Oak Ridge Cleanup Contract 89303322DEM000067/ 89303322DEM000067/89303523FEM400032

United Cleanup Oak Ridge LLC (UCOR)

Subtask No: 000343

Subtask 4-3: HQ-Funded Technology Development

U.S Department of Energy
Oak Ridge Office of
Environmental Management

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Section B – Supplies or Services and Prices/Costs

This Subtask work shall be performed under Contract Line Item Number (CLIN)-00003 of the Oak Ridge Reservation Cleanup Contract (ORRCC) Master Indefinite Delivery/Indefinite Quantity (IDIQ) Contract (herein referred to as the Master IDIQ Contract). Section B of the Master IDIQ Contract and Task Order 89303322DEM000067/89303523FEM400032 is incorporated by reference.

B.1 DOE-B-2012 Supplies/Services Being Procured/Delivery Requirements (Oct 2014)

The Contractor shall furnish all personnel, facilities, equipment, material, supplies, and services (except as may be expressly set forth in this Subtask as furnished by the Government) and otherwise do all things necessary for, or incidental to, the performance of work as described in Section C, Performance Work Statement under this Subtask.

B.2 Type of Subtask

(a) DOE-B-2001 *Cost-Plus-Fixed-Fee Task Order: Total Estimated Cost and Fixed Fee (Oct 2014)* (Revised)

(1) This is a Cost-Plus-Fixed-Fee type Subtask. In accordance with the clause at FAR 52.216-8, *Fixed Fee*, the total estimated cost and fixed-fee for this Subtask are as follows:

Table B-1. Estimated Total Price

Total Estimated Cost	$375,000
Fee	$ 15,000
Total Estimated Price	$390,000

(2) The Total Estimated Cost and Fee of the Subtask, and/or the Total Estimated Cost and Fee of the Subtask Contract Line Items, is as follows:

CLIN/ SubCLIN	CLIN/SubCLIN Title	CLIN Type	Estimated Cost	Fee	Total Estimated Price
00003	ORRCC End State Task Orders 89303322DEM000067/89303523FEM400032				
000343	Subtask 4-3: HQ-Funded Technology Development				

CLIN/ SubCLIN	CLIN/SubCLIN Title	CLIN Type	Estimated Cost	Fee	Total Estimated Price
0003431	*Mobile Robotic Hot Cell/Glovebox System for Hazardous and Radioactive Waste Disposition – Phase 2*	CPFF	$375,000	$ 15,000	$390,000
Total			**$375,000**	**$ 15,000**	**$390,000**

(3) Payment of fee will be made in accordance with Clause I.228, *DEAR 970.5232-2, Payment and Advances (Dec 2000) – Alt I (Dec 2000), Alt II (Dec 2000) and Alt III (Dec 2000)(DEVIATION)* of the Master IDIQ Contract.

B.9 Basis for Change

In accordance with Clause B.9 *Basis for Change*, the identification of fee risk ownership for both the Government and the Contractor is set forth in Appendix B.9.

B.12 Performance Management Incentive

In accordance with Clause B.12, *Performance Management Incentive*, of the Master IDIQ Contract, Performance Management Incentive is applicable to this Subtask.

Section C – Performance Work Statement

C.1 Subtask Requirements

The Contractor shall perform the requirements in accordance with the Master IDIQ Contract and Task Order 89303322DEM000067/89303523FEM400032 and the information included below:

PERFORMANCE BASED STATEMENT OF WORK
Subtask 4-3, HQ-Funded Technology Development

1.0 INTRODUCTION

The desired outcome of this Subtask is the implementation of technology development (TD) activities that support OREM cleanup.

The initial award of Subtask 4-3 (SubCLIN 0003431) includes the completion of support to the Office of Environmental Management – Technology Development Office (TDO) for the *Mobile Robotic Hot Cell/Glovebox System for Hazardous and Radioactive Waste Disposition – Phase 2*, a collaborative TDO initiative involving ANL, ORNL, University

of Illinois – Chicago (UIC), Northwestern University (NWU), and UCOR – the OREM cleanup contractor. The "Technical Task Plan" provided as Government-Furnished Services and Information in Subtask 4-3 Attachment J-8 constitutes the TDO guidance for this initiative.

This overall initiative is centered around the development of a cost-effective, mobile robotic hot cell/glovebox system designed for easy on-site deployment for nuclear waste handling at EM sites. The demonstration is being carried out in three phases.

- **Phase 1:** Development of robotic and remote systems infrastructure for robotic hot cell, and technology demonstration in non-radiological environment. Phase I is complete.
- **Phase 2:** Technology adaptation and demonstration for on-site deployment at ORNL hot cell facility cleanup site.
- **Phase 3:** Technology adaptation for broad acceptance by various EM sites.

This Subtask will initially support completion of Phase 2 as described in Section 3.0, *Scope*.

