SAND2016-11152PE

Used Fuel Disposition Campaign

Advanced Sensors and Instrumentation: Used Nuclear Fuel Program Storage and Transportation Overview

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2016 DOE NE Advanced Sensors and Instrumentation Webinar

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Current Status

- **The Spent Fuel and Waste Storage and Transportation (SFWS&T) Program is not directly funding sensor or instrumentation development at this time.**
- **DOE is funding development work through NEUP Integrated Research Programs (IRPs). These activities address two needs:**
  - *Non-Destructive Detection (NDE) and characterization of chloride-induced stress corrosion cracking (SCC) on the surfaces of spent nuclear fuel (SNF) stainless steel interim storage canisters within their overpacks.*
  - *Non-intrusive evaluation of dry storage canister/cask internals for degradation during and after extended storage, and also during and after nominal conditions of transport and hypothetical accident scenarios.*

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Active IRPs

Three active Integrated Research Projects (IRPs):

First year	***Title***	***Lead Institution***	***Total Funding***	***Project Description***
FY16	Innovative Approach to SCC Inspection and Evaluation of Canisters in Dry Storage	Colorado School of Mines (CSM)	$3M	Goals: (1) utilize experimental studies of stress corrosion crack initiation and growth to develop improved prediction of SCC damage of SNF dry storage canisters; (2) develop improved NDE methods for detection and monitoring of canister SCC within the overpacks.
FY16	Multimodal Nondestructive Dry Cask Basket Structure and Spent Fuel Evaluation	University of Mississippi	$3M	Develop non-intrusive techniques to monitor the structural integrity of canister internals and spent fuel in interim storage casks. Proposed NDE techniques are emmission source tomography, acoustics-based methods, and muon imaging
FY17	Cask Mis-Loads Evaluation Techniques	University of Houston	$3M	Develop nonintrusive techniques to evaluate the structural integrity of canister internals and spent fuel in interim storage casks following nominal conditions of transport and hypothetical accident scenarios. Proposed NDE techniques are time-tagged neutron interrogation, elastodynamic waveform tomography, and non-invasive acoustic sensing.

Stress Corrosion Cracking of SNF Interim Storage Canisters

Background

- An increasing fraction of commercial SNF in the U.S. is stored in on-site dry storage systems that were initially licensed for 20-40 years, with the possibility of future renewals.
- Given the current status of the U.S. repository program, under all foreseeable scenarios, some SNF will remain in interim storage for much longer than the original design specifications for the storage systems.
- The majority SNF in dry storage is stored in stainless steel canisters placed in passively-ventilated concrete, or concrete and steel, overpacks.
- Salts entrained in the air are deposited on the canister surface, and over time as the canister cools, will deliquesce to form potentially corrosive brine films. SCC may initiate, and because of potentially long interim storage times, could eventually penetrate the canister wall ($^{1}/_{2}$″ to $^{5}/_{8}$″ thickness).

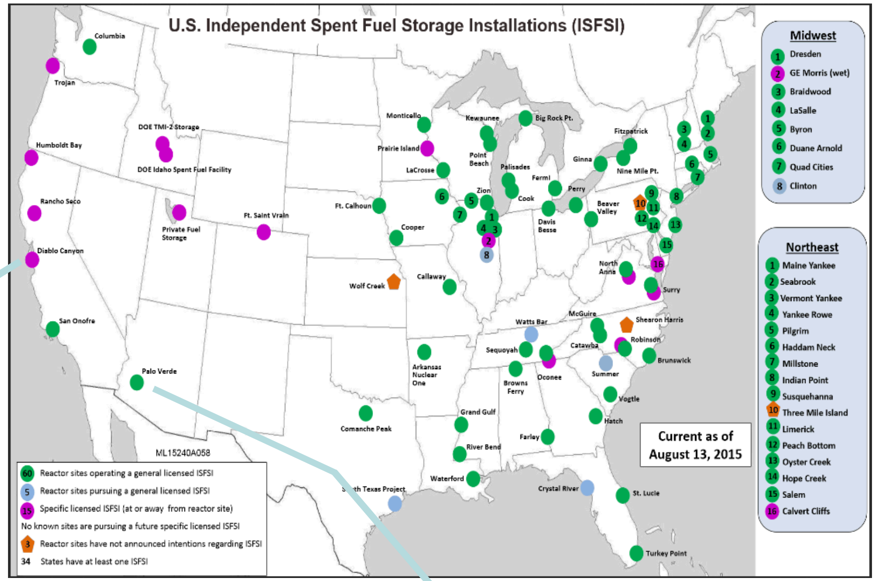
Improved understanding of the risk of SCC of interim storage canisters has been identified as a critical data gap in analyses by the DOE, Nuclear Waste Technical Review Board (NWTRB), Electric Power Research Institute EPRI).

