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Nuclear Robotic Applications for Risk Mitigation:

The SRNL Experience

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EM & NSF Robotics Meeting
December 7, 2015

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Agenda

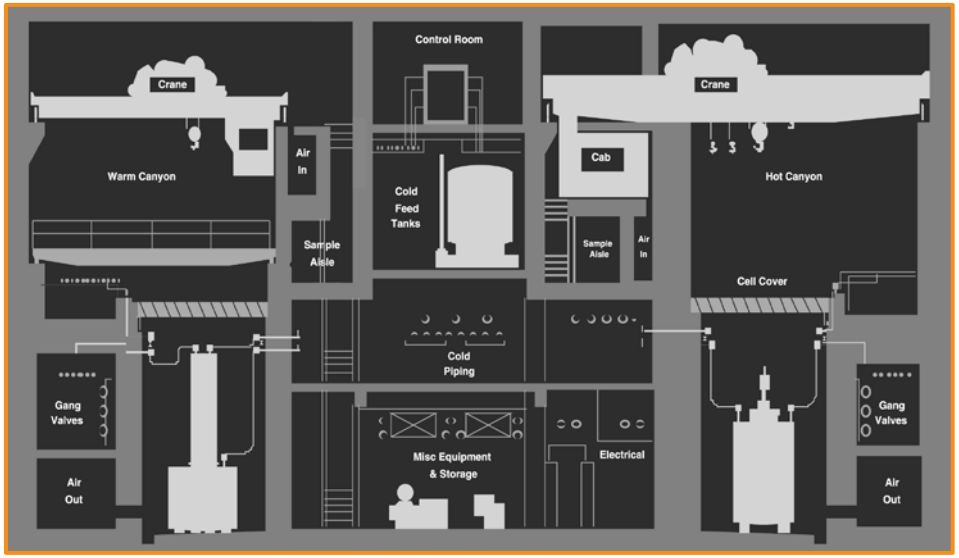
- Historical Perspective
- Key Challenges
- Application Examples
  - Typical requests
  - Specific projects
- Lessons Learned
- Observations / Future Needs

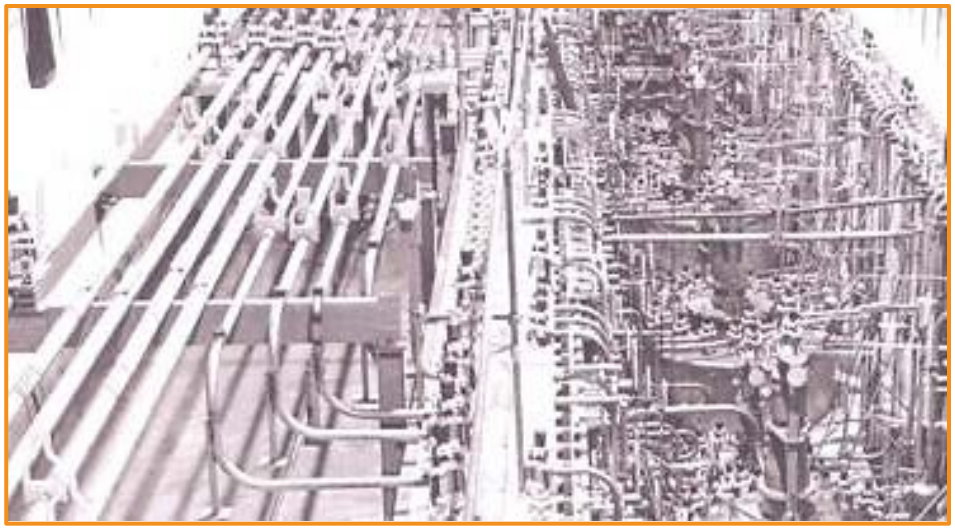
Historical Perspective – Robotics, Remote Systems and Risk Mitigation

Remote systems first used to handle high gamma, and high neutron dose materials:

- Spent Fuel / Fission Products

Electro mechanical systems, designed for frequent maintenance. Operator in the loop, visual feedback.





Canyon Crane Example

Proven capability for handling high gamma materials in special facilities

Historical Perspective – Robotics, Remote Systems and Risk Mitigation

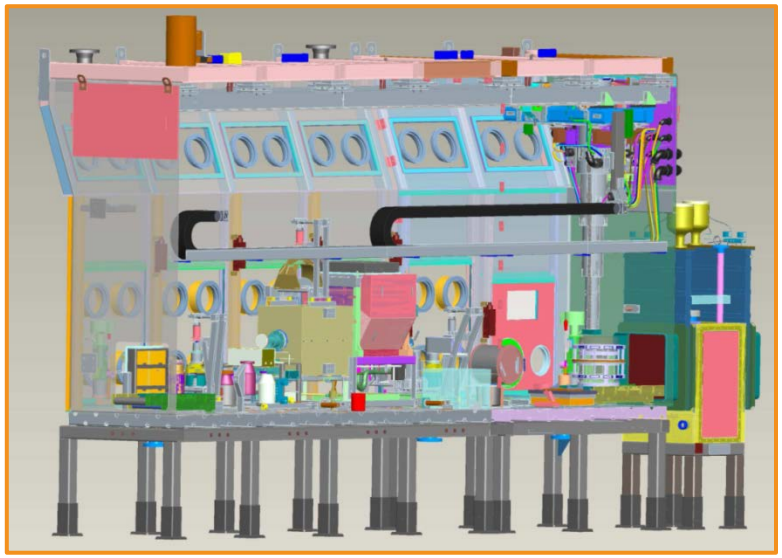
Gloveboxes for alpha/beta emitters

- Place equipment inside confinement boundary or build confinement around equipment.
- Limited by human ergonomics
- Guard against sharps, heat sources
- Limited manual dexterity

Operations require 2 added persons on station for one worker:

- Hands on operator
- Radiological control inspector
- Backup operator or supervisor

Glovebox equipment must be carefully designed



Historical Perspective – Risk Mitigation & Personnel Protective Equipment

Personnel Protective Equipment for contamination control:

- Lab Coat
- Coveralls (1 or 2 pair)
- Hood
- Booties w/ rubber overshoes
- Gloves (layers and types)
- Tape all garment joints
- Full Face Respirator
- Fresh Air Hood
- Fresh Air Suit

Personnel are trained, tested, and requalified on proper use and best practices

Equipment Provides Protection, but Comes with Hidden Costs

SRS Data: (12 months)

- > 228,500 pounds of Radiological Laundry (~$1,000,000)
- > 23,500 respiratory protection devices issued
- 4574 persons qualified as RAD Worker II
- 2343 persons fit tested for respiratory protection
- 25 training courses for 15 types of respirators
- 82 cubic meters of plastic suits disposed as rad waste

70 % max biological efficiency while performing plastic suit work

> 7300 glove ports in radiological glove boxes

- $400 / glove pair

Tens of $ Millions spent each year on Protective Equipment

Risk Factors

Traditional Factors:

- Radiation dose
- Contamination potential
- Release of nuclear material
- Nuclear criticality

Likelihood	Negligible	Marginal	Significant	Critical	Crisis
Very Likely	Low 5	Moderate 14	High 20	High 22	High 25
Likely	Low 4	Moderate 13	Moderate 16	High 21	High 24
Unlikely	Low 3	Low 8	Moderate 15	Moderate 18	High 23
Very Unlikely	Low 2	Low 7	Low 10	Moderate 17	Moderate 19
Non-Credible	Low 1	Low 6	Low 9	Low 11	Low 12

Consequence

Additional Factors that must be considered:

- Highest safety performance expectations
- Human reliability
- Cost of human staffing, training, supervision, oversight
- Efficiency
- Facility Aging / Equipment Life Extension
- Capital vs Operational funding

Noun	Range
Non-Credible	0%
Very Unlikely	0% to 15%
Unlikely	15% to 45%
Likely	45% to 75%
Very Likely	75% to 100%

Key Challenges

Remote hazardous environments

- Radiation, chemical, & physical hazards
- Unstructured environment or unknown conditions

Limited access

- Small entry port, long distances, circuitous routing

Tethered Systems

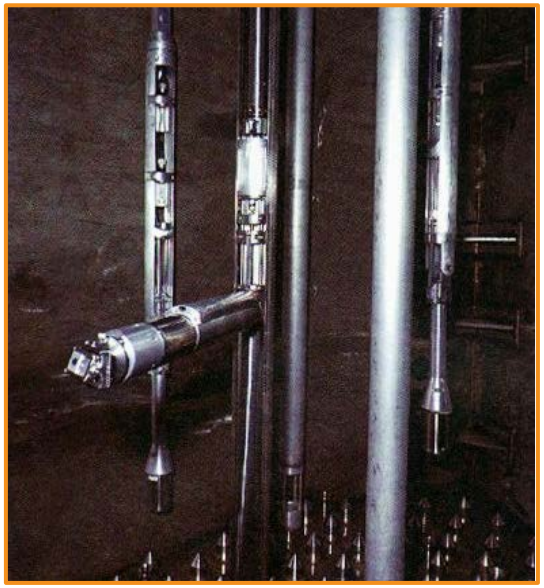
- Potential for tangling and catching

Untethered Systems

- Limited mission time due to battery power
- No retrieval if system fails
- Robust concrete structures limit wireless range

Radioactive contamination

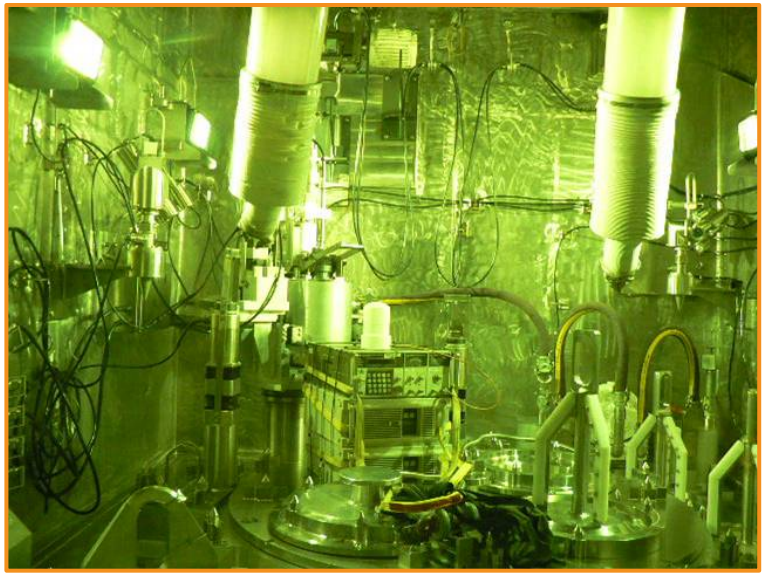
- Limited equipment reuse or maintenance



Application Examples – Typical Requests

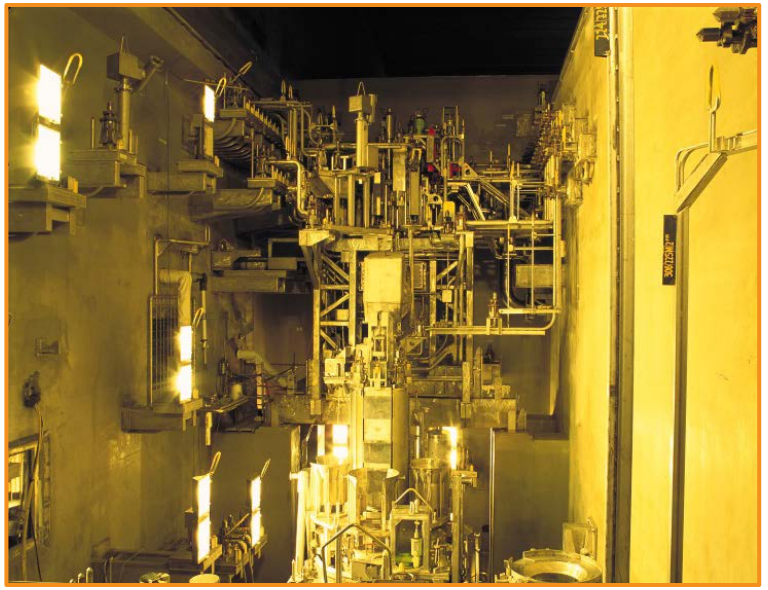
Inspect facilities and equipment

- Assess conditions for life extension, Visual, Ultrasonic Thickness, Eddy Current, NDE
- Take Measurements – Radiation level, Physical Dimensions / mapping, etc.
- Gather material samples for lab analysis
- Investigate process upset, aid in recovery planning



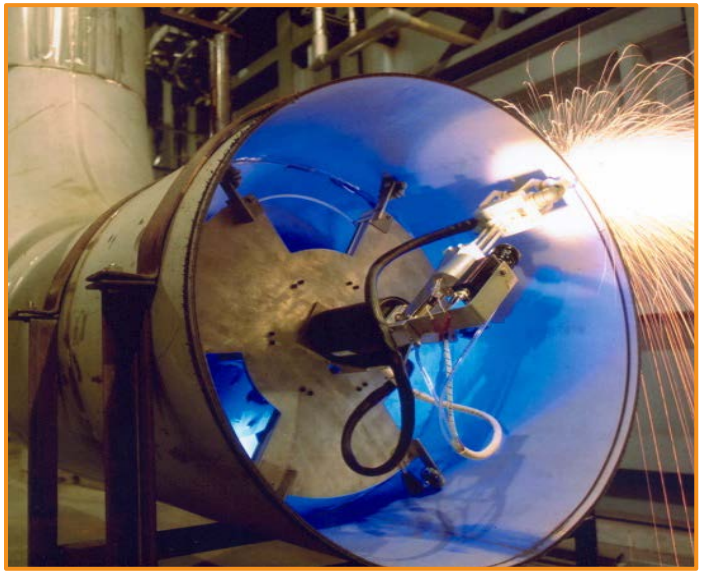
Replace hands on workers for safety, efficiency and improved quality

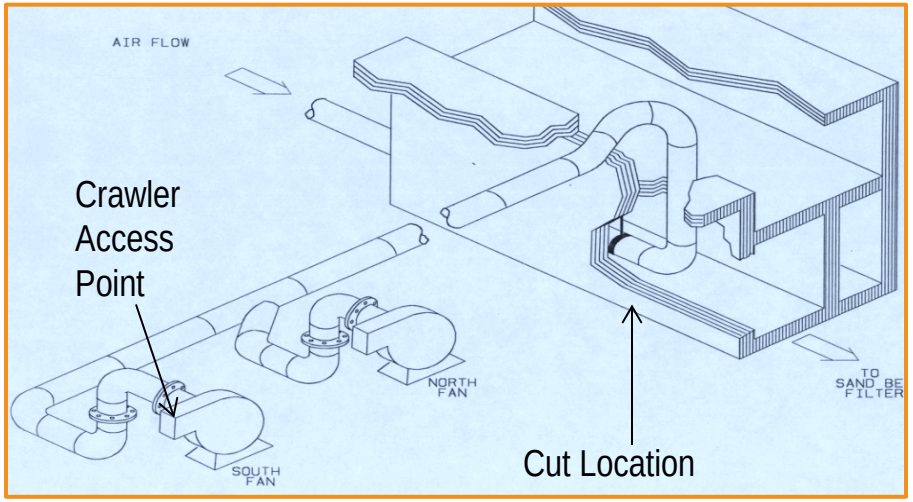
- Remote cell automation
- Glovebox process automation



Application Examples – Large Diameter Pipe Crawler

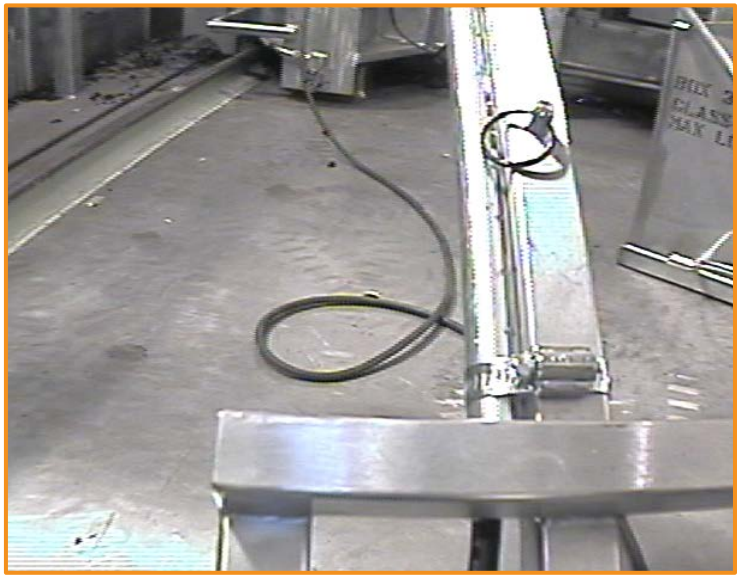
- Redirect air flow to a sand filter
- 36” diameter pipe
- Travel Over 300 ft
- Plasma arc cutter and cameras on board crawler
- Tethered system, operator in the loop
- Successfully removed pipe section and removed crawler
- Custom system





Application Examples – DWPF Melt Cell Cleanup

- Clean Melt cell floor during melter outage
- 19 days to design, test, deploy, clean floor, and remove system
- Used available commercial parts
- Some custom designed parts
- Tethered system, operator in the loop
- Facility crane flew vehicle in and removed



Application Examples – H Canyon Air Tunnel Inspection

- Enter air tunnel near sand filter
- Travel more than 400 ft
- Inspect tunnel walls and ceiling
- Acid vapors degrade concrete walls
- Need to verify tunnel integrity

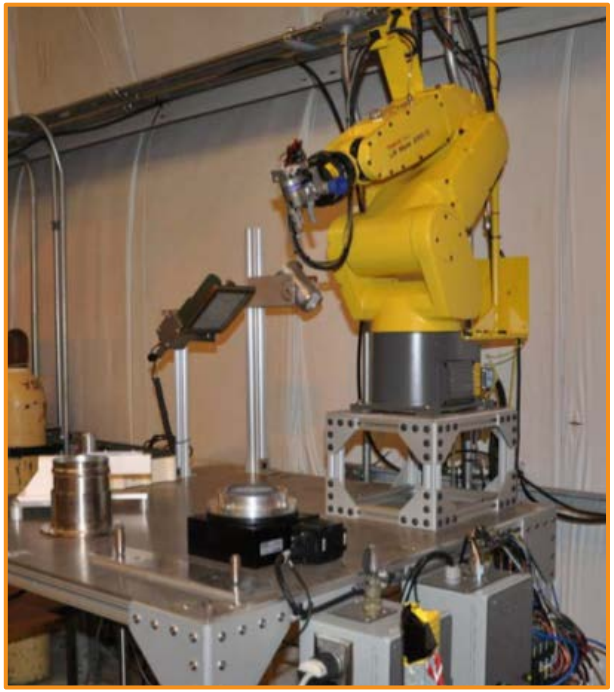
Application Examples – Plutonium Automated Canning

Automated / Remote canning of Pu Oxide

- Load convenience cans (in glove box)
- Inner can welding and cutting (bagless transfer)
- Inner can weld inspection, rad survey & leak check
- Load inner can into outer can
- Outer can welding, survey, & inspection

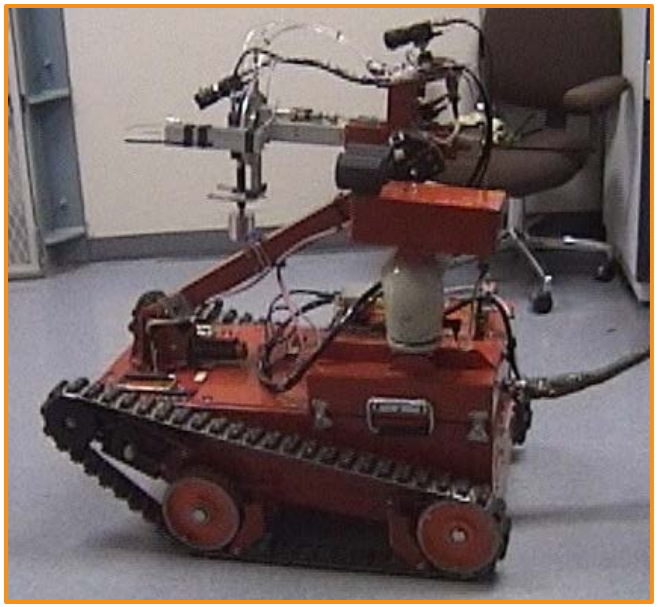
Special features

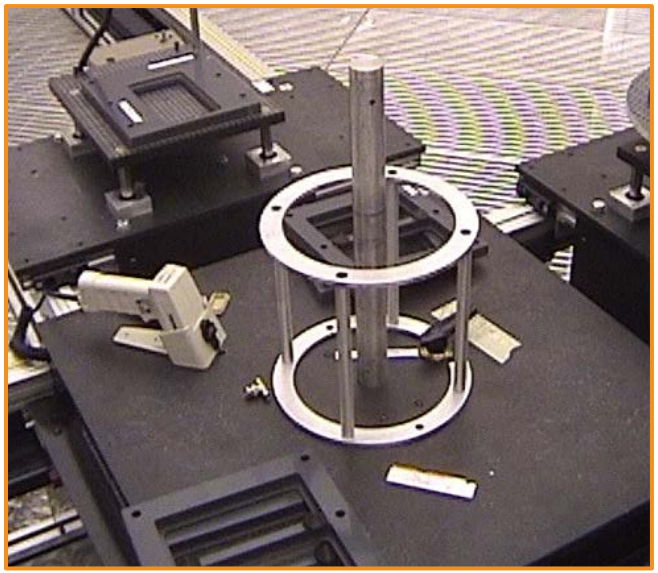
- Interlocks on gripper for criticality control
- Robot speed and height limits ensure can integrity



Application Examples – Cesium Source Recovery

- 100 Curie Cesium Source Stuck in a Calibration Facility
- 6,000 R/Hr at 6 inches
- Used available vehicle and custom end of arm tooling
- Removed allen screw and unscrewed transfer tube end cap
- “Caught” source container when blown out of transfer tube
- Placed source in shielded cask
- Tethered system, operator in the loop
- Mockup testing invaluable



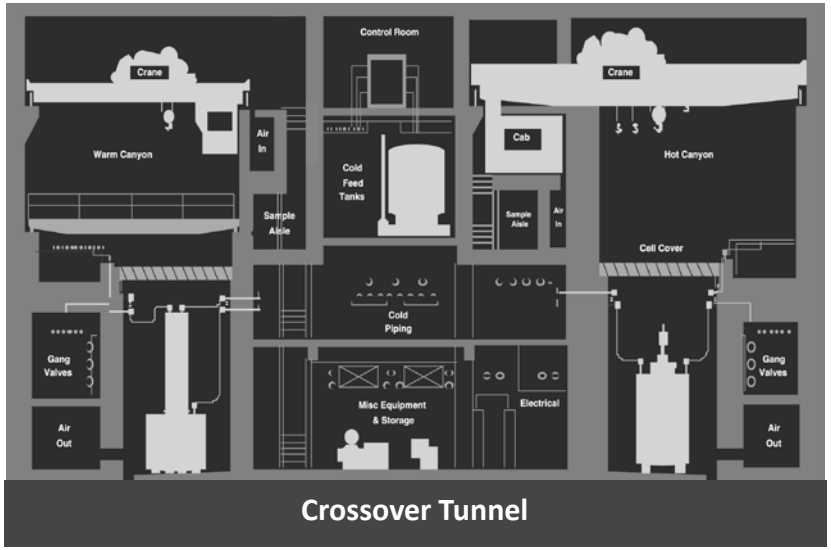


Application Examples – Tank 18F Sampling

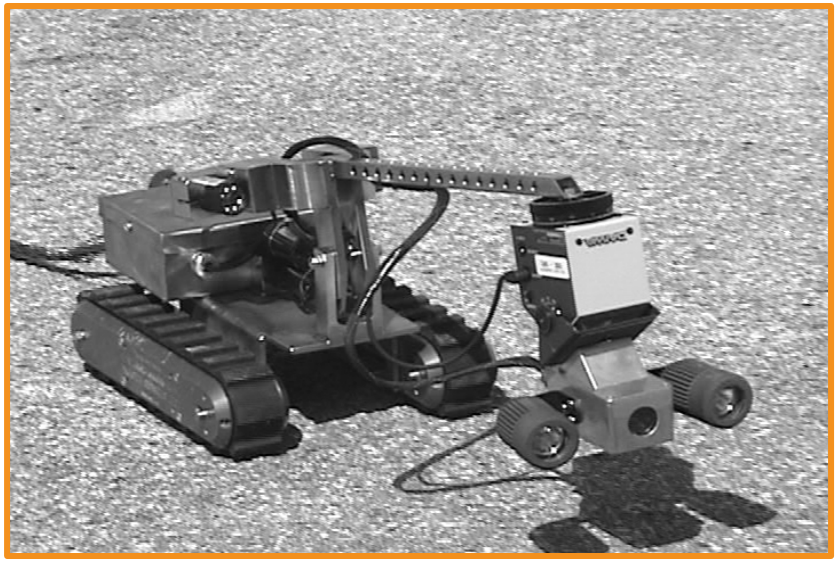
- Samples required from waste mound inside of High Level Waste tank
- 23” diameter riser to deploy system
- Traveled 40’ out from under access riser
- Used available commercial parts
- Some custom designed parts
- Tethered system, operator in the loop
- System removed using tether

Application Examples – H-Canyon Duct Inspection

- Contamination detected on Canyon Exhaust HEPA filters
- Suspected leak in OHBL exhaust duct
- Deploy system into tunnel through a 1’ x 1’ opening
- Lowered vehicle 10 feet
- Crawl horizontally 40 feet to the retention curb
- Visually Inspect duct
- Lowered by hand, max weight is 75 pounds
- Considered disposable - Simple design, Inexpensive components
- Tethered system, operator in the loop
- Mockup testing



Crossover Tunnel



Application Examples – Reactor Tank Inspection

- Ultrasonically inspect SRS reactor tank walls for cracking
- 4 inch diameter access hole, 16 ft long reach
- Scanning performed under water
- Calibrate transducer in tank before and after each scan
- Certifiable UT scan results
- Scan mapping accuracy in sub millimeter range
- SRNL designed, built, integrated, and operated this system and all support equipment
- Completed scans of 3 SRS reactors
- Multi-million dollar program with full-scale reactor tank mockup for testing

Convinced regulators that no cracks were present – Safe to Operate

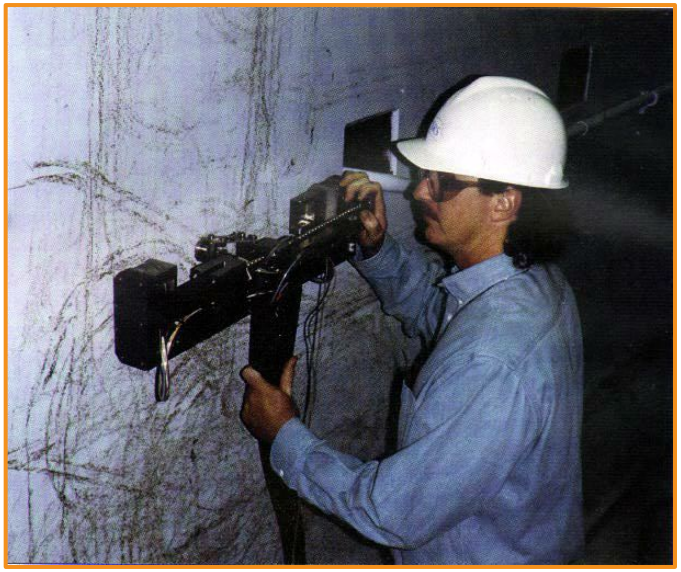
Application Examples – Autonomous Floor Survey

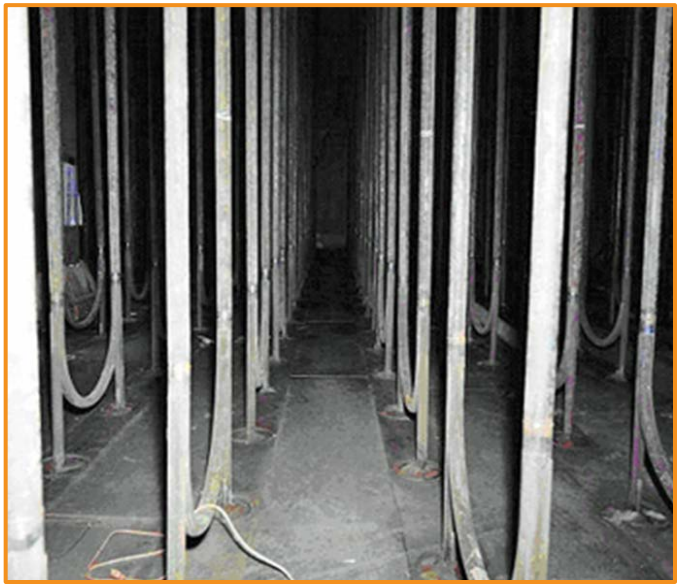
- Low level alpha contamination periodically found on lab floor corridors
- Manual surveys require slow (1 in/second) detector scan speeds
- Human inspectors tire easily or go too fast
- SRNL adapted a commercial autonomous robot platform to perform automated floor scanning

Due to consistent scan speeds, SIMON located many previously unknown fixed contamination spots.

Application Examples – Magnetic Wall Crawler

- Inner waste tank walls are made of carbon steel
- The walls are monitored for corrosion via periodic ultrasonic thickness measurements
- A magnetic “skate” and gravity were originally used to deploy a sensor in a strip below an access riser
- Ultrasonic inspections were needed in other regions of the tank
- SRNL developed a set of magnetic wheeled crawlers:
  - deployed though the access riser,
  - move around the waste tank annulus
  - clean the surface
  - perform ultrasonic inspection
  - perform camera visual inspections





Lessons Learned

Mockup testing is critical to successful deployments (Saves time and money)

- Helps train operators and maintenance staff
- Identifies problems before equipment is contaminated
- Reduces operational risk

Design for operations in rad environments is different than conventional design

- Many vendors bid too low or equipment fails prematurely
- Design for decontamination and remote maintenance is not common

Must plan for equipment failures and recovery

Software surety for critical automated activities is expensive and complex

- Difficult to get safety / risk approval
- Requires multiple levels of interlocks and redundancy
- Requires much testing and recovery planning from multiple failure scenarios

Observations

Nuclear Industry is slow to adopt new technologies, risk adverse

- Prefer Manual vs. Automatic controls – Safety / surety of operation
- Demand reliability as maintenance is expensive or impossible
- Prefer simple and cheap if evolutions are seen as one time events

Customers have limited budgets

- Some commercial systems are available, but cost is high for one time use deployment
- Limited Nuclear Marketplace, few vendors willing to make unique products for limited sales

Simple systems reduce risks and reduce cost

- Operator in the loop vs automation
- Camera feedback
- Requires operators familiar and practiced with the equipment

People are the first choice for performing tasks

- Robotics only deployed when: 1) dose is too high, 2) access is difficult or risky
- Costs of personnel performing routine tasks in PPE vs robotics not considered

Future Needs

Modular components

- Enable quickly arranged / inexpensive systems

Glove box automation “through the glove”

- Enable manipulation while maintaining confinement

Consistent cost modelling

- Guidance / best practices for comparing operational life cycle costs vs. capital costs for automation

Vendor Ecosystem for High Hazard Robotics

- Limited market for these systems drive up costs,

Automatic / Autonomous operations

- Understanding, predicting, and managing failures and recovery to enable better safety and consequence analysis.