Cleanup of Facility 3517 is currently ongoing as authorized in Subtask 5-1 (PWS Section C.3.1.11, *3517 and Support Facilities*).

The Contractor shall ensure this Subtask scope is integrated with other Subtasks, as necessary.

2.0 BACKGROUND

DOE-EM has a technical need to limit worker exposure to radioactive contamination and other hazardous environments. A robotic system to assist the worker in sorting out hazardous waste in many EM cleanup sites has significant potential for gains in work safety and efficiencies/meaningful cleanup cost reduction. Currently, hot cells and gloveboxes are widely used for handling radioactive and nuclear materials within hermetically sealed, and controlled environments. However hot cell manipulation is inefficient, expensive, requires substantial installation, and glove box operation is labor intensive and requires frequent maintenance. This TDO initiative addresses the development of a robotized hot cell/glovebox system, which incorporates human-like dual collaborative robot arms and mobile hot cell structure, and mixed-reality digital twin for effective remote operations.

3.0 SCOPE

The Contractor shall perform the scope of work and requirements in accordance with the Section C PWS sections and subsections of the Master IDIQ Contract and Task Order 89303322DEM000067/89303523FEM400032 identified below:

– ***C.6.2.4 Technology Development***

For the scope of work performed under the Master IDIQ Contract and Task Order 89303322DEM000067/89303523FEM400032 PWS section listed in the Scope, the Contractor shall incorporate the following assumptions and completion objectives into Subtask 4-3:

Subtask 4-3, SubCLIN 0003431: ***Mobile Robotic Hot Cell/Glovebox System for Hazardous and Radioactive Waste Disposition – Phase 2***

- Complete Phase 2, Task 8.2. *Environmental Safety and Health*.
    - In accordance with the TD project team's site task analysis, perform thorough environmental safety and health (ES&H) analysis on the site conditions in preparation for the on-site technology deployment.
    - Provide ES&H support required for the TD project team to obtain permission for site access, establish work planning and control, and establish supporting task procedures for onsite deployment activities.
- Assume:
    - TDO is incrementally funding the completion of this Subtask. The maximum value of services under Subtask 4-3 and associated allocation of general and administrative costs shall not exceed the funding allocated by the TDO for completion of the authorized scope.
    - This technology development task will be completed as described in Attachment J-8-4-3.
    - Information and coordination to the TD project team members identified in Attachment J-8-4-3 will be provided as needed to support completion of Phase 2.
- Complete Phase 2, Task 12.2. *Operator Training Program*.
    - Complete participation in the provision of training programs for the site workers on robotic and remote systems operations for the waste handling operations scenarios.
    - Assume:
        - The training may determine changes that have to be made to the workcell design that will be incorporated before it gets transferred for deployment.
        - The training program will utilize the mixed-reality robotic training system developed by the TD project team in Phase 2, Task 11.
        - The operator training program will be provided throughout the

phase 2 period of performance.

- Complete Phase 2, Task 12.3. *Onsite Technology Demonstration*.
    - Complete participation in the on-site demonstration of deployment of the robotic workcell system for waste handling operations in the ORNL Facility 3517.
    - Complete close collaboration with demonstration participants for facility entrance facilitation and site preparation.
    - Before the workcell is transferred, support the demonstration team with identifying the utility connections available in the Facility 3517 highbay to accommodate the workcell.
    - Coordinate rigging and transfer of the workcell from ORNL Facility 7603 to Facility 3517 with ORNL/UCOR riggers.
    - Since the operator will be in another room, support the demonstration team with extending the electrical, video, and other connections needed to this area.
    - Support completion of a functional test once the workcell has been moved before actual operation commences.
    - Provide the manpower, scheduling and engineering support throughout the onsite technology demonstration.
- Complete Phase 2, Task 13. *Phase 2 Summary Report*
    - Provide a summary report on the activities completed under this Subtask for integration into a combined report by ANL.
- Assume:
    - All tasks will be completed as described in Attachment J-8-4-3.
    - Information and coordination to the TD project team members identified in Attachment J-8-4-3 will be provided as needed to support completion of Phase 2.

4.0 APPLICABLE DIRECTIVES

In addition to the Directives included in the Master IDIQ Contract, additional Directives are included in Attachment J-2 to this Subtask.

5.0 INTERFACES

In addition to the Interfaces included in the Master IDIQ Contract, additional Interfaces are included in Attachment J-3 to this Subtask.

6.0 DELIVERABLES

In addition to the Deliverables included in the Master IDIQ Contract, additional Deliverables are included in Attachment J-7-4-3 to this Subtask.

7.0 GOVERNMENT-FURNISHED SERVICES AND INFORMATION

In addition to the Government-Furnished Services and Information (GFS/I) included in the Master IDIQ Contract, additional GFS/I are included in Attachment J-8-4-3 to this Subtask.

