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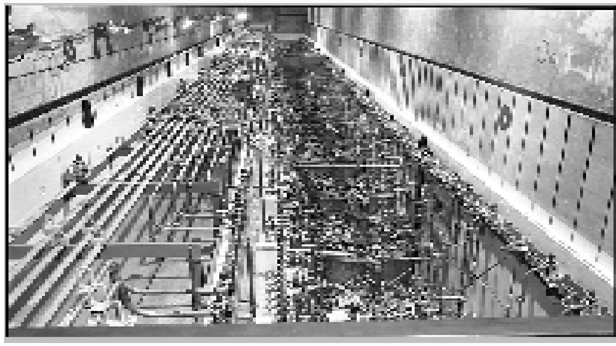

A Roadmap for Robotics and Remote Systems in Nuclear Cleanup

Jason Wheeler, Ph.D., Sandia National Labs

U.S. DEPARTMENT OF ENERGY | Environmental Management

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NNSA National Nuclear Security Administration

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Overview

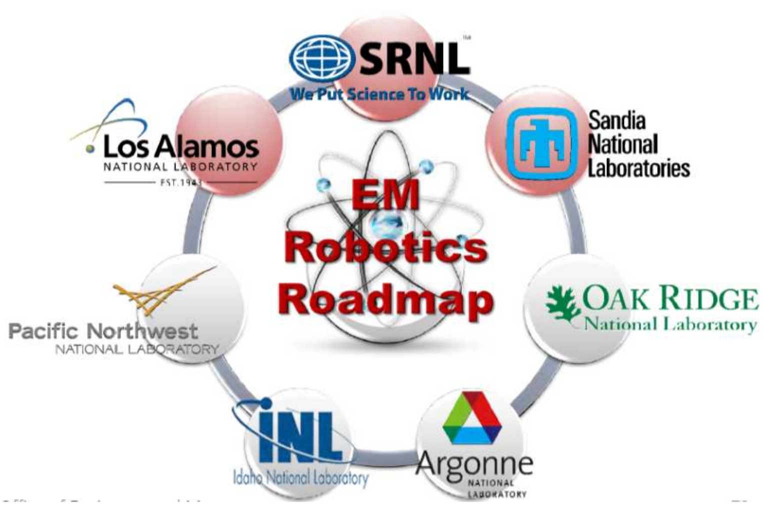
- DOE Environmental Management recognizes the unique technological challenges associated with their mission over the coming decades

- Worker safety is the primary concern
  - Exposure
  - Acute injury
  - Overuse and ergonomic injuries
- Cost and mission execution is also important
- Robotics have the potential to enable the safe and efficient completion of EM's mission

- The EM Office of Technology Development commissioned a robotics and remote systems roadmap to accelerate and guide technology development and insertion

Roadmap Team

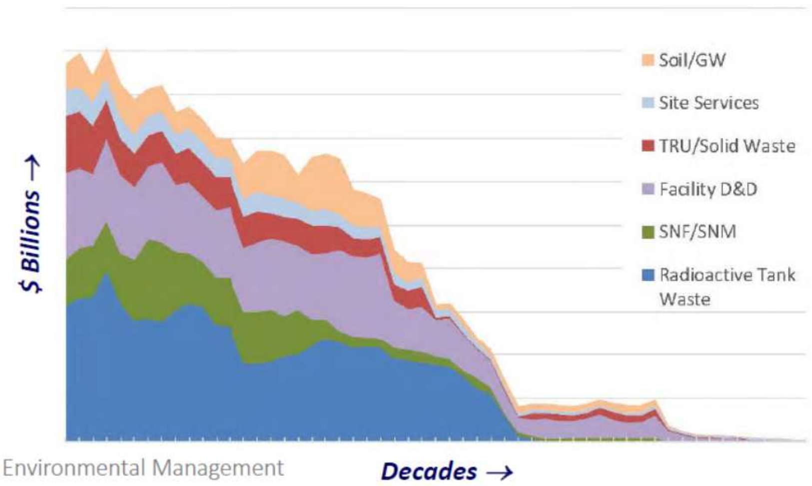
- Core Team
  - EM-3.2: John Lee
  - SNL: Jason Wheeler
  - SRNL: Rick Minichan/Eric Kriikku
  - LANL: Troy Harden
  - Univ. of Colorado: Wendell Chun
  - Univ. of Tennessee: Bill Hamel
  - Purdue Univ.: Richard Voyles



