ?
  - If yes, what are the selection criteria ? There are many :
    - Materials composition and damage levels
    - Operation history (neutron fluence, irradiation temperature)
    - Availability of reliable surveillance data
    - Availability of archive materials
    - Other aspects : material variability, presence of segregated zones, ...
- Choice dependent on the targeted objectives
  - What are the priorities
  - International participation
- There is no ideal choice (except if infinite available budget)
  - Consensus

Selection Criteria

- Materials
  - Preferably representative of modern reactors (→ LTO)
  - More systematic examination using many parts of the vessel (axial and azimuthal)
  - Available archive materials
- Irradiation environment
  - LTO–representative fluence levels (> … 10^{19} n/cm^2, E>1MeV)
  - Irradiation temperature ~290°C (majority of operating reactors)
- Operation history and monitoring
  - Well documented operation history
  - Reliable temperature monitoring
  - Reliable dosimetry
  - Reliable surveillance program

Material Variability

- Material variability → scatter
  - Complicates the interpretation of the test results
  - Increase the number of tests and use statistics
  - Important details might be shadowed by the large scatter
- If the vessels are really inhomogeneous
  - This should be taken into account in safety integrity assessment
  - Check the adequacy of the surveillance program with respect to representativity of the whole vessel
- What should we favor and at which cost ?
  - For better understanding and validation of procedures with a minimum of tests (least scatter)

    or
  - Application (real components) to check whether such material variability is covered by the available safety margins
  - Alternative : availability of multiple locally homogeneous areas

Issues

- Materials (at multiple locations)
  - Homogeneity of chemical composition
  - Homogeneity of mechanical properties
  - Identification of segregated area and further analysis
  - Identification of LTO-relevant areas and further analysis
- Neutron exposure
  - Verification of the neutron calculations ←→ dosimetry measurements
  - Through-wall fluence attenuation
- Vessel versus surveillance program
  - Mechanical properties : vessel versus surveillance
- Verification of master curve shape at high K_{Jc}
- Thermal ageing assessment
- Neutron flux/spectrum effects
- Assessment of regulatory procedures

Organizational Aspects

- International participation
  - As large as possible
  - In-kind contributions
  - Agreement on the project contents
- Main topics
  - Vessel selection and sampling
  - Materials transportation
  - Work share and distribution
- Timeline
  - Start date : ... 2017
  - 4–5 yr project (benefit of operating reactors)

Financial Aspects

- Vessel trepanning
  - If the vessel will be anyway cut in small pieces for final storage, the costs will be limited → additional work mainly
  - If the vessel was planned to be buried as a whole, then we will have to pay very much → all costs

- SCK•CEN experience
  - BR3 sampling : several trepans taken from the inner side of the vessel → ~0,4 M€ (€ of 1995) by PCI Energy Services, Illinois US
  - BR3 dismantling team : several large trepans → ~100 k€ (€ of 1995)

- Possible more accurate evaluation
  - Westinghouse Belgium : Mr Joseph Boucau
  - …

Closing Remarks

- To be effective, need of international program (work sharing)
- Focus on most critical issues (prioritization)
- Discussion : What do we want to do ?
  - Which reactor vessel ? Materials compositions ? Irradiation conditions (temperature, fluence) ?
  - Specifications and requirements ?
  - Technical issues to be addressed ?
  - Work sharing ?
  - Financial aspects ? Vessel sampling costs : depend on decommissioning strategy
  - Materials management and transportation
  - Planning
  - …

Thanks for your attention

SCK•CEN
Studiecentrum voor Kernenergie
Centre d'Etude de l'Energie Nucléaire
Belgian Nuclear Research Centre

Stichting van Openbaar Nut
Fondation d'Utilité Publique
Foundation of Public Utility

Registered Office: Avenue Herrmann-Debrouxlaan 40 – BE-1160 BRUSSELS
Operational Office: Boeretang 200 – BE-2400 MOL

STUDIECENTRUM VOOR KERNENERGIE
CENTRE D'ETUDE DE L'ENERGIE NUCLEAIRE

KHNP
Central Research Institute

Kori-1 Harvesting Plan for Materials Aging Degradation Research

Al Ahluwalia (EPRI) for Han-sub Chung (KHNP)

March 7-8, 2017

Contents

1. Background

2. Research planning using materials from retired Kori-1

3. Future Plans

1. BACKGROUND

KHNP PWRs and Kori-1

- **Kori-1 is a Westinghouse two loop PWR**
  - SG replaced in 1998, RV head replaced in 2015
- **Kori-1 will be shutdown on 2017.6.18**

  (30 year original design life + 10 year extended life)
- **Seven additional PWRs complete their original 40-year design lives beginning 2023, nearly one plant each year**
  - KHNP intends to seek license renewals but it will be a challenging task due to public concern for safety
- **KHNP is planning a comprehensive research program on long-term materials aging degradation**

Schedule of decommissioning Kori-1 (tentative)

KHNP Central Research Institute

- **Submission of a KHNP decommissioning plan (2020.6.)**
  - Approval procedures including public hearings
- **Final approval of the decommissioning plan (2022.6.)**
- **Completion of the cutting and dismantling (2024.12.)**

Central Research Institute

2. RESEARCH PLANNING USING MATERIALS FROM RETIRED KORI-1

Planning sub committees (2016.1.~4.)

KHNP Central Research Institute

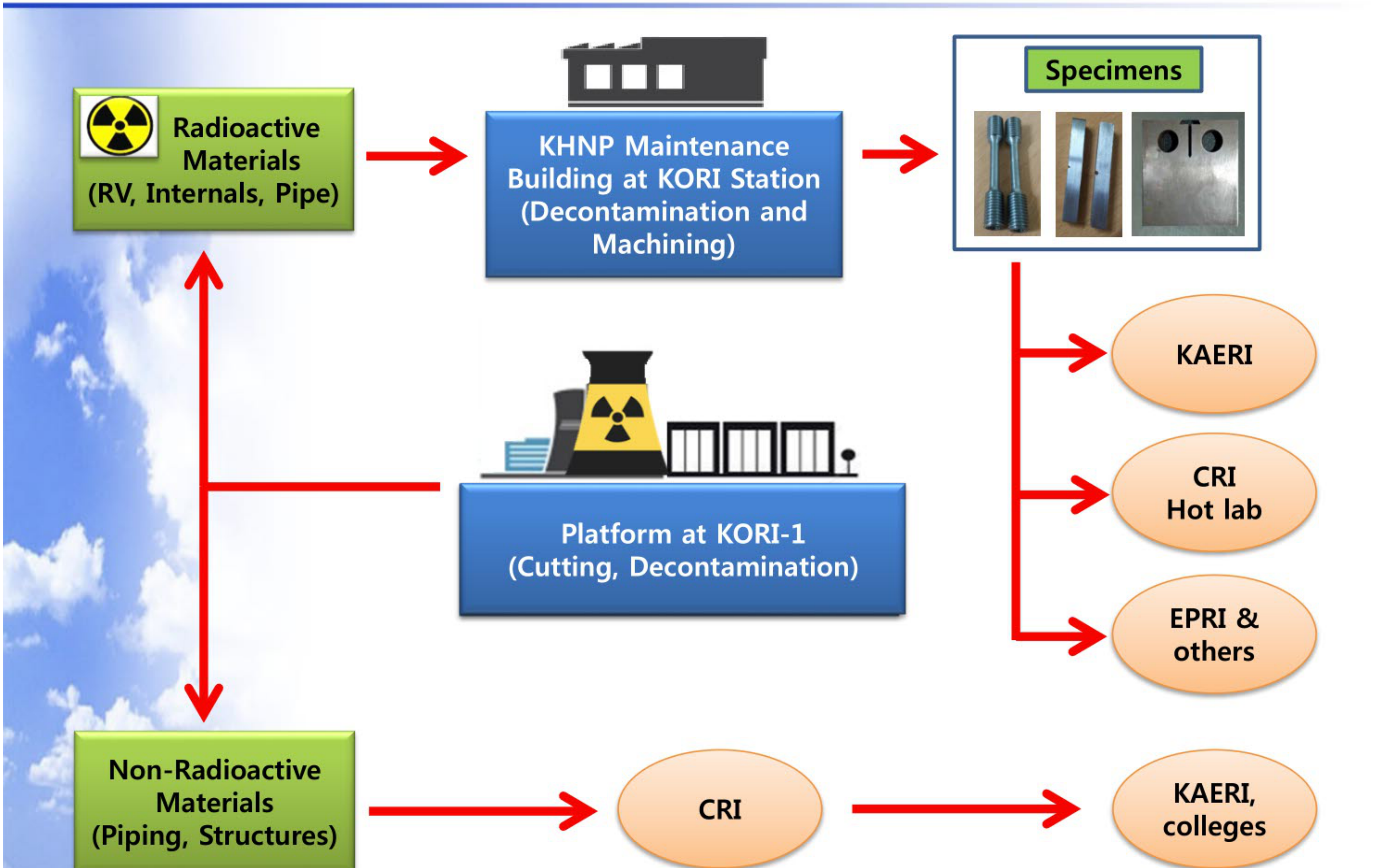
classification	Chair/secretary	Members
Neutron irradiation embrittlement of RPV	BS Lee(KAERI)/ JS Yang(CRI)	5~10 members each group from relevant organizations (KAERI, KPS, KEPCO-E&C, DHIC, KAIST, and a few universities)
Reactor internals	SS Hwang(KAERI)/ JS Yang(CRI)	
SCC of Alloy 600 weld nozzles and penetrations (CRDM, BMN, DMW)	HP Kim(KAERI)/ HD Kim(CRI)	
Steam generators	HP Kim(KAERI)/ HD Kim(CRI)	
Thermal embrittlement	CH Jang(KAIST)/ MW Kim(CRI)	
FAC & buried pipes	DJ Kim(KAERI)/ SK Park(CRI)	

12 tasks proposed at the subcommittees

KHNP Central Research Institute

1. Irradiation Embrittlement of the Reactor Pressure Vessel Beltline Material
2. Irradiation Embrittlement of RPV Nozzle steel
3. Investigation of the IASCC mechanism
4. Material properties of aged RVI components
5. Residual stress and susceptibility to PWSCC of Alloy 600 welds and penetrations
6. Residual stress and susceptibility to PWSCC of Alloy 690 CRDM penetration nozzles
7. Degradations of steam generator
8. Thermal embrittlement in cast and weld austenitic stainless steel
9. FEM integrity assessment and actual test of a bend portion in an aged real plant pipe
10. Thermal embrittlement of low alloy steel and its weld exposed to PZR temperature
11. FAC and erosion in CS piping in the secondary system and BOP
12. Degradations in buried pipes and inspection performance demonstration

Course of test materials and specimens



KHNP maintenance building in Kori station

RCP maintenance facilities

Separate rooms

Old original Kori-1 RV head

Current Activities

KHNP Central Research Institute

- **Input of research plan to KHNP decommissioning plan by 2017.12**
- **Planning of improving KHNP facilities for handling irradiated materials (2016.5.~2018.4.)**
  - KHNP maintenance building in Kori station
  - CRI materials test building
- **Improvement of KAERI Irradiated Materials Evaluation Facility**
  - KAERI IMEF is overcrowded
- **An EPRI project**
  - Analytical assessment of residual stress in a few selected dissimilar metal nozzles in Kori-1

3. FUTURE PLAN

Project Schedule (draft)

Phases	Description
Phase One (2020~2024)	▪ Improvement of KHNP and KAERI facilities ▪ Decontamination, movement, machining, and storage of test materials ▪ Preliminary analytical studies - irradiation dose, residual stress, and others
Phase Two (2024~2030)	▪ Test and evaluation
Phase Three (2031~, as needed)	▪ Remaining tasks after completion of Phase Two - additional irradiation test, international collaboration, and others

Others

- Planning of specific projects among Korean organizations
- Planning of international collaboration via EPRI

Central Research Institute

Thank you !