8.0 PERFORMANCE OBJECTIVES AND STANDARDS

Fee will be determined upon completion of the End State requirements in Section 3.0 and work scope/completion criteria as follows:

Subtask 4-3 (SubCLIN 0003431): ***Mobile Robotic Hot Cell/Glovebox System for Hazardous and Radioactive Waste Disposition – Phase 2***	
End State Requirement	**Work Scope/Completion Criteria**
Complete support to the *Mobile Robotic Hot Cell/Glovebox System for Hazardous and Radioactive Waste Disposition – Phase 2*: Technology adaptation and demonstration for on-site deployment at ORNL hot cell facility cleanup site.	• Perform thorough environmental safety and health (ES&H) analysis on the site conditions in preparation for the on-site technology deployment. • Provide ES&H support required for the TD project team to obtain permission for site access, establish work planning and control, and establish supporting task procedures for onsite deployment activities. • Complete participation in the provision of training programs for the site workers on robotic and remote systems operations for the waste handling operations scenarios.
	• Complete participation in the on-site demonstration of deployment of the robotic workcell system for waste handling operations in the ORNL Facility 3517. • Complete close collaboration with demonstration participants for facility entrance facilitation and site preparation. • Before the workcell is transferred, support the demonstration team with identifying the utility connections available in the Facility 3517 highbay to accommodate the workcell.

Subtask 4-3 (SubCLIN 0003431): ***Mobile Robotic Hot Cell/Glovebox System for Hazardous and Radioactive Waste Disposition – Phase 2***	
End State Requirement	**Work Scope/Completion Criteria**
	• Coordinate rigging and transfer of the workcell from ORNL Facility 7603 to Facility 3517 with ORNL/UCOR riggers. • Since the operator will be in another room, support the demonstration team with extending the electrical, video, and other connections needed to this area. • Support completion of a functional test once the workcell has been moved before actual operation commences. • Provide the manpower, scheduling and engineering support throughout the onsite technology demonstration. • Provide a summary report on the activities completed under this Subtask for integration into a combined report by ANL.

In addition, the performance requirements, made up of objectives and respective standards, for this Subtask will be used to determine quality of performance in CPARS evaluation and PMI, as applicable. The performance objectives and standards are as follows:

Subtask 4-3, HQ-Funded Technology Development	
Objectives	**Standard**
Safety and Operational Performance	See ORRCC PMI Plan
Meeting Regulatory or Court Ordered Milestones	See ORRCC PMI Plan
Quality Assurance Performance per Section C and Section E Clause FAR 52.246-11, where Continuous Monitoring and Performance Improvement are Evident	See ORRCC PMI Plan
Maintaining the Operability of Facilities and Other Infrastructure throughout the Performance Period such that Degradation is Addressed to Prevent Mission Impact	See ORRCC PMI Plan
Management of the Contractor's team, including teaming subcontractors to ensure efficient and effective partnering with the Government and all parties;	See ORRCC PMI Plan

Subtask 4-3, HQ-Funded Technology Development	
Objectives	**Standard**
Establishment, maintenance, and implementation of sound business systems to ensure efficient and effective business management performance in a complex IDIQ task order environment	See ORRCC PMI Plan
IDIQ management, including timely, good faith and fair dealings in conducting negotiations with DOE with the goal of a reasonable outcome, including equitable risk sharing, for all parties	See ORRCC PMI Plan

Section D – Packaging and Marking

Section D of the Master IDIQ Contract is incorporated by reference.

Section E – Inspection and Acceptance

In addition to the following requirements, Section E of the Master IDIQ Contract is incorporated by reference:

E.1 Inspection and Acceptance Delegation

In accordance with Clause E.2, DOE-E-2001, Inspection and Acceptance, the Contracting Officer assigns inspection and acceptance of all items to the Contracting Officer's Representative; however, the Contracting Officer's Representative is not authorized to accept nonconforming items or services.

Section F – Deliveries or Performance

Section F of the Master IDIQ Contract is incorporated by reference. The requisite clause information specific to this Task Order included below is consistent with the clause numbering structure established by the Master IDIQ Contract.

F.3 Period of Performance

(a) The Subtask 4-3 SubCLIN 0003431 Period of Performance (POP) is from award to March 31, 2025. The Contractor is expected to complete the Subtask end states as defined in Section C of the Subtask within the Subtask POP.
(b) The Contractor shall not be paid for work performed or costs incurred prior to the Subtask effective date, unless specifically authorized by the Contracting Officer.

Section G – Contract Administration Data

Section G of the Master IDIQ Contract is incorporated by reference in addition to the following:

G.1 Subtask Administration

To promote timely and effective contract administration, correspondence delivered to the Government under this Subtask, shall reference the contract number, Task Order number, Subtask number, and subject matter, and shall be subject to the following procedures:

(a) Technical correspondence. Technical correspondence shall be addressed to the COR for this Subtask, and a copy of any such correspondence shall be sent to the CO for this Subtask, with an informational copy to the Contract COR and Contract CO. As used herein, technical correspondence does not include correspondence where patent or rights in data issues are involved, nor technical correspondence that proposes or involves waivers, deviations, or modifications to the requirements, terms, or conditions of this Contract.