- Advisory Group
  - EM-3.2: Rod Rimando
  - SNL: Philip Heermann
  - SRNL: Tom Nance
  - LANL: Paul Dixon
  - NASA JSC: Josh Mehling
- External Contributors and Reviewers
  - EM Field Elements
  - EM HQ and National Labs
  - 20+ Federal Agencies (SMEs)
  - 30+ Universities (SMEs)

DOE-EM Mission Challenges

- The Roadmap is a **mission need-driven** document, not a technology-push document
- The EM Mission spans several decades and will cost tens of billions of dollars
- Occupational exposure (to radiation and other hazards) is a unique DOE-EM challenge
- Musculoskeletal injuries due to acute/ergonomic hazards are a significant concern



Understanding EM Site Needs

- EM Office of Technology Development and the roadmap team visited several sites and sent requests for information to each site (examples below)

- Savannah River
  - Roadmap feedback form
  - H-Canyon Site Visits
  - Presentations at ANS and WM Meetings
- Portsmouth GDP
  - Site visits
  - Technology demo reports
- Hanford
  - ORP Roadmap feedback form
  - ORP Technology Roadmap
  - Site visits and report (R. Voyles)
- WIPP
  - Site visits and SNL discussions
- OREM / Y-12
  - Roadmap feedback form
- Other sites providing feedback (partial list)
  - LLNL Site 300
  - WVDP
  - SPRU
  - MOAB
  - LBNL
  - BNL
  - ANL

Sample Feedback Form

Sandia National Laboratories

Completed Form

EM Site-Specific Technical Challenge Data Collection (Rev 1, Feb 2017)

Site: Office of River Protection-Hanford
Contact: Naomi Jaschke
Email: naomi.jaschke@orp.doe.gov
Phone: 509-376-5594
Date: 5/25/2017

Use Chart to classify each challenge

	Improvement Category		Task Category				Time Horizon		
Challenge / Problem Statement	Safety	Performance	Dull	[illegible]rty	Dangerous	[illegible]	0-5 Years	6-10 Years	Out years
1. Structural integrity inspections / automated Double Shell Tank (DST) annulus camera system / Non-destructive examination (NDE) sen[illegible] development	M	H	M	M			M		
2. Deployable device capa[illegible] the Effluent Treat[illegible] (ETF) process tanks [illegible] and roofs without [illegible] entry	M	M		M		M	M		
3. [illegible] to improve waste retri[illegible]ities	L	H		L		H	M	M	
4. Imp[illegible]ved sampling / detection / monitoring system(s)	M	M	L				M		
5. Remote tank farm above-ground inspection capability	M		M	M			M	M	
6. Waste transfer pipe unplugging		L				M		L	

*Place an H (High), M (Medium), or L (Low) in each category applicable to the challenge

Narrative (Describe each technical challenge in detail)

1. Numerous opportunities exist to enhance the structure integrity inspections. This including improving the capability of DST tank bottom inspections through development of a visual inspection technology for inspecting the DST primary tank bottom via the refractory air channels (e.g., use of a steerable needle), development of non-destructive examination techniques for assessing structural integrity of the DST primary tank bottoms (e.g., flash thermography, Synthetic and Tandem Synthetic Aperture Focusing Techniques (SAFT and T-SAFT), etc.), and utilizing advanced UT techniques to quantitatively assess the DST tank bottom. Improvements to primary tank wall inspections can also be made through development of electromagnetic acoustic transducer (EMAT) and phased array

Completed Narrative

technologies, which will provide faster and more comprehensive inspections capability of the primary tank walls, including welds and heat affected zones. Additionally, development of an automated annulus camera inspection could significantly reduce the amount of time needed to perform visual inspections of the annulus in support of the inspection program, which ultimately reduced the exposure to operators and provides more comprehensive data throughout the year (versus the current three-year cycle data is currently collected for the DST annulus).

2. The ETF process tanks build up scale that cannot be removed by soaking or recirculating with chemicals. The scale provides a mechanism for accelerated corrosion and inhibits Resource Conservation and Recovery Act (RCRA) required tank integrity inspections. Deployment of a device to clean the ETF process tanks interior walls and roofs (up to 15'W x 20'H) would reduce manned entries and reduce the risk of ETF process tank failure.