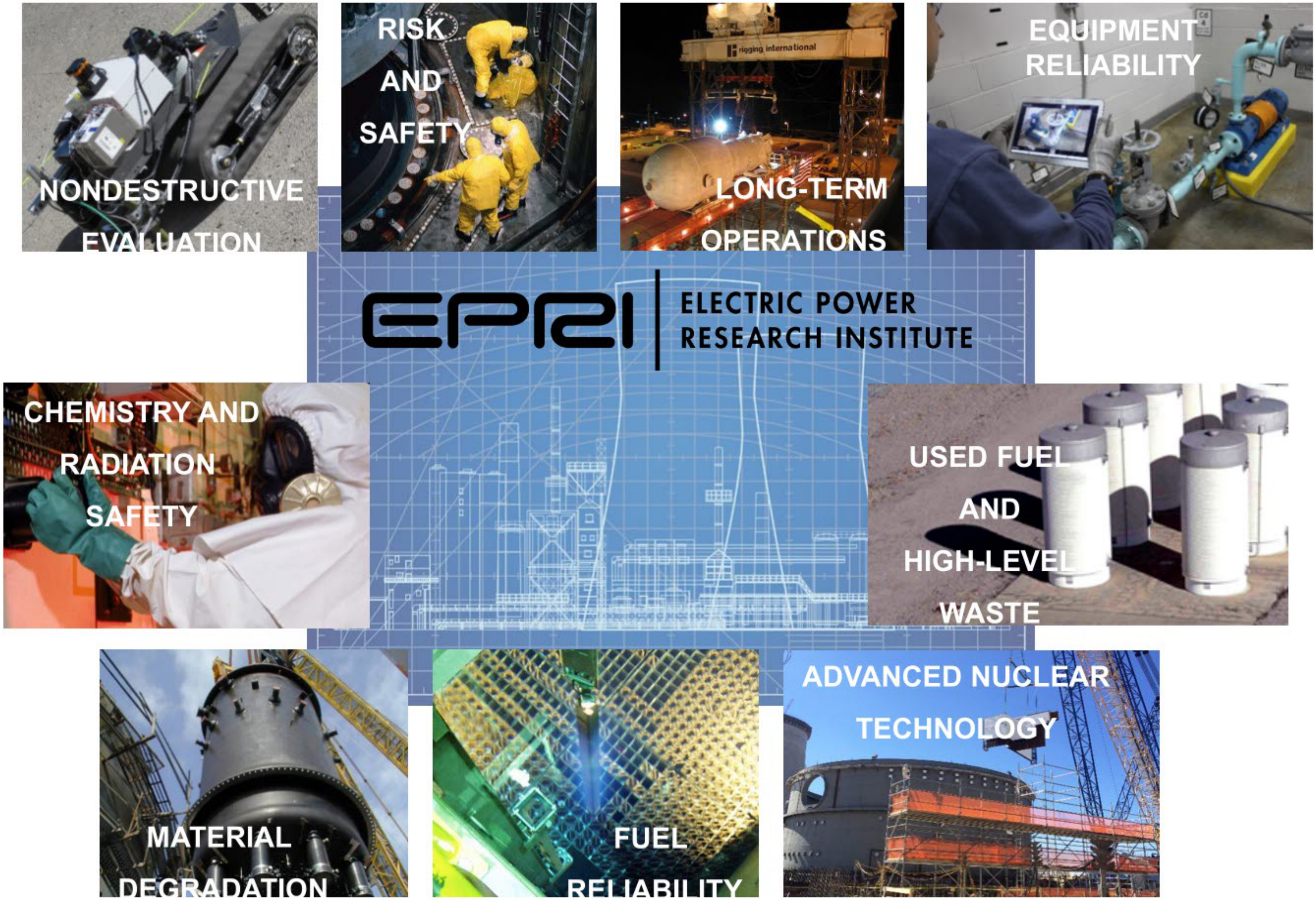
Ex-Plant Harvesting Workshop Session 1

EPRI Perspective

Sherry Bernhoft
Senior Program Manager

NRC Ex-Plant Harvesting Workshop
March 7 & 8, 2017

Nuclear Sector Research Areas



EPRI's Global Membership

GLOBAL PARTICIPANTS

>320 reactors worldwide

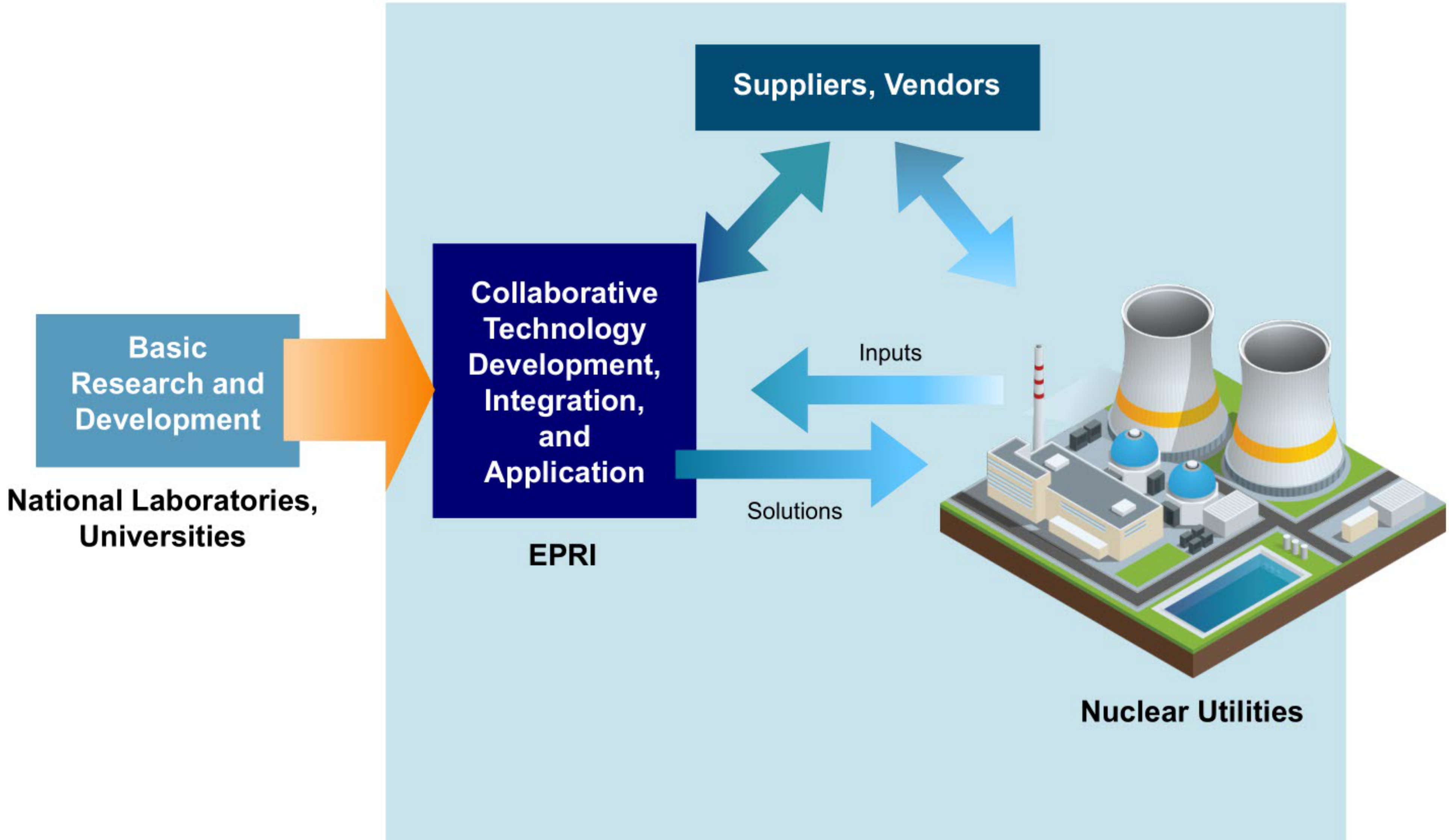
GLOBAL BREADTH & DEPTH

>75% of the world's commercial nuclear units

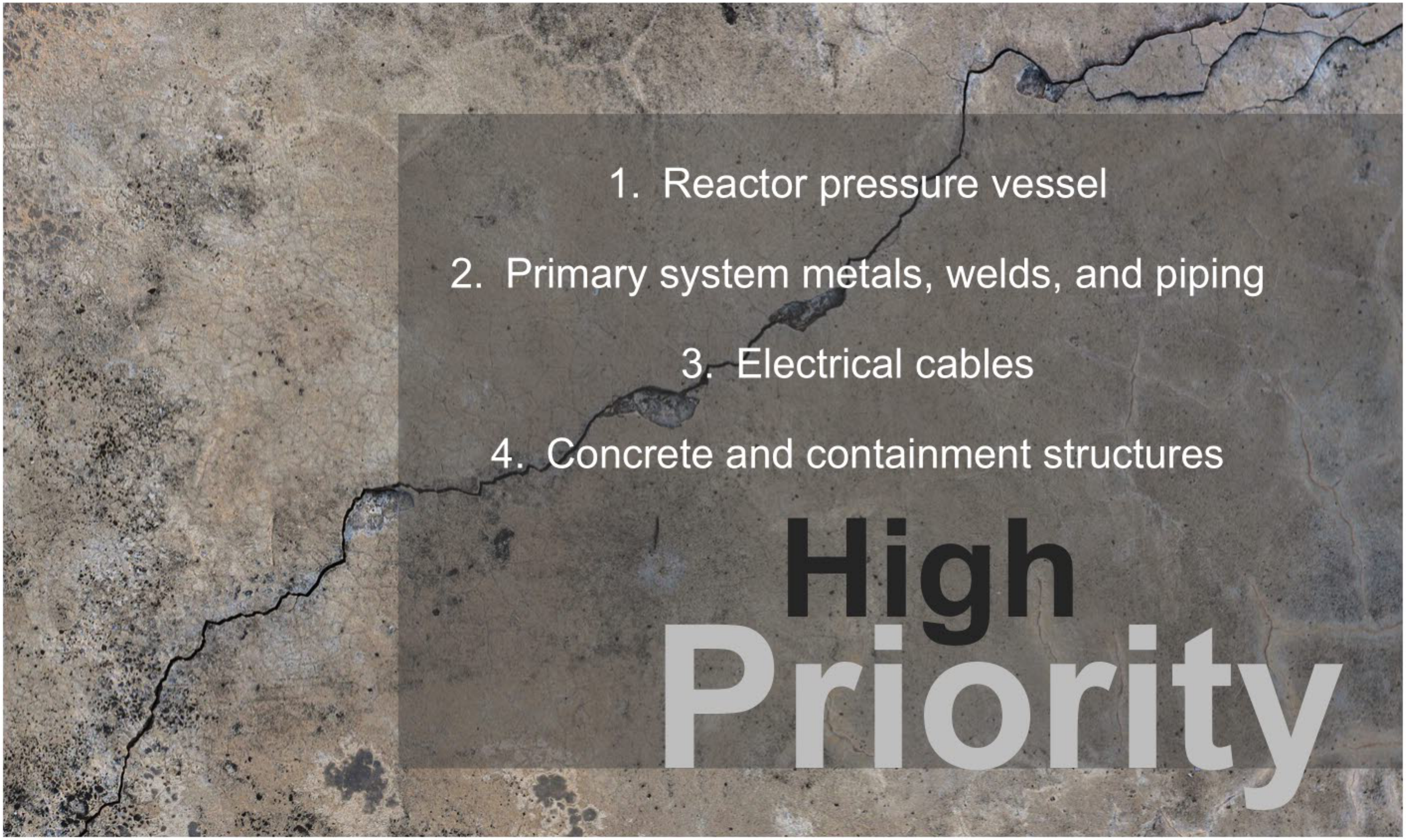
Participants Encompass Most Nuclear Reactor Designs

EPRI | ELECTRIC POWER RESEARCH INSTITUTE

EPRI Collaborative Model



LTO Research Focus is on Aging Management



ELECTRIC POWER RESEARCH INSTITUTE

Experience With Harvesting

- Takes longer and cost more than anticipated
- Incomplete knowledge on the pedigree of the harvested materials
- Roles and responsibilities not well defined
- Contracting is complicated
- Logistics, i.e. transportation and storage are challenging

You can spend a lot of money and not get any value

EPRI's Criteria for Harvesting

- Needs to be of value for our members
- Is prioritized as a need by our members
- Fills a knowledge gap that can not otherwise be filled
- Needs to start with a well developed project plan including:
  - Funding
  - Risk Management plan
  - Exit Ramps
  - Clear roles and responsibilities

Together…Shaping the Future of Electricity

Plants in Decommissioning in Germany

Uwe Jendrich, GRS

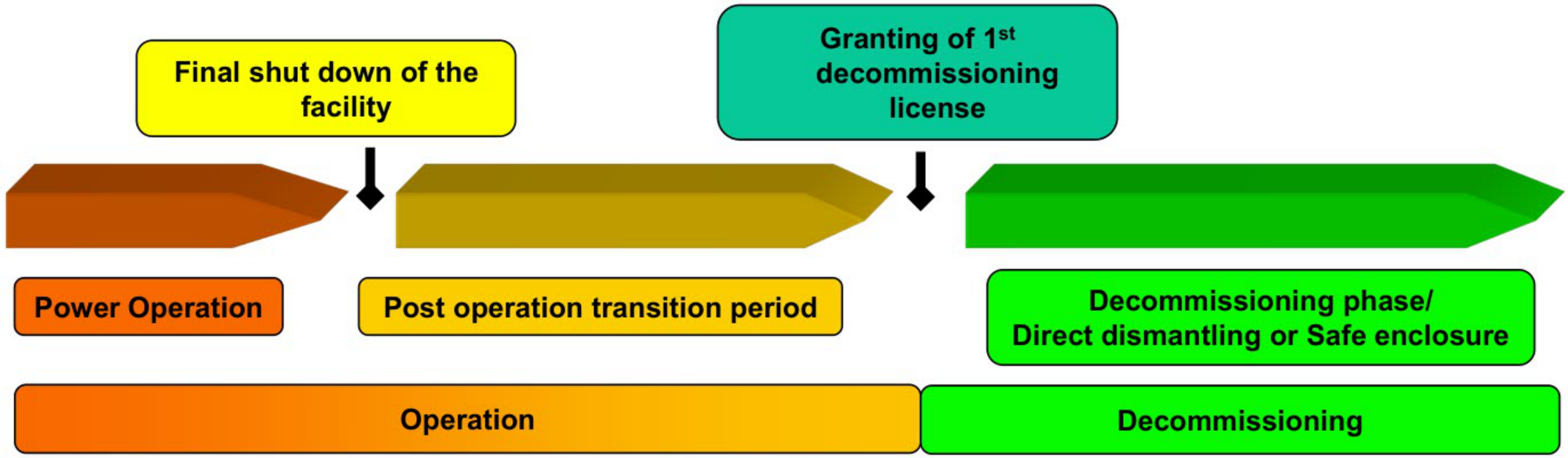
March 7, 2017

Ex-Plant Materials Harvesting Workshop

US NRC Headquarter, Rockville/MD, USA

Basic Requirements for Decommissioning

Regulation of decommissioning in Germany



The German Regulatory System

- Basic requirements
  - For a nuclear facility the atomic energy act allows either
    - to **immediate dismantle** or
    - to dismantle after a **safe enclosure**

    Note: **no entombment** (near surface disposal) is allowed
  - The **operator** of a nuclear facility is **fully responsible** for the decommissioning and dismantling of a nuclear facility.

→ For any requests on materials: Contact the operator!

  - There are 4 operators of commercial nuclear reactors in Germany:
    1. PreussenElektra[1)] (KKS, KKI, KKU, KWG, KKG, KBR, KKE)
    2. EnBW[2)] (KWO, GKN, KKP)
    3. RWE (KMK, KRB, KWB)
    4. Vattenvall (KKB, KKK)

1) until recently known as E.ON Kernkraft
2) Energie Baden-Württemberg

Overview on Decommissioning Projects in Gemany

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

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

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

Overview on Decommissioning Projects in Gemany

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

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

UC: unconditional clearance
SE: safe enclosure

NPPs Preparing for Decommissioning in Gemany

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

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

RPV design fluence after 40 years $< 5 \cdot 10^{18}$ n/cm²

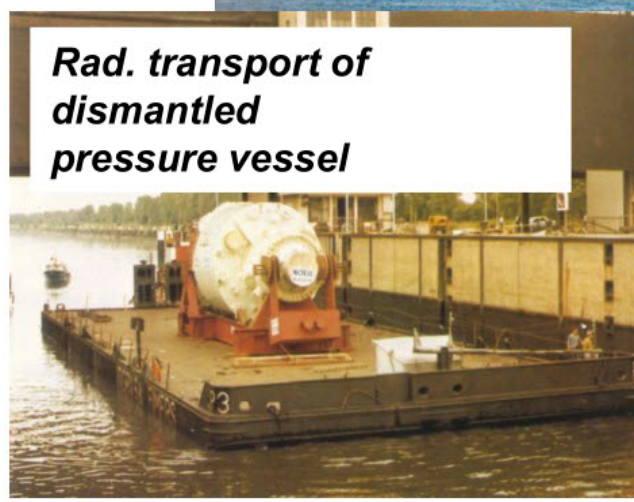
