U.S. DEPARTMENT OF ENERGY | OFFICE OF ENVIRONMENTAL MANAGEMENT

Opportunities for Advanced Robotics in Nuclear Cleanup

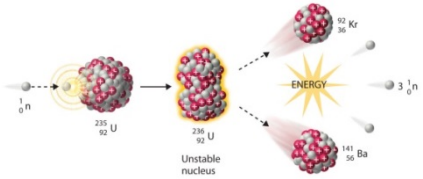
International Workshop on the Use of Robotic Technologies at Nuclear Facilities

February 4, 2016

Overview

EM's Nuclear Cleanup Mission

Timeline: Nuclear Weapons Legacy



1938

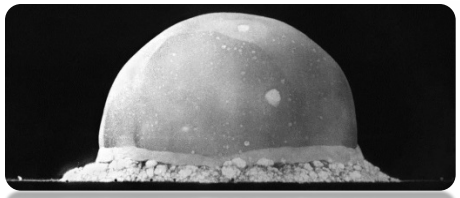
Nuclear Fission

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

Atomic Energy Act of 1946. Now under civilian control.

1954

Atoms for Peace

Atomic Energy Act of 1954. Allowed for a civilian (peaceful, non-defense) nuclear industry.

1974

Energy Reorganization Act of 1974

Nuclear Regulatory Commission

Regulate civilian uses of nuclear materials

Energy Research and Development Administration

Nuclear weapons program

1977

Department of Energy

Formerly ERDA

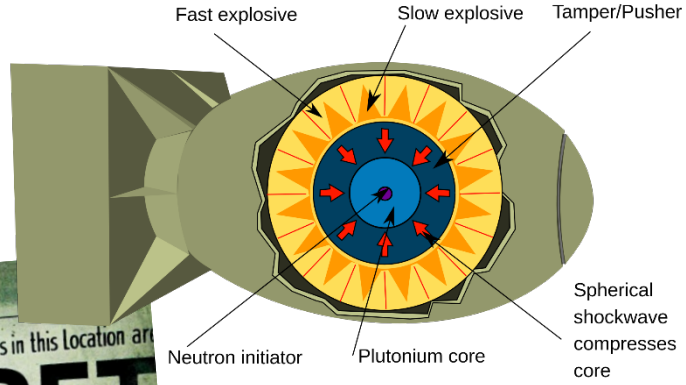
1989

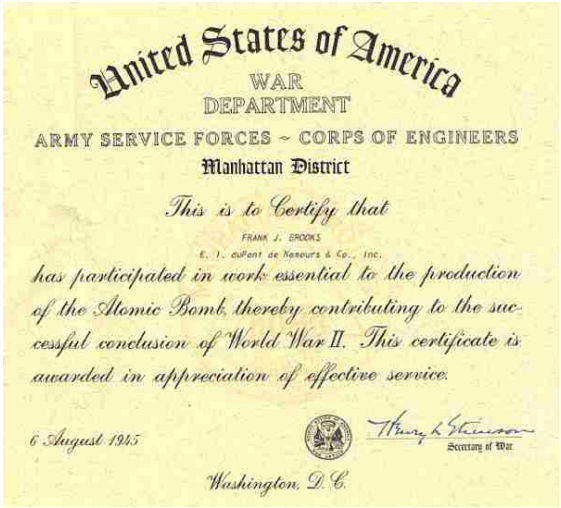
Environmental Management

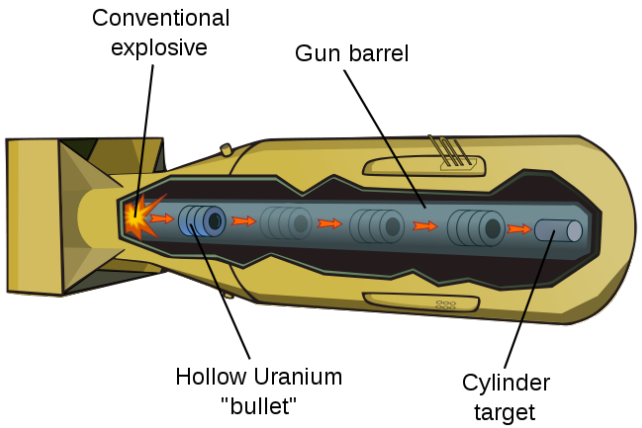
Nuclear weapons legacy

Legacy Scope: Manhattan Project

Codename: Development of Substitute Materials

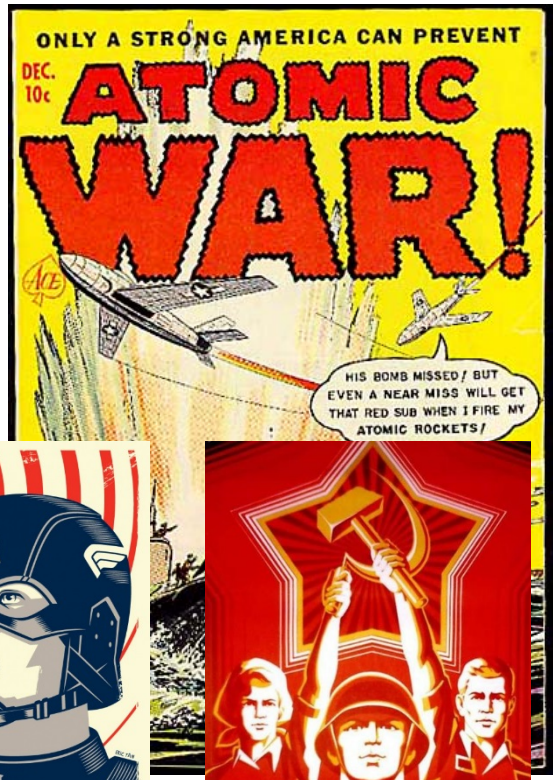




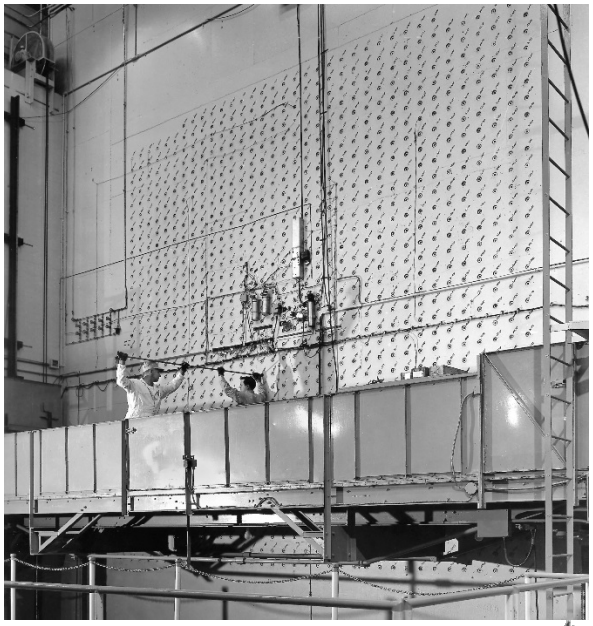


Legacy Scope: Cold War Expansion

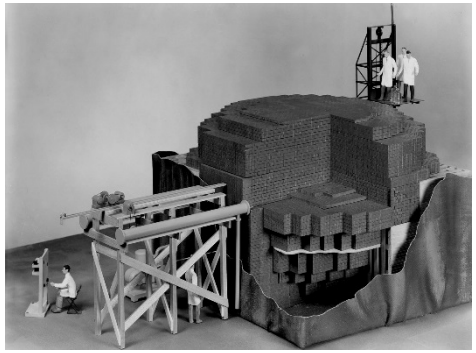
Nationwide Industrial Complex for the Cold War Nuclear Arms Race



Legacy Scope: Early Nuclear S&T



Early Years of Government-Sponsored Nuclear Science and Technology



"Go play in the park."

It's possible, you know. The grounds adjacent to nuclear power plants are safe and clean enough for children's playgrounds.

In fact, today, most nuclear power plants are places of education and enjoyment for thousands of adults and children

equate nuclear fuel sources with nuclear explosions. This is the result of far more publicity about bombs than about power-producing nuclear fuel.

The fact is, rigid safety precautions make the nuclear industry in the United States and abroad perhaps the safest industry in the history of technology. Before the go-ahead is ever given to build a nuclear power plant, the Atomic Energy Commission re... owner...

nuclear power

each American to an average of 5 millirems of radiation a year. (A millirem is 1/1000 of a rem, the standard unit of measurement of the biological effect of radiation.)

