



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



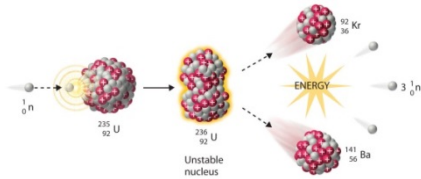
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Overview

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

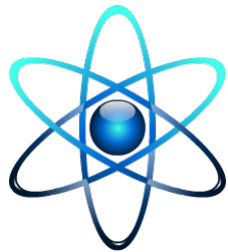
First detonation of a nuclear weapon. ≈20 kilotons of TNT.



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

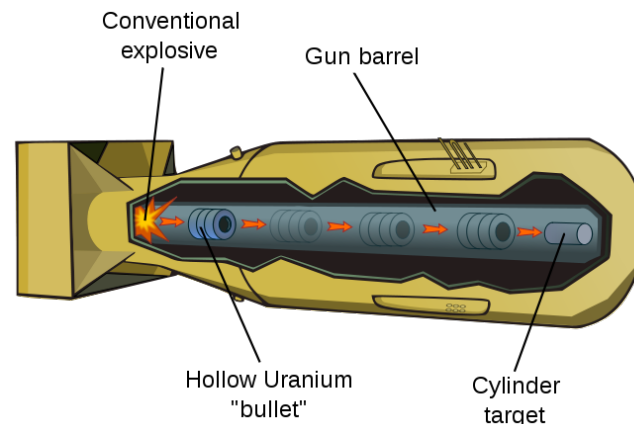
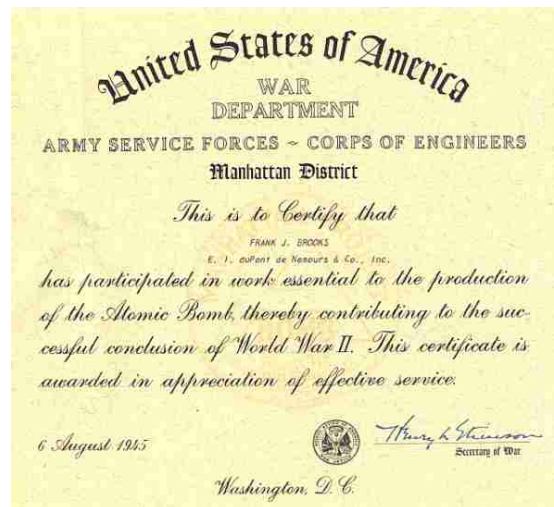
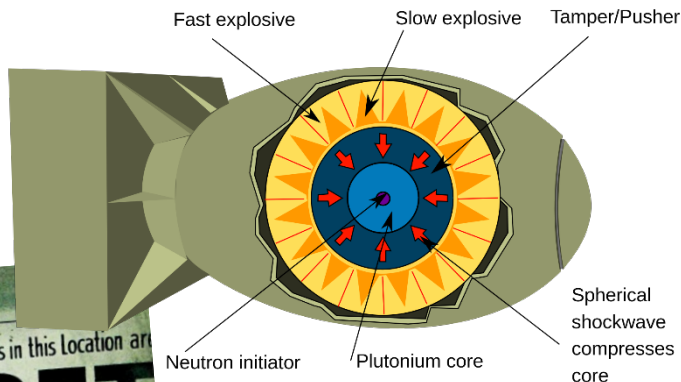
Department of Energy Formerly ERDA

1989

Environmental Management

Nuclear weapons legacy

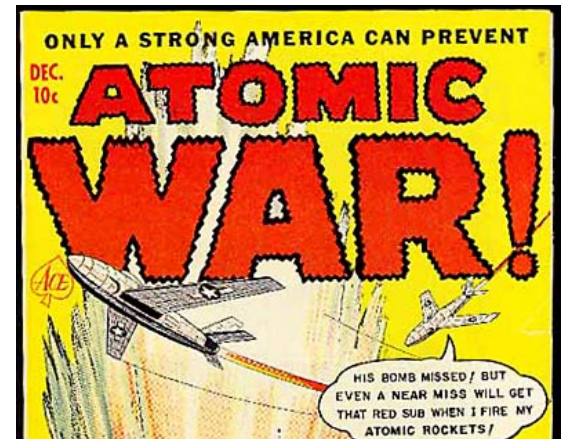
Codename: Development of Substitute Materials



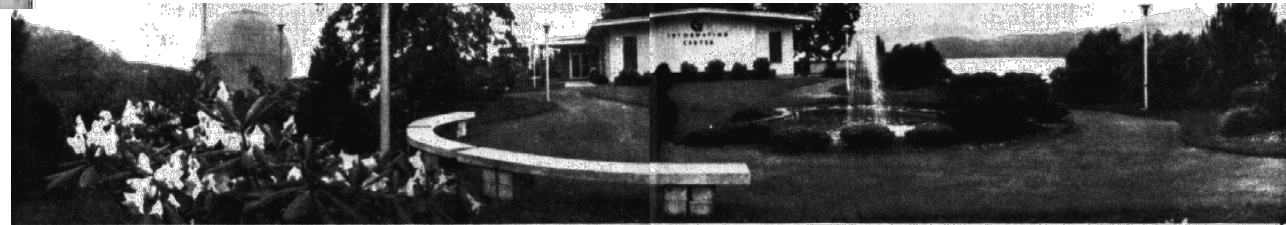
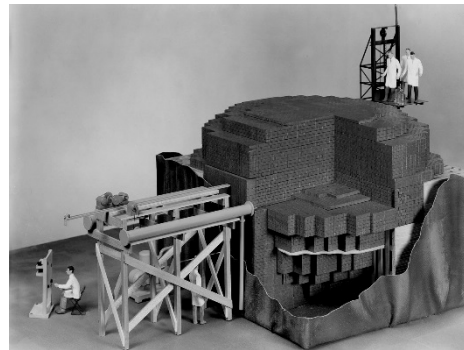
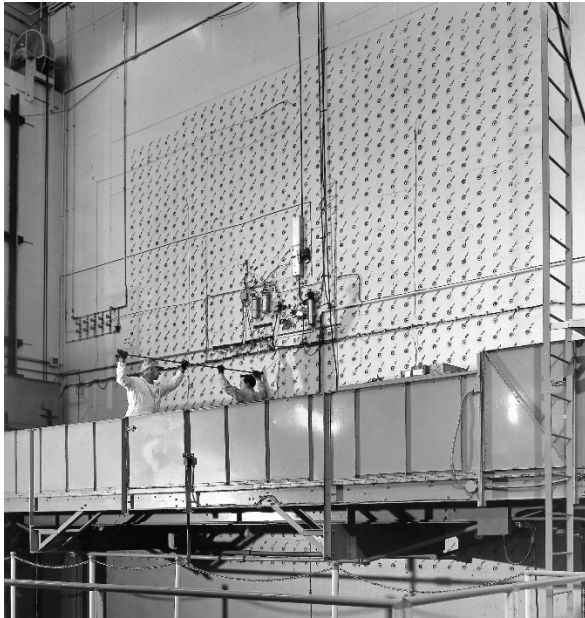
Intel. Tickets obtained, the pair picked up the suitcase and made their way to the New York branch office of Security and Intelligence, to deliver the envelope destined for that branch. Their honor at the discovery that the suitcase contained only five 18 shirazi and five 42 pajamas was indescribable. All of Capt. Dave Tingle's forces in the New York branch and Chief John O'Connell's best Police Department detectives to boot were immediately mobilized to search for the missing suitcase and a subliminal to search for the missing suitcase and a large, well-dressed man who wore Size 18 slacks and Size 42 pajamas. The two unfortunate couriers and Security Division really began to sweat. The next day, Col. John Lunsdale, the head

Legacy Scope: Cold War Expansion

Nationwide Industrial Complex for the Cold War Nuclear Arms Race



Early Years of Government-Sponsored Nuclear Science and Technology



"Go play in the nuclear power 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.

equating 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 must first determine that the owner

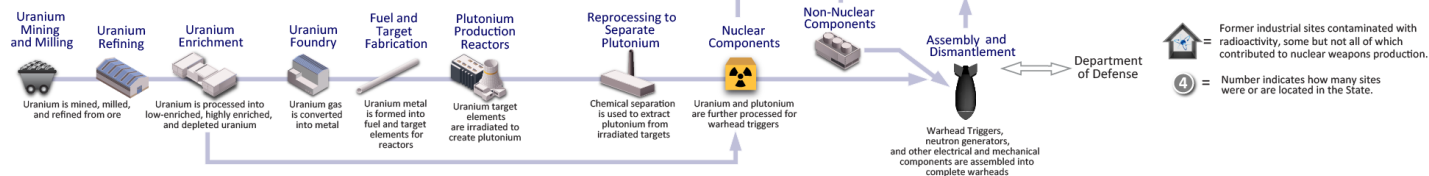
each American to an average of 5 millirems of radiation a year. (A millirem is 1/1000 of a rem, the standard unit of measurement of the biological effect of radiation.) Cosmic rays expose us to another 30 millirems. This varies widely depending on what elevation we live. Just living on a hill exposes 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 us to an average of 20-30 millirems a year.