NPPs Preparing for Decommissioning in Gemany

- **Commercial Reactors in operation**

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

Overview on Decommissioning Projects in Gemany

- Past and current decommissioning projects of **Research Reactors**
  - Total: 35
  - Removed: 29
  - Final Shut down / under dismantling: 4
  - Safe Enclosure: 2
  - Variety of types of Research Reactors
    - Argonaut type
    - Critical assembly
    - Educational reactors
    - Liquid homogenous reactor
    - Propulsion reactor
    - Pool reactor (incl. TRIGA type)
    - Heavy Water reactor (incl. DIDO type)



Overview on Decommissioning Projects in Gemany

- Past and current decommissioning projects of **Prototype or Commercial Reactors**
  - Total: 21
  - Removed: 3
  - Final shut down / under dismantling: 17
  - Safe enclosure: 1
  - Reactor types:
    - PWR
    - BWR
    - Fast Breeder
    - High Temperature Gas Cooled
    - Heavy Water Gas Cooled

© Forschungszentrum Karlsruhe

Thank you for your attention!

Role of GRS
in Decommissioning and LTO

Uwe Jendrich, GRS

March 7, 2017

Ex-Plant Materials Harvesting Workshop

US NRC Headquarter, Rockville/MD, USA

Introduction

GRS with its staff of about 430 is

- **Main Technical Support Organization (TSO) in nuclear safety for the German federal government**
  - **BMUB** (Federal Ministry for the Environment, Nature Conservation, Building and **Nuclear Safety**),
  - **BMBF** (Federal Ministry of Education and **Research**),
  - **BMWi** (Federal Ministry of Economic Affairs and **Energy**) and
  - **AA** (Federal Ministry of **Foreign Affairs**) and

GRS participates in international activities of

- **IAEA**, **OECD**, **EU** (DG Energy, DG RTD, DG DevCo), …

Services of GRS in Decommissioning of Nuclear Installations

- **Advice and assessment**
  - concrete technical and legal issues
  - strategy and planning of decommissioning projects
- **Project management, progress monitoring and documentation** of decommissioning projects
- **Support in the drafting of regulations**
  - taking into account national specifics
- **Know-how transfer**
  - individually tailored seminars and coaching
  - elaborations on specific issues

GRS Customers and References in Decommissioning

- **BMUB**:
  - Various projects (since 1998):
    - technical and organizational requirements
    - analysis of technical aspects,
    - assessment of application and licensing documents
- **BMBF**:
  - Project management (since 2013):
  - 'Decommissioning, dismantling and waste management projects relating to nuclear test facilities'
- **IAEA**:
  - Decommissioning and Remediation of Damaged Nuclear Facilities (DAROD) (since 2015)
  - Decommissioning Risk Management (DiRiMa) (since 2012)
  - Constraints to implementing decommissioning and environmental remediation programs (CIDER) (2013-2015)
- **EBRD**:
  - Assistance to Bulgaria Nuclear Regulatory Agency (BNRA)
    - decommissioning of Kozloduy NPP units 1-4 (since 2008)

Federal Ministry for the Environment, Nature Conservation, Building and Nuclear Safety