Cosmic rays expose us to another 30 millirems. This varies widely depending at what elevation we live. Just living on a hill exposes us to 5 more millirems than if we lived in a valley 400 feet below.

—Natural radiation is in the earth. Radioactive materials in the soil and rock expose... to an average 30 ...

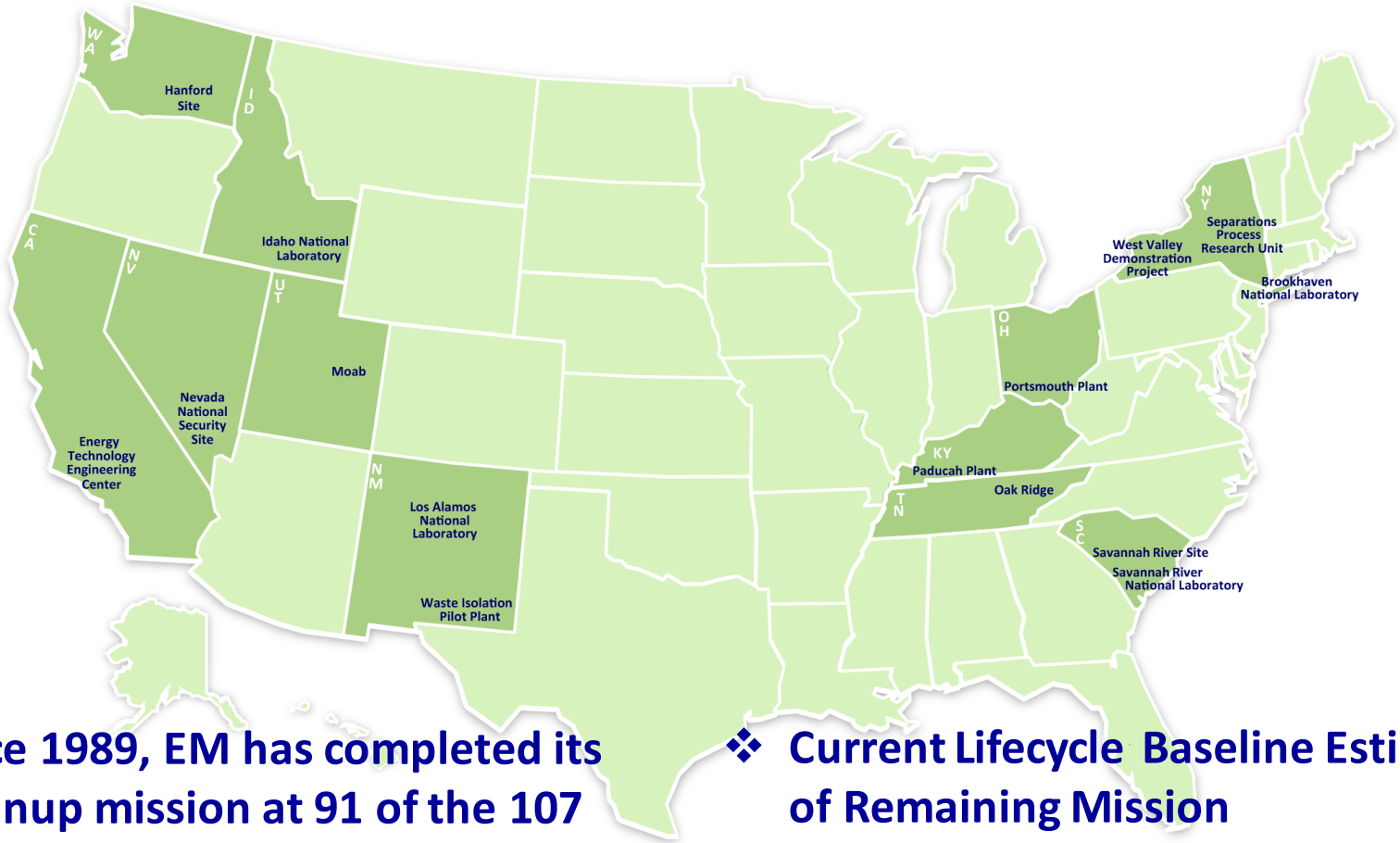
"Why can't electricity be made like it always has without using anything nuclear?"

It can, and is. Right now, only 1% of the electricity generated in this country is produced by nuclear power plants. The other 99% comes from fossil fuel (coal, gas or oil) or hydro (falling water) plants.

However, this ratio will have to change to keep up with future ...

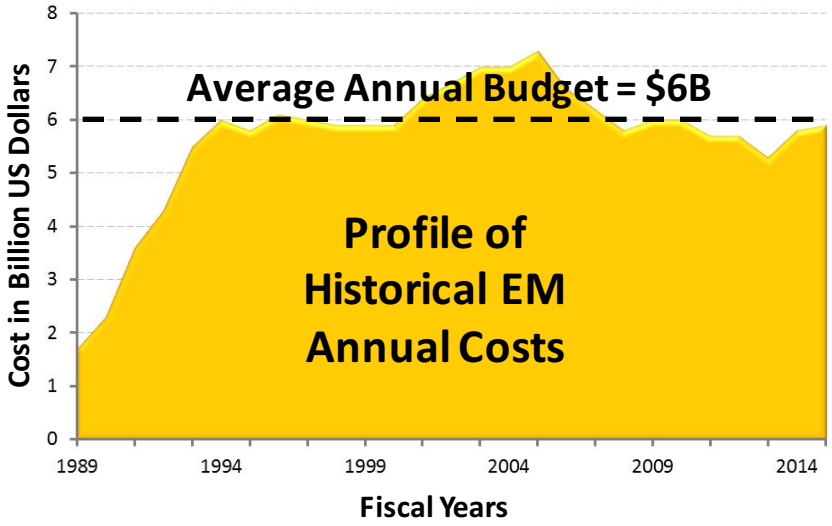
Original Scope of EM's Mission

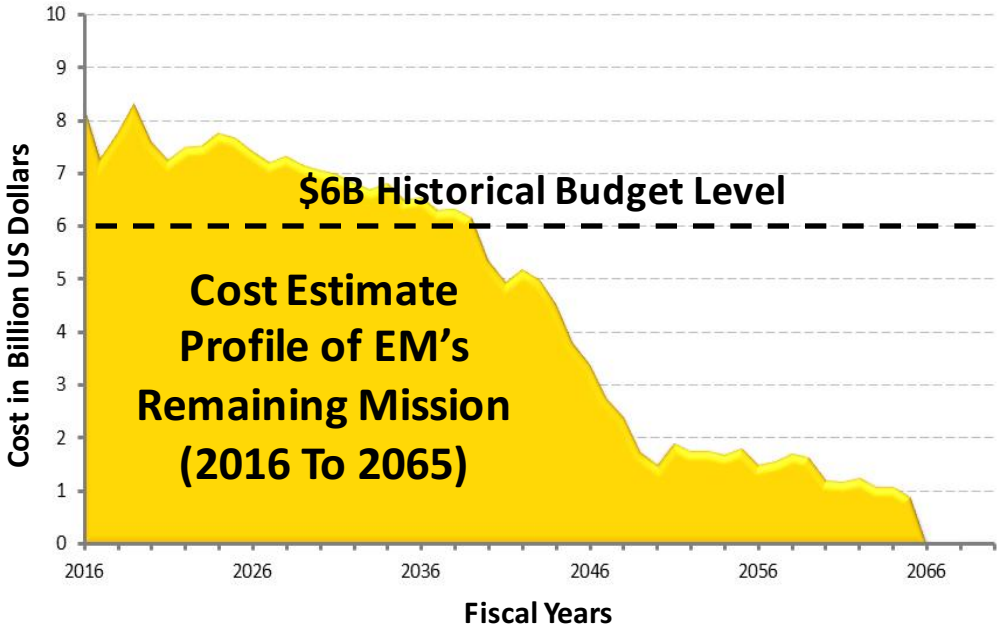
Remaining Scope of EM's Mission



- Since 1989, EM has completed its cleanup mission at 91 of the 107 major nuclear weapons and nuclear research sites
  - $152 billion spent
- Current Lifecycle Baseline Estimate of Remaining Mission
  - $235 billion
  - 2065 completion