"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 needs.

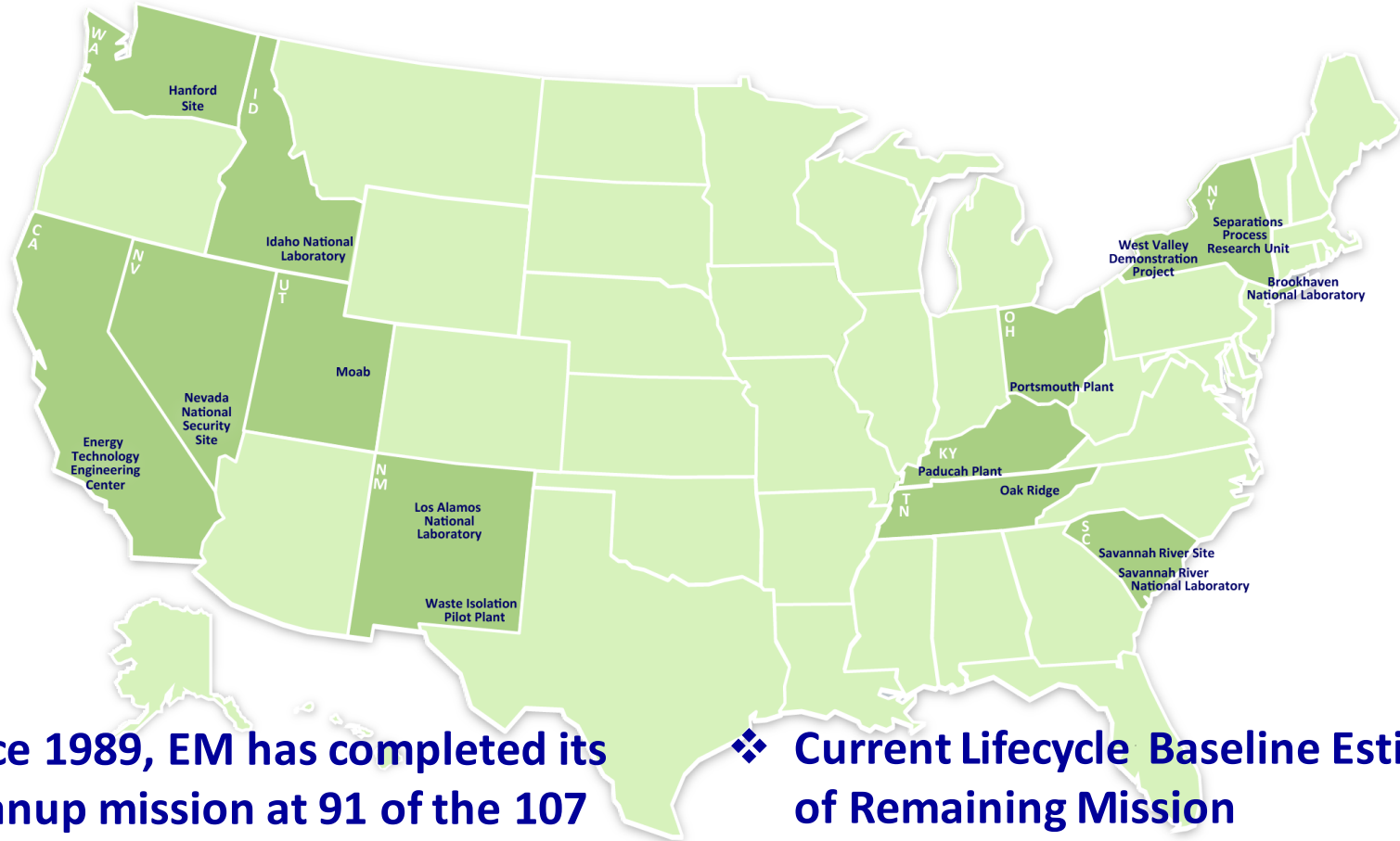
Original Scope of EM's Mission



Nuclear Weapons Production

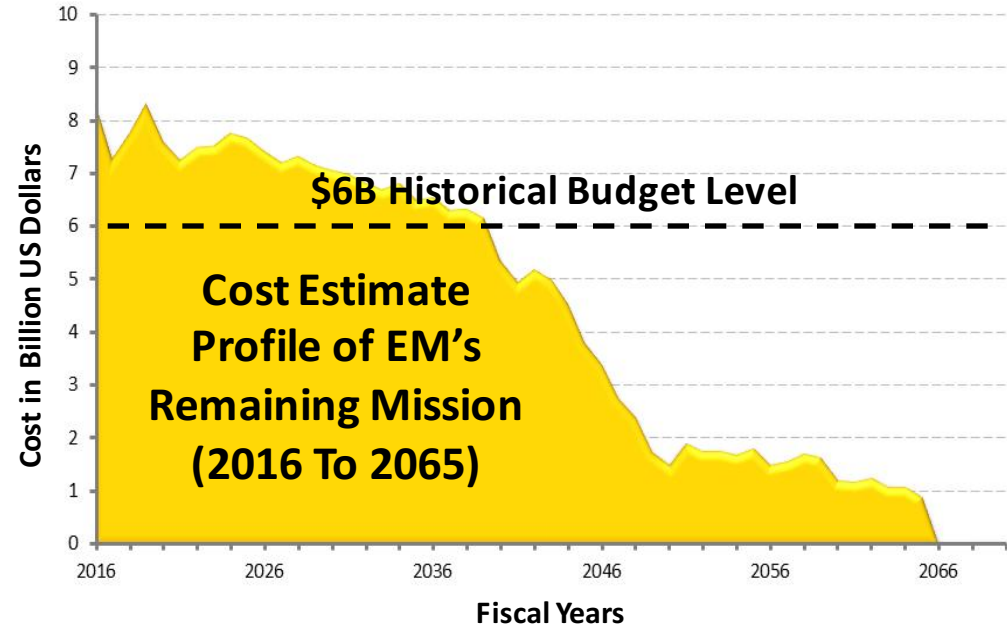
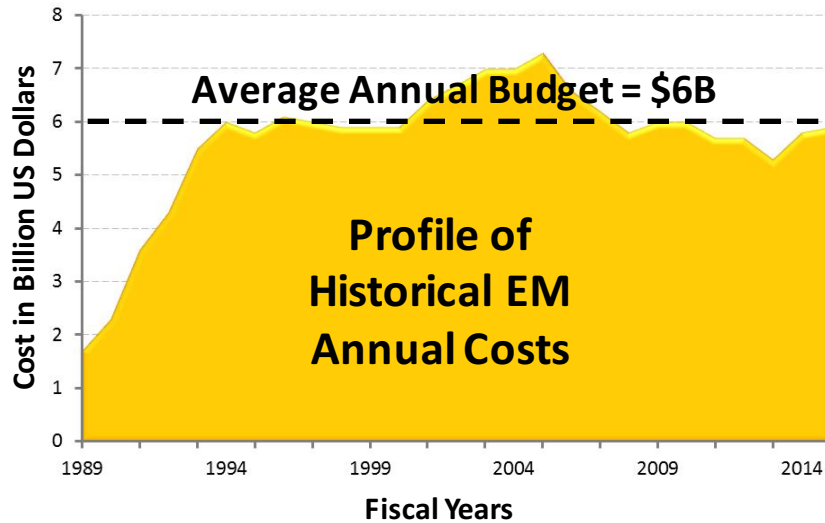


Remaining Scope of EM's Mission



- ❖ 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



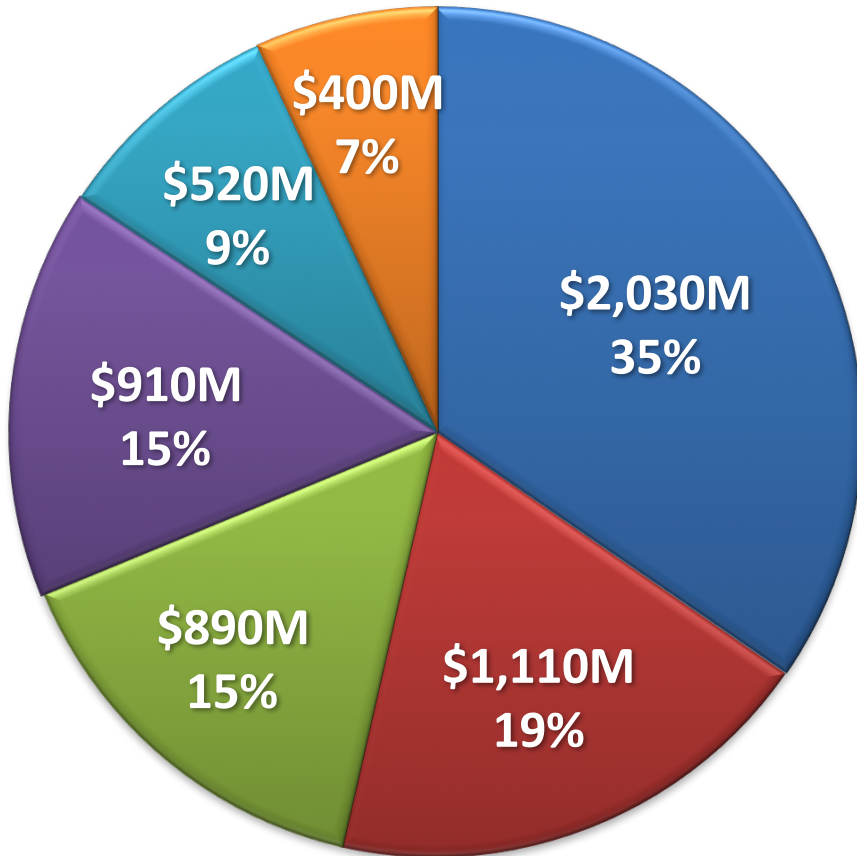
Past Investment

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

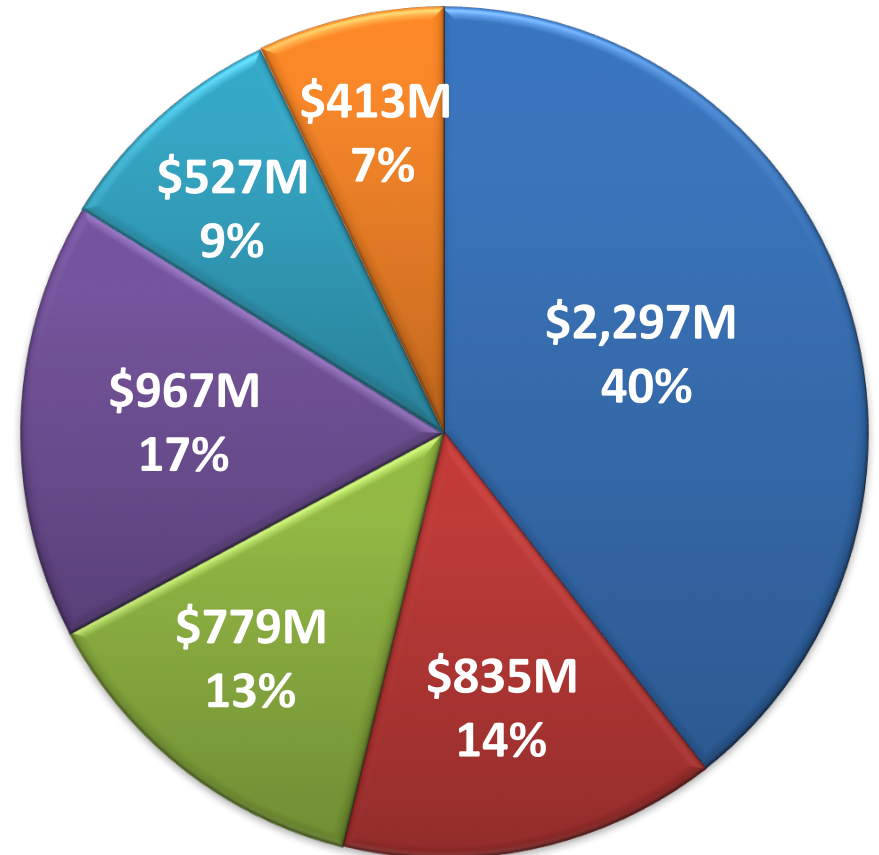
Current Lifecycle Baseline

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

FY 2015 Enacted: \$5,861M



FY 2016 Request: \$5,818M



■ Tank Waste

■ D&D

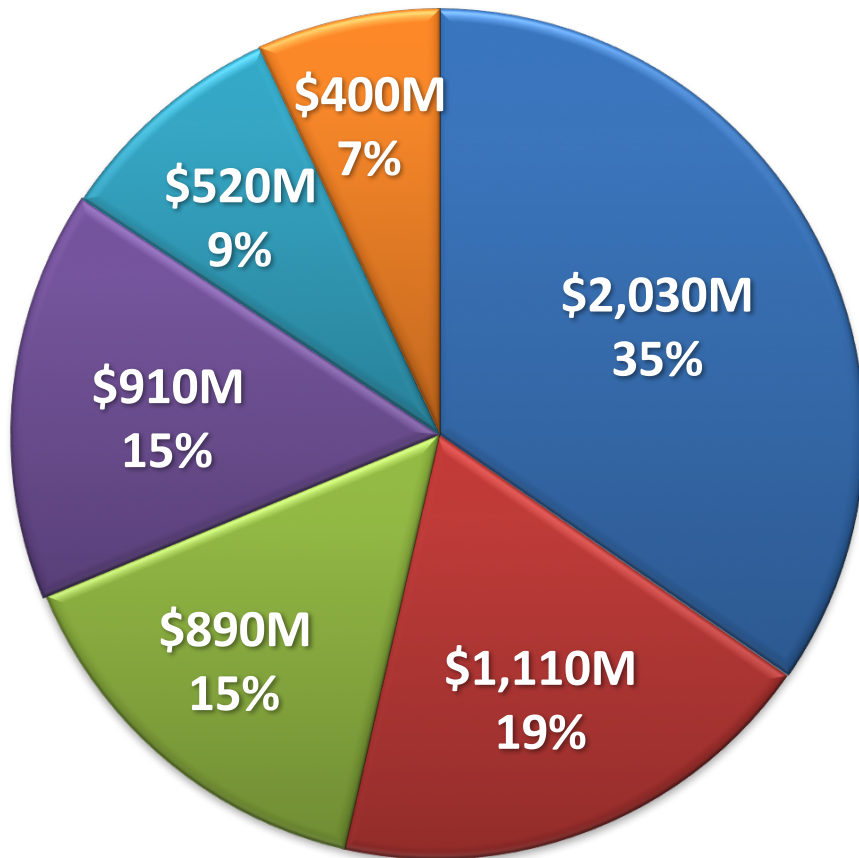
■ Solid Rad Waste

■ SNM & SNF

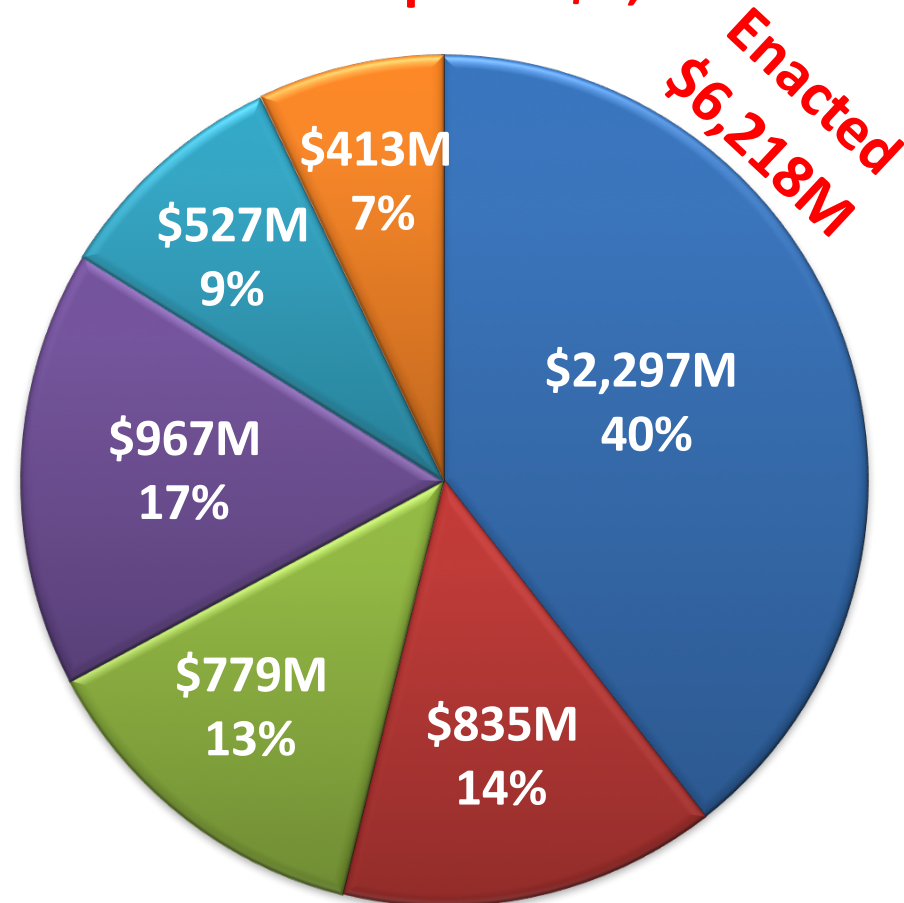
■ Soil & Water

■ Mission Support

FY 2015 Enacted: \$5,861M



FY 2016 Request: ~~\$5,818M~~



■ Tank Waste

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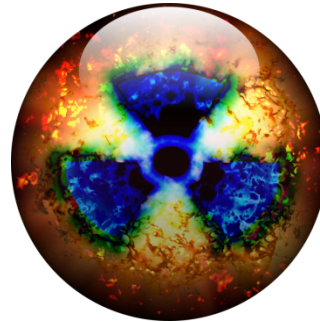


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Robotics

EM's Nuclear Cleanup Mission



❖ Handling of high-hazard, high-consequence materials and waste



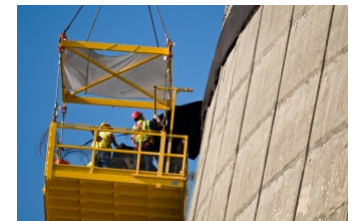
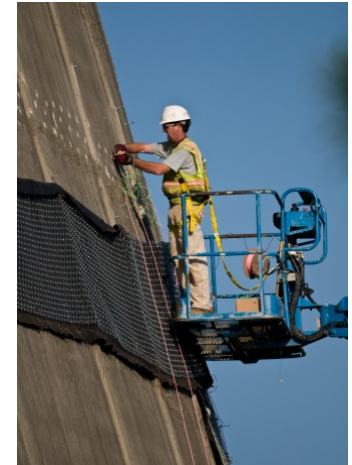
- **Chemical**
- **Biological**
- **Radiological**
- **Nuclear**
- **Explosives**



- ❖ 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



- ❖ **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)

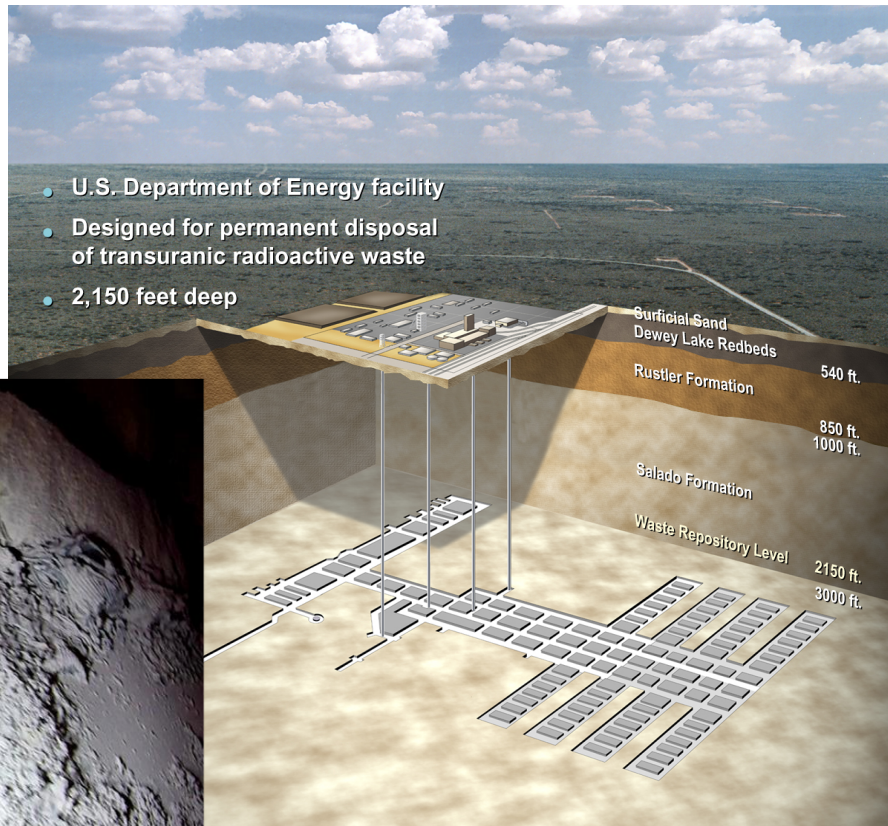
❖ Heavy Operations

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

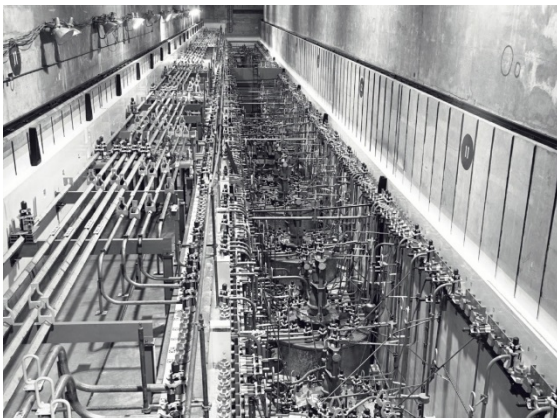
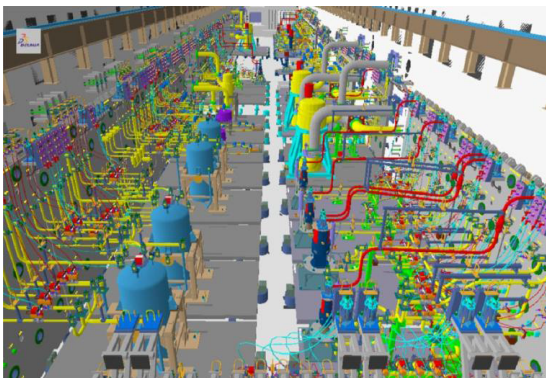
❖ Task Automation

- Systems for more efficiently performing routine or repetitive tasks and operations such that worker interface is needed only for performance monitoring and quality control

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



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





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Operating Domains

EM's Nuclear Cleanup Mission

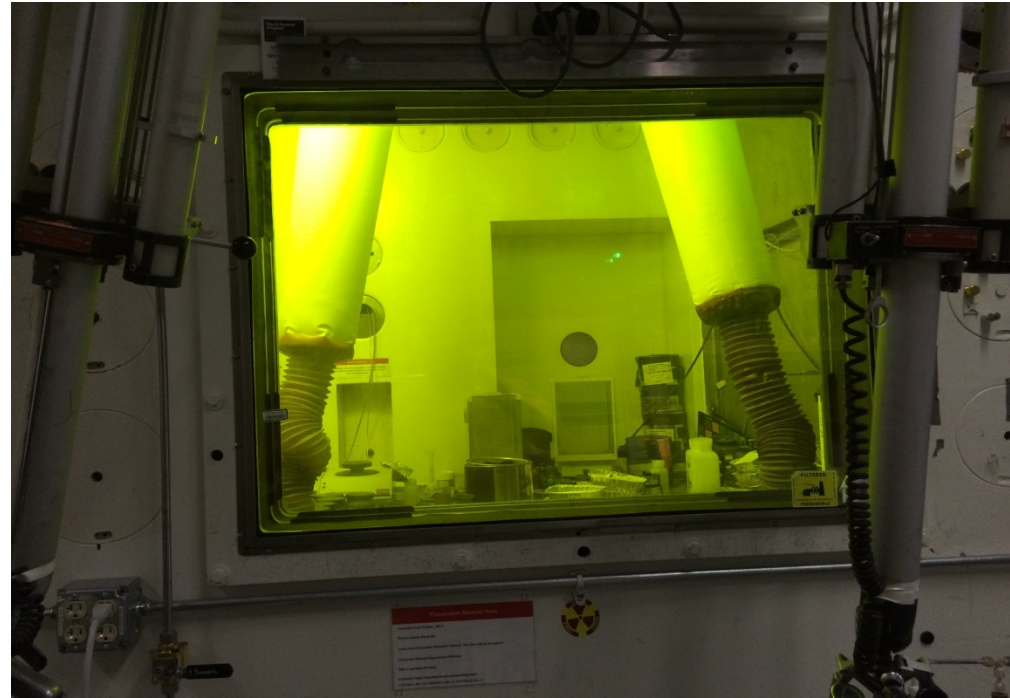
- ❖ **Typical hazards**
 - Radiation
 - Chemicals
 - Sharps and heavies
- ❖ **Degraded Worker Performance**
 - Lack of flexibility and dexterity
 - Challenged visibility
 - Over-work and over-stress injuries
 - Repetitive motion injuries



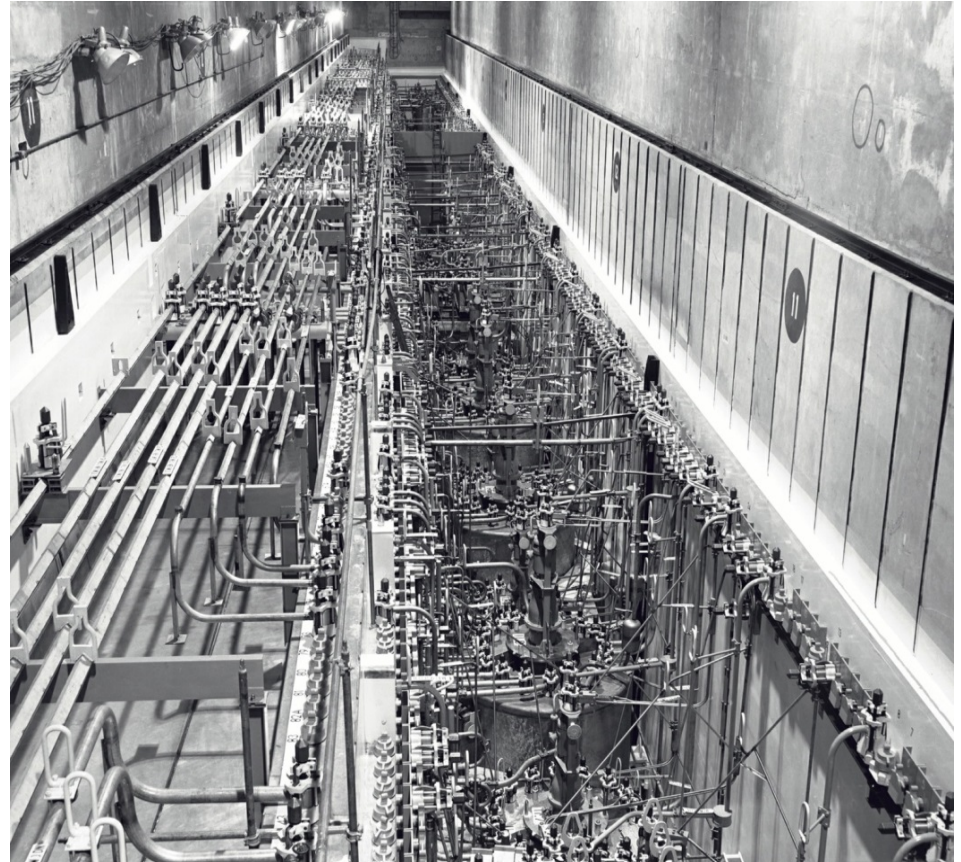
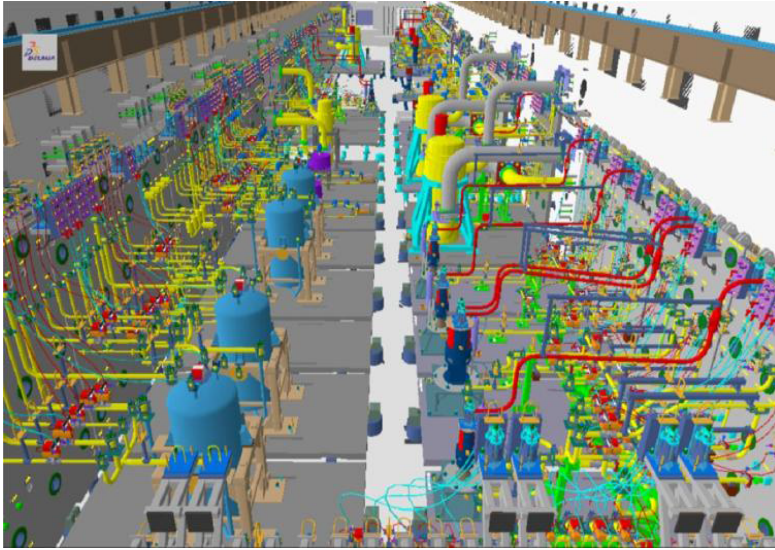
Operating Domain: Gloveboxes



Operating Domain: Hot Cells

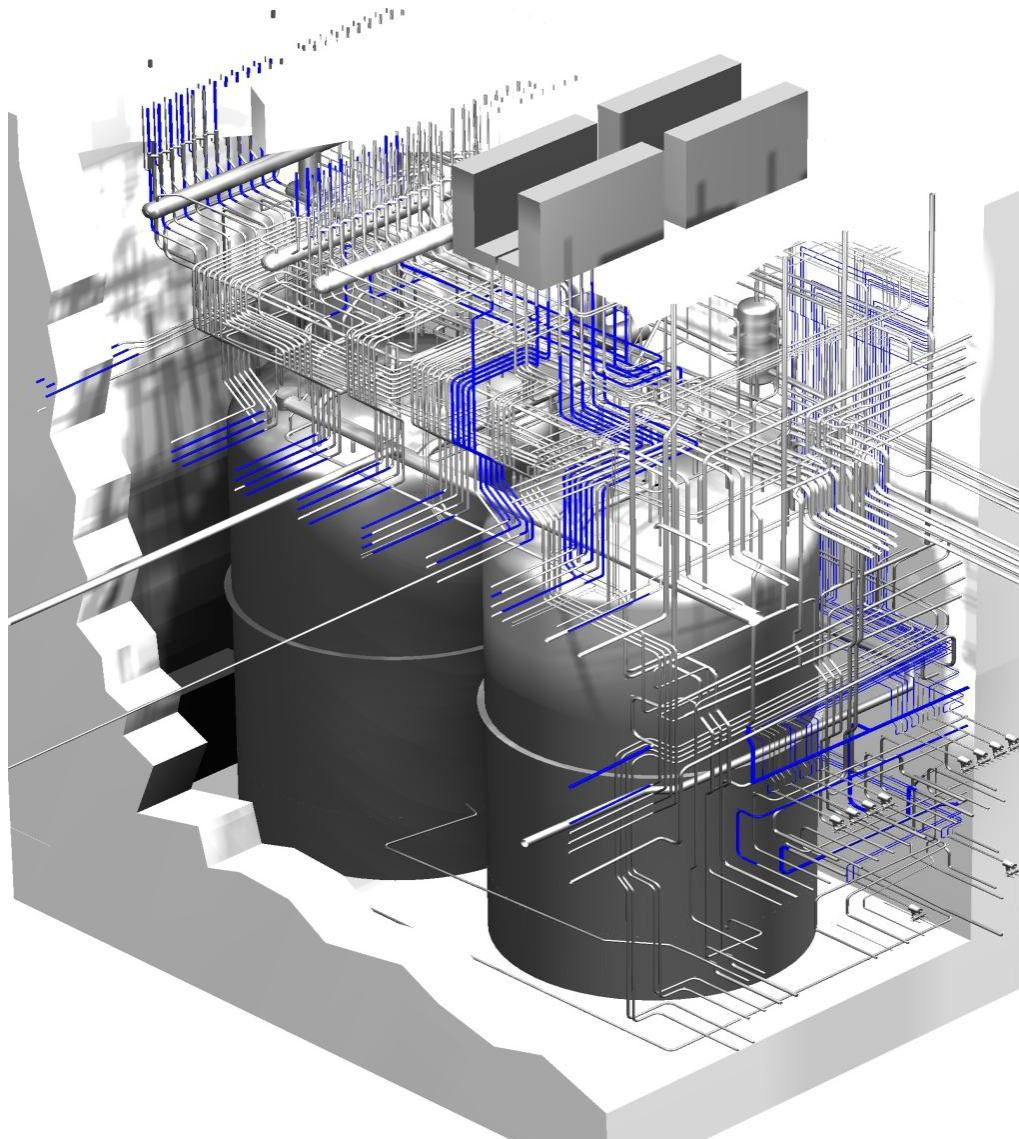


Operating Domain: Nuclear Facilities

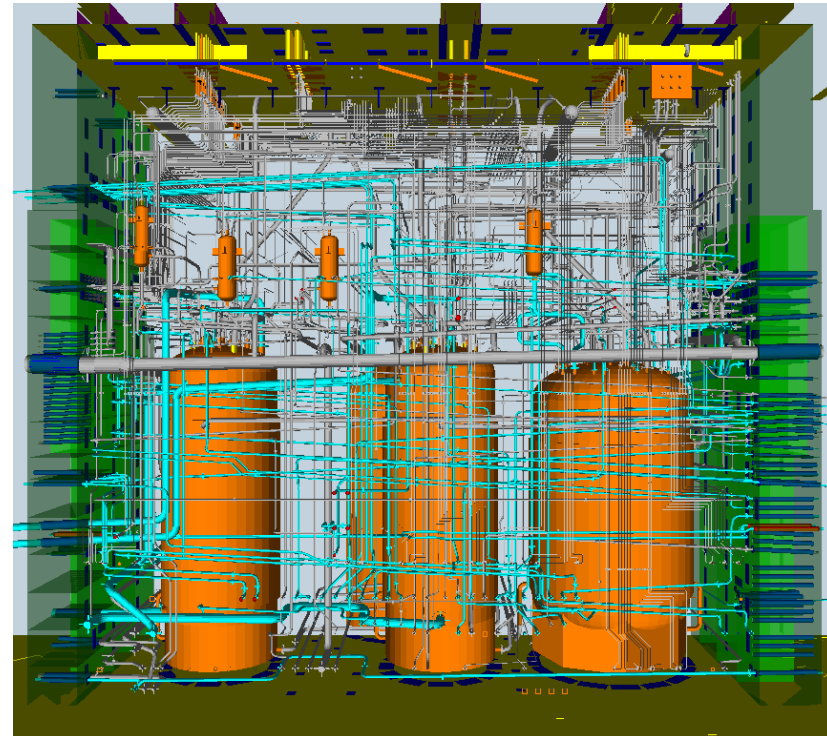


Facility operations and maintenance

Operating Domain: Nuclear Facilities




**Facility operations and
maintenance**





**Decontamination,
demolition and
dismantlement
operations**

DANGER

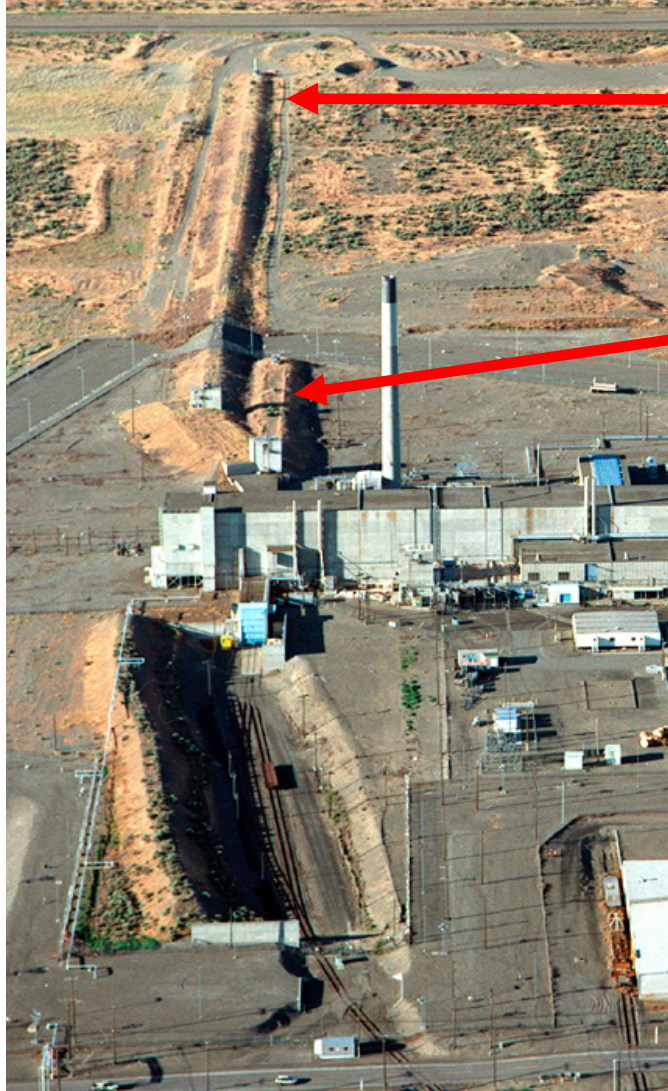


**HIGH RADIATION AREA
and
HIGH CONTAMINATION AREA**

Entry Requirements:

- Personnel Dosimeter (TLD)
- Supplemental Dosimeter
- Radiological Work Permit (RWP)
- Respiratory Protection (SEE RWP)
- Entrance Must be Locked or Continuously Guarded

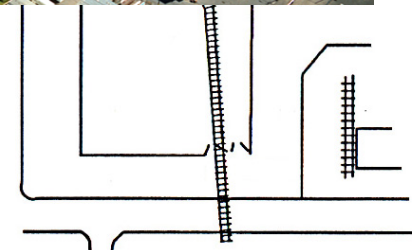
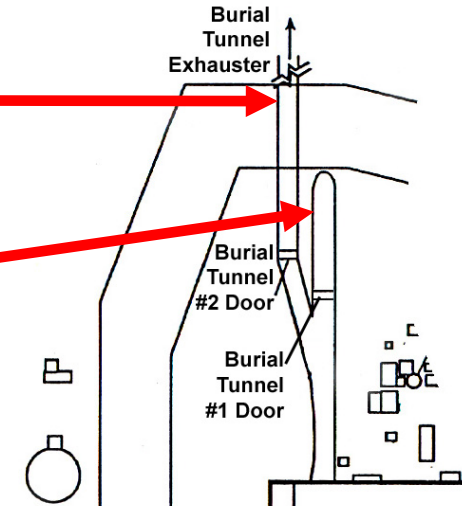
Operating Domain: Underground



Tunnel #2

Tunnel #1

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

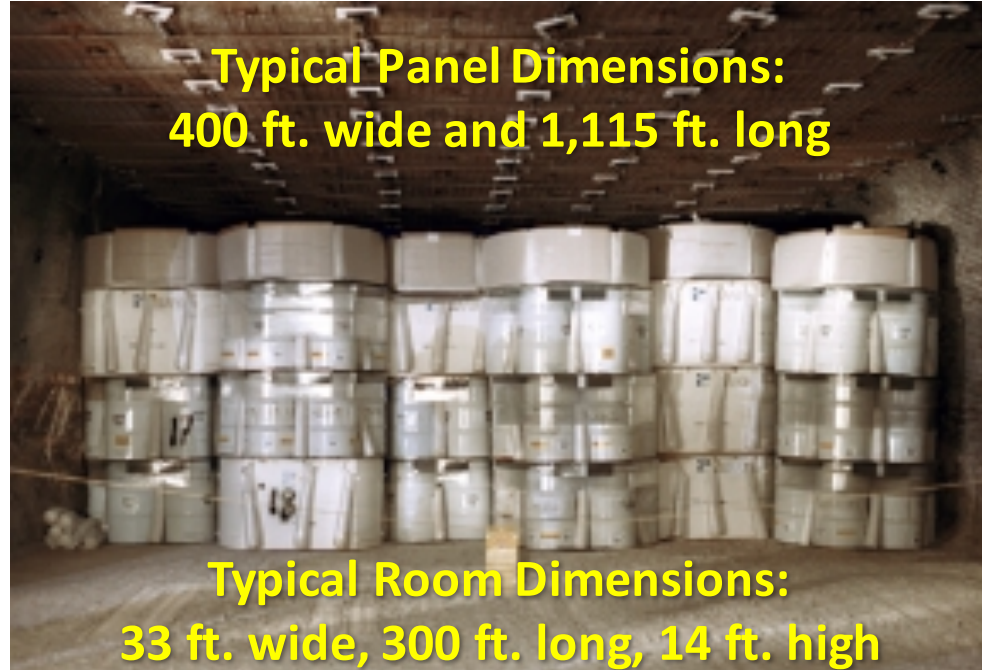


Operating Domain: Underground

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



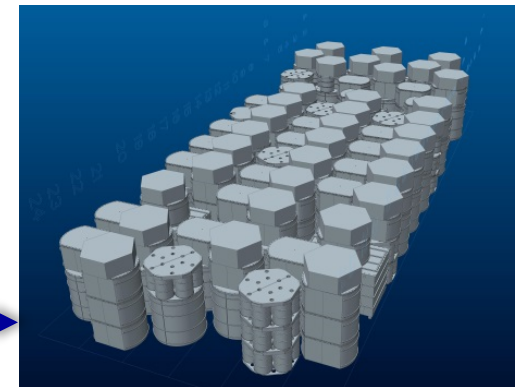
**Typical Panel Dimensions:
400 ft. wide and 1,115 ft. long**



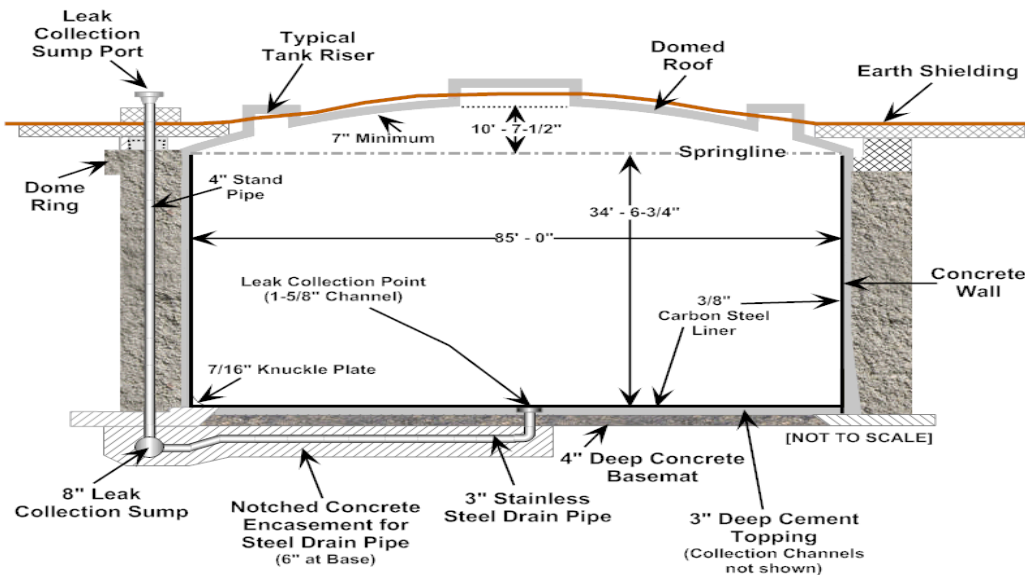
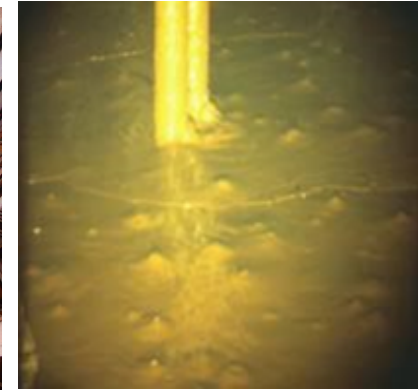
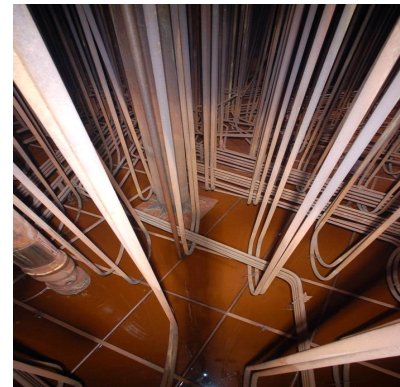
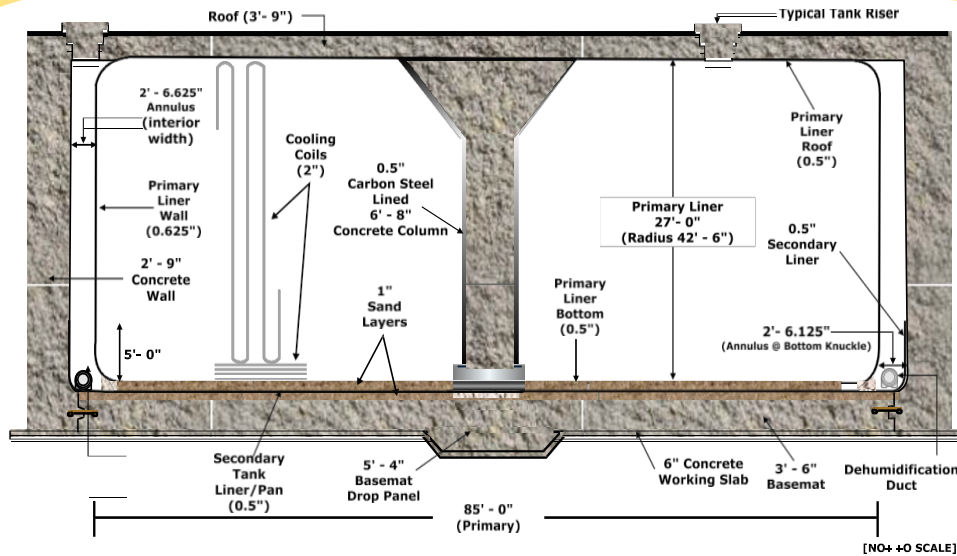
**Typical Room Dimensions:
33 ft. wide, 300 ft. long, 14 ft. high**



**Typical Placement
Configurations for
Contact-Handled TRU
Waste Containers**

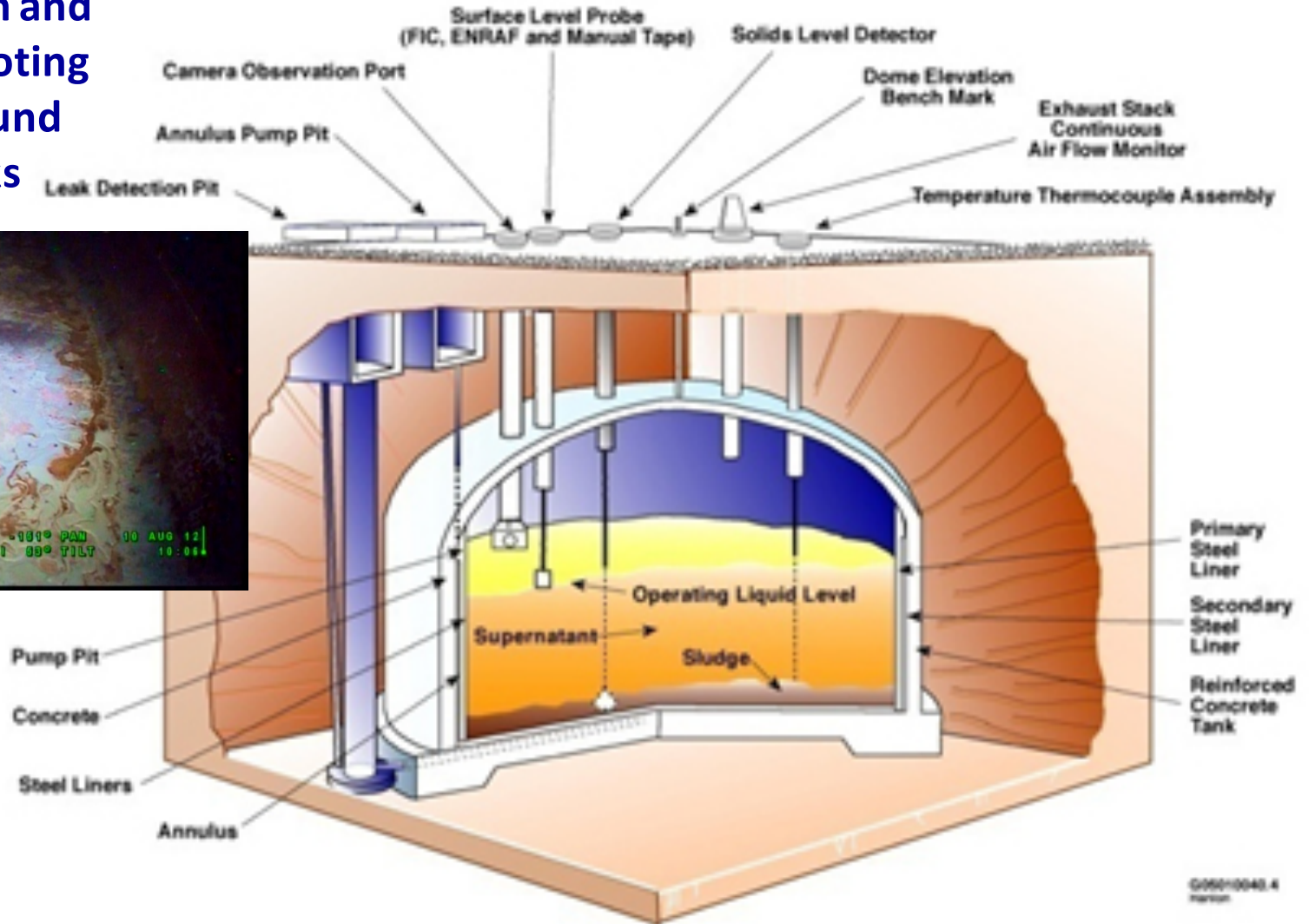


Operating Domain: "Underground"



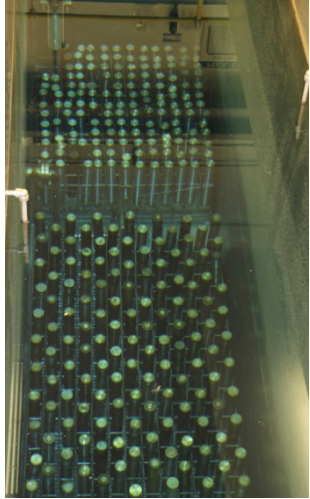
Surveying, characterization and inspection in underground storage tanks

Investigation and trouble-shooting in underground storage tanks

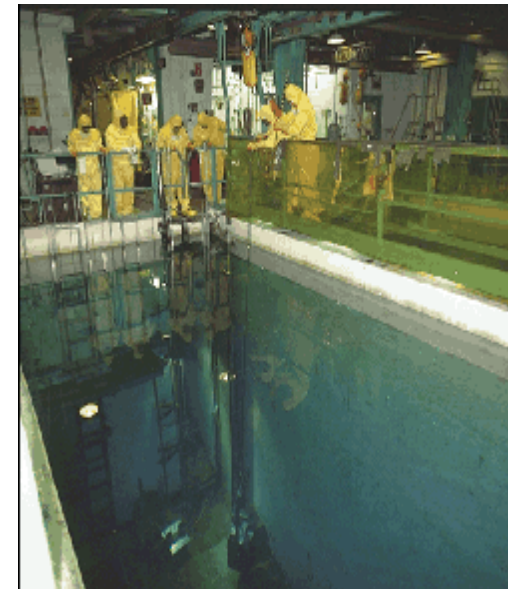


G05010040.4
Harrison

Operating Domain: Underwater



**Underwater inspections,
surveying and
characterization of storage
pools and basins**

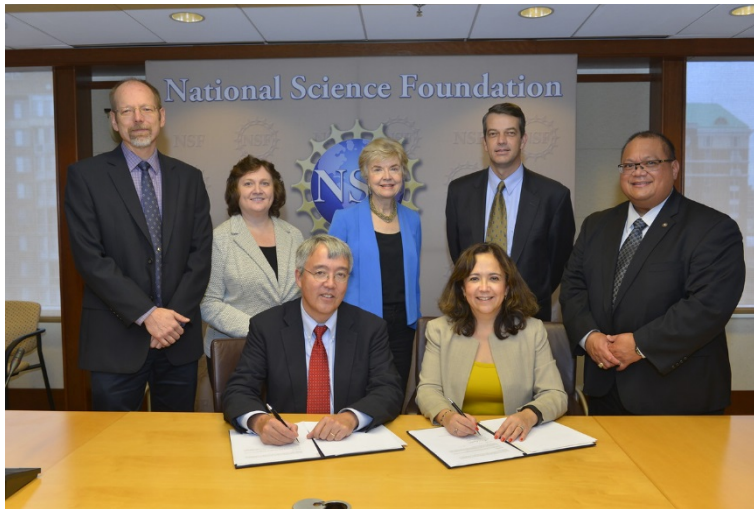




2015 Robotics Initiatives

EM's Nuclear Cleanup Mission

- ❖ 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**

❖ 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**



- ❖ 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.

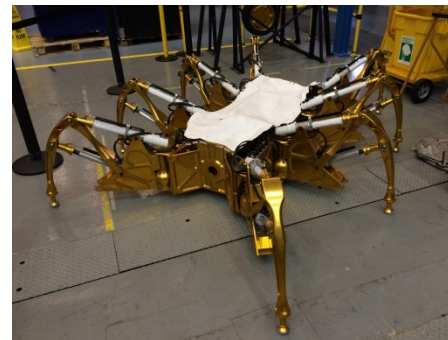
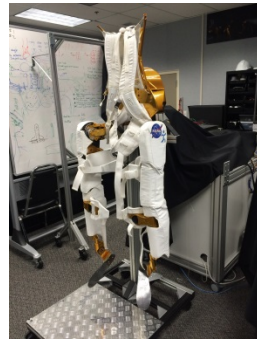


❖ December 2015: Savannah River Site

➤ Over 40 university, government, and international



- ❖ **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**



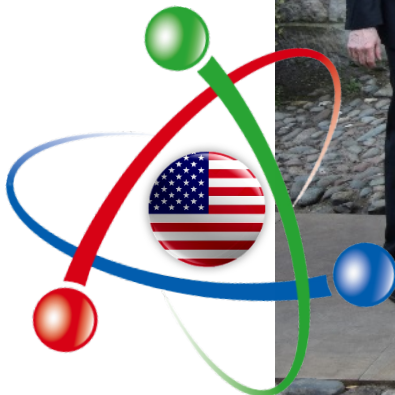


NIST
National Institute of Standards and Technology
U.S. Department of Commerce

❖ **Standard Test/
Evaluation Methods
and Practices**



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



- ❖ 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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