Federal Ministry of Education and Research

IAEA International Atomic Energy Agency

European Bank for Reconstruction and Development

GRS Activities in Ageing Management and Long Term Operation

- **BMUB**:
  - Evaluation of nat. & internat. operating experience
  - Nat. & internat. Regulations and Guidelines on AM
- **EU:**
  - Several INSC projects on
    - Regulatory aspects of LTO, Specific technical aspects
  - JRC Database EMAR (R&D results on ageing of materials)
- **IAEA**:
  - International IGALL
- **OECD/NEA**:
  - Database projects CODAP (components), CADAK (cable)
  - WG IAGE, NUGENIA
- **ANVS (NL)**:
  - Assessment of licensing documents for LTO of Borssele

EnergySolutions

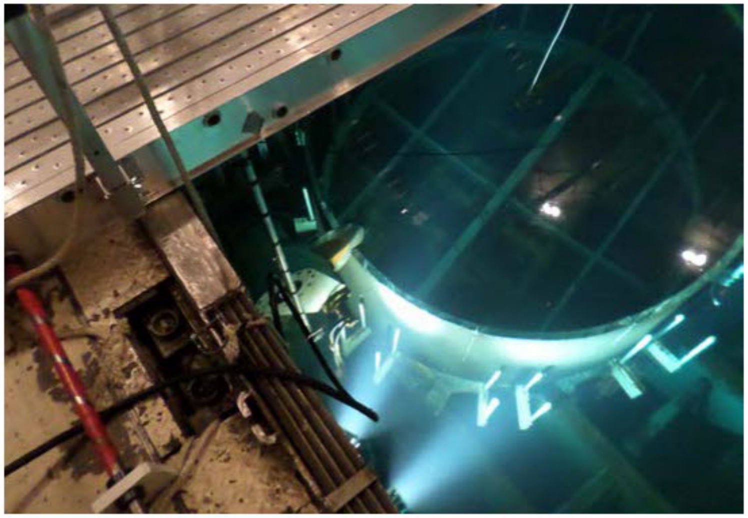
Future Harvesting Opportunities at Decommissioning Power Plants

Gerry van Noordennen

March 7, 2017

Successful Harvesting Opportunities Require Clear Scope and Schedule

- **Plant View**
  - There is no financial incentive to support harvesting
  - The research agency must be willing to pay for the costs to surgically remove components
  - The research agency must provide a clear scope and schedule at the beginning of the active decommissioning period (DECON)
  - Delays in federal approvals mean lost opportunities



Flexibility is Key

- Flexibility in the removal schedule is key
  - Schedule changes result in components becoming available on short notice
  - The research agency must have the funds set aside from one year to the next or miss out on harvesting opportunities

Future Opportunities

ENERGYSOLUTIONS

- Reactor vessel surveillance coupons
  – Best removed when work begins on cutting up reactor internals
- Reactor vessel weld specimens
  – Only applicable for large vessels
  – Smaller vessels like SONGS 1 and Ft. Calhoun shipped intact to disposal facility

Reactor Vessel Cutting Head

Future Opportunities

ENERGYSOLUTIONS

- Spent fuel rack coupons
  - Best removed before or after spent fuel transferred to the ISFSI
  - Cannot not interfere with fuel characterization or fuel transfer
- Spent fuel rack
  - Removed after pool completely empty including GTCC waste
- Cabling from Harsh Environments
  - Some can be harvested at any time
  - High rad environment requires timing of harvest to mesh with source term removal schedule in each area

Future Opportunities

ENERGYSOLUTIONS

- Switchgear, Bus Ducts, Control Panels, Breakers
  - Some can be harvested at any time
  - Specify cable lengths needed
  - High rad environment requires timing of harvest to mesh with source term removal in area
- Concrete Cores
  - Cores best taken consistent with site characterization needs for License Termination Plan

Harvesting Plans Needed Now

ENERGYSOLUTIONS

- Plants that are entering DECON in the next 2 years need to know now if the NRC or DOE are interested in harvesting materials at these sites:
  - San Onofre 2 & 3 (January 2018)
  - Vermont Yankee (2019)

- Plants potentially entering DECON in the next 2 years should be contacted now:
  - Kewaunee
  - Crystal River
  - Ft. Calhoun

EnergySolutions

Zion Harvesting Experience and Lessons Learned

Gerry van Noordennen

March 8, 2017

Zion Nuclear Power Station

ZIONSOLUTIONS LLC
An EnergySolutions Company

Two 4-Loop Westinghouse PWR 3250MWt (1085 MWe)

• Construction permit	December 1968
• Operating Licenses	April 1973 (Unit1) November 1973 (Unit 2)
• Shutdown (unexpected)	February 1998
• Permanently Defueled	March 1998
• License transferred to Energy*Solutions*	September 2010
• All Spent Fuel in Dry Storage	January 2015
• Expected Completion	April 2019

Decommissioning Progress

ZIONSOLUTIONS LLC
An EnergySolutions Company

- Plant Decommissioning is on schedule and on budget
- Currently demolishing Auxiliary Building
- Containment buildings ready for open air demolition in May 2017
- Complete building demolition by early 2018
- Show demolition video

Scope

- **Zion Harvesting Program Experience**
  - Extensive harvesting conducted from 2011 to 2016
  - Senior management supportive of program
  - Reassignment of plant personnel to support harvesting program
  - Demolition organization generally not supportive but tolerated surgical removal of components
  - Demolition did not stop for harvesting
  - Harvested items only have scrap value

Items Harvested

EnergySolutions

- Reactor Vessel Material Surveillance Capsules
  - Capsules were removed during reactor internals cutting and stored on the reactor cavity floor
  - Capsule designators were very hard to read
  - Only one capsule had research value (X)
  - Zion attempt to identify capsule markings failed
  - Capsule X ended up being disposed of by the time contract issues were worked out with Westinghouse to retrieve capsule
  - Result: All capsules disposed as radwaste

Reactor Vessel Weld

- Reactor vessel beltline weld
  - Reactor vessels cannot be rotated in cutting machine
  - Vessel cutting plan looked like it would work for vessel specimen harvesting plan
  - Unit 2 beltline weld was too close to cut line so torch could have affected metal properties
  - Unit 1 cut line was far enough away from weld to obtain a successful specimen

Safety-Related Cabling

Cabling harvested from Unit 1 (11 Tasks)

1. East Valve House near Steam Tunnel
2. Instrument cabling inside missile barrier
3. Loop Isolation Valve cabling
4. Accumulator discharge valve MOV cabling
5. Instrument Rack cabling in containment
6. Air-operated valve cabling
7. Electrical penetrations assembly and cables
8. Electrical penetration cabling in Aux Bldg.
9. Pressurizer heater cables
10. Cables in steam tunnel
11. Submerged cable in Turbine Bldg. to Crib House

ENERGYSOLUTIONS

Experience

- Only some of the cables harvested.
  - Changing priorities
  - Demolition crew not cognizant of research needs
- Cable lengths of 30 feet were difficult to obtain in some instances. Could only get 10 feet.
- Cable type, age and environment were generally available from plant records

Fire Testing Program

EnergySolutions

- Bus bar section (8 feet) removed along with any remaining support hardware and isolators
- 480-volt distribution center removed
- 480-volt motor control center removed
- Control Room Control Panel removed
- Instrument Rack removed in Aux. Bldg..
- 4KV Switchgear, Relays and Breakers removed
- ISO-Phase Bus Duct removed

Concrete Core Bores

ENERGYSOLUTIONS

- Planned to take core bores in containment and under spent fuel pool liner
- Task cancelled by ORNL

Spent Fuel Pool Storage Racks

- Spent Fuel Pool Testing completed for boron degradation
- Remaining coupons retrieved
- Storage rack piece cut and shipped
- Good onsite coordination with EPRI and NRC
- Most work completed during weekend

Lessons Learned

EnergySolutions

- Changing scope leads to frustration on both sides
- Delays in paper work for each task authorization lead to lost opportunities
- Plan early
- Obtain senior plant management support
- Have someone on site when harvesting takes place
- Be able to deal with changing plant support personnel

U.S. DEPARTMENT OF ENERGY | Nuclear Energy

US Nuclear Science User Facilities (NSUF) Overview

NSUF Nuclear Science User Facilities

J. Rory Kennedy, Ph.D.
Director, NSUF
Idaho National Laboratory

March , 2017

U.S. DEPARTMENT OF ENERGY
Nuclear Energy

NSUF General

NSUF Nuclear Science User Facilities

- Established 2007 as DOE Office of Nuclear Energy first and only user facility
  - Idaho National Laboratory is lead institution
  - Irradiation effects in nuclear fuels and materials
  - Provide access to capabilities and expertise at no cost to user
  - Support design, fabrication, transport, irradiation, PIE, disposition
  - Link intellectual capital with nuclear research infrastructure to fulfill mission of DOE-NE
- Generally select projects through open competitive proposal processes
  - Consolidated Innovative Nuclear Research (CINR FOA, 1 call/year)
    - Irradiation + PIE ($1.0M - $4.0M, up to 7 years)
    - PIE only (~$500K, up to 3 years)
    - Irradiation only ($500K - $3.5M)
    - Beamlines at other user facilities
  - Rapid Turnaround Experiments (RTE, 3 calls/year, limited $$, executed within 9 months)
  - Proposals welcome from University, National Laboratory, Industry, Small Business, Int'l researchers

NSUF – A consortium

A group formed to undertake an enterprise beyond the resources of any one member

2007	2008	2009	2010	2011	2012	2013	2016
Idaho National Laboratory	Massachusetts Institute of Technology	Center for Advanced Energy Studies; Illinois Institute of Technology; NC State University; University of Michigan; UNLV; The University of Wisconsin Madison	Oak Ridge National Laboratory; Pacific Northwest National Laboratory	Berkeley University of California	Purdue University	Westinghouse Electric Company LLC	Argonne National Laboratory; Brookhaven National Laboratory

- **Expanded capabilities**
  - Need for additional capabilities outside INL recognized early
  - Partner facilities program established in 2008