(b) Information regarding correspondence addresses and contact information will be provided through official correspondence:

(1) Subtask Contracting Officer

(A) Name: Talia Burchfield

(B) Telephone number: 865-574-8007

(C) Address:
U.S. Department of Energy
Oak Ridge Office of Environmental Management
200 Administration Road
Oak Ridge, TN 37830

(D) Email address: Talia.Burchfield@orem.doe.gov

(2) Subtask Contracting Officer's Representative

(A) Name: James Daffron

(B) Telephone number: 865-241-9504

(C) Address:
U.S. Department of Energy
Oak Ridge Office of Environmental Management
200 Administration Road
Oak Ridge, TN 37830

(D) Email address: James.Daffron@orem.doe.gov

Section H – Special Contract Requirements

In addition to the following requirements, Section H of the Master IDIQ Contract is incorporated by reference:

None.

Section I – Contract Clauses

In addition to the following requirements, Section I of the Master IDIQ Contract is incorporated by reference:

None.

Section J – List of Documents, Exhibits, and Other Attachments

In addition to the following requirements, Section J of the Master IDIQ Contract is incorporated by reference:

1. Attachment J-2 – Directives

In addition to the following requirements, Attachment J-2 of the Master IDIQ Contract is incorporated by reference:

None.

2. Attachment J-3 – Interfaces

In addition to the following requirements, Attachment J-3 of the Master IDIQ Contract is incorporated by reference:

Attachment J-3-4-3, Subtask Specific Interfaces	
Category	**Description of Interface**
Technology Development	For Subtask 4-3 (SubCLIN 0003431): *Mobile Robotic Hot Cell/Glovebox System for Hazardous and Radioactive Waste Disposition – Phase 2*, the ORRCC Contractor shall coordinate with the Department of Energy Office of Environmental Management – Technology Development Office (TDO) to collaborate and execute assigned, TDO-funded Technology Development tasks in accordance with the TDO Technical Task Plan (TTP). The TDO TTP will define the roles and responsibilities of all participants. The TDO TTP will be provided as Government-Furnished Services and Information.

3. Attachment J-5 – Small Business Subcontracting Goals

The following goals for this Subtask are appended to the Master Small Business Subcontracting Plan:

Table J-5-4-3a. Subtask Small Business Subcontracting Goals

Category	Total to be Subcontracted ($)	Minimum Small Business Goals as a percent of total subcontracted dollars
Total Subcontracted	$0	
Total Small Business Subcontracts	$0	45%
Veteran-Owned Small Business (VOSB)	$0	3%
Service-Disabled Veteran-Owned Small Business (SDVOSB)	$0	3%
Historically Underutilized Business Zone (HUBZone)	$0	3%
Small Disadvantaged Business	$0	5%
Women-owned Small Business	$0	5%

In accordance with Clause H.52, Subcontracted Work, Government-Provided Costs for Reservation Management and Post-Retirement Benefits and Long-Term Disability and Pension Contribution, and costs for the site usage fees provided to other site contractors are included in the Subtask value, but not included in the cumulative Subtask value for subcontracting goals, are provided in Table J-5-4-3b.

Table J-5-4-3b. Government-Provided Costs Not Included in Subcontracting Goals

Reservation Management	N/A
Post-Retirement Benefits and Long-Term Disability and Pension Contribution	N/A
Site Usage Fees	N/A
Services Acquired under Parent Organization Support Plan	$0

4. Attachment J-7 – Deliverables

Attachment J-7-4-3, includes the following additional deliverables for this Subtask:

Attachment J-7-4-3. Subtask 4-3 Deliverables

Number	Deliverable	Deliverable Due Date	DOE Action Response[1]	Reference
T4-3-001	Subtask 4-3-1 Performance Measurement Baseline	Final Within 30 days of Subtask issuance	Approve – 30 days	Section C.6.1.1, *Project Support Performance Requirements* Section H.51, *Task Ordering Procedure*
T4-3-002	Integrated Master Schedule	Final Within 30 days of Subtask issuance	Approve – 30 days	Section C.6.1.1, *Project Support Performance Requirements* Section H.51, *Task Ordering Procedure*
T4-3-003	Input to Task 8 Technical Report to TDO and OREM	8/5/2024	Review	Section C.6.2.4, Technology Development Attachment J-8-4-3, *Technical Task Plan (TTP) - Mobile Robotic Hot Cell/Glovebox System for Hazardous and Radioactive Waste Disposition*