ISFSI Locations in the U.S.

Possible deposition of chloride-containing salts

Atmospheric salt aerosols

- Near-marine
  - Component of sea salt in dust/aerosols
  - Deliquescent brines potentially chloride-rich, corrosive
- Inland
  - Salts largely derived from anthropogenic activities and terrestrial sources
  - Ammonium, sulfate, and nitrate-rich aerosols.
  - *However, possible chlorides from cooling tower emissions, road salts*



Source: U.S. NRC website, downloaded 7/10/2016

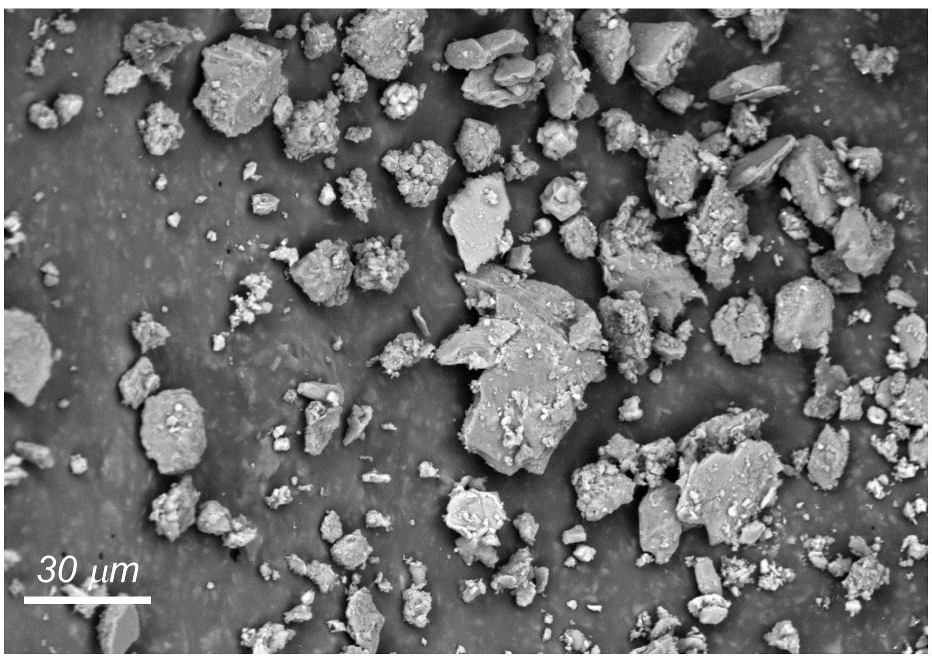
Diablo Canyon Nuclear Plant

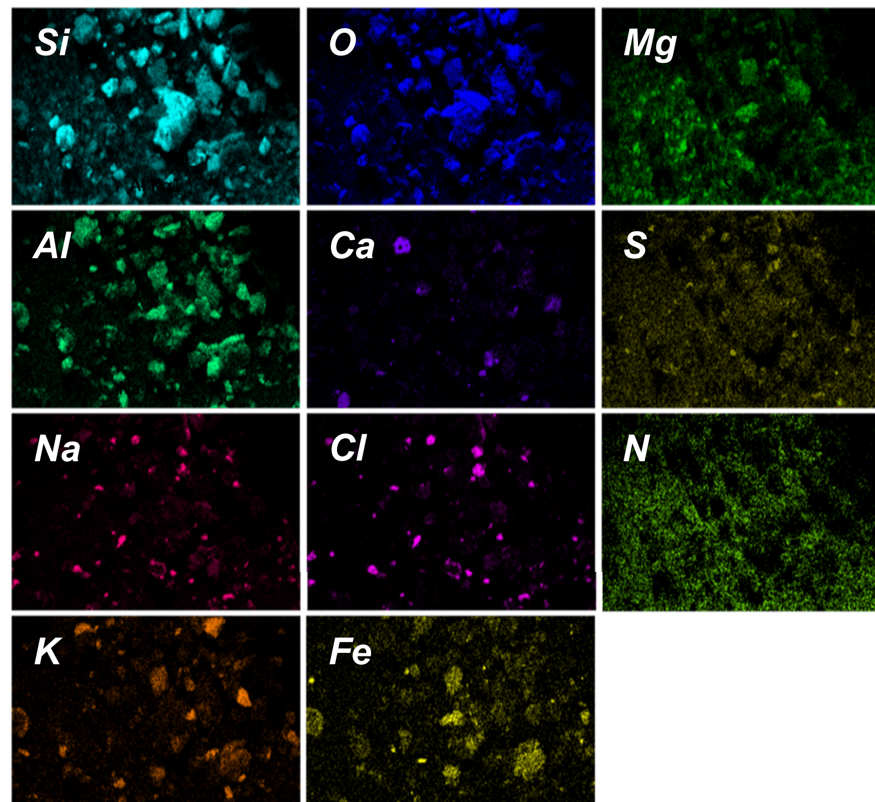
Palo Verde Nuclear Plant

Example Near-Marine Site:
Canister Surface Dusts at Diablo Canyon

- *Canister sides lightly coated, tops more heavily coated.*