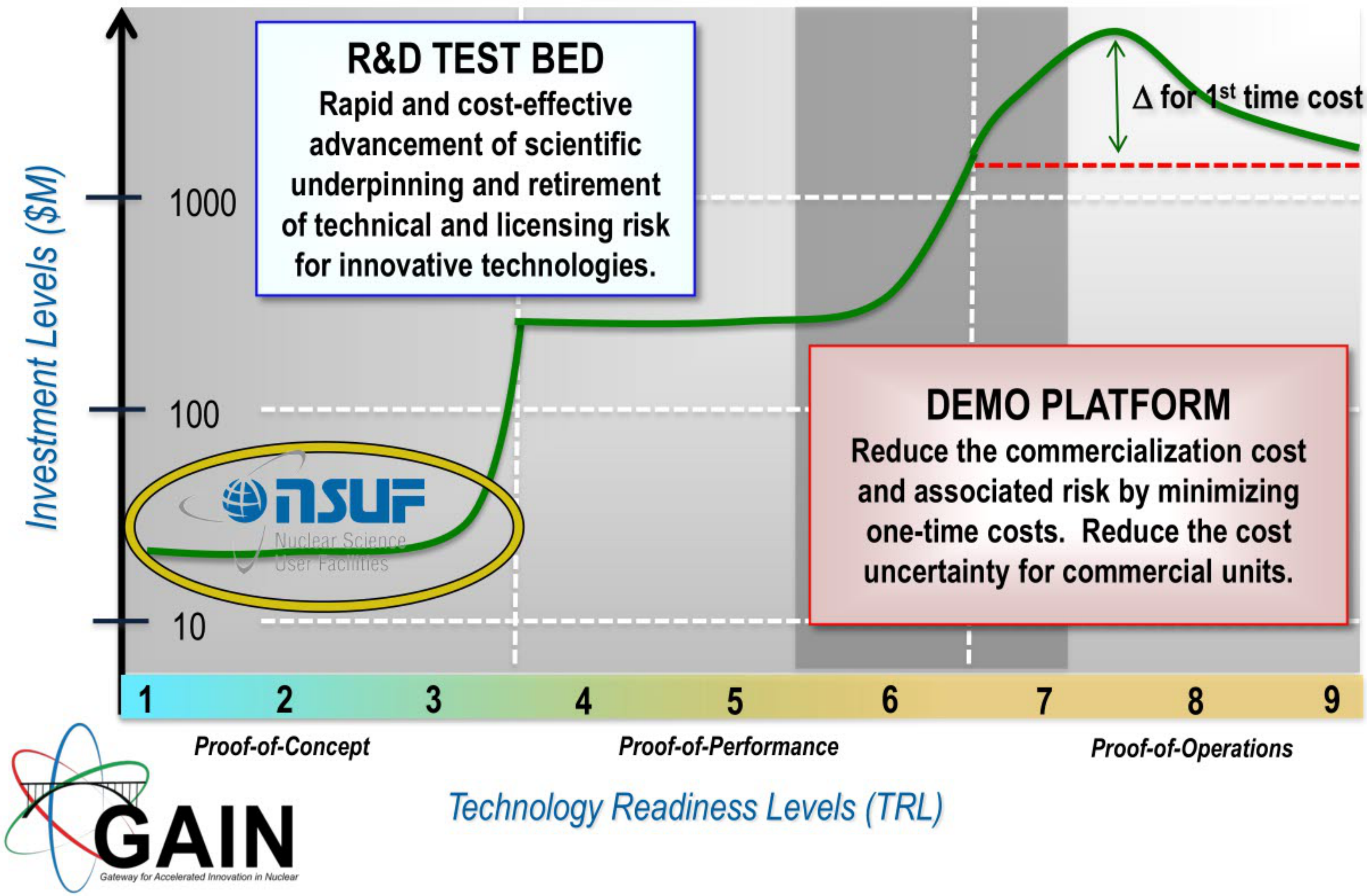
- **Partner Facilities to date**
  - 8 Universities + 3 Universities in CAES (3 currently expressed interest)
  - 4 National Laboratories (4 expressed interest)
  - 1 Industrial

NSUF General Capabilities

- **Neutron Irradiations**
  - **ATR (loop, rabbit), ATRC, HFIR (rabbit), MITR (loop), PULSTAR, NRAD (Future: BR2 – SCK-CEN Belgium), Halden – Norway ?)**
- **Ion Irradiations**
  - **Tandem Accelerator Ion Beam (U. Wisc), Michigan Ion Beam Lab (U. Mich), IVEM (ANL) (Future: TAMU, SNL, LANL)**
- **Hot Cells**
  - **INL(HFEF, FCF, AL, IASCC), ORNL (IFEL, IMET, REDC), PNNL (RPL), U. Mich (IMC), Westinghouse (MCOE)**
- **High radiation level measurements/instrumentation**
  - **Neutron radiography, elemental & isotopic analyses, gas sampling and analyses, profilometry, gamma scanning, mechanical testing, electron and optical microscopy, thermal analyses, eddy current, IASCC, EPMA, AES, XPS, SIMS, focused ion beam (FIB)**
- **Low radiation level measurements/instrumentation**
  - **SEM, TEM, APT, FIB, hardness, micro- & nano-indentation, tensile, thermal analyses, XRD, XPS, AES, SIMS, NMR, PAS**
- **Beamlines**
  - **X-ray (ANL APS: MRCAT, IIT; BNL NSLS-II: XPD, NST Dept)**
  - **Neutron, positron (PULSTAR, NCSU)**
- **High Performance Computing**
  - **FALCON machine**
  - **Moose-Bison-Marmot**
- **Visit nsuf.inl.gov under Research Capabilities tab for details at individual facilities**

NSUF and GAIN

Gateway for Accelerated Innovation in Nuclear (GAIN)



High Impact Nuclear R&D

Project portfolio spans a variety of research objectives that are ultimately focused on both near and long-term technology development goals

- **Understanding atomic level phenomena in fuels that affect thermal transport, elemental migration/diffusion, interface interaction, etc. as complex microstructures develop under irradiation**
  - **ceramic, metallic, TRISO, ATF**
- **Understanding fundamental defect evolution in irradiated structural materials across multiple length scales as they affect mechanical properties.**
  - **RPV, austenitic, F/M, Zr alloys, ATF**
- **Development of innovative radiation resistant materials for advanced reactor systems**
- **Development of radiation resistant sensors for collecting high fidelity on-line irradiation test data**
- **Development of materials from advanced manufacturing techniques**
- **Providing fundamental actinide nuclear data that can help inform advanced reactor and fuel cycle modeling and simulation campaign.**

J. Cole contributed to content of slide

Infrastructure Management Program

- NSUF created a searchable and interactive database of all pertinent infrastructure supported by, or related to, the DOE Office of Nuclear Energy (DOE-NE).
- Database known as the Nuclear Energy Infrastructure Database (NEID) and is located at nsuf-infrastructure.inl.gov (public launch Nov 2015)
- Used for analyses to identify needs, redundancies, efficiencies, distributions, etc., to best understand the utility of DOE-NE's available infrastructure, inform the content of infrastructure calls, and provide information to NSUF users.
- Infrastructure information collected can be combined with information on R&D needs as part of infrastructure gap analysis

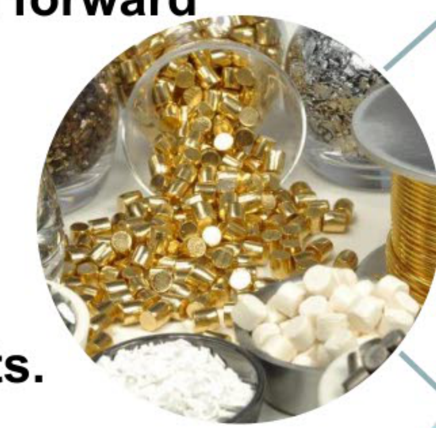
U.S. DEPARTMENT OF ENERGY
Nuclear Energy

Nuclear Fuels and Materials Library (NFML)

Nuclear Science User Facilities

- Provides irradiated samples for users to access for experimentation through one of the competitively reviewed proposal processes.
- Critical to reducing costs and taking advantage of new ideas and future analysis techniques and equipment.
- The library includes over 3500 specimens as part of the NSUF awarded research. 6K – 7K additional specimens by year end.
- Most materials in NFML neutron irradiated with small number ion irradiated.
- SAM irradiation series to stock library moving forward
- Effort to consolidate materials into easily accessible locations to reduce costs of retrieval.
- Web-based searchable database through nsuf.inl.gov (public launch Sept 14, 2016).
- Interest in collaboration on international efforts.
- <u>Materials Include:</u>

• Steels	• Pure materials
• Other alloys	• Actinides
• Ceramics	• Fission products



U.S. DEPARTMENT OF ENERGY
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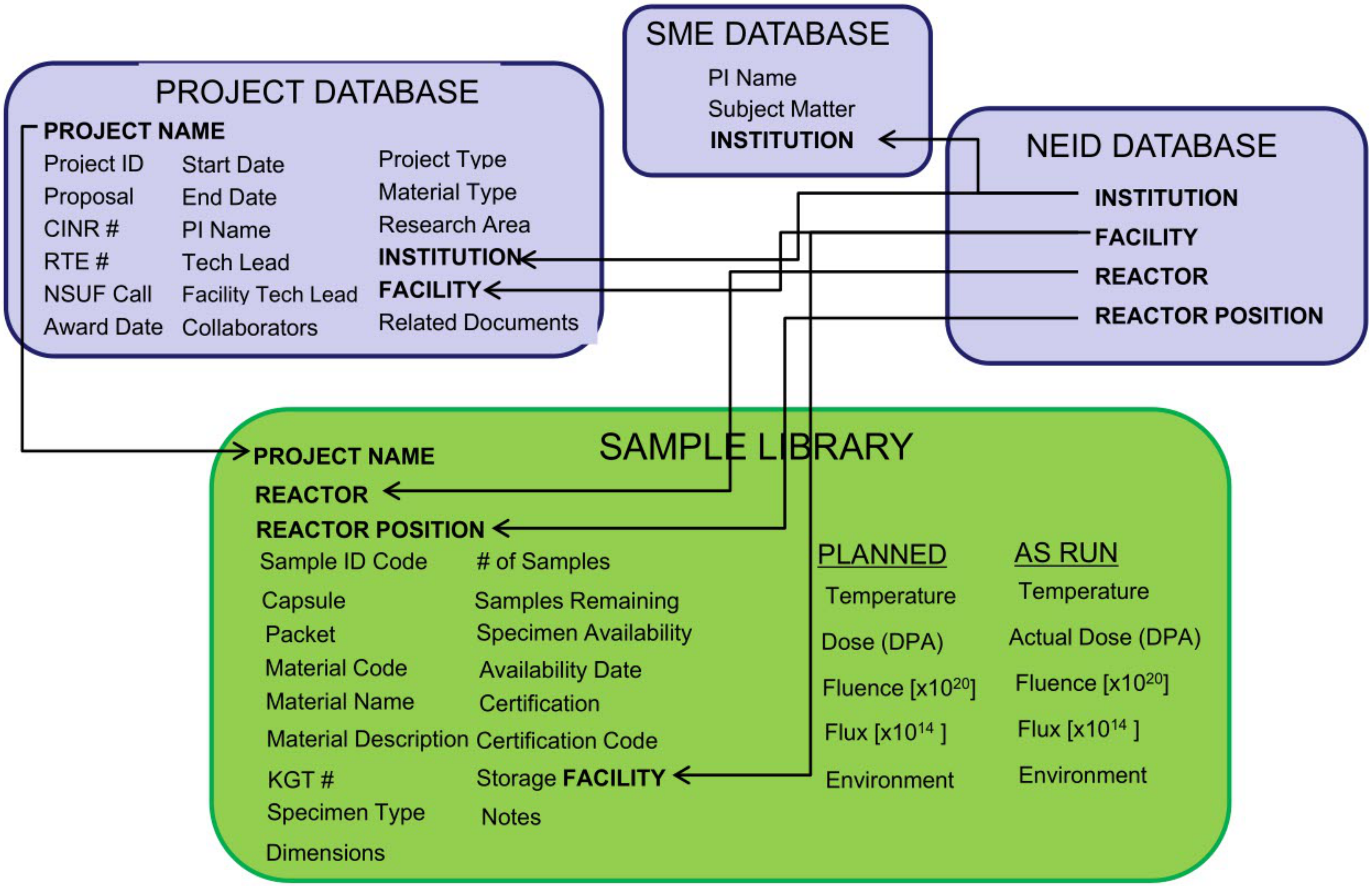
Databases Design