Attachment J-7-4-3. Subtask 4-3 Deliverables

Number	Deliverable	Deliverable Due Date	DOE Action Response[1]	Reference
T4-3-004	Input to Task 12 Technical Report to TDO and OREM	12/31/2024	Review	Section C.6.2.4, Technology Development Attachment J-8-4-3, *Technical Task Plan (TTP) - Mobile Robotic Hot Cell/Glovebox System for Hazardous and Radioactive Waste Disposition*
T4-3-005	Phase 2 Summary Report to TDO and OREM	1/14/2025	Review	Section C.6.2.4, Technology Development Attachment J-8-4-3, *Technical Task Plan (TTP) - Mobile Robotic Hot Cell/Glovebox System for Hazardous and Radioactive Waste Disposition*

Attachment J-7-4-3. Subtask 4-3 Deliverables

Number	Deliverable	Deliverable Due Date	DOE Action Response[1]	Reference

[1]The DOE action is defined as follows:

- Approve – The Contractor shall provide the deliverable to DOE for review and approval. DOE will review the deliverable and provide comments or approve as submitted. If necessary, the Contractor shall revise the document to incorporate mandatory DOE comments and resubmit for DOE approval. Once approved by DOE, the deliverable shall be placed under change control with changes requiring DOE approval. It is not intended that editorial changes or corrections that do not alter commitments would require new DOE approval.
- Review – The Contractor shall provide the deliverable to DOE for review. DOE will review the information and will provide comments, as necessary. If necessary, the Contractor shall revise the document to incorporate mandatory DOE comments.
- Information – The Contractor shall provide the deliverable for information purposes only. DOE will review the information and may provide comments. Such comments do not require resolution under the Contract.

Acronyms:

OREM	Oak Ridge Office of Environmental Management
TDO	Office of Environmental Management – Technology Development Office

5. Attachment J-8 - Government-Furnished Services and Information (GFS/I)

Attachment J-8-4-3 includes the following additional GFS/I for this Subtask:

Attachment J-8-4-3, Subtask 4-3 Specific GFS/I	
GFS/I	**REQUIREMENT**
Technical Task Plan (TTP) – Mobile Robotic Hot Cell/Glovebox System for Hazardous and Radioactive Waste Disposition	TDO will provide participation by ANL, ORNL, University of Illinois – Chicago (UIC), and Northwestern University (NWU) for Phase 2 Tasks as described in the TTP.

Attachment J-8-4-3: *Technical Task Plan (TTP) - Mobile Robotic Hot Cell/Glovebox System for Hazardous and Radioactive Waste Disposition*

INTRODUCTION

The Department of Energy's Environmental Management Office (DOE-EM) has identified a critical technical need to minimize worker exposure to radioactive contamination and other

hazardous environments. The implementation of a robotic system to assist workers in sorting hazardous waste across multiple EM cleanup sites holds significant potential for improving work safety and operational efficiency, leading to meaningful cost reduction in cleanup efforts.

The tasks associated with EM site cleanup and waste management, particularly the handling of highly radioactive nuclear waste, involve processes such as opening containers, sorting, processing, and packaging. Currently, these tasks are performed manually within hot cells or glovebox, methods that are deemed obsolete, challenging, inefficient, and associated with high maintenance costs. However, the recent emergence of human-like collaborative robots (co-robots) and various digital technologies present unique opportunities to replace manual operations, thereby achieving enhanced safety and efficiency.

To address the presented technical challenges and the opportunities, this proposal is centered around the development of a cost-effective, mobile robotic hot cell/glovebox system designed for easy bon-site deployment for nuclear waste handling at EM sites. The key objectives of this initiative include:

- Prototyping a dual-arm robotic manipulation system for human-like manipulation.
- Developing a multi-modal teleoperation interface capable of effective remote operations.
- Prototyping a portable workcell structure and remote handling equipment.
- Developing a mixed-reality digital twin system for effective planning, training, and operation.
- Demonstrating on-site technology deployment.

In this project, we are focused on cleaning B3517, a nuclear chemical processing facility built in 1958. Presently in a shutdown condition, the facility has all hotcell windows darkened and non-functional due to radiation and environmental damage. The hot cells are primarily located on the ground floor, with some on the second floor. Within these hotcells are canisters listed as containing radioactive elements, necessitating verification before disposition. The primary demonstration of this project is to verify the contents of these canisters, characterize the contents if not empty, transfer the contents to a DOT- approved new canister, and securely seal the canisters.

