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# DOE National Laboratory Robotic System Applications for Nuclear Facility Operations and Legacy Cleanup

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# Overview

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- **Historical Perspective**
- **Application Examples**
- **Recent Developments**
- **Current Challenges**
- **Future Needs**



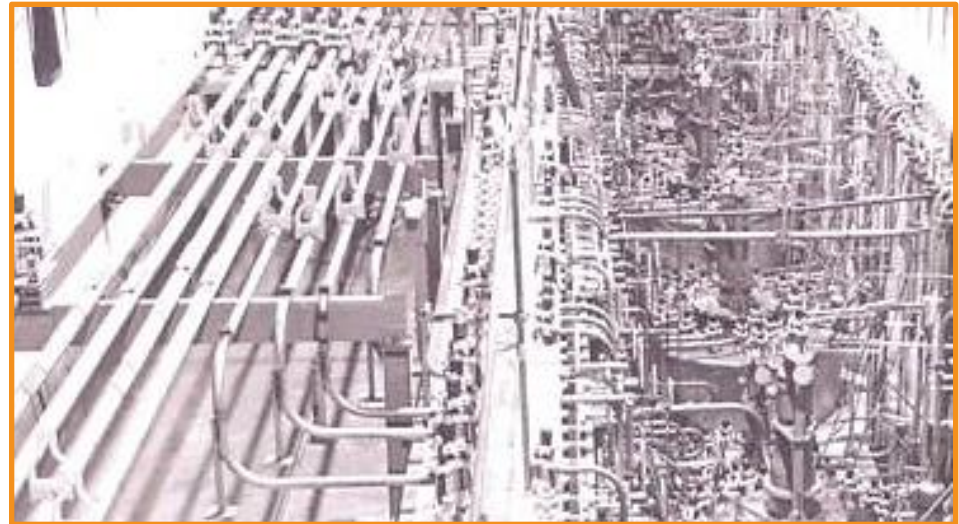
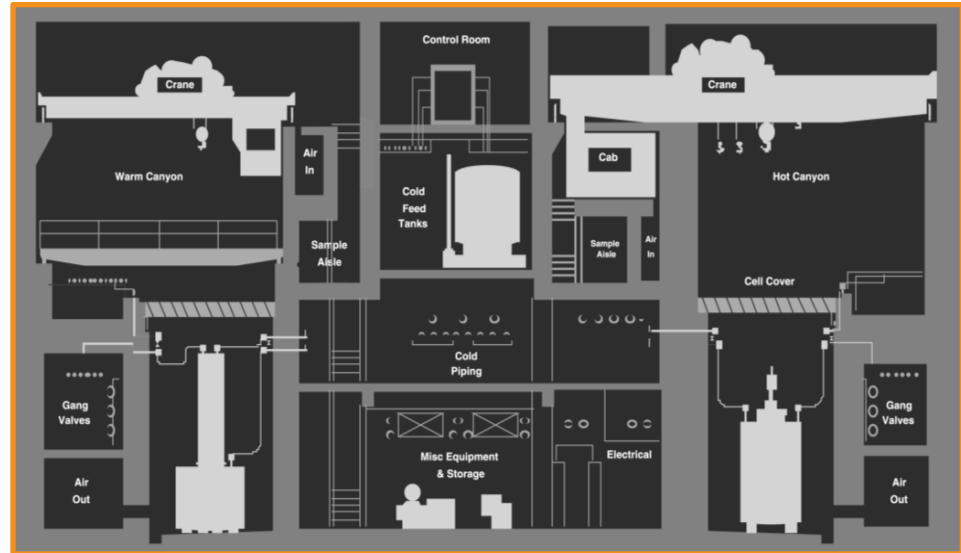
# Historical Perspective – Robotics, Remote Systems and Risk Mitigation

**Remote systems to handle high dose (gamma and neutron) materials:**

- Shielded Process Buildings (Canyon) via cranes, optical periscopes.
- Hot Cells – mechanical manipulators and viewing windows.

**Electro mechanical systems, designed for frequent maintenance. Visual feedback.**

**Proven capability for handling high gamma materials in special facilities**



**Canyon Crane Example**

# Historical Perspective – Robotics, Remote Systems and Risk Mitigation

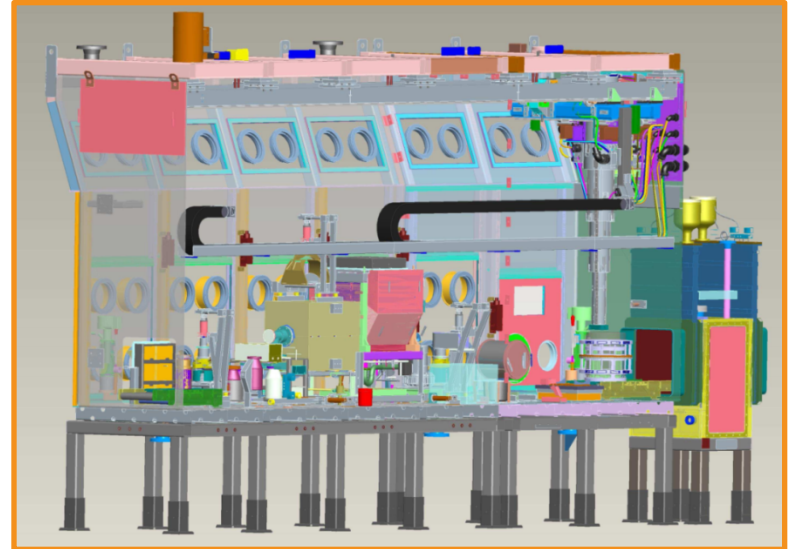
## Gloveboxes for alpha/beta emitters

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

## Glovebox operation challenges:

- Limited by human reach / ergonomics
- Operator **at risk**
- Radiological control inspector
- Backup operator or supervisor

**Glovebox equipment must be carefully designed for both operations & maintenance**



# Application Examples – Typical Categories

## Inspection / Life Extension

- 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.



## Decontaminate & Decommission (D&D)

- Remove contaminated items
- Remove nuclear materials

## Replace hands-on workers

- Hot cell automation
- Glovebox process automation



# Application Examples – Reactor Tank Inspection

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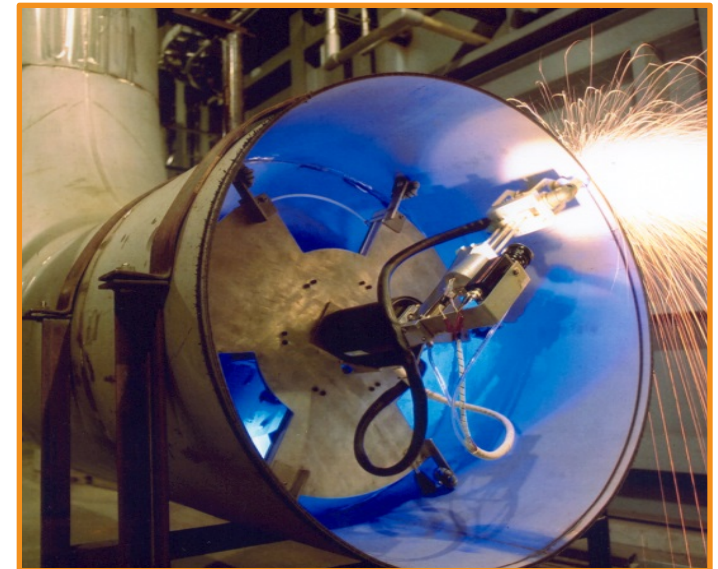
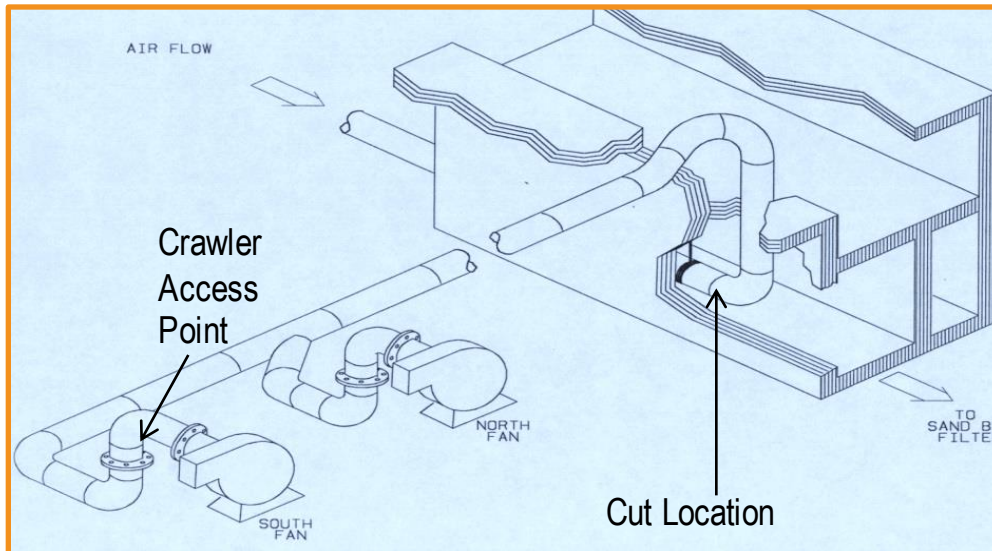
- Ultrasonically inspect SRS reactor tank walls for cracking
- 4 inch diameter access hole, 16 ft long reach
- Scanning performed under water
- Calibrate transducer in tank before and after each scan
- Certifiable UT scan results
- Scan mapping accuracy in sub millimeter range
- Completed scans of 3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



**Convinced Regulators:  
Reactors are Safe to  
Operate**

# Application Examples – Large Diameter Pipe Crawler

- Redirect air flow to a sand filter
- 36" diameter pipe - heavy alpha contamination
- Travel Over 300 feet
- Plasma arc cutter and cameras on board crawler
- Tethered system, pneumatically driven
- Successfully removed pipe section and removed crawler



# 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 Example – Dual Arm Manipulator Systems

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- Developed by Oak Ridge National Laboratory (ORNL) 6 DOF arms, 5 DOF torso.
- Perform D&D of Argonne National Laboratory CP-5 graphite reactor
- Removed aluminum reactor vessel, graphite blocks, process piping, support hardware, etc.
- ORNL has a long history of dual arm manipulation systems:
  - ASM – Advanced Servo Manipulator  
Remotely maintainable
  - SNS In-Cell Servo Manipulator  
Force reflecting



# Application Example – Guniting Tank Remediation – Key Equipment

## **MLDUA**–8 DOF robotic arm

- 15 ft. reach, 200 lb. payload
- Deployed end effectors for:
  - Characterization
  - Modification
  - Waste retrieval
  - Wall-cleaning
  - Cameras
- Teleoperation or preprogrammed



## **Houdini ROV**–1000-lb tethered collapsible vehicle

- 4 x 5 ft. expanded footprint
- 6 DOF robotic arm and gripper
- Plow blade for pushing sludge

Please See  
Poster Session #3

## **Waste Dislodging and Conveyance System** – Dislodges and retrieves waste

- Confined Sluicing End-Effector
- Manage the in-tank hoses and lines,
- Jet pump
- Flow Monitoring & Sampling

Campaign completed in 2001,  
5.5 years ahead of baseline,  
Saved >\$120 Million



# Application Example – Spent Fuel Waste Package Closure

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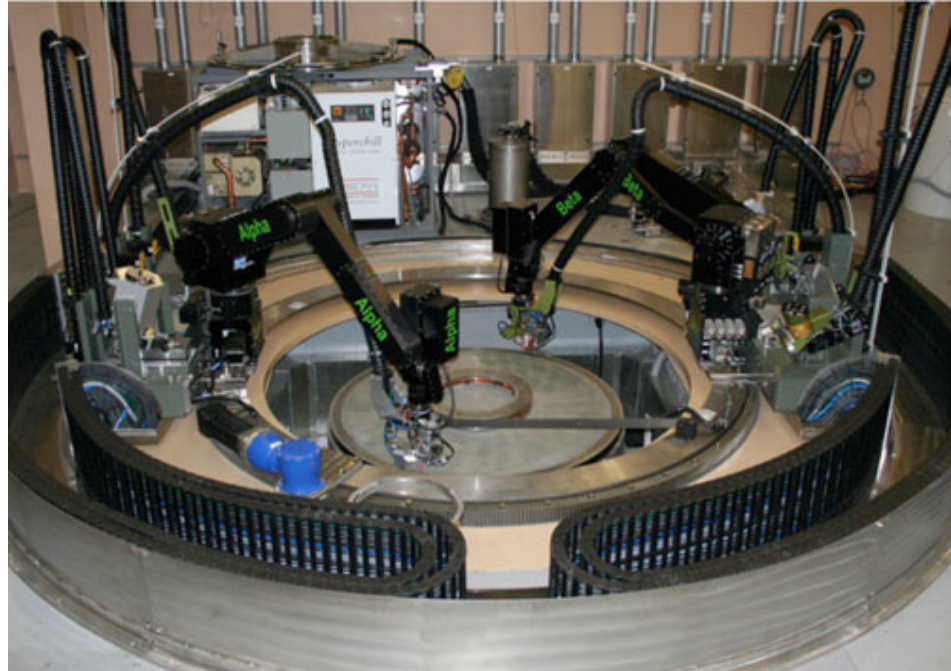
Developed by Idaho National Laboratory (INL)  
High Rad Environment

Two 6 DOF robots on a bearing (13 DOF)

- Seal Weld 2 containers
- Dress weld area
- Purge and backfill container with inert gas
- Seal Weld the purge port
- Burnish outer weld
- Leak test
- Non Destructively examine welds
  - UT, ET,
- Repair defective welds

Six operator work stations

- 2 Welding
- 2 NDE
- 1 Material Handling
- 1 Supervisory



**Please See  
Poster Session #4**



# Examples of Recent Developments

## ORNL's 3D Printed Hydraulic Manipulator

- 7 DOF human scale arm
- Additively manufactured
- Fluid and electrical passages printed into the arm structure
- Neutrally buoyant



## SNL's HAND

- 3D printed
- Four fingers, 3 DOF each
- **Modular:**
  - identical finger modules
  - magnetic attachment
  - hot swapping of fingers



## ANL's Advanced Controls

- Augmented Teleautonomy
- Simulation with Augmented Virtual fixtures

See Poster  
Session #2



# Current Challenges

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## **Nuclear Industry is slow to adopt new technologies, risk adverse**

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

## **Customers have limited budgets / limited technology planning cycle**

- 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
- Advanced planning needed for new technology development / test

## **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 vs robotics generally not considered

# Current Challenges

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## **Multiple Codes, Standards, and requirements for robotics in nuclear service.**

- Quality Assurance, DOE Order 414.1C, ASME NQA-1
- ASCE 4, Seismic Analysis of Safety-Related Nuclear Structures
- DOE-STD-1021-93 - Performance Category (PC) Guidelines
- DOE Order 420.1C, Facility Safety
- DOE-STD-1189, Integration of Safety into the Design Process
- ANSI/ISA 84.00.01 Safety Interlock (SIL) Level 2 calculations for electrical
- ANS Design Guide for Radioactive Material Handling Facilities & Equipment (1988)
- ANSI/RIA R15.06, Industrial Robot Safety Requirements
- ANSI/RIA R15.05-3, Industrial Robot Acceptance Testing
- NEMA MG1, Motors and Generators
- NEMA 250, Enclosures for Electrical Equipment
- NFPA 70, National Electric Code
- NFPA 79, Electrical Standard for Industrial Machinery
- IEEE 383, Class 1E Electric Cables
- ASME NOG-1, Rules for Construction of Overhead Cranes
- AWS D1.6, Structural Welding Code
- OSHA 29 CFR Part 1910.303 safety evaluation for non listed devices

# Future Needs

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## Bring Down the Costs!

- Vendor ecosystem – limited markets for “one of a kind” systems
- Modular components
- Software portability
- Re-useable / re-deployable systems
- Consistent cost modelling:
  - operational life cycle vs capital
  - teleoperation / automation / hands - on

## Smaller, Lighter, & Smarter Sensors

## Consistent safety and consequence analysis

- Understanding, predicting, and managing failures / recovery

## Glove box automation “through the glove”

- Enable manipulation while maintaining confinement