Nuclear Science User Facilities



NSUF

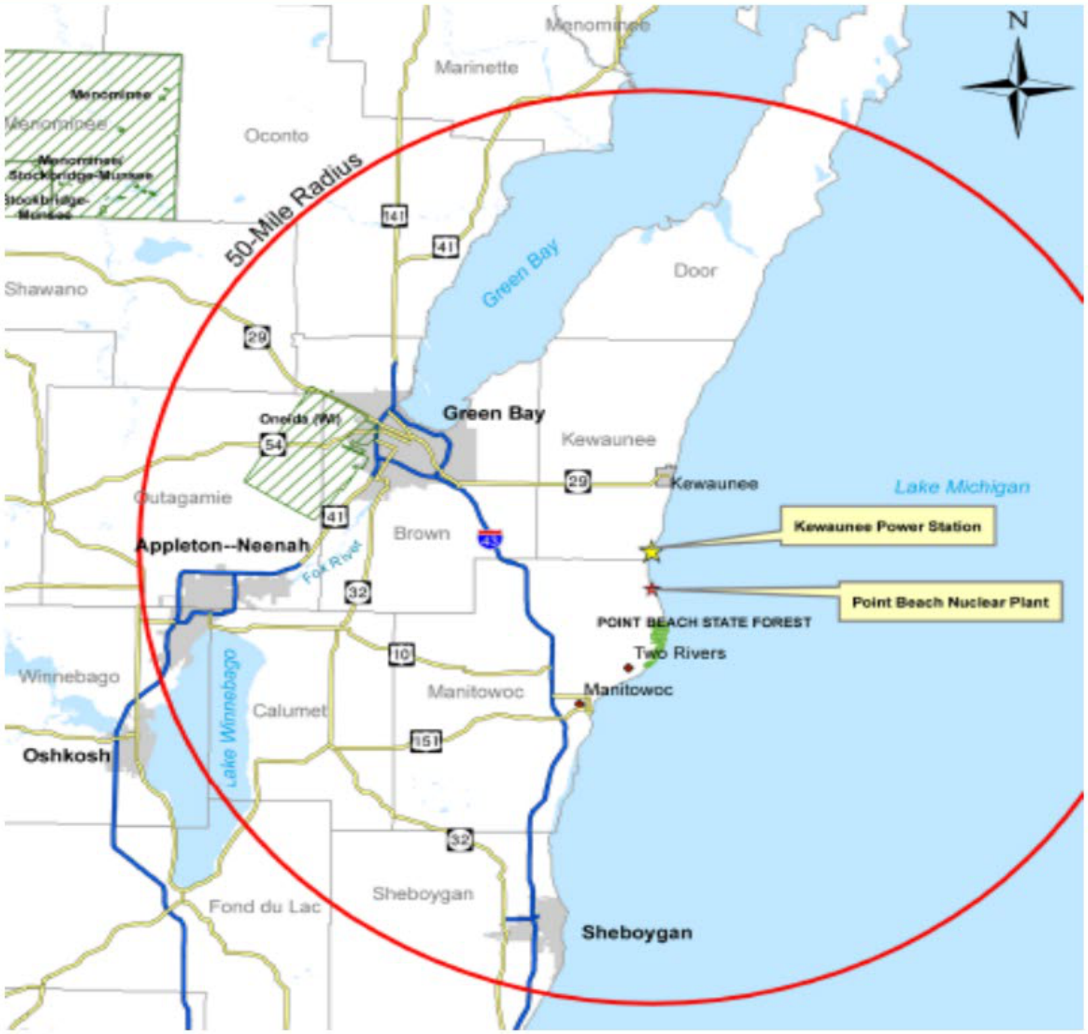
Nuclear Science
User Facilities

Dominion

Kewaunee Power Station

Insights on Material Harvesting

Kewaunee Power Station



Dominion

Kewaunee Power Station

Kewaunee Power Station

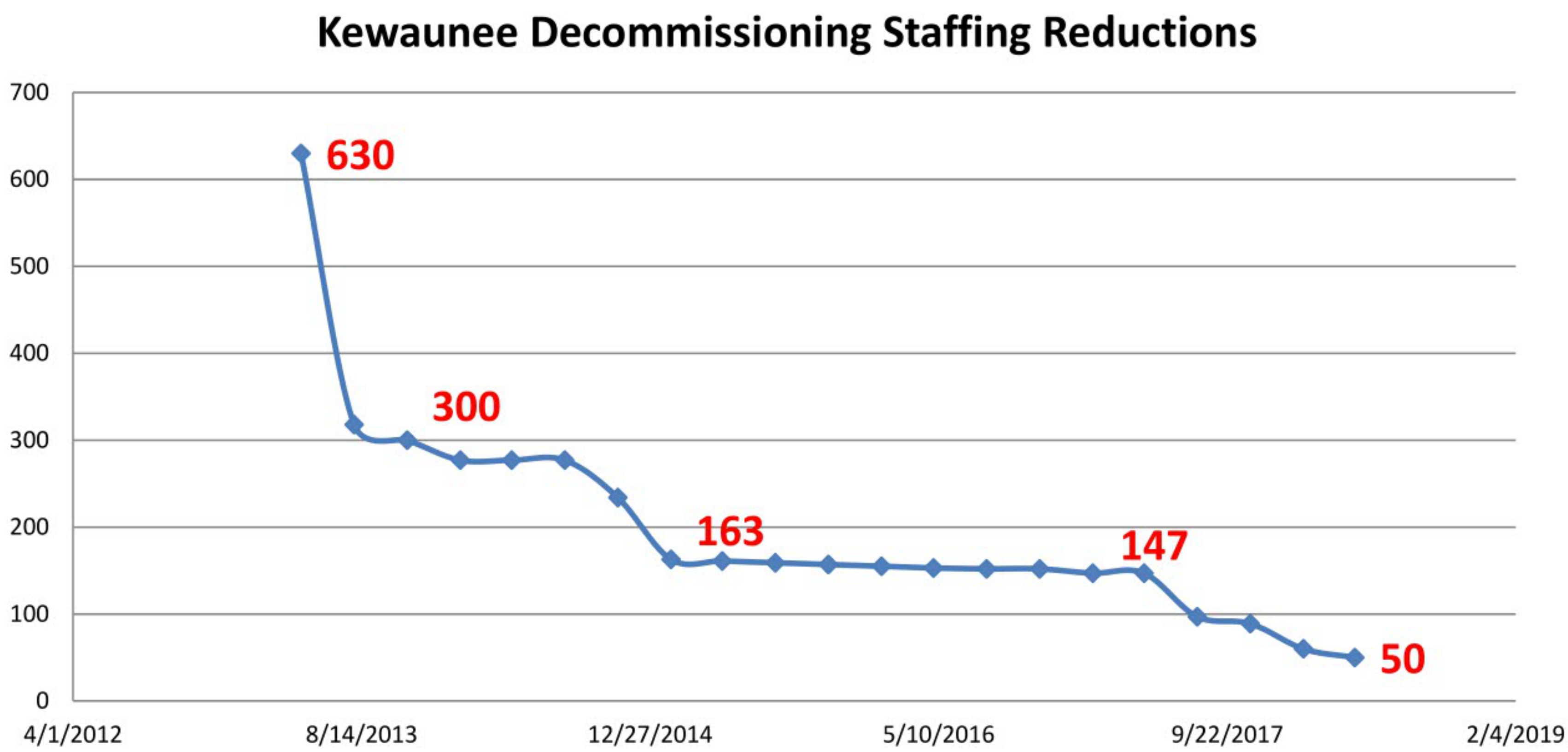
2-Loop Westinghouse PWR (590MWe)

• Construction permit	August 1968
• Operating license	December 1973
• Initial operating license expiration	December 2013
• Renewed Operating License Issued	February 2011
• Shutdown decision (unexpected)	October 2012
• Permanently Shutdown	May 2013
• ERO offsite response eliminated	November 2014
• All nuclear fuel in dry storage	July 2017

Kewaunee Perspective

- Top priority for decommissioning plants is **preserving and good stewardship of the decommissioning trust fund**
- Highest fund drain is staffing
- Station electrical use also expensive
- Initial decommissioning actions focus on safety and cost reduction.
  - ◇ Use initial required large staff to prepare plant for long term dormancy and decommissioning
  - ◇ Abandon or downsize equipment to reduce ongoing costs.
  - ◇ Then reduce staff commensurate with reduction in risk

Kewaunee Power Station



Kewaunee Perspective

- Timing is everything!
- Perhaps best discussed via an example:
  - ◇ Reactor vessel surveillance capsules
  - ◇ Two remain in the vessel
  - ◇ Logistical considerations:

Dominion

Kewaunee Perspective

- Circulating Water pumps were high energy consumers
- Therefore we wanted to retire them as soon as possible
- Circulating Water pumps were high capacity, low head, very good at dilution for meeting ODCM requirement for radiological discharges
- Without CW pumps, much smaller capacity service water pumps will be used in the future for dilution..

Kewaunee Perspective

- Therefore – prior to retiring CW pumps, we processed as much radioactive water as possible
- This included draining the RCS
- RCS at Kewaunee has no loop isolation valves
- RCS today is drained to the bottom of the cold legs, about 7 feet below the RV flange
- RV internals are installed, RV head is on the vessel, flux thimbles are installed in the vessel

Kewaunee Perspective

- So if we wanted to remove surveillance capsules today we would face unique challenges that would not have been present at initial plant shutdown:
  - ◇ Shielding – need to refill the RV (and cavity?)
  - ◇ Lifting the RV head and internals – polar crane is in place, but maintenance has been discontinued
  - ◇ Qualified staff – Crane operators, RP technicians, maintenance, operators
  - ◇ Rad monitors (many have been abandoned)
  - ◇ Ventilation and atmosphere control, lighting

Dominion

Kewaunee Perspective

- What generic issues could be resolved or simplified by harvesting and additional testing?
- GALL aging management program examples
  - ◇ Electrical cables and connections – test power cables taken from adverse localized environments
  - ◇ SG divider plates; autogenous welds
  - ◇ Buried piping;
  - ◇ Inaccessible power cables (buried; underground)

Additional Considerations

- Who will pay?
- Why is the material needed?
  - ◇ "What's in it for me?"
  - ◇ Are we solving an industry problem? (example – SFP neutron absorbing material GL 2016-01)
  - ◇ Objectively needing more information to determine if we have a new problem?
  - ◇ What's the plan? What is done with the information gathered? Is there a driver to review impact on existing programs?