3. Enhancements to waste retrieval techniques can improve the amou[illegible] of waste removed during retrieval activities, reduce liquid additions to the tank (and potential [illegible] to the environment), and simplify the retrieval techniques which reduces the cost of retri[illegible]. The [illegible]nford Waste End Effector (HWEE) is being developed to reduce water addit[illegible] waste retrieval efforts. Additionally, development of an in-tank mechanical [illegible] system, development of simplified sluicers, development of scaled versio[illegible] equipment, and enhancements to the Mobile Arm Retrieval System-Vacuum (MA[illegible]) [illegible] additional ways the retrieval efforts can be improved.

4. Sampling, detection, and mo[illegible] are utilized t[illegible]ough the [illegible] waste operations at Hanford. Improved waste [illegible] systems can be [illegible] improve tank waste characterization, [illegible] cost-effective means to [illegible] the interface between solids and liquids, provide [illegible] to select a more eff[illegible] retrieval system, and improve leak de[illegible] capability (e.g., 3-dim[illegible] light detection and ranging (LIDAR), solid-liquid interface monitoring system (SLIM) [illegible] penetrometers, improved annulus air monitors, plutonium detection devices, and [illegible] monitoring systems). Further, development of automated systems could re[illegible] exposure to routine tasks such as liquid observation well (LOW) scans, which are performed approximately four times a year to detect intrusions or leaks. Advancements to the off-riser sampler system (ORSS) hard heel sampler and ORSS car would also be beneficial, as the existing systems cannot reliably collect required tank closure samples of hard heel-material that is not directly under a tank riser; enhancements in technologies could be leveraged to improve reliability, maneuverability, and reduce cost associated with demobilization of the ORSS. After retrieval, remote operated vehicles to perform post retrieval sampling.

5. Use of remote monitoring, from the operations control trailer, could significant reduce manned entries, would reduce slips, trips and falls hazards, and would reduce radiation exposure hazards. This could be done by using remote field inspection techniques, including drones, static-mounted cameras, mobile wire-mounted cameras, and remote operated vehicles.

6. The risk of a plugged transfer line can significantly impact planned operations, including delays to retrieval efforts, transferring material to / from the evaporator, and providing feed to the Waste Treatment Plant (WTP). Development of techniques to efficiently unplug the transfer lines are necessary (e.g., development of the peristaltic crawler and pressure pulsing method being developed by Florida International University (FIU) as part of the cooperative agreement with DOE HQ).

Aggregation of EM Needs

- Information from forms and visits was integrated into a set of aggregated, cross-cutting EM needs

No.	Need Title	Sites with This Need
1	Nondestructive Assay (NDA) of Process Equipment and Piping	5
2	Remote Structural Evaluation	3
3	Site Modeling, Work Planning, and Training	2
4	Hazardous Material Handling	5
5	Fluid and Liquid Waste Processing and Removal	4
6	Process Equipment Removal	3
7	Visual Inspections and Inventory Control	6
8	Hazardous, Reactive, and Explosive Gas Monitoring and Removal	2
9	Access and Assessment of Confined, Physically Challenging Spaces	6
10	Mapping and Assessment of Underwater Radiation Environments	3
11	Material Handling and Manipulation in Glove Boxes and Hot Cells	1
12	Remote Remediation of Contaminated, Physically Challenging Spaces	11
13	Emergency Response	1
14	Worker Enhancement and Injury Reduction	6
15	Waste Material and Landfill Operations	7
16	Soil Characterization and Handling	3
17	Remote Equipment Maintenance and Repair	4

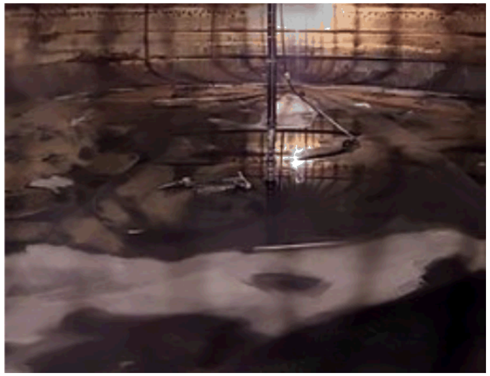
Aggregated EM Needs

- Nondestructive Assay of Process Equipment and Piping
  - Classify level of contamination for waste management
  - Ergonomically challenging and expensive
- Remote Structural Evaluation
  - Aging structures need to be evaluated to determine if they are safe to enter
  - Many have not been entered for many years
- Site Modeling, Work Planning and Training
  - Drawings may be outdated or not comprehensive
  - Work planning can be difficult if areas cannot be readily accessed without extensive PPE