EM Success and Challenge





Past Investment

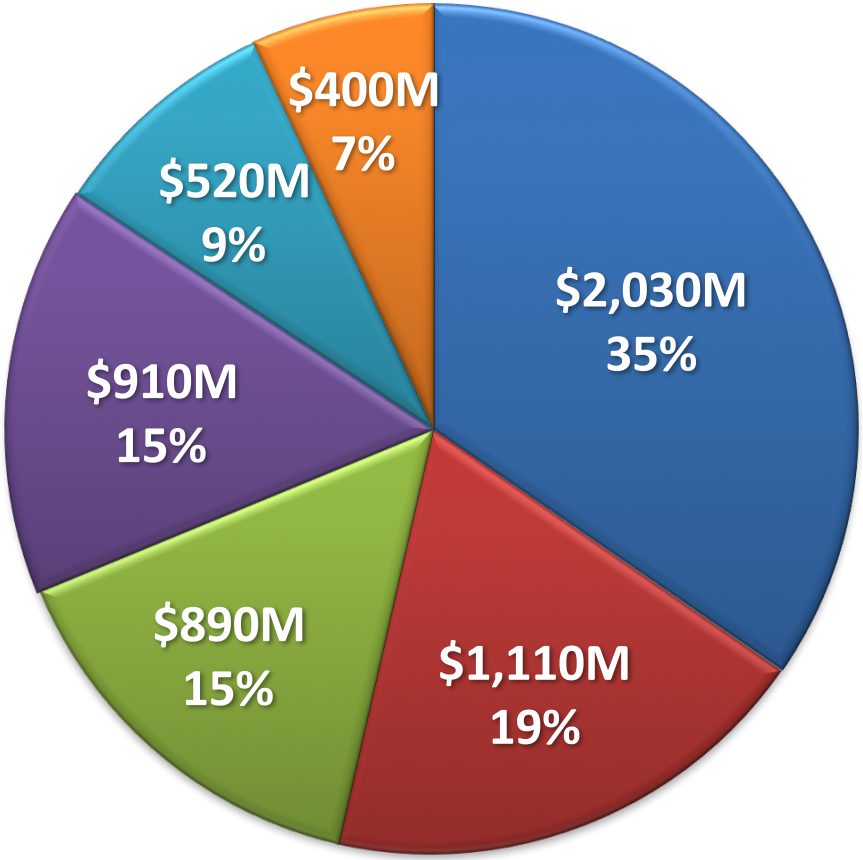
- $152 billion spent
- Completed cleanup at 91 of 107 major sites

Current Lifecycle Baseline

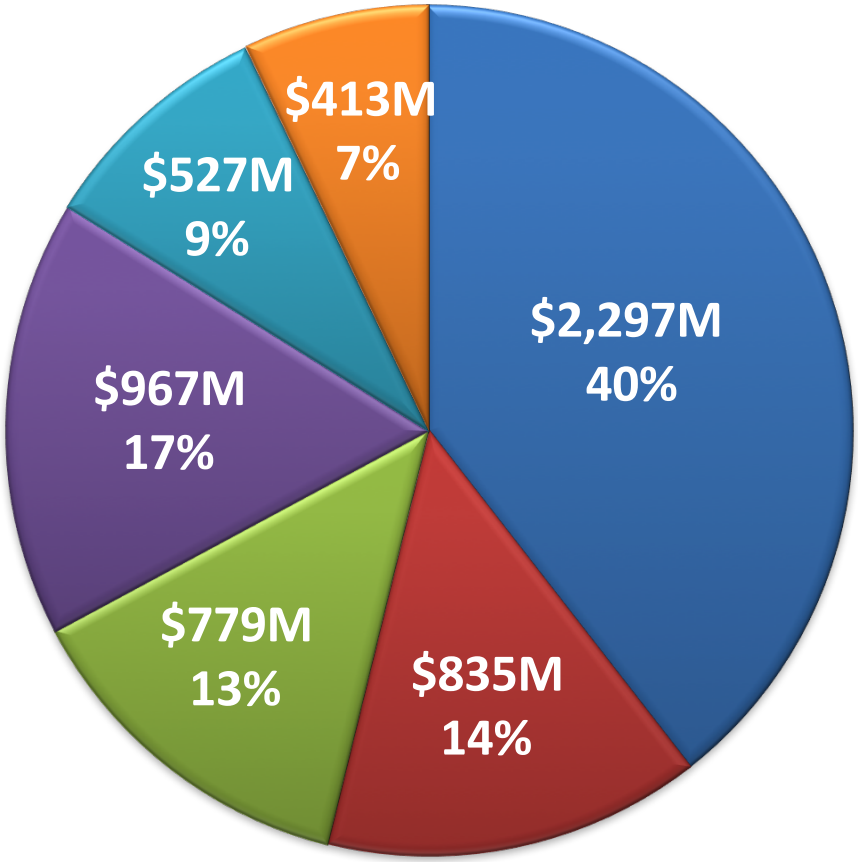
- To-Go Estimate
  - $235 billion
  - 2065 completion
- $28 billion gap

Current Budgets

FY 2015 Enacted: $5,861M



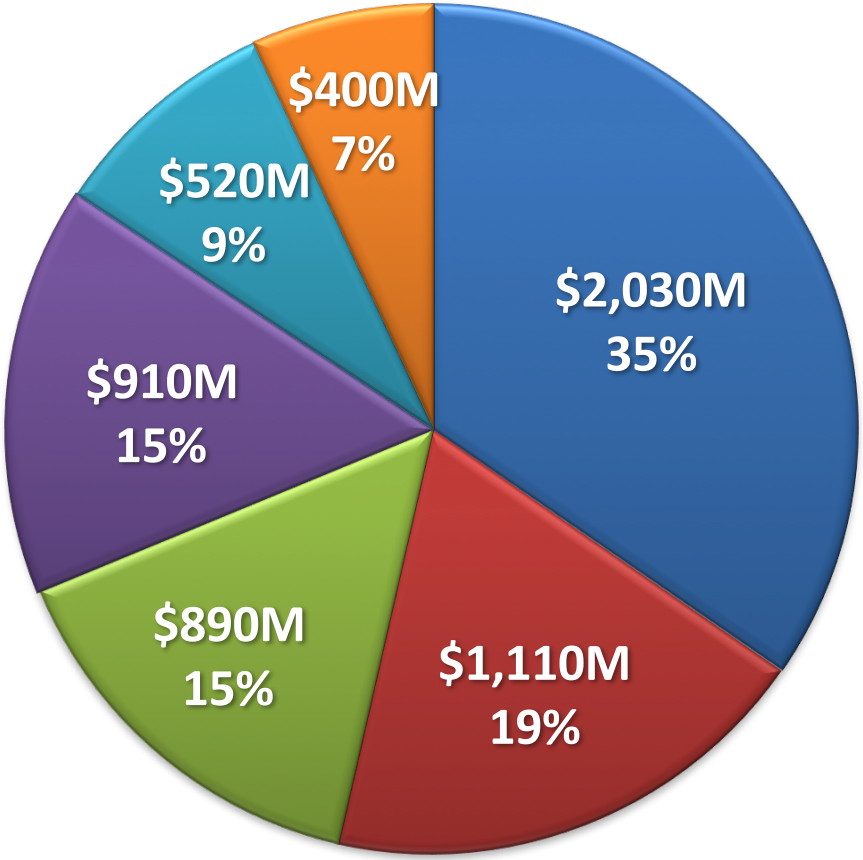
FY 2016 Request: $5,818M



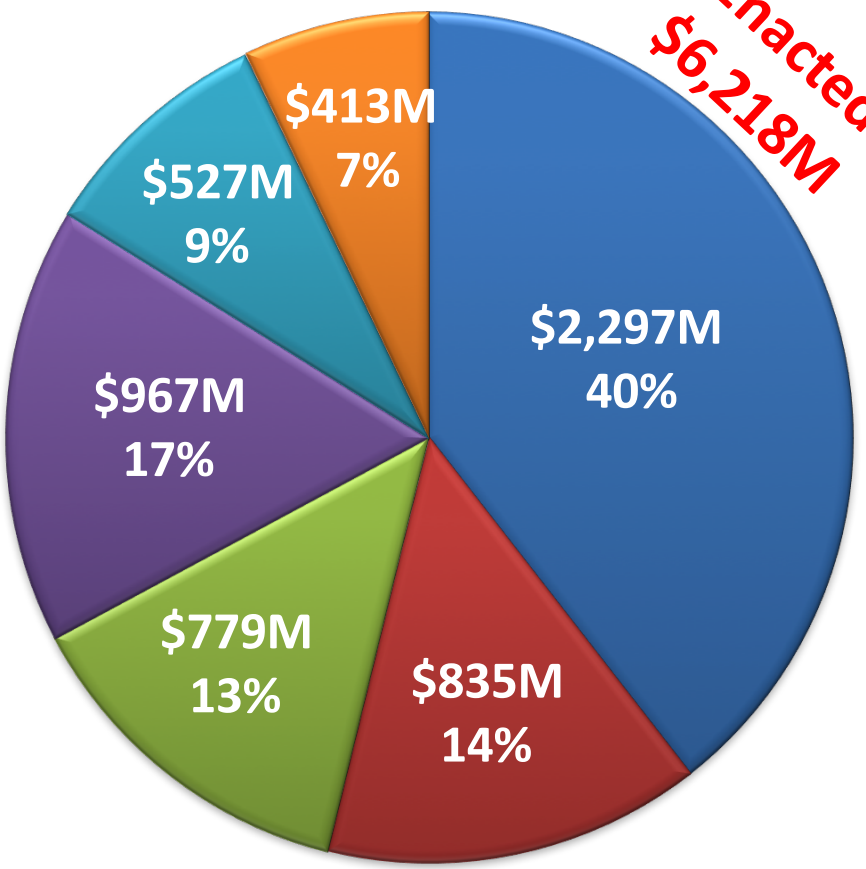
Tank Waste
D&D
Solid Rad Waste
SNM & SNF
Soil & Water
Mission Support

Current Budgets

FY 2015 Enacted: $5,861M



FY 2016 ~~Request: $5,818M~~ Enacted $6,218M

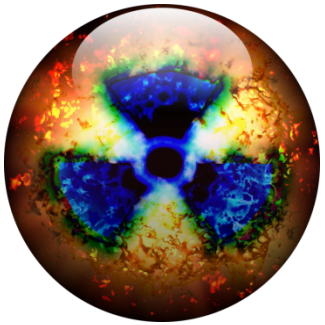


- Tank Waste
- D&D
- Solid Rad Waste
- SNM & SNF
- Soil & Water
- Mission Support

Robotics

EM's Nuclear Cleanup Mission

Emphasis: ALARA

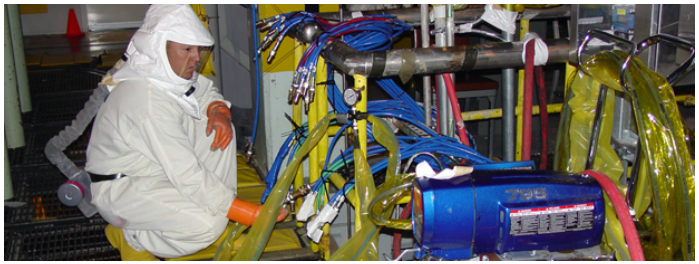


Emphasis: CBRNE

- Handling of high-hazard, high-consequence materials and waste
  - Chemical
  - Biological
  - Radiological
  - Nuclear
  - Explosives

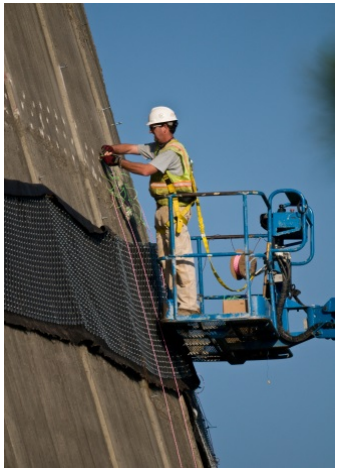
Emphasis: 3D Tasks

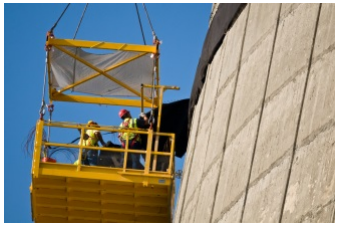
- Performing worker/operator tasks that are
  - Dirty (contaminated, toxic, nuisance)
  - Dull (routine, labor-intensive, repetitive, mundane)
  - Dangerous (pose significant occupational hazards)



Emphasis: Performance

- 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





Mission Execution: *Worker Enhancements*

- Wearable and prosthetic-like robotic devices (a.k.a., co-robots) that
  - Improve worker health and safety or
  - Enhance 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

Mission Execution: Remote Access
Motion, Mobility and Maneuverability

- **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**

Mission Execution: Data, Data, Data
Monitoring, Measuring and Mapping

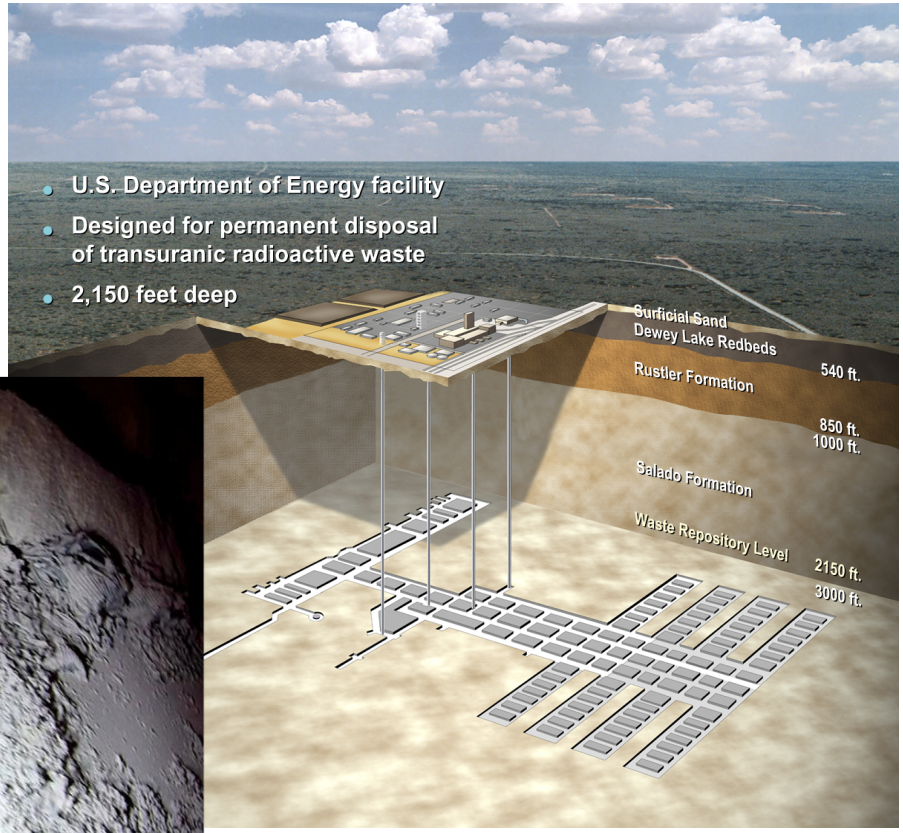
- **Non-Destructive Evaluation/Examination and *In Situ* Characterization**
  - **Acoustic, optical, radiographic, thermographic, electromagnetic, climatic, and other tooling and methods for non-destructive sensing, detecting, monitoring, measuring, characterizing, and assaying a wide variety of radiological,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

Mission Execution: Doing Work
Manipulation and Man-Power

- **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**

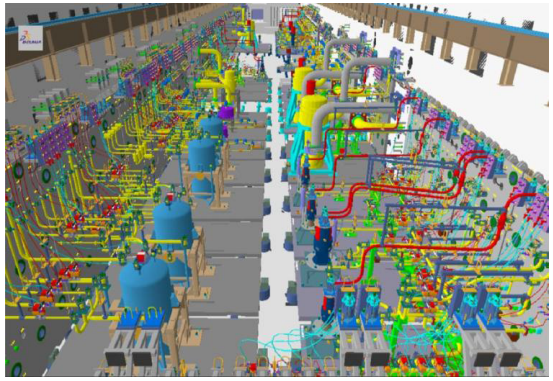
Mission Execution: 911
Emergency Response

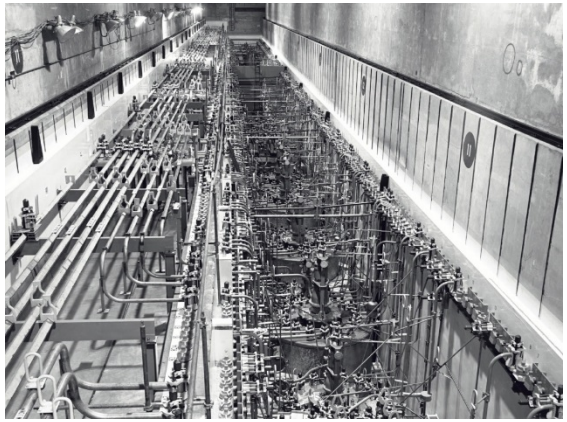
- **Remote access for emergency response, initial re-entry, trouble-shooting, and recovery, particularly when conditions are unknown.**



Mission Execution: Facility Operations

- Improving the safety, quality, efficiency, and productivity of facility operations
- Process Intensification





Operating Domains

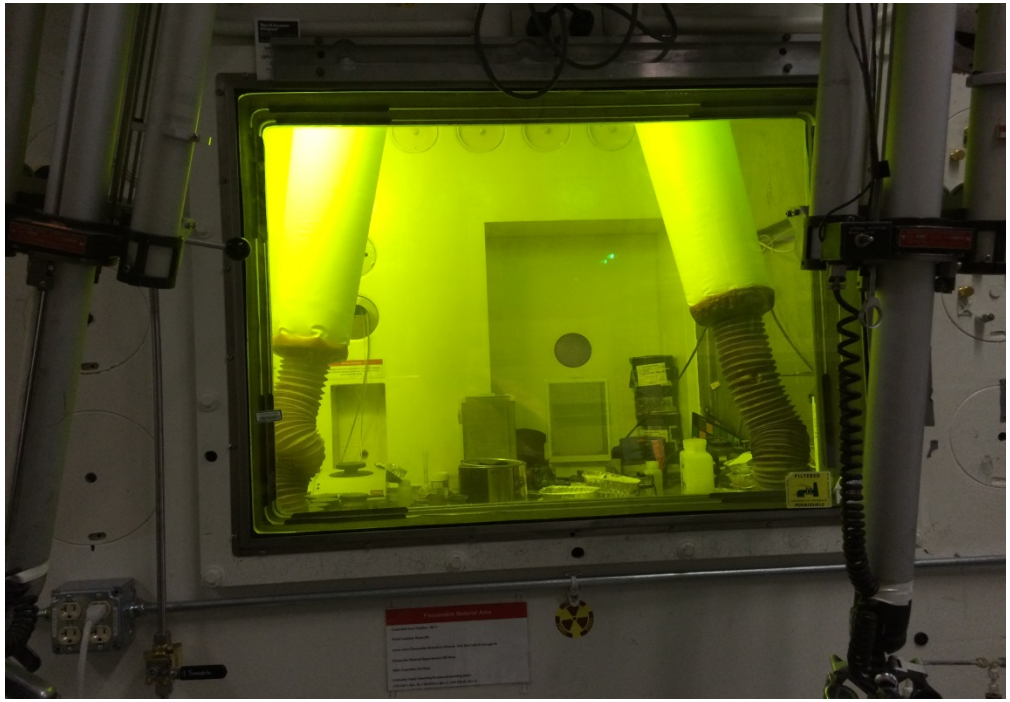
EM's Nuclear Cleanup Mission

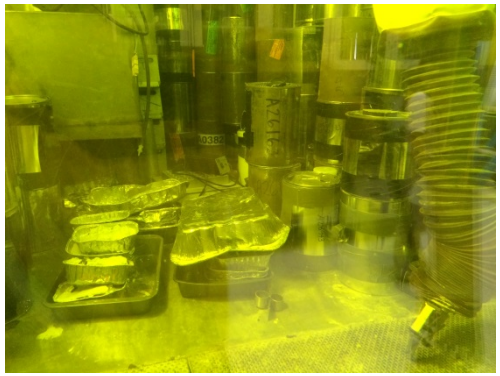
Operating Domain: Radiological Containments

- 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

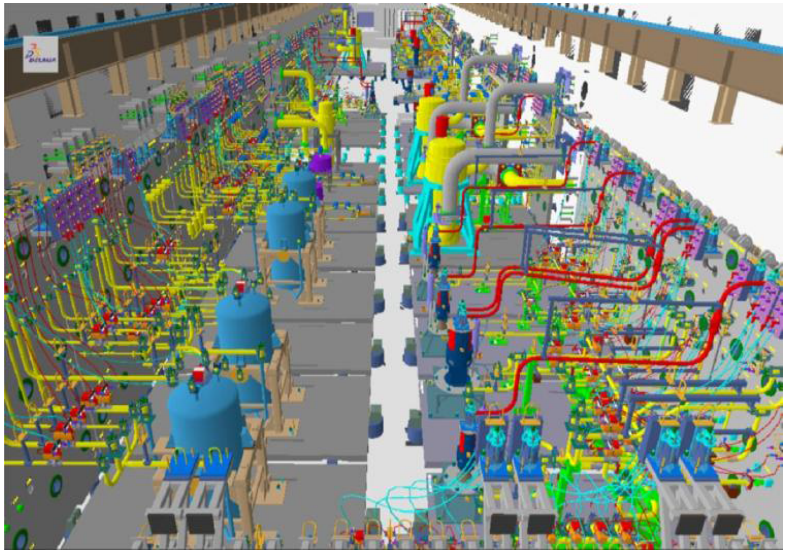
Operating Domain: Gloveboxes

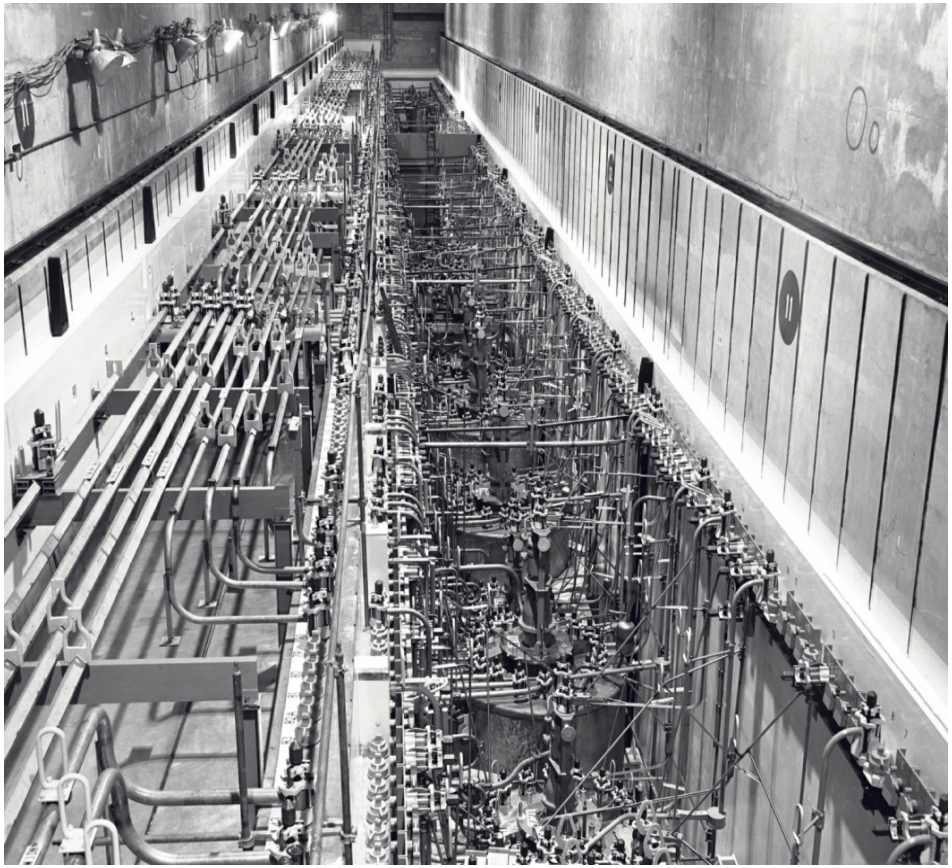
Operating Domain: Hot Cells





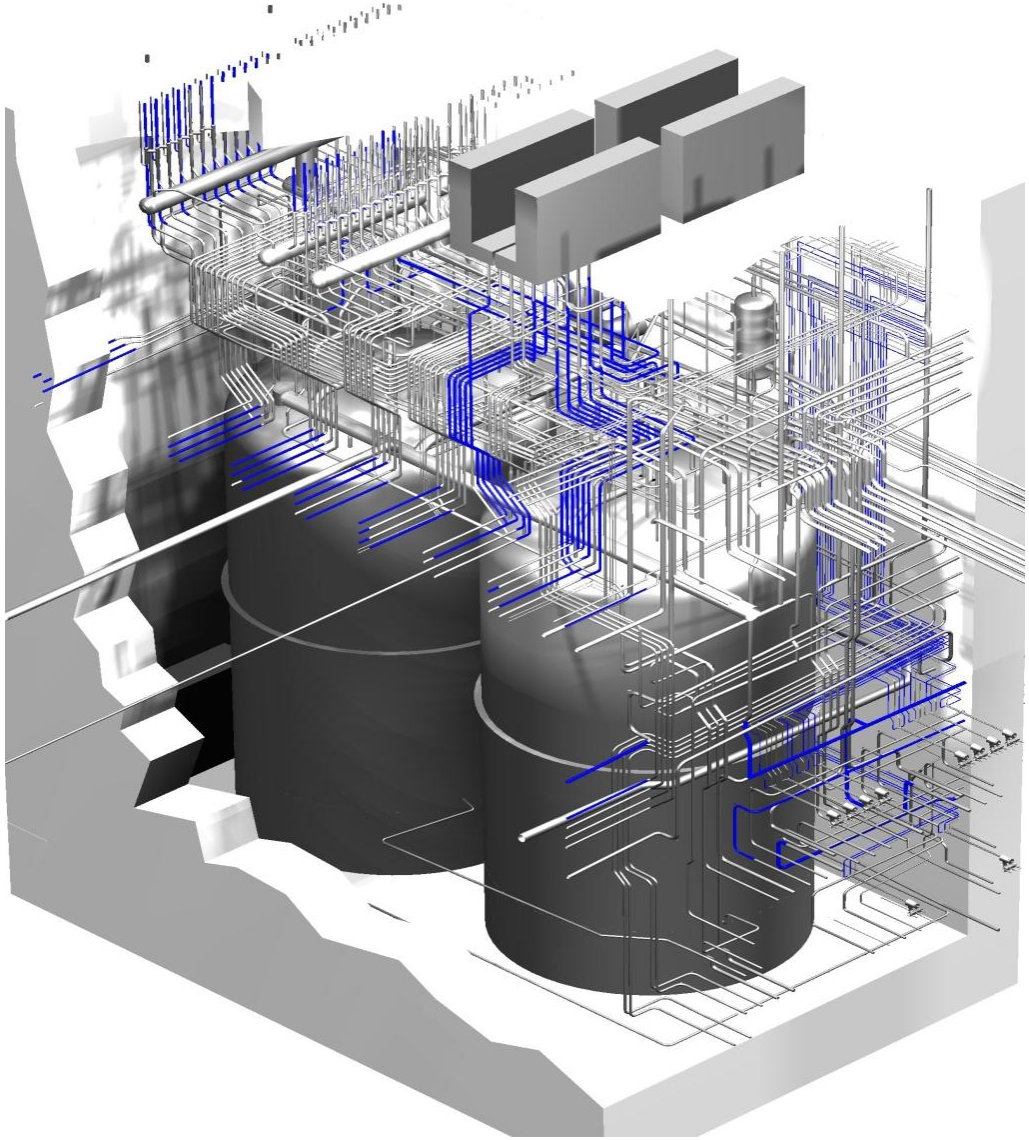
Operating Domain: Nuclear Facilities



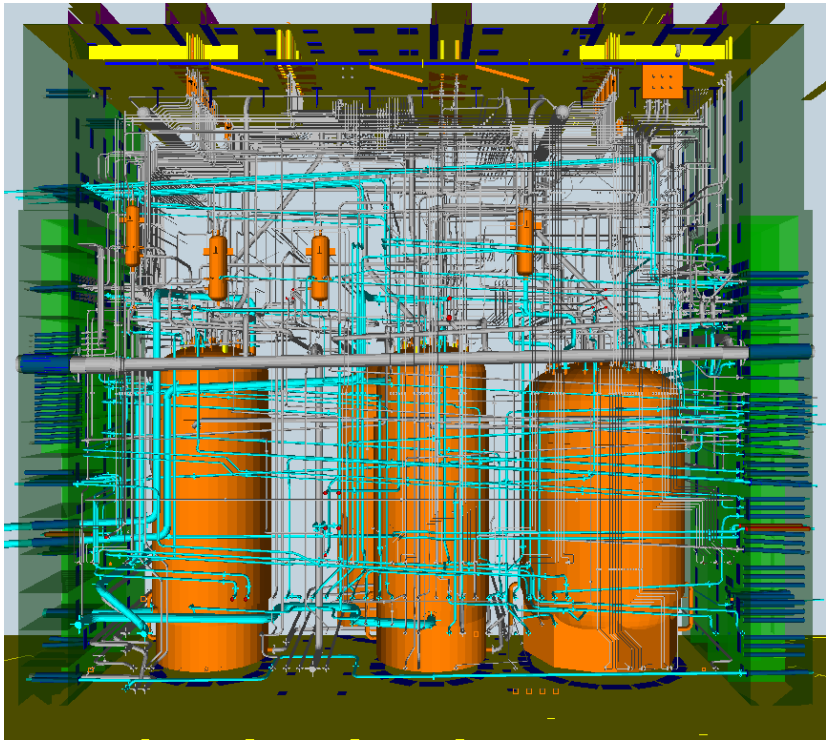


Facility operations and maintenance

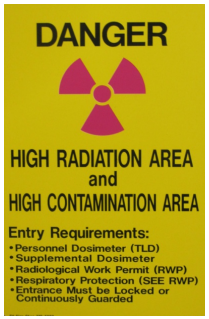
Operating Domain: Nuclear Facilities



Facility operations and maintenance

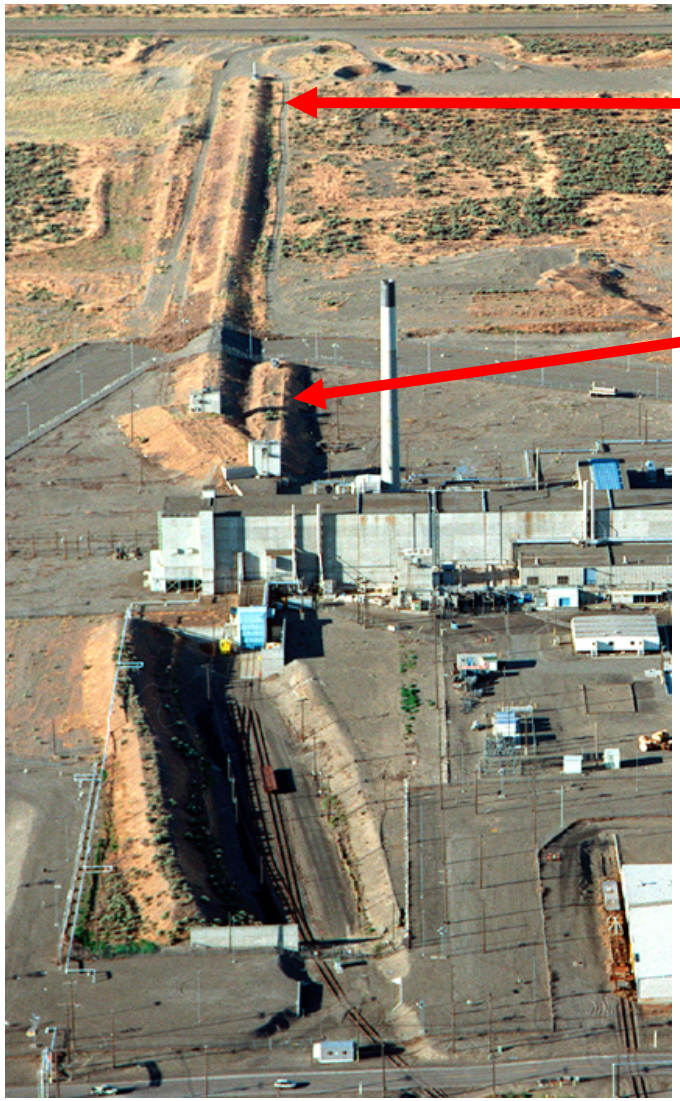


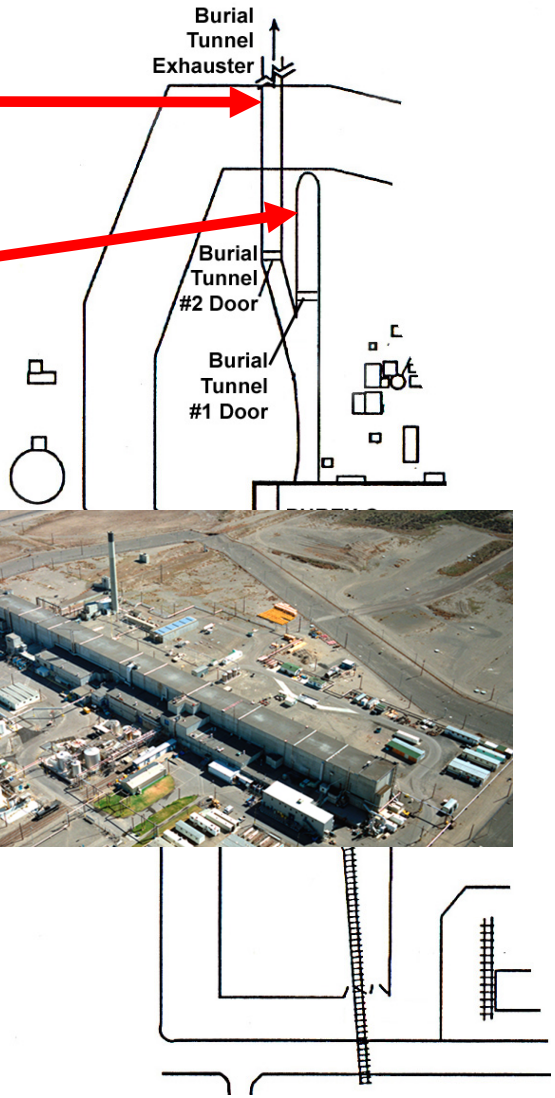
Operating Domain: Nuclear Facilities



Decontamination, demolition and dismantlement operations

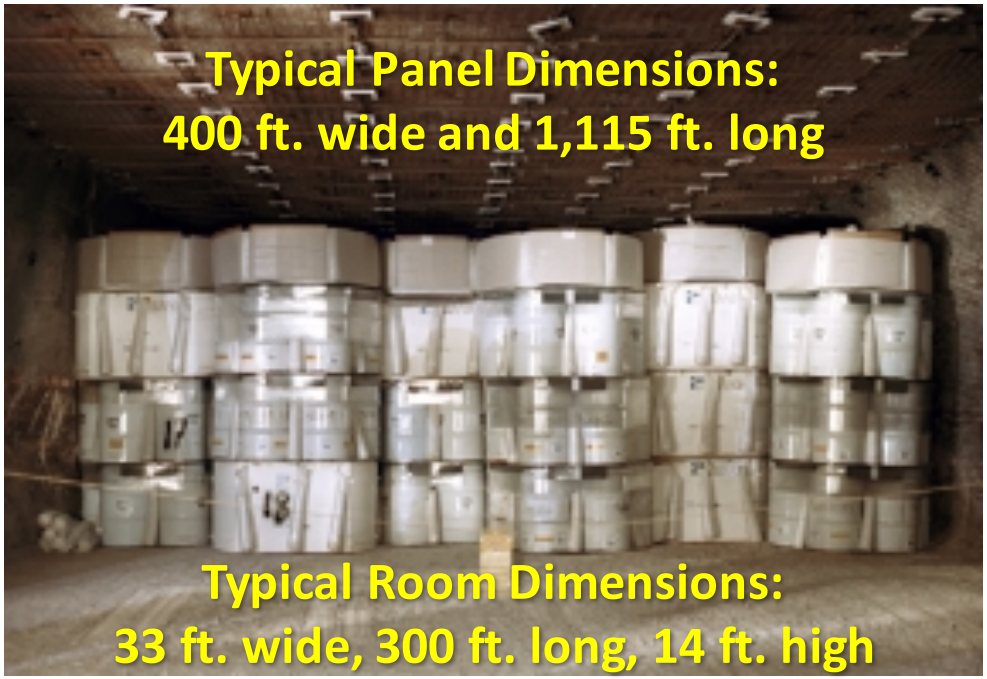
Operating Domain: Underground



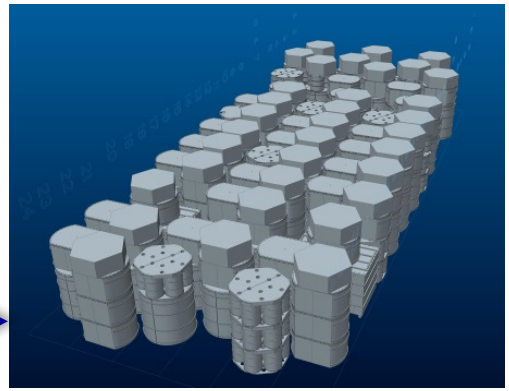


Remote access is needed for initial entry into the tunnels for surveying and characterization

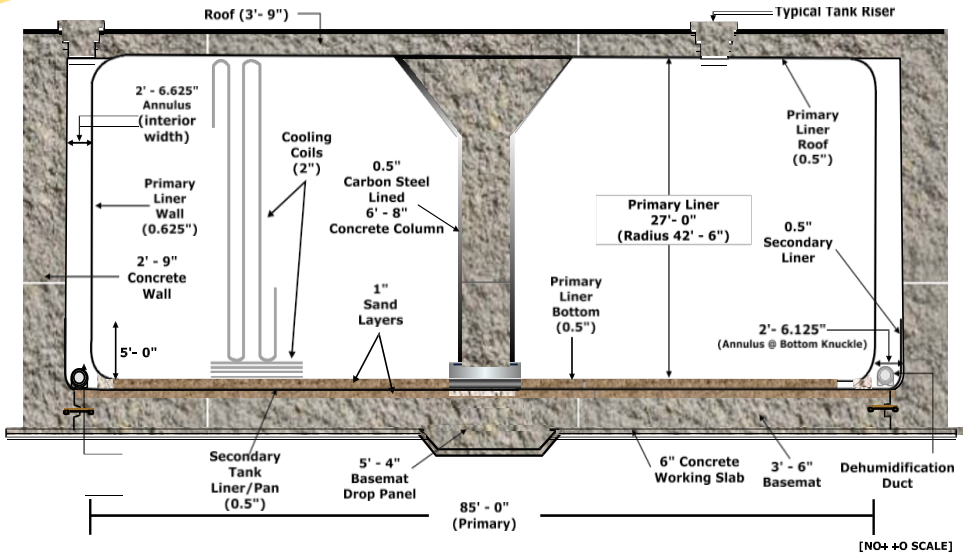
Operating Domain: Underground

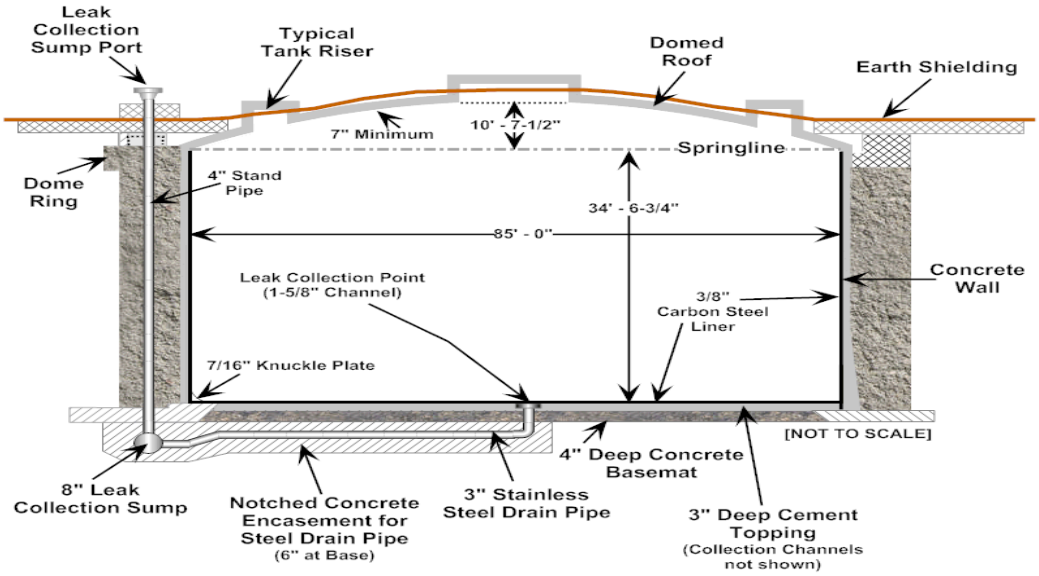


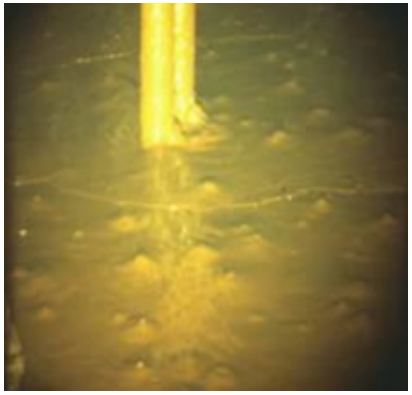
Typical Placement Configurations for Contact-Handled TRU Waste Containers



Operating Domain: "Underground"





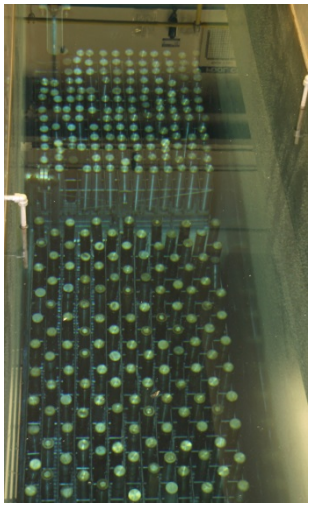


Surveying, characterization and inspection in underground storage tanks

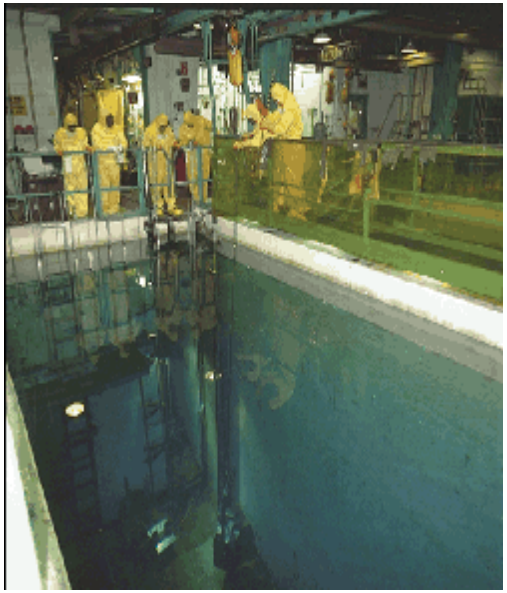
Operating Domain: "Underground"

Investigation and trouble-shooting in underground storage tanks

Operating Domain: Underwater



Underwater inspections, surveying and characterization of storage pools and basins



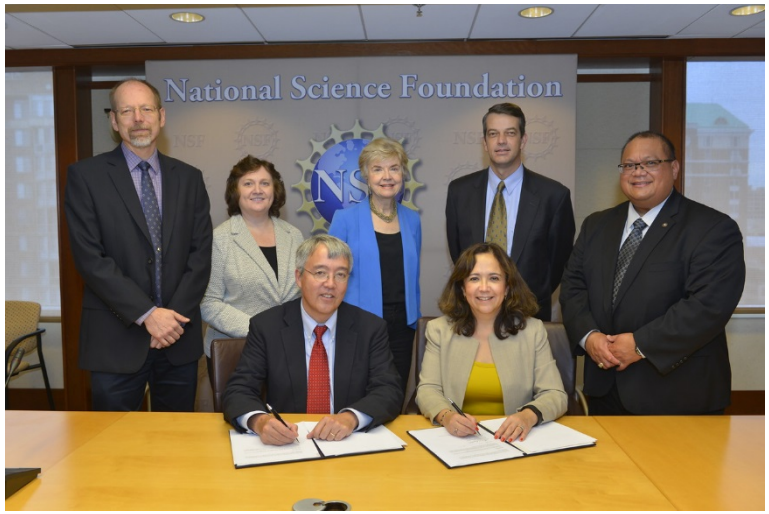
Operating Domain: Aerial

2015 Robotics Initiatives

EM's Nuclear Cleanup Mission

Joined the National Robotics Initiative

- Robotics is a high-priority mission enabling technology being pursued
- National Robotics Initiative
  - MOU with National Science Foundation signed (October 2015)



  - Annual NRI Principal Investigator's meeting (November 2015)
  - NSF Program Solicitation 16-517, "National Robotics Initiative (NRI): The realization of co-robots acting in direct support of individuals and groups" (December 2015) - DOE-EM interests included

Partnered with Office of Nuclear Energy

- Leveraging DOE Office of Nuclear Energy programs
  - FOA for Integrated Research Projects
    - Funding Opportunity Number DE-FOA-0001281, "FY2016 Consolidated Innovative Nuclear Research Funding Opportunity Announcement"
      - Radioactive Waste Management (MS-EM-1)
      - Enhanced Glass Forms For Nuclear Waste Immobilization (IRP-FC-EM-1)
      - Advanced Capabilities For Nuclearized Robotics For Integrated Mapping (IRP-EM-1)
      - Advanced Capabilities For Underwater Nuclearized Robotics (IRP-EM-2)
  - FOA for DOE Traineeships
    - Robotics, DE-FOA-0001374
    - Radiochemistry, pending

NEUP Nuclear Energy University Program
U.S. Department of Energy

Hosted Roboticists at EM Nuclear Facilities

- April: Sellafield Site
- June: WIPP
- August: Idaho National Lab
- August: Hanford Site
- Team
  - Robert Ambrose, NASA
  - Wendell Chun: Univ. of Colorado, Denver
  - Bill Hamel: Univ. of Tennessee
  - Blake Hannaford: Univ. of Washington
  - Veronica Santos: UCLA
  - Satoshi Tadokoro: Tohoku Univ.
  - Richard Voyles: Purdue Univ.
  - Red Whittaker: Carnegie Melon Univ.

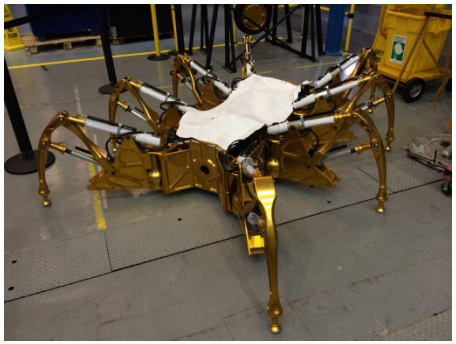
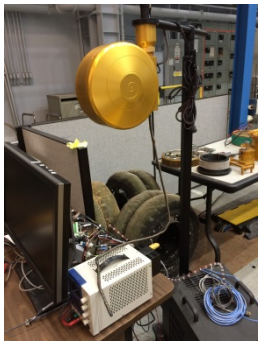
Hosted Roboticists at EM Nuclear Facilities

- **December 2015: Savannah River Site**
  - **Over 40 university, government, and international**

Collaborated with NASA

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



- 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 MOU


Collaborated with NIST

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

- Standard Test/ Evaluation Methods and Practices

Collaborated with UK NDA and UK NNL

- Renewed Statement of Intent
  - US DOE EM, US DOE NE, UK NDA, UK NNL
- Knowledge and technology transfer
  - Robotic snake arm

Closing

- 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 → rad-hardened, rad-tolerant
- EM mission and problem-set cross-cut many robotics applications
  - Commercial nuclear industry (power, medicine, consumer products)
  - Nuclear-capable countries
- Collaborate with the broader robotics community
  - Leverage federal expertise and assets
  - Collaborate with universities and colleges
    - Attract future workforce generations
  - Cooperate and collaborate with other countries
- Many opportunities to engage with DOE-EM

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