Dominion

Additional Considerations

- Need to think ahead, plan ahead
- Some harvesting is very plant condition specific, others maybe not
- What plants will be entering decommissioning in the future?
- Have you reached out to them?
- Scope, Schedule, Budget

Dominion

Kewaunee Perspective

Importance of Harvesting to Evaluate Radiation Effects on Concrete Properties

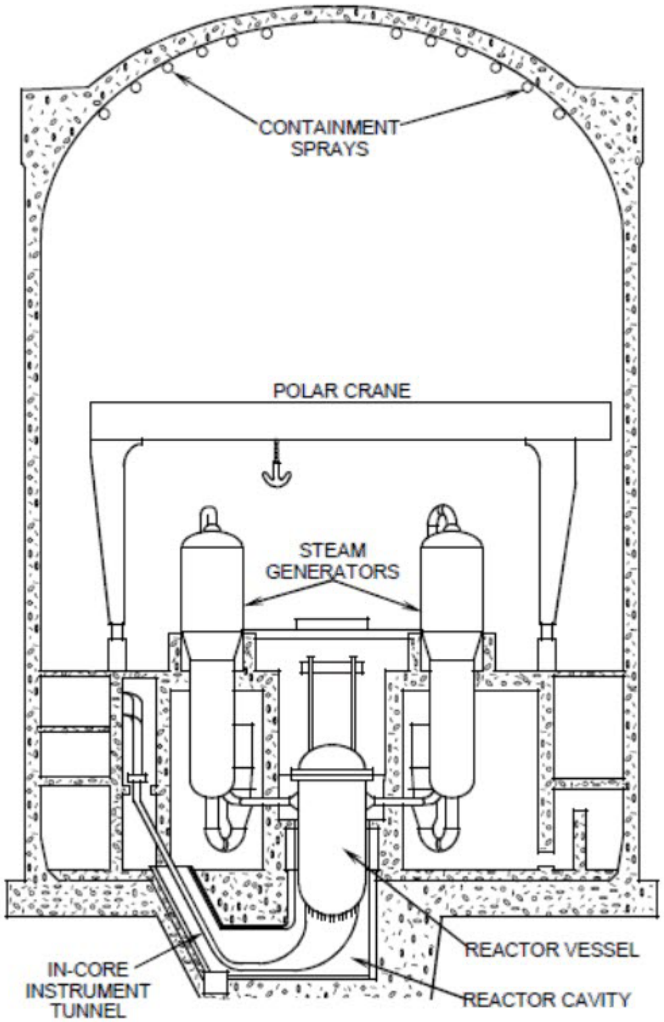
Arzu Alpan, Principal Engineer

Westinghouse

Nuclear Power Plant Concrete Structures

- There are various safety-related concrete structures in nuclear power plants (primary containment, containment internal structures, secondary containment/reactor buildings, other structures)

- Near the pressure vessel:
  - Biological shield concrete is placed around the pressure vessel to reduce radiation to allowable levels for humans
  - Some plants use concrete as the pressure vessel support structure



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Radiation Effects on Concrete

- The radiation types important for the concrete biological shield and reactor vessel support structure are gamma rays and neutrons

- Effects of radiation on concrete for long-term nuclear power plant operation has been of interest to various organizations

- Radiation effects on the properties of concrete depend on the intensity of the radiation field, period of exposure, and concrete composition

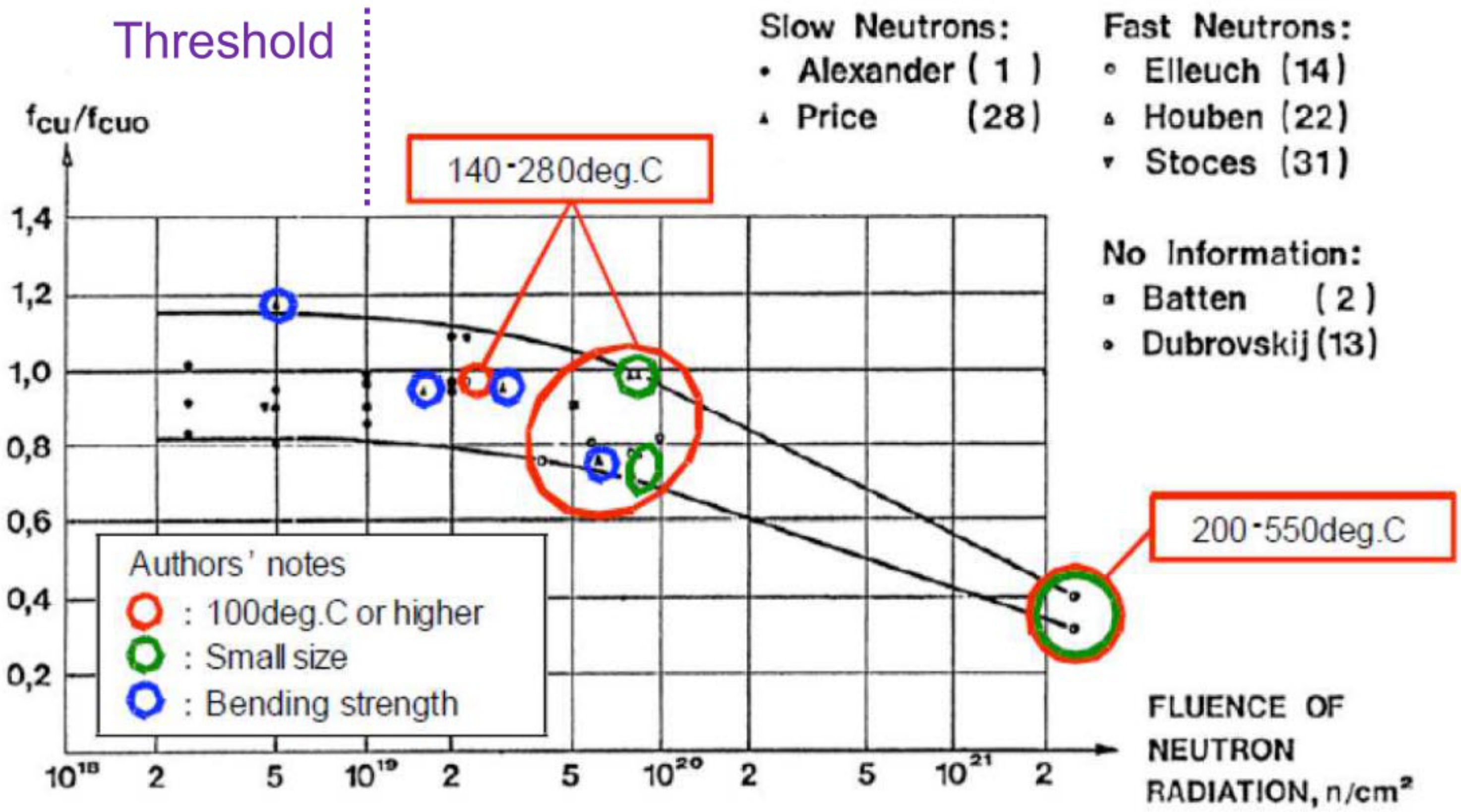
- Radiation affects concrete properties such as compressive and tensile strength, modulus of elasticity, creep, volumetric variation

Westinghouse

Radiation Effects on Concrete

- Effects of radiation on concrete has been addressed in various reports; the work by Hilsdorf et al. (1978) is cited frequently:
  - H.K. Hilsdorf, J. Kropp, and H.J. Koch, "The Effects of Nuclear Radiation on the Mechanical Properties of Concrete," American Concrete Institute Special Publication SP-55, 223-251 (1978)
- The change in compressive strength under neutron radiation exposure was selected for evaluation for this presentation, from the work by Hilsdorf et al. (1978)
- Purpose is to find a threshold radiation level where significant strength reduction will occur

Compressive Strength of Concrete Exposed to Neutron Radiation - Hilsdorf et al (1978)



NUREG/CR-7171, ORNL/TM-2013/263, “A Review of the Effects of Radiation on Microstructure and Properties of Concretes Used in Nuclear Power Plants,” November 2013

Need for New Data for Irradiated Concrete

- Data providing information on the effect of radiation on concrete properties are limited and an expansion of the irradiated concrete database is needed

- New data should be representative of conditions associated with nuclear power plants, indicating the need to obtain and test concrete samples from shutdown nuclear power plants

- Furthermore, reliable fluence data from radiation transport calculations is also needed

- Reliable fluence data is achieved by dosimetry measurements
  - Measurement data validates the radiation transport calculational methodology and determines the uncertainty in fluence calculations

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Neutron Dosimetry for Reactor Pressure Vessel Fluence Calculations

- Reactor pressure vessel fluence calculational methodology validation and uncertainty determination is obtained from:
  - Surveillance capsules
  - Pressure vessel clad sampling
  - Ex-vessel neutron dosimetry (EVND)