Aggregated EM Needs

- Hazardous Material Handling
  - Substantial PPE required
  - Ergonomically challenging

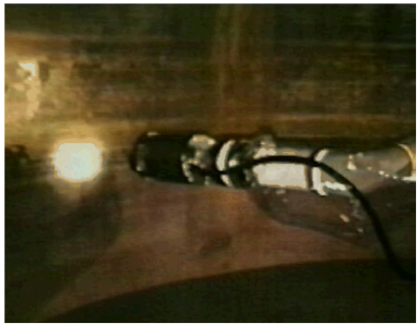
- Fluid and Liquid Waste Processing and Removal
  - Pumping and processing of liquid waste
  - Drumming, transport, and disposal is ergonomically challenging



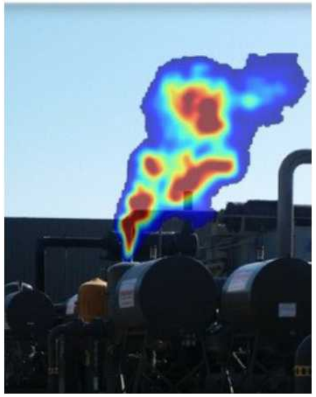
- Process Equipment Removal
  - Segmentation and size reduction
  - Large equipment and hazardous tools

Aggregated EM Needs

- Visual Inspection and Inventory Operations
  - Inventory items are often radioactive, increasing worker exposure
  - Highly repetitive, potential for human error



- Hazardous, Reactive and Explosive Gas Monitoring and Removal
  - Dangerous for human workers to assess



- Access and Assessment of Confined, Physically Challenging Spaces
  - Many areas have not been entered in many years
  - Challenging terrain and unknown hazards

Aggregated EM Needs

- Mapping and Assessment of Underwater Radiation Environments
  - Assess structures and contamination levels
  - Poor visibility and high radiation

- Material Handling and Manipulation in Glove Boxes and Hot Cells
  - Ergonomically challenging
  - Limited dexterity

- Remote Remediation of Contaminated, Physically Challenging Spaces
  - Many areas have not been entered in many years
  - Challenging terrain and unknown hazards

Aggregated EM Needs

- Emergency Response
  - May not be safe to send workers to respond
  - Dual-use capability of technology

- Worker Enhancement and Injury Reduction
  - Reduce strain on joints
  - Level playing field for workers

- Waste Material and Landfill Operations
  - Worker exposure a concern
  - Material classification and transport

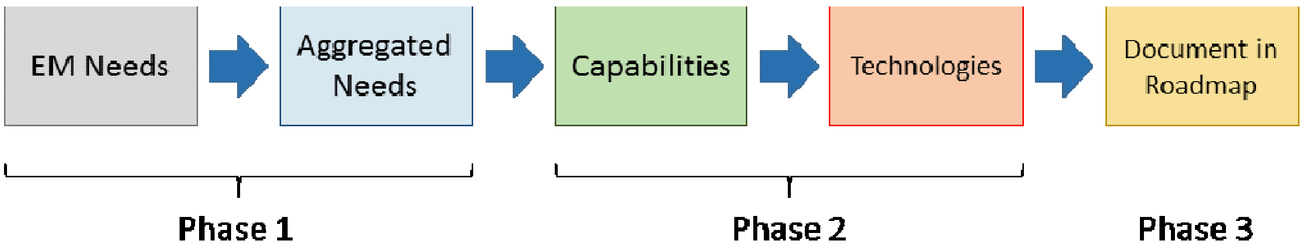
Aggregated EM Needs

- Soil Characterization and Handling
  - Assess soil contamination levels
  - Soil mixing and moving
  - Worker exposure a concern

- Remote Equipment Maintenance and Repair
  - Equipment and tools may be contaminated
  - PPE limits repair worker effectiveness