The project will involve a collaborative effort among Argonne National Laboratory (ANL), Oak Ridge National Laboratory (ORNL), University of Illinois – Chicago (UIC), and Oak Ridge Em site cleanup contractor (ORCC). It also involves international collaboration to facilitate and expedite the EM mission critical technology development work for timely site deployment by contributing with critical elements of the robotic system operational capabilities. The Department of Energy's Environmental Management Technology Development Office (DOE-EM TDO) and Oak Ridge EM Office (OREM), in conjunction with the collaboration team, will operate as an integrated project team. DOE-OREM, serving as the site owner, has the technical requirement of effectively limiting worker exposure to radioactive contamination and mercury vapor. DOE-EM TDO sponsors this work, overseeing

progress and playing the crucial role project's success in the present and future. Additionally, this project capitalizes on the effort of UIC through the DOE-EM TDO minority serving institution partnership program (MSSIP) competitive research awards program.

PROJECT TASKS

To achieve the objectives, the project will be carried out in three phases:

- **Phase 1:** Development of robotic and remote systems infrastructure for robotic hot cell, and technology demonstration in non-radiological environment.
- **Phase 2:** Technology adaptation and demonstration for on-site deployment at ORNL hot cell facility cleanup site.
- **Phase 3:** Technology adaptation for broad acceptance by various EM sites.

Fig. 1 illustrates the project team participating in the project phases.

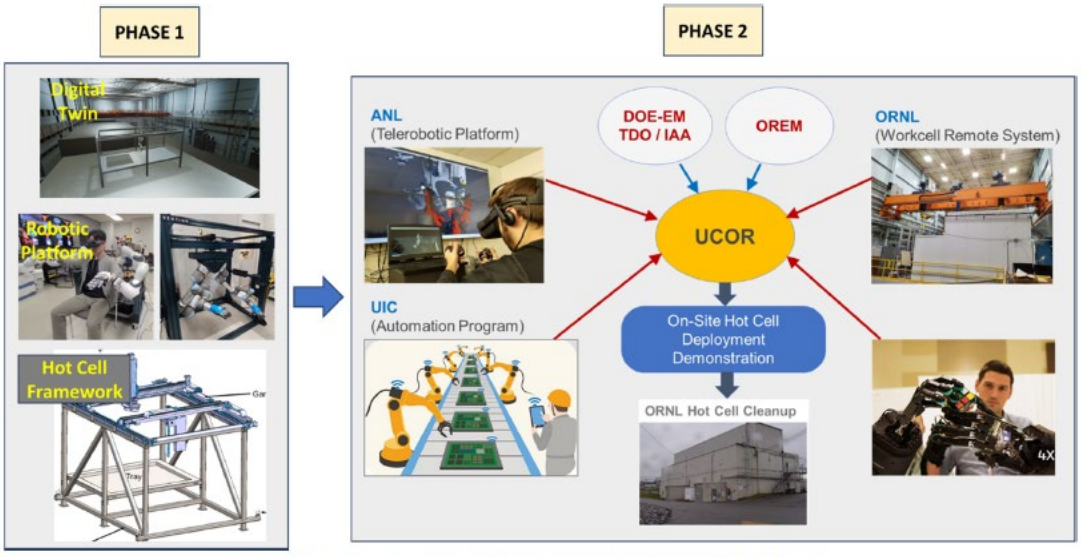

Figure 1. Project Team Participating in the Project Phases

Phase 1: Development of Robotic and Remote Systems Infrastructure

The objective of Phase 1, spanning over one year in FY2023, is to establish critical robotic systems infrastructure for advanced remote manipulation, poised to revolutionize hazardous waste handling and hot cell/glovebox operations. The focused activities in this phase involve the conceptual design and prototyping of the robotic hot cell, coupled with a cold demonstration, and include the following tasks:

Task1: Site Application Task Analysis (All): This task employs a systems engineering approach to identify task needs, design requirements, and project planning for the

proposed development.

Task 2: Development of a Robotic Manipulator Platform (ANL): This task encompasses the design and prototyping of a dual-arm robotic manipulator system along with its control system, tailored to meet the design requirements for hot-cell/glovebox operations in EM waste cleanup missions.

Task 3: Prototyping of Dexterous Robotic Hand (NWU): This task focuses on the development of end- effectors and control methods for human-like dexterous contact manipulation. It includes the implementation of multi-fingered robot hands and tactile feedback to replicate human dexterity in glovebox operations.

Task 4: Development of Mobile Hot Cell Structure (ORNL): This task involves the comprehensive design, construction, and testing of a portable hot cell structure. It includes engineering provisions for mounting the manipulator systems, camera systems, shielding, portability, and remote handling systems.

Task 5: Development of Digital Mock-up (ANL): This task addresses the construction of a virtual- reality model of the task environment and the robotic systems. First-hand utilization will address implementing various concept of operations (ConOps) simulations.

Task 6: System Integration and Cold Demonstration (All): This task focuses on demonstrating the integrated system's operation in a non-radioactive mock-up test environment.

Task 7: Phase 1 Summary Report: A comprehensive summary report will be prepared, encompassing integration and test results.

The key deliverables at the end of Phase 1 will include: 1) a virtual mockup of the robotic equipment and test environment for simulation and training, and 2) prototype of integrated robotic hotbox system demonstrated in a cold mock at ORNL's remote systems testing facility.

Phase 2: Technology Adaptation and On-site Deployment Demonstration

The goal of the Phase 2, scheduled over the course of one year (FY2024), is to enhance the operational capabilities of robotic workcell system for applications and on-site deployment at ORNL B3517 hot cell facility for waste handling operations. The primary objectives involve implementing 1) hardware systems updates, 2) operation technology enhancements, 3) a training program, and 4) a hot demonstration. To realize these aims, the Phase 2 activities build upon the phase 1 technology infrastructures and include the following tasks:

1) Site application task analysis
2) Enhancement of robotic systems
3) Enhancement and modification of the work cell and remote systems
4) Enhancement of operation system
5) Provision of operator training program

6) Integrated system operation test
7) Demonstration of on-site technology deployment

The culmination of Phase 2 activities will result in the technological demonstration of robotic work cell, showcasing the proven effectiveness for on-site deployment at the ORNL hot cell facility.

To effectively tackle the diverse array of developmental tasks, Phase 2 activities will be collaboratively undertaken by multiple teams including partnering institutions (ANL, ORNL, UCOR), as well as subcontractors, such as Inspection Experts Inc. (IEI), Northwestern University (NWU), Northern Illinois University (NIU), Korea Advanced Institute of Science and Technology (KAIST), Seoul National University (SNU), and Novatech. Our international collaborators KAIST, SNU and Novatech bring unique capabilities as presented in Task 9 that address the EM unstructured and hazardous environments that are significantly different from those in manufacturing. This expertise will aid in the enhancement of the operational capabilities of robotic work cell system for EM application and will aid in enabling the technology system to be timely developed and deployed. The established ANL sub contracts and any future ANL subcontracts with the foreign institutions went through/or will go through ANL export control, IP and legal reviews.

Task 8: Site Application Task Analysis

8.1. *Site Task Analysis (ANL, ORNL, IEI)*: This task involves evaluation of deployment site and deployment plan coordinated with the TDO supported by IEI and the site contractor, UCOR. The key objective is to identify the design requirements and safe procedures to ensure the operations are carried out within an adequate safety envelope.

To ensure a mature and field-ready technology upgrade, ANL will lead, as requested by TDO, the team through a system engineering process, starting with requirements (performance and environmental), constraints (non-technical requirements), a concept of operations (CONOPs), functional decomposition, using the current technologies as the starting concept, architecture (physical and functional), and leading to a detailed design. ANL and team will follow the systems engineering process with key reviews such as the requirements review, a preliminary design review, and a critical design review as formal gates for the hot cell development. Upon construction or modification of the design changes, integration of the systems will be conducted. The requirements are a contract between the team and TDO and will also include the test methodology for verification of the requirements. The team will validate the capability of the mobile hot cell to TDO which will certify the TRL of the technology.

8.2. *Environmental Safety and Health*: In accordance with the project team's site task analysis, the site cleanup contractor, United Cleanup Oak Ridge (UCOR), will perform thorough environmental safety and health analysis on the site conditions in preparation for the on-site technology deployment. This activity will be required to obtain permission for the project team's site access, establishing the work planning and control, and supporting

task procedures in the deployment activities.

Task 9: Enhancement of the Robotic System

Based on the phase 1 test experience, improvements will be made on the robotic systems, which include the dual-arm manipulator, camera, and teleoperator interface systems. Our first aim in telerobotic system design is to facilitate 'telepresence', i.e., to make the operator feel as though they are present within the hotcell, able to manipulate the objects with both hands, and to experience multi-modal sensory feedback e.g., visual, haptic, and auditory, in a direct, natural way. It will provide an essential starting point in terms of manual teleoperation. In addition, we will also implement additional task-specific practical improvements in teleoperation methods, including uses of extended reality, and teleautonomy, etc. To cover the diverse spectrum of robotic technology innovations, we plan to foster extensive collaborations through subcontracts with various institutions, both within the US and internationally, each bringing unique expertise to address crucial areas.

9.1. *Enhancements on Bilateral Control (ANL, KAIST)*: In the first phase, a bilateral control algorithm was developed for the telerobotic manipulator system which is essential for achieving force- reflection as well as spatial awareness for the operator. This task will involve tunning the telerobot control system for stable and optimal operations under task-specific conditions. For example, time- delay under our network-based control may cause instability or deterioration in the control loop. Also, the kinematic dissimilarity between the master and slave robots may result in challenging control issues. KAIST has proposed several approaches guaranteeing stability, well received in the research community and as ongoing research, focuses in maximizing the achievable impedance range of haptic and telerobotic systems towards highly transparent haptic interaction. In collaboration with KAIST, we will explore and implement advanced control methods for the resolution of such problems. Additional task-specific adjustments may be required in the robot hardware and operation software for collision and singularity avoidance, workspace optimization, and motion limits in compliance with the task environments.

9.2. *Grippers and End-effectors (ANL, SNU)*: In robotic manipulation applications, adopting the right kind of gripper is a crucial factor for successful task performance. In phase 1, we have explored several commercially available gripper devices to be tested on robot arms for tasks. However, it is expected each gripper choice will have limitations, for example, durability, tactile sensibility, dexterity, payload, etc. To address such limitations, this task will focus on developing a custom gripper design optimized to meet task-specific requirements for hot cell/glove box applications. In this context, we will leverage the expertise of SNU for the creation of multi-fingered gripper designs. These designs include: 1) a tendon driven multi-finger system utilizing fiberoptic cables for both power transmission and force sensing, 2) a tactile fingertip sensor, 3) resizable grippers, and 4) an electrostatic gripper. Subsequently, we will assess these designs and further customize them to meet task-specific functional requirements.

9.3. *Camera System (ANL, NWU)*: In phase 1, for the robot, we adopted a camera head consisting of a stereo camera on a manipulandum, similar to that of the Nimbro Avatar system. In this task, we will collaborate with NWU to further investigate the camera system configuration to be able to intuitively convey hand-eye coordination and reduce sea sickness. We will also explore the use of multiple cameras to extend the scope of visual perception, for example to move the eyes across the room. In this regard, we will explore the use of 3D reconstruction technology and our previous research on mental transformation vision.

9.4. *Operator Interface (ANL, NIU)*: In phase 1, we have provided a teleoperator interface with multi- modal (visual-haptic) sensory feedback to achieve telepresence for the operator. In this task we will collaborate with NIU to further enhance the fidelity and performance of this system better perception- action loop with extended reality. In this regard, we will explore the use of enhanced human-machine interfaces such as eye-tracking VR headset and brain wave interface, tactile gloves, and 3D sensing and augmented reality display technologies. In addition, we will explore the development of supernumerary operator interfaces for robotic arms and various remote handling systems.

9.5. *Radiation Protection and Decontamination (ANL, ORNL)*: The robotic platform is deployed in the radiation environment and subject to contamination. This task addresses the engineering provisions for radiation protection, and decontamination.

Task 10: Enhancement of the Workcell Structure

10.1. *Modification of the Workcell Structure (ORNL)*: During phase 2, ORNL will learn from testing and make any modifications to the design. We also need to make modifications to the design to add side panels, lifting fixtures, penetration for utility connections, attach electrical panel to the side, make provisions for particulate fixing spray, cover over the workcell, and lighting for the workspace. HEPA filter will be identified working with Mississippi State University and installed and attached to workcell using a hose. Also, provisions have to be made to attach fixing solutions for particulate immobilizations. All these will be assembled and tested before the workcell is transferred to the B3517 facility.

10.2. *Enhancement of the Remote Handling Systems (ORNL)*: In this task, based on the phase 1 test operations, ORNL will enhance the remote handling systems, including the push-pull chain and various grippers, for operations in the hot cell deployment. Apart from testing we will also conduct training for the operators. The training of UCOR personnel may determine changes that have to be made to the workcell design and that will be incorporated before it gets transferred for deployment.

10.3. *Enhancement of Control System (UIC)*: This task addresses the enhancement and refinement of the workcell operation system and user interfaces, which includes the control, monitoring, and workflow sequence logic execution. This task will be carried out by University of Illinois – Chicago, with the support from the EM Minority Serving Institution Partnership Program (MSIPP) fund.

Task 11: Development of Integrated Robotic Operation System

Expanding upon the digital mockup and teleoperator interface established in phase 1, this task involves the creation of an integrated operation system designed to offer informed guidance throughout operational procedures. Consequently, the Mixed-Reality Operations Navigation System (MR-ONS) will be developed, incorporating the following capabilities for task analysis, planning, and enhanced remote operation.

11.1. *Mixed Reality Environment (ANL)*: The system will feature a multi-modal (visual-haptic) operator interface comprising VR/AR devices, establishing a perception-action loop with the robots and peripheral sensors. Leveraging Argonne's Robotic Digital Twin (RDT) framework, a mixed-reality model of the task environment will be created by integrating virtual models, sensory display, and hardware controls capable of simultaneously managing both physical and virtual robots. This mixed- reality model will serve as the foundation for simulation, training, as well as operational platforms.

11.2. *Task Planning (ANL)*: Within the mixed-reality environment, this task will deliver the capability for step-by-step simulation and planning of the task procedures. The process mirrors the surgical navigation process seen in many robotic surgery systems, where operator (surgeons) dedicate a significant amount of time to operational planning. This involves defining motion points, task sequences, applying motion trajectories. The planned operational procedures can then be tested and practiced within the mixed-reality environment until a safe and optimal procedure is confirmed. This iterative approach will allow for the generation of optimal task operations.

11.3. