U.S. Manhattan Project Legacy: Opportunities for Advanced Robotics in Nuclear Cleanup

2nd Workshop on Robotics and Automation in Nuclear Facilities
IROS 2015, Hamburg, Germany
October 2, 2015
Introduction to EM’s Nuclear Cleanup Mission
1938
Nuclear Fission
First observed by German Physicist Otto Hahn and his assistant Fritz Strassmann

1942
Manhattan Project
Manhattan District of the US Army Corp of Engineers

1945
Trinity Test Shot
First detonation of a nuclear weapon. ≈20 kilotons of TNT.

1946
Atomic Energy Commission

1945
Trinity Test Shot
First detonation of a nuclear weapon. ≈20 kilotons of TNT.

1974
Energy Reorganization Act of 1974

1977
Department of Energy
Formerly ERDA

1989
Environmental Management
Nuclear weapons legacy

Atoms for Peace
The U. S. Nuclear Weapons Complex

Nuclear Weapons Production:
- Uranium mining and milling
- Uranium enrichment
- URx Savannah River Site
- Chemical separation
- Nuclear components
- Assembly and Disassembly
- Testing
- Weapons Design
- Weapons Triggers, nuclear generators, and other electrical or mechanical components are assembled into compact warheads.

Former industrial sites contaminated with radioactivity, some but not all of which contributed to nuclear weapons production.

Number indicates how many sites were or are located in the State.
Mission

- Safe cleanup of the environmental legacy from six decades of nuclear weapons production and Federal Government-sponsored nuclear energy research

Mission Units

- Site Restoration
- Tank Waste and Nuclear Materials
- Waste Management
Since 1989, EM has completed its cleanup mission at 91 of the 107 major nuclear weapons and nuclear research sites.
EM Accomplishment and Challenge

Average Annual Budget = $6B

Profile of Historical EM Annual Costs

Cost in Billion US Dollars

Fiscal Years

Past Investment
- $152 billion spent
- Completed cleanup at 91 of 107 major sites

Current Lifecycle Baseline
- To-Go Estimate
  - $235 billion
  - 2065 completion
- $28 billion gap

Cost Estimate Profile of EM’s Remaining Mission (2016 To 2065)

Cost in Billion US Dollars

Fiscal Years

$6B Historical Budget Level
**Current Budgets**

**FY 2015 Enacted: $5,861M**
- Tank Waste: $2,030M (35%)
- SNM & SNF: $910M (15%)
- Solid Rad Waste: $890M (15%)
- Mission Support: $910M (15%)
- Soil & Water: $520M (9%)
- D&D: $400M (7%)

**FY 2016 Request: $5,818M**
- Tank Waste: $2,297M (40%)
- SNM & SNF: $967M (17%)
- Solid Rad Waste: $779M (13%)
- Mission Support: $835M (14%)
- Soil & Water: $527M (9%)
- D&D: $413M (7%)
Robotics will Enable
EM’s Nuclear Cleanup Mission
General Needs for Robotics

- Handling of high-hazard, high-consequence materials and waste
- Performing worker/operator tasks that are
  - Dirty (contaminated, toxic, nuisance)
  - Dull (routine, labor-intensive, repetitive, mundane)
  - Dangerous (pose significant occupational hazards)
- Easing the performance of worker/operator tasks that are
  - Physically demanding on or stressful to human body or
  - Otherwise ergonomically challenging
- Performing tasks that are beyond human abilities
- Improving the ability to respond to and recover from unplanned events or operational emergencies
- Improving the safety, quality, efficiency, and productivity of facility operations
Systems that provide remote entry into areas and spaces that are otherwise inaccessible or prohibit direct access by workers due to:

- Unsafe, unstable, or unknown physical or structural conditions
- Configurations that are hard to reach or beyond reach without taking extraordinary mechanical measures
- The presence or potential presence of radiological, chemical, biological, or physical hazards that will or may result in unacceptable occupational exposure or increased health or safety risk
- Other conditions that preclude safe entry or are otherwise uninhabitable such as areas or spaces that have or potentially have:
  - Oxygen-deprived environments or other conditions of poor air quality;
  - Explosive gases, materials or devices
  - Extreme temperatures
  - Extreme pressures
  - Poor or no visibility or no direct line of sight
  - Submerged or substantially liquid-covered surfaces
Robotics for Surveying, Inspection and Characterization

- Non-Destructive Evaluation/Examination and *In Situ* Characterization
  - Acoustic, optical, radiographic, thermographic, electromagnetic, climatic, and other tooling and methods for non-destructive sensing, detecting, monitoring, measuring, characterizing, and assaying a wide variety of radiological, chemical, environmental, and physical parameters

- Surveillance and Monitoring
  - Photography, videography
  - Change detection

- Imaging, Surveying, Mapping, and 3D Rendering
  - Graphical depictions and representations
  - Computer-generated replications, simulations and models
Robotics for Doing Work

- **Manipulation and End-Effectors**
  - Systems for remotely performing tasks in harsh environments or work conditions to keep occupational exposure to hazards as low as reasonably achievable (ALARA)

- **Heavy Operations**
  - Systems for performing tasks that are beyond worker capability and require substantially greater strength, dexterity, reach and access, or capacity

- **Task Automation**
  - Systems for more efficiently performing routine or repetitive tasks and operations such that worker interface is needed only for performance monitoring and quality control
Wearable and prosthetic-like robotic devices (a.k.a., co-robots) that

- Improve worker health and safety or
- Enhance worker performance and endurance, or compensate for physical limitations of extremities by relieving physical stresses on the body and avoiding occupational injuries such as those caused by
  - Repetitive and forceful exertions and motions
  - Frequent, heavy, or overhead lifts or tasks
  - Ergonomically incorrect work positions
  - Use of vibrating (shock-inducing) equipment
  - Muscle fatigue
Demonstrating Robotics on “Rad” Test Beds

- Physical platforms to demonstrate innovative tooling, treatment technologies, and other technical solutions at existing EM nuclear facilities and assets

- Provides technologists the unique opportunity to
  - Directly use radioactive and chemically reactive wastes and nuclear materials
  - Conduct technology demonstrations in spaces and areas
    - Having radiation fields
    - Are contaminated with surface and/or fixed radioactivity
    - Are inaccessible, inhabitable, or not safe for worker entry
    - Under conditions and configurations that are difficult and too expensive to replicate or mock-up
Current EM Activities and Initiatives

- Robotics is a high-priority mission enabling technology
- Evaluating in-house (within DOE) capabilities
  - EM is well-postured to lead and synergize DOE robotics
- National Robotics Initiative
  - Finalizing MOU with National Science Foundation
  - Provided nuclear cleanup input to next solicitation
- Leveraging DOE Office of Nuclear Energy University Program
  - FOA for Nuclear Traineeships
  - FOA for Integrated Research Projects
    - Integrated surveying, mapping and characterization
    - Underwater surveying, mapping and characterization
Collaboration with NASA

- Non-NASA Panel Review Member: End-of-year PI review of NRI research projects sponsored by NASA Johnson Space Center

- Proposal Reviewer: GCD Hosting of Humanoid Robots and Validation of Task Performance for the Space Robotics Challenge

- Pursuing hosting Valkyrie at EM facilities for tasking and demonstrations in actual nuclear spaces

- Developing Interagency Agreement
Collaboration with NIST

- Standard Test/Evaluation Methods and Practices
- ASME NQA-1, *Nuclear Quality Assurance-1*: Consensus standard of guidance and best industry practices for delivering quality goods or services that provide a safety function for nuclear facilities
Visits to EM Nuclear Facilities

- Jun. 9: Waste Isolation Pilot Plant
- Aug. 10: Idaho National Lab
- Aug. 11-13: Hanford Site
- Team
  - Robert Ambrose, NASA
  - Wendell Chun: Univ. of Colorado, Denver
  - Bill Hamel: Univ. of Tennessee
  - Blake Hannaford: Univ. of Washington
  - Veronica Santos: Univ. of California, Los Angeles
  - Satoshi Tadokoro: Tohoku Univ.
  - Richard Voyles: Purdue Univ.
  - Red Whittaker: Carnegie Melon Univ.
- Dec. 7-10: Savannah River Site
  - Expanded team
Robotics Opportunities in EM’s Nuclear Cleanup Mission
Robotics for Protecting Workers ➔ ALARA

- DANGER
- CONFINED SPACE
- ENTER BY PERMIT ONLY
- POISON INHALATION HAZARD
- 6
- DANGER
- HAZARDOUS CHEMICALS
- WARNING
- BIOHAZARD
- DANGER
- FALL HAZARD
Glovebox and Hot Cell Operations

- Typical hazards
  - Radiation
  - Chemicals
  - Sharps and heavies
- Degraded Worker Performance
  - Lack of flexibility and dexterity
  - Challenged visibility
  - Over-work and over-stress injuries
  - Repetitive motion injuries
Glovebox and Hot Cell Operations
Exploring Glovebox and Hot Cell Solutions

Robotics arms and hands are needed for glovebox and hot cell tasks

Industrial Reconfigurable Anthropomorphic Dual-arm (IRAD) System for use in gloveboxes and other hazardous environments. Courtesy UT-Austin ReNeu Robotics Laboratory
The Plutonium-Uranium Extraction (PUREX) Plant is located at the Hanford Site in eastern Washington. It operated from 1956 to 1972 and then from 1983 to 1991 for the recovery of uranium, plutonium and neptunium from irradiated reactor fuel via chemical separation.
- PUREX Storage Tunnels #1 & 2 are used for storage of large, failed and outworn PUREX process equipment.
Current PUREX Tunnels Status

- Tunnels are sealed with no access points
  - Possible entry via vent shafts
- High levels of radiation inside tunnels
  - Signage prohibits/restricts direct entry into tunnels
- All utilities and ventilation systems are isolated or removed
- Annual external surveillances and inspections
  - Overall structural deterioration
  - Subsidence
  - Erosion of earth cover
  - Ventilation stack seal/blank
  - Monitor for radioactive contamination migration and changes in radiation levels
- Remote access is needed for initial entry into the tunnels for surveying and characterization
Waste Isolation Pilot Plant

- U.S. Department of Energy facility
- Designed for permanent disposal of transuranic radioactive waste
- 2,150 feet deep

- Geological repository for the disposal of defense transuranic waste
- Built in a 250-million-year old, nearly impermeable salt basin
WIPP Typical Dimensions and Layouts

Typical Access Drifts: 40 ft. wide and 14 ft. high

Typical Panel Dimensions: 400 ft. wide and 1,115 ft. long

Typical Room Dimensions: 33 ft. wide, 300 ft. long, 14 ft. high

Typical Placement Configurations for Contact-Handled TRU Waste Containers
Two recent unplanned events highlighted the need for improved operational capabilities such as remote access for emergency response, initial re-entry, trouble-shooting, and recovery, particularly when conditions are unknown.
H-Canyon is located on the Savannah River Site in Aiken, SC, and is a radio-chemical separation facility built to support the production of nuclear materials. Its main purpose was to reprocess spent uranium fuel and other enriched uranium fuels. H-Canyon began operations in 1955 and remains in operation today. It is an 835-feet long, multilevel facility and is referred to as a canyon because of its long, rectangular shape.
SRS H-Canyon Air Tunnel: Past Inspections

- 2003
- 2009
- 2011
- 2014
- 2015

Warm Canyon Exhaust Tunnel

Hot Canyon Exhaust Tunnel

Crossover Tunnel

221-H H-Canyon

Rail Road Tunnel

Canyon Exhaust Tunnel

292-H Fan House

294-H Old Sand Filter

294-1H Sand Filter

Stack

Not To Scale

2015 Approx. 660 ft

2014 Approx. 330 ft

NORTH
Over the last 60 years of operation, the interior surfaces of the reinforced concrete tunnel have been exposed to 25 to 40 mph air flows of moist, nitric acid-laden air

Interior surfaces of the tunnel have eroded away the top 2-inch layer of concrete exposing the inner layer of reinforcing steel

Remote access is needed for more comprehensive inspection, surveying, and characterization
Remote access is needed to support surveying, characterization and inspection.
Remote access is needed to support investigation and trouble-shooting in DSTs.
Radio-Chemical Waste Processing Facilities

Remote access to support operations and maintenance
Radio-Chemical Waste Processing Facilities

Remote access to support operations and maintenance
Aging Facilities and Life Extension

Remote access for underwater inspections, surveying and characterization of storage pools and basins
Remote access to support decontamination, demolition and dismantlement operations
Remedial Action Surveillance and Inspection

Remote access for aerial inspections, surveillances and mapping
EM mission success over last 25 years

Significant cleanup challenges ahead
  - 50 years, $235 billion (likely to be longer, more costly)

Technology → smarter and safer mission execution
  - Robotics is a key mission enabler

Partner with the international robotics community
  - Leverage expertise and assets
  - Share experiences and technological advancements