- *Dust dominated by insoluble minerals (quartz, clays, aluminosilicates), but chloride-rich soluble salts are abundant, present as sea-salt aggregates.*

As canisters cool, these salts will eventually deliquesce, producing a potentially corrosive brine.





Non-Destructive Evaluation of Storage Casks for SCC

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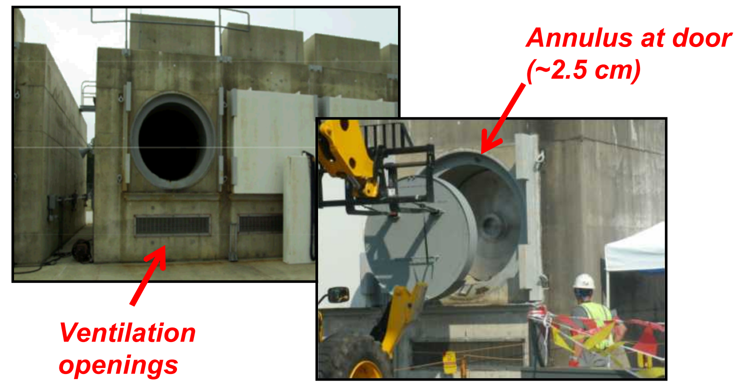
Interim Storage Systems: Basic Designs

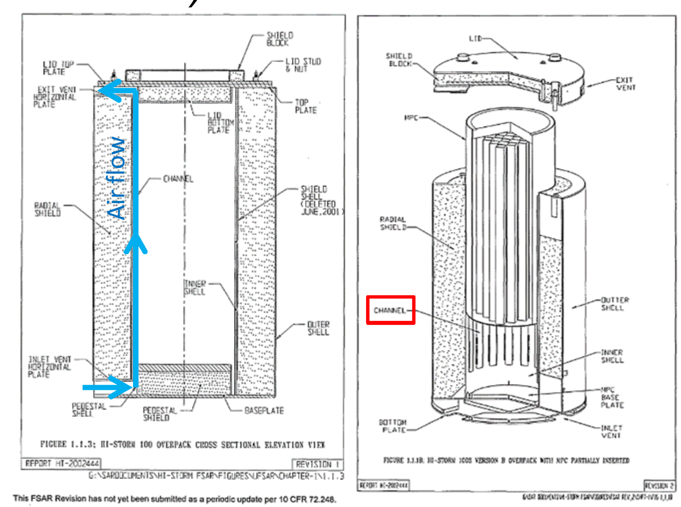
Horizontal Systems (~40% of total)



Vertical Systems (~60% of total)

Annulus between canister and overpack wall ~5-10 cm

Clearance at alignment rails ~ 1 cm



Storage systems: Access

Access to canister surfaces is NOT trivial!

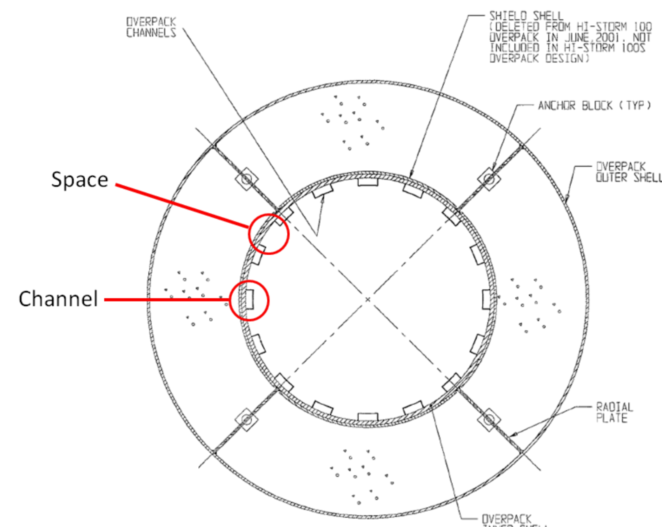
Difficulties

- ***Access extremely limited (air inlet and outlet vents, narrow annulus at door for vertical systems). Vents do not provide direct line of sight to avoid radiation shine. For some designs, tack-welded gamma shield must be cut loose and removed, and replaced at the end of the exercise***
- ***Inside, channels limit access to surface and make navigating difficult. However, narrow annulus (2-4 inches in vertical systems, depending on design) has benefits—helps constrain device location (provides surface to push against).***
- ***Access requires concerted effort of site operator, storage system vendor, and others. Dose plan must be developed, worker exposure monitored. (expensive—estimated dust sampling costs were ~$20K per sample)***

Removing the Gamma Shield

Sampling dust on a HI-STORM 100 canister at Diablo Canyon

Sampling with the remote sampling tool

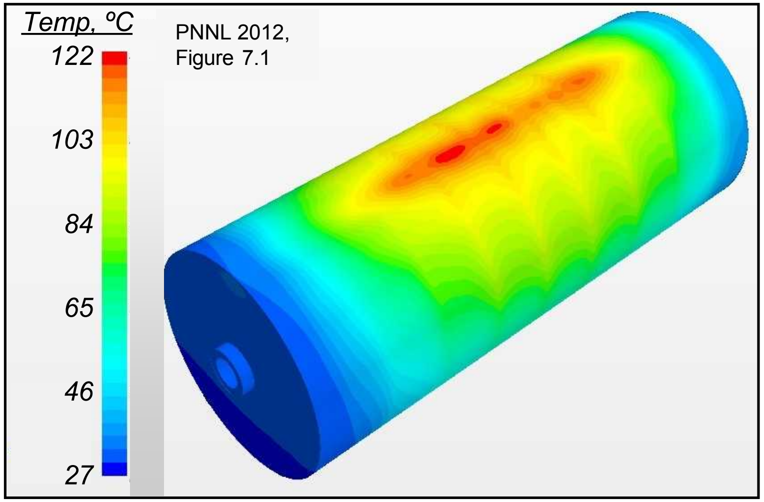


Storage systems: Environmental Factors

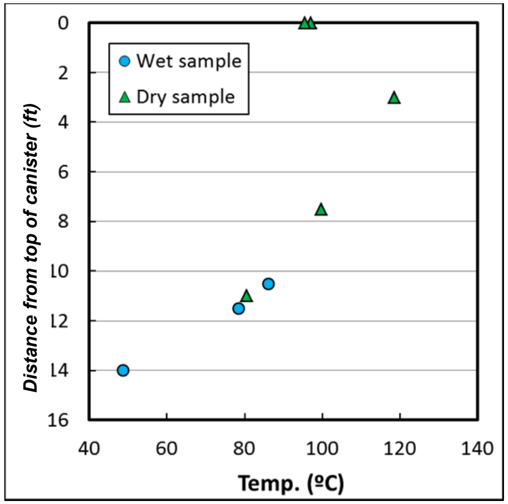
Environment

- ***High radiation levels (1000-10,000 Rem/hr on the canister surface) may affect equipment performance/lifetimes, and make removal of the canister from the overpack undesirable.***
- ***Canister surfaces will be dusty and dirty. Washing is not currently being considered (concern that salts will be washed into crevices, increasing the potential for corrosion).***
- ***For ultrasonic systems, use of couplants is currently not considered an option (perceived risk associated with leaving couplant residue on the canister surface).***
- ***Elevated and spatially variable canister surface temperatures:***

Modeled horizontal canister surface temperatures, fuel heat load ~7.61 kW.



Measured vertical canister surface temperatures, Diablo Canyon



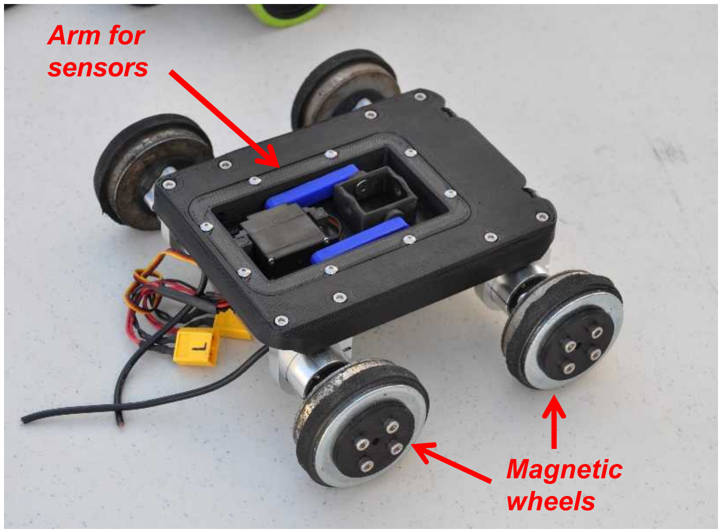
Current Efforts

- **NRC as requested ASME to develop a standard for NDE inspection of storage canisters within their overpacks. Current plans are to develop a standard for visual inspections (VT-1 an VT-3), because other technologies are not yet sufficiently developed.**
- **EPRI is working with industry to develop and test robotic deployment of ultrasonic and eddy current probes.**
- **Colorado School of Mines — evaluating use of non-contact ultrasonic methods.**

EPRI:

Tethered Robotic Delivery Systems: Magnetic Robot

Magnetic Robot
(Robotic Technologies of Tennessee)



Testing a magnetic robot on a storage system cutaway, Palo Verde Nuclear Plant Education Center

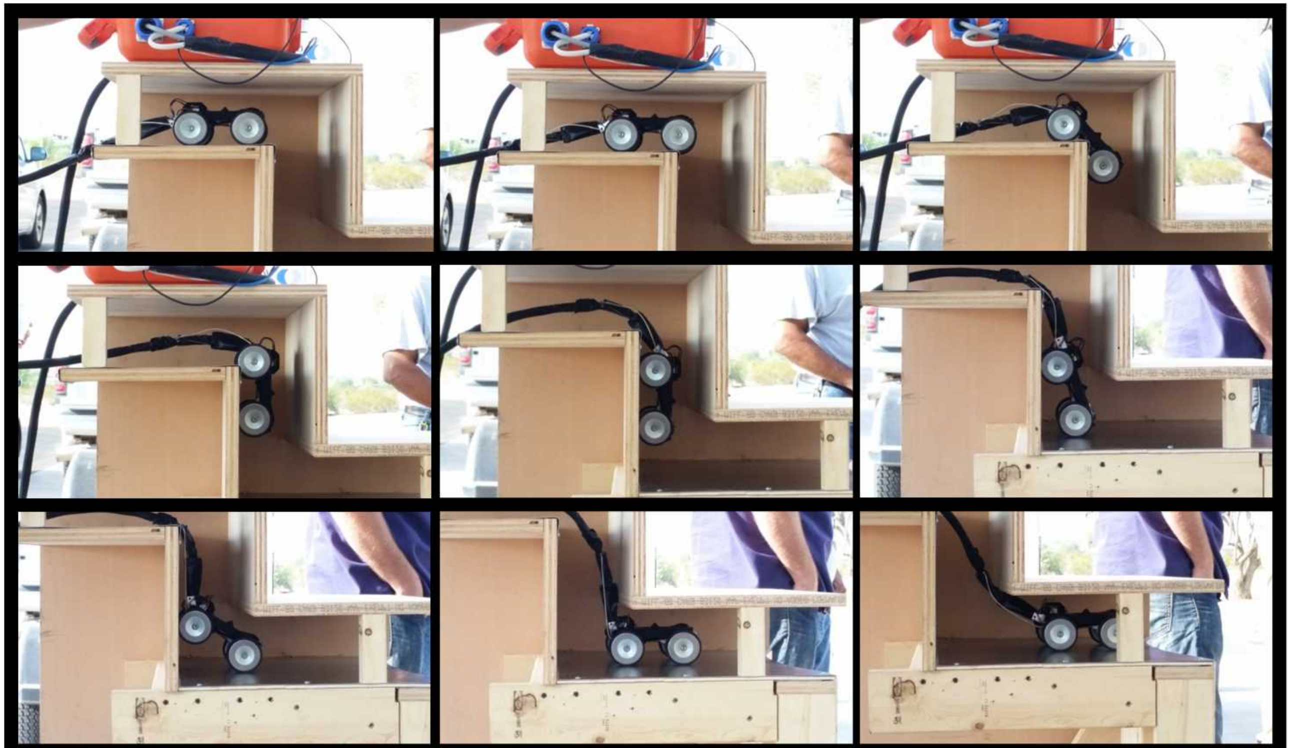
<u>Magnetic Robots</u>: *Robots with magnetic wheels can be used in storage systems that have a carbon steel-lined overpack*

- *Wheels contain powerful permanent magnets, allowing the robot to adhere to magnetic metals.*
- *Cannot be used on the canister itself (stainless steel is non-magnetic)*
- *Solenoid-driven arm presses NDE sensors onto metal surface*

EPRI:

Magnetic Robot Navigates Through a Mockup of an Overpack Exhaust Vent

Robot navigates two right-angle bends in a mockup of the vent channel



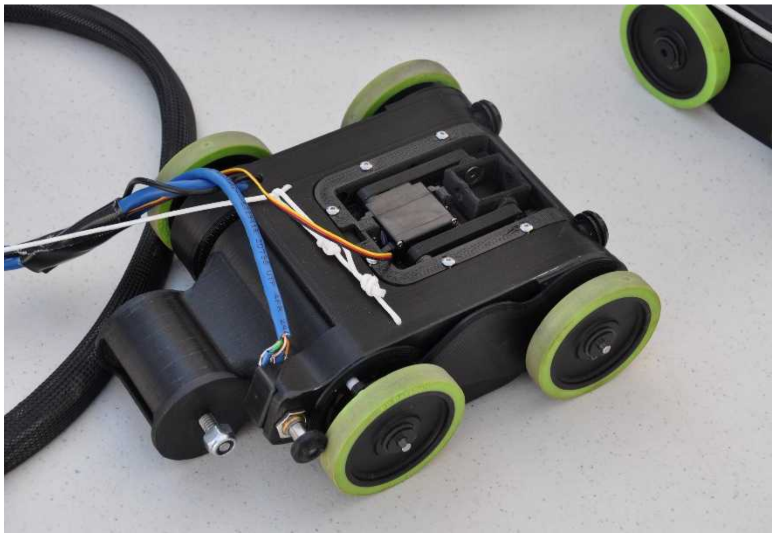
Magnetic robot (Robotic Technologies of Tennessee)

Robot rolls down overpack wall and enters annulus

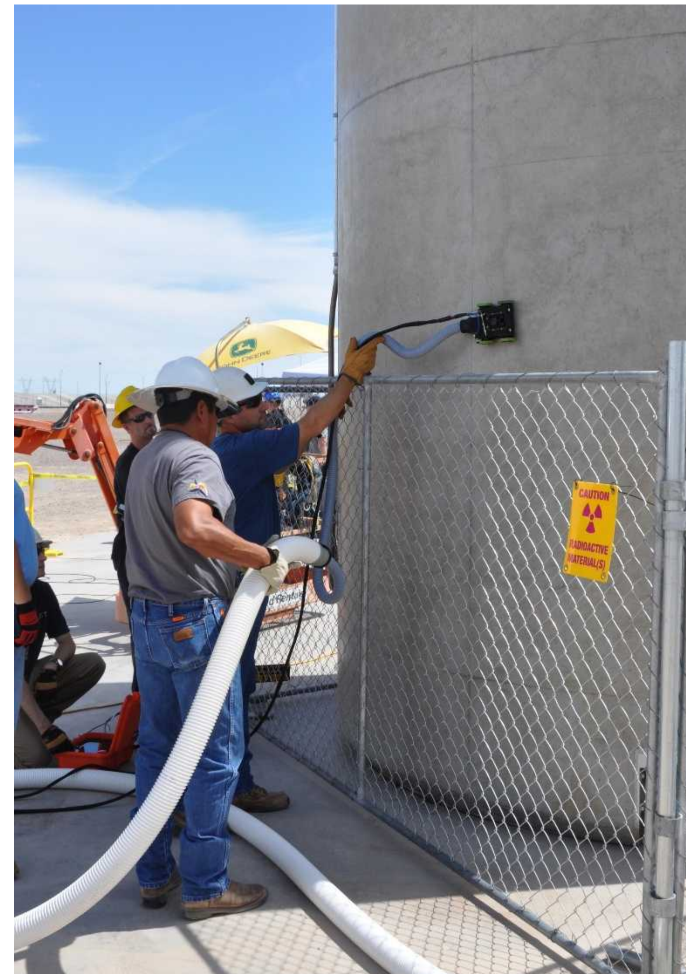
EPRI:

Tethered Robotic Delivery Systems: Vacuum Robot

Vacuum Robot
(Robotic Technologies of Tennessee)



Testing a vacuum robot on a storage system outer surface, Palo Verde Nuclear Plant



Vacuum Robots*: Robots use vacuum suction to adhere to any smooth surface*

- *Sliding panels along the sides form a shutter, allowing the robot to pass over right-angle corners.*
- *Size limitations preclude building vacuum into robot; a vacuum line is necessary.*
- *Ineffective so far. Vacuum line is heavy, and friction in the line limits suction efficiency.*

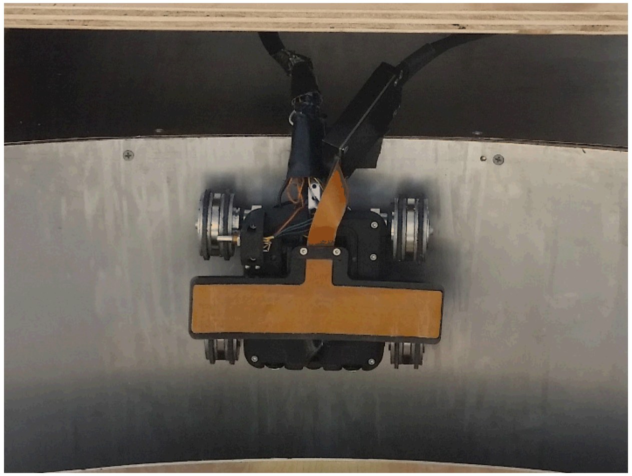
EPRI: NDE Sensors

NDE methods for SCC cracks currently being evaluated:

- Visual inspections
  - Efficiency may be limited by high radiation field
    - "Snow" in images
    - Electronics degradation and failure
- Eddy current sensors
  - Arrays of coils allow inspection of broad strips
  - Motion control and "lift-off" problems
- Ultrasonic inspections
  - No couplant can be used
  - Acoustic or magnetic coupling
  - Some types can look sideways, allowing inspection under rails

Ultimate goal—determining inspection intervals.

Flexible eddy current array sensor (Eddyfi, Inc.), on magnetic robot (Robotic Technologies of Tennessee)

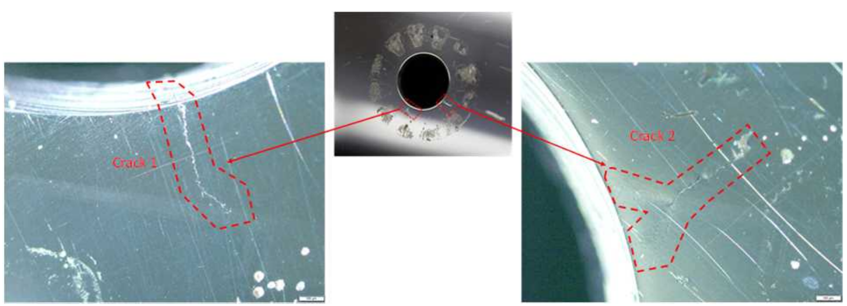


Magnetically coupled, side-looking ultrasonic sensor (Integrity Engineering, Inc.), on magnetic robot (Robotic Technologies of Tennessee)

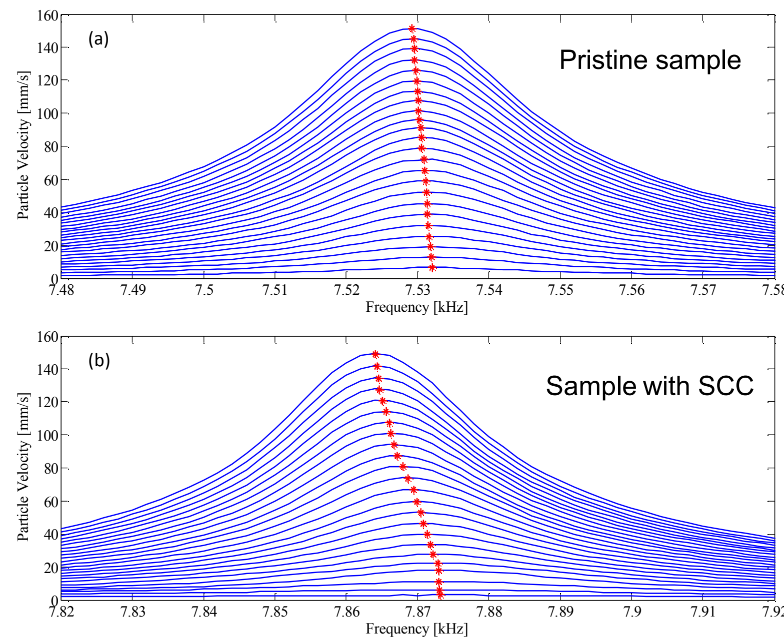
CSM IRP:
Sensor Development at LANL/BYU

- **Nonlinear Resonant Ultrasound Spectroscopy (NRUS)**
  - Sample is vibrated at one of its resonant frequencies with increasing vibration amplitude. A shift in resonance frequency with amplitude indicates the presence of a flaw.
  - A second technique must be used to determine the location of the flaw.

Images of SCC cracks in a corrosion test sample



Particle velocity spectra, 4th resonance mode



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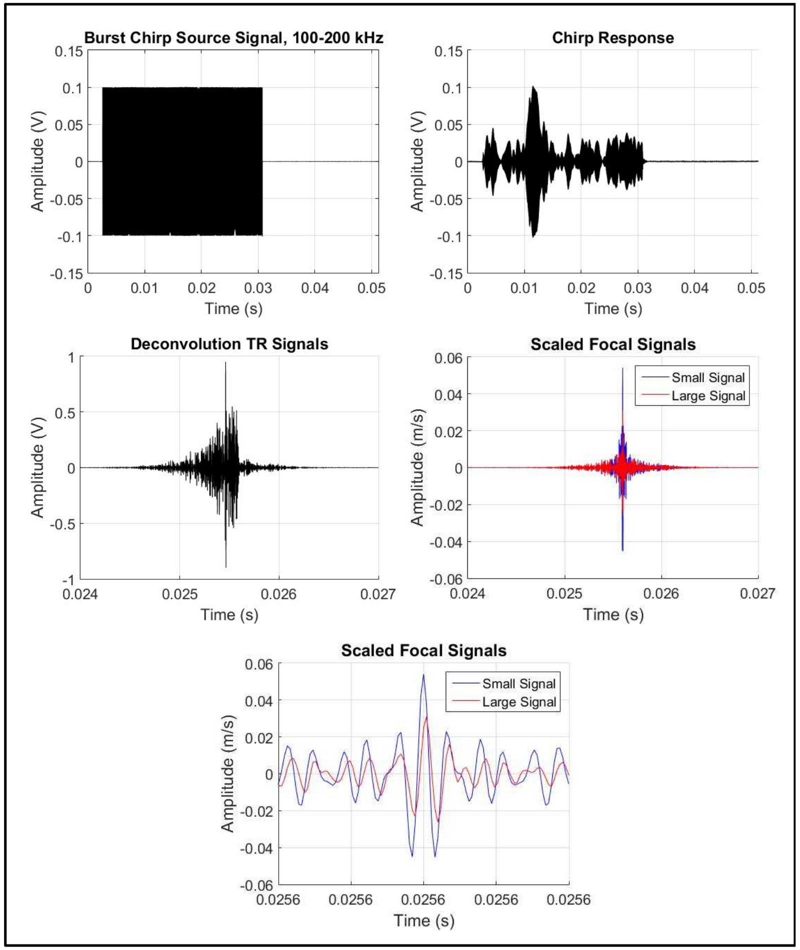
CSM IRP: Sensor Development

- **Time Reversed Elastic Nonlinearity Diagnostic (TREND)**
  - Source transducer(s) mounted on the sample broadcast an ultrasonic signal (a chirp), that is monitored at a given location using a laser vibrometer.
  - The chirp signal and the response signal are used to obtain a transfer function between the source and the receiver and to create a reversed impulse response.
  - The reversed impulse response is fed into the sample to create time reversal focusing.
  - Comparison of the responses when the reversed impulse response is broadcast at two different amplifications allows detection of local sample damage (SCC).

Example signals obtained using TREND on a SCC sample obtained from EPRI



Non-Destructive Evaluation of Storage Cask Internals During Storage and Transportation

University of Mississippi IRP:

Multimodal Nondestructive Dry Cask Basket Structure and Spent Fuel Evaluation (FY16-18)

External evaluation of the integrity of cask internals during storage. Three methods will be evaluated:

- **Emission source tomography**
  - Monitors penetrating radiation (gammas and neutrons) emitted by the fuel
  - Provides information about the source (the fuel) and the cask components between the source and the detectors
- **Acoustics and ultrasonic methods**
  - Both passive and active methods will be used to evaluate the integrity of cask internals
- **Muon imaging**
  - Interrogates cask internals by monitoring naturally-occurring muon fluxes though the cask.

University of Houston IRP:
Cask Mis-Loads Evaluation Techniques (FY17-19)

External evaluation of the integrity of transport cask internals during normal conditions of transport and hypothetical accident conditions. Three NDE techniques will be tested:

- **Time-tagged neutron interrogation**
- **Elastodynamic waveform tomography**
- **Noninvasive acoustic sensing**