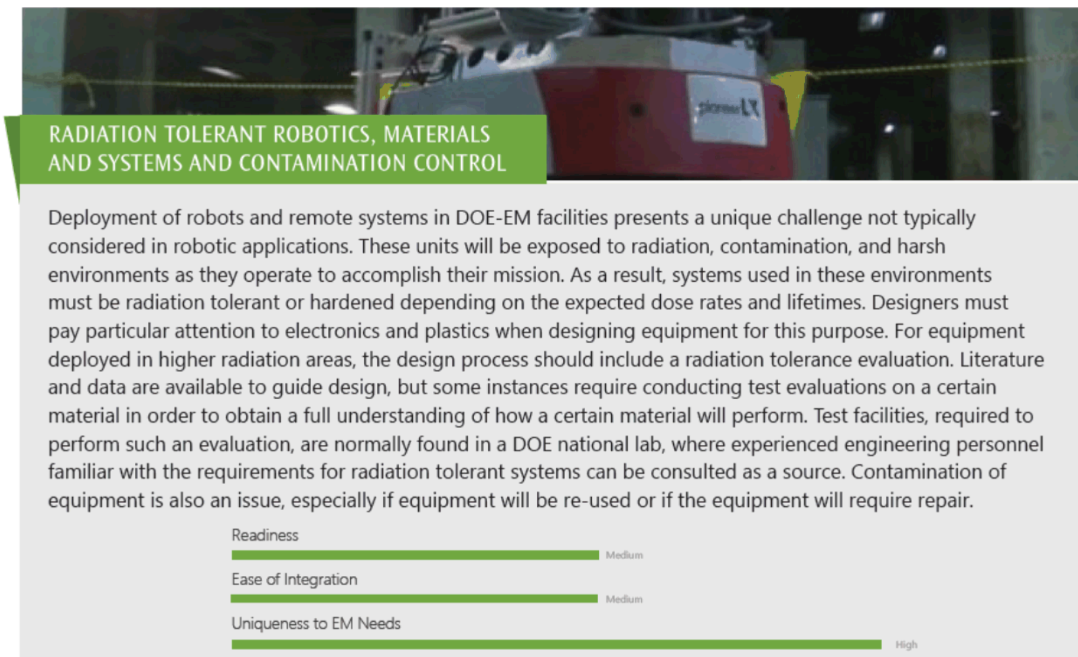
Identification of Key Technologies

- For each aggregated need, the roadmap team
  - Identified up to 10 capabilities needed to meet the need
  - Identified up to 10 robotic and remote systems technologies needed based on those capabilities
- These technologies were analyzed and aggregated to define key technologies for roadmapping



Technology Roadmapping

- A preliminary list of key technologies was identified
- A questionnaire assessing the appropriateness and maturity of these technologies was created and sent to several robotics experts in government, industry and academia
- Additional technologies were added based on survey results
- These technologies were assessed in the following areas
  - Readiness
  - Ease of Integration
  - Uniqueness to EM



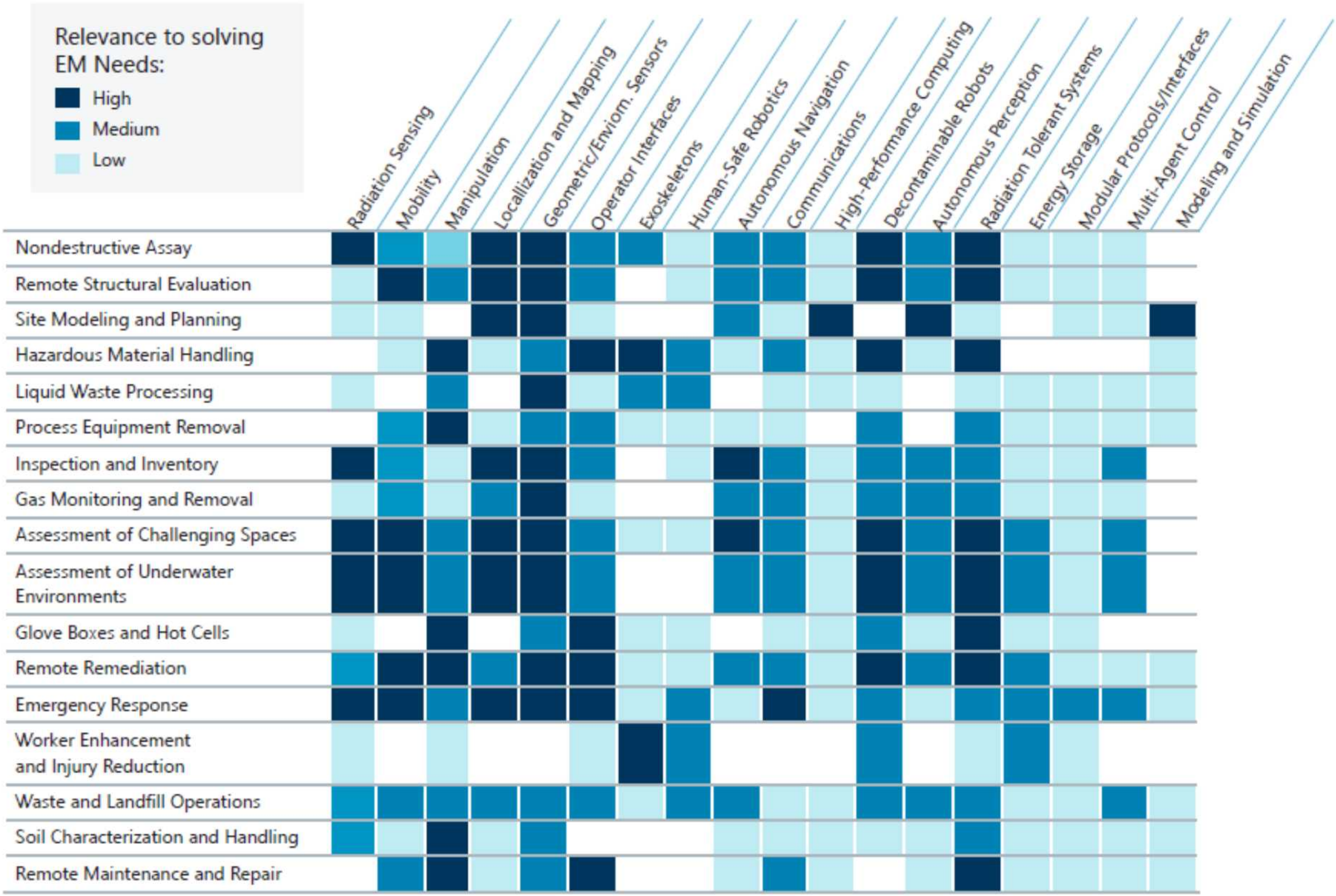
RADIATION TOLERANT ROBOTICS, MATERIALS AND SYSTEMS AND CONTAMINATION CONTROL

Deployment of robots and remote systems in DOE-EM facilities presents a unique challenge not typically considered in robotic applications. These units will be exposed to radiation, contamination, and harsh environments as they operate to accomplish their mission. As a result, systems used in these environments must be radiation tolerant or hardened depending on the expected dose rates and lifetimes. Designers must pay particular attention to electronics and plastics when designing equipment for this purpose. For equipment deployed in higher radiation areas, the design process should include a radiation tolerance evaluation. Literature and data are available to guide design, but some instances require conducting test evaluations on a certain material in order to obtain a full understanding of how a certain material will perform. Test facilities, required to perform such an evaluation, are normally found in a DOE national lab, where experienced engineering personnel familiar with the requirements for radiation tolerant systems can be consulted as a source. Contamination of equipment is also an issue, especially if equipment will be re-used or if the equipment will require repair.

Key Technology Assessments

	LOW READINESS	MEDIUM READINESS	HIGH READINESS
HIGH UNIQUENESS	Decontaminable Robots	Radiation Tolerant Systems Geometric/Environmental Sensors	Radiation Sensing
MEDIUM UNIQUENESS	Autonomous Navigation	Exoskeletons Human-Safe Robotics Manipulation Communications Localization and Mapping Mobility	Operator Interfaces
LOW UNIQUENESS	Multi-Agent Control Autonomous Perception	Modular Protocols/Interfaces Energy Storage High-Performance Computing	Modeling and Simulation

Mapping Technologies to Needs



Conclusions and Path Forward

- The roadmaps provides considerations for next steps for DOE-EM Leadership, EM Sites and Contractors and the Technology Development Community, for example:
  - Which technologies are most in need of development to meet EM missions?
  - Methods for worker training and engagement
- Copies available at WM
- Roadmap will be updated as needed
- POC

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