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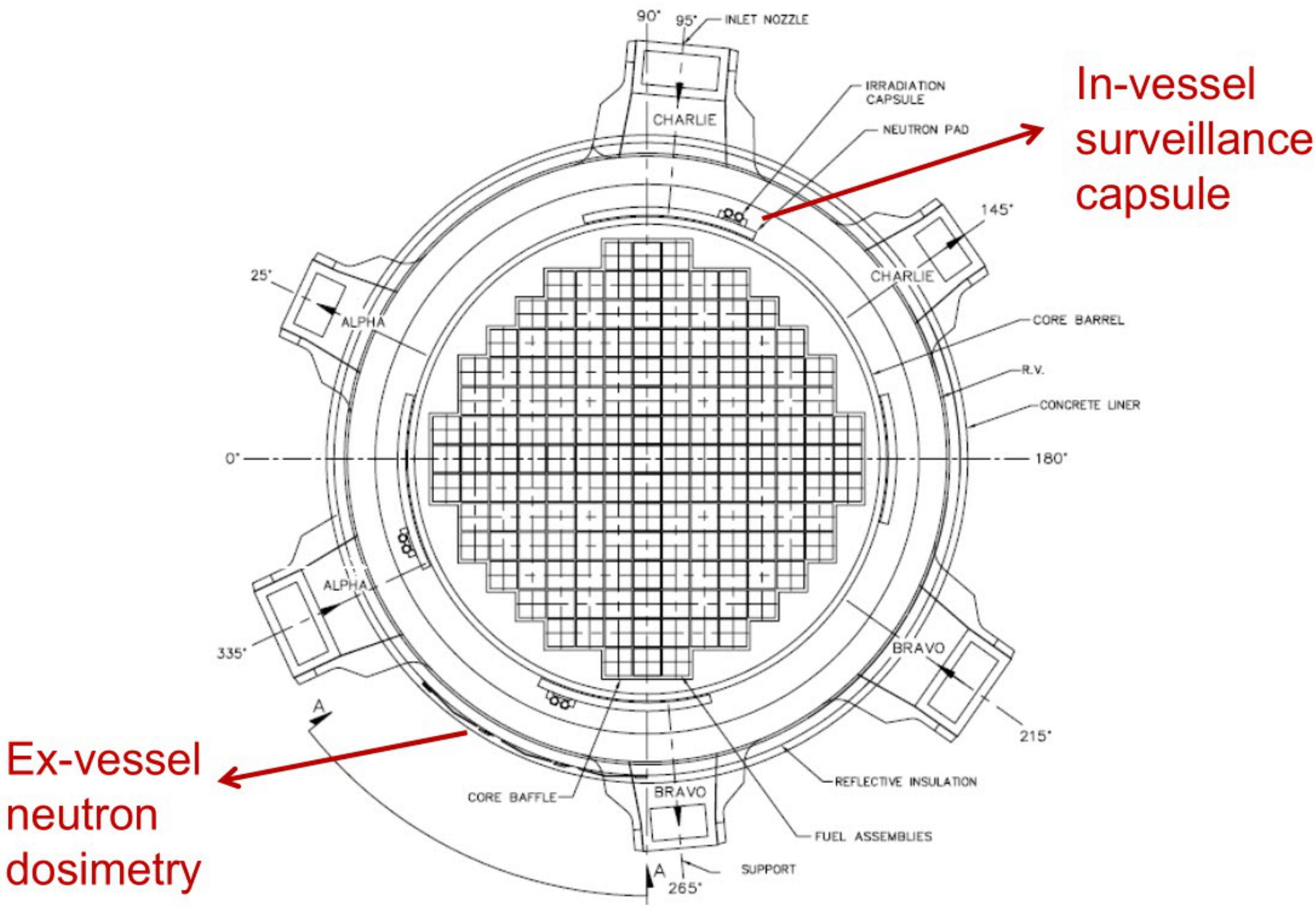
In-Vessel and Ex-Vessel Neutron Dosimetry Plan View



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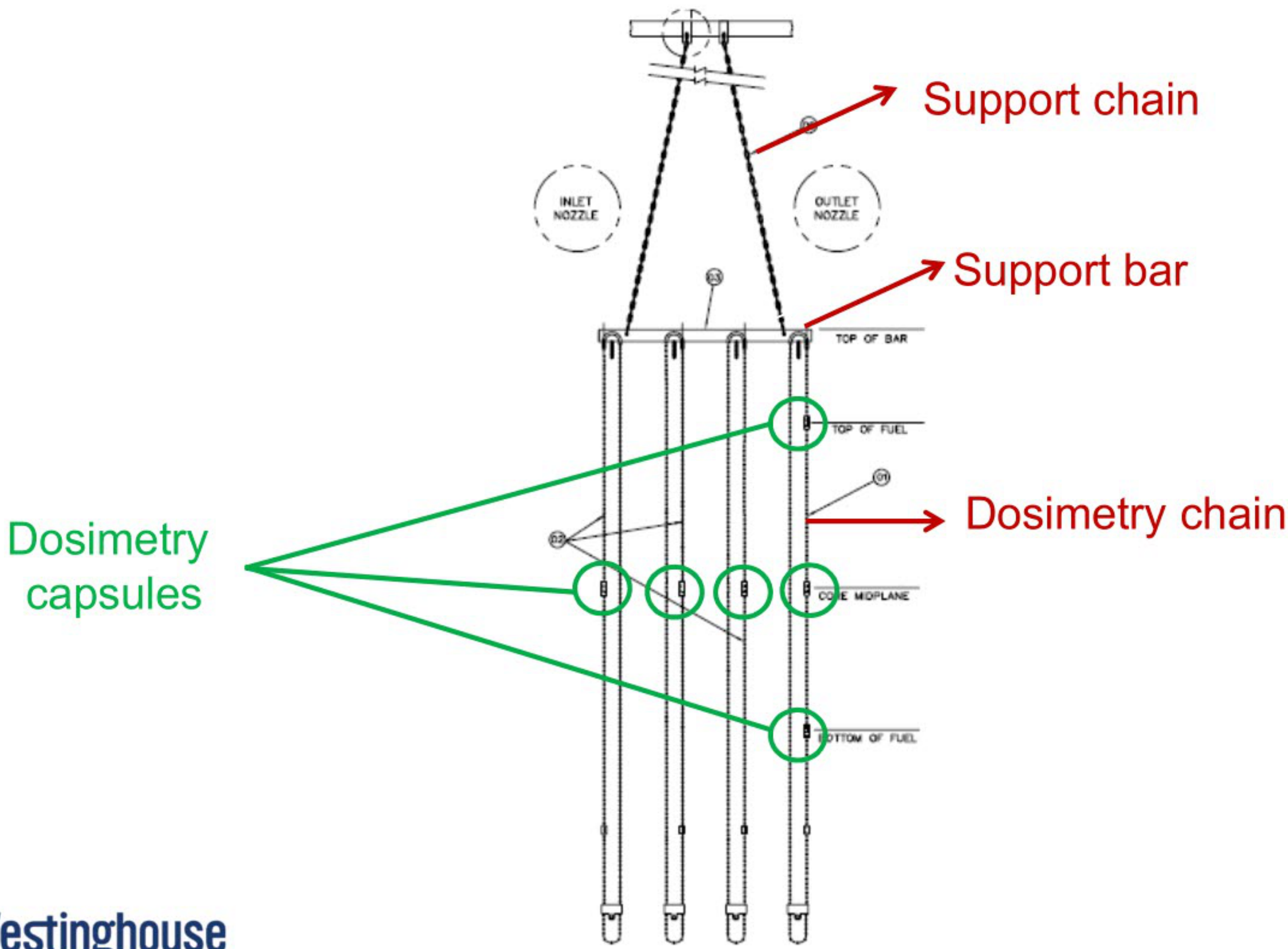
Ex-Vessel Neutron Dosimetry Section View



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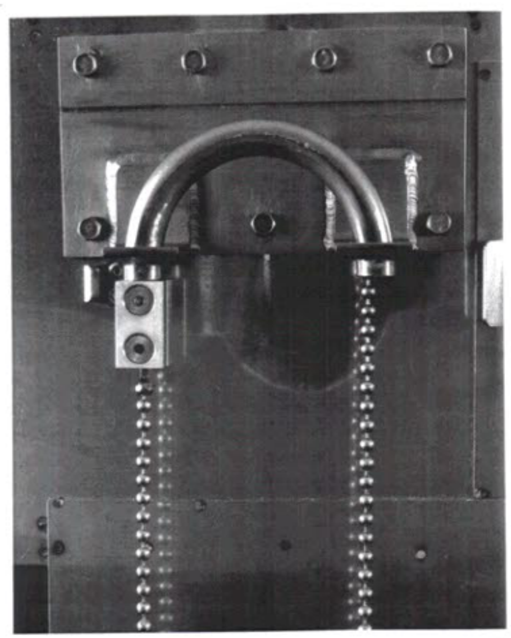
Ex-Vessel Neutron Dosimetry

Support Bar



U Tube on Support Bar

EVND Capsule

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Ex-Vessel Neutron Dosimetry

Westinghouse has successfully provided ex-vessel neutron dosimetry programs to nuclear plants since 1974, including:

- Almaraz • Asco
- Beaver Valley • Braidwood • Brunswick • Byron
- Callaway • Catawba • Comanche Peak • Connecticut Yankee
- Diablo Canyon
- Farley
- H. B. Robinson
- Kori • Krsko
- McGuire • Mihama
- Palisades • Point Beach
- Ringhals
- South Texas • St. Lucie
- Turkey Point
- Ulchin
- Vogtle • V. C. Summer • Vandellos
- Wolf Creek
- Yonggwang (Hanbit)
- Zion

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Neutron Dosimetry Measurements for Concrete

- Similar to the pressure vessel fluence analysis, fluence calculations for concrete should utilize measurements for calculational methodology validation and fluence uncertainty determination

- Since EVND is installed at the cavity in front of concrete, it provides dosimetry measurement data useful for concrete fluence calculations

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Conclusions

- Data on irradiation effects on concrete properties are limited; existing data has deficiencies and may be non-representative of the conditions associated with nuclear power plants

- New data is needed to evaluate irradiated concrete degradation; this is best achieved through testing concrete samples obtained from nuclear power plants

- Materials testing data are coupled with fluence data in the evaluation of irradiated concrete degradation

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Conclusions

- Neutron dosimetry measurements should be used in qualifying the fluence calculational methodology and determining the uncertainty in fluence calculations for concrete
  - EVND is appropriate to use for concrete fluence calculations
  - A potential nuclear power plant to harvest concrete that also has neutron dosimetry measurement data will be discussed in Session 3

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Potential Harvesting of Concrete from Mihama Unit 1

Arzu Alpan, Principal Engineer

Westinghouse

Concrete Harvesting / Testing / Fluence Analysis

- Harvesting of concrete from nuclear power plants is needed to understand the mechanisms that cause radiation damage

- Materials testing data is used with exposure data to evaluate irradiated concrete degradation

- It is important to validate the fluence calculations using measurement data

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Mihama Unit 1 Neutron Dosimetry for Concrete

- Westinghouse installed and analyzed neutron dosimetry for one fuel cycle at Mihama Unit 1 at the reactor cavity in front of concrete and away-from-reactor side (back of) concrete

- The dosimetry measurements were used to validate the radiation transport calculations and estimate the water content of concrete at Mihama Unit 1

- Other dosimetry measurement data (e.g. from surveillance capsules) could be used as supplemental data to validate the radiation transport calculations

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Opportunity to Harvest Concrete from Mihama Unit 1

- Mihama Unit 1 was shutdown in 2015
  - Kansai submitted its decommissioning plan to the Nuclear Regulation Authority (NRA)
- Westinghouse is in communication with Kansai to investigate the possibility of extracting cores from the concrete biological shield of Mihama Unit 1

Collaboration Possibilities

- Westinghouse allocated internal funding to investigate the possibility of harvesting concrete from Mihama Unit 1 and explore feedback from the industry, with the expectation of external funding to complete the project
- We would like your feedback on this possible opportunity and determine if there is an industry interest for this work

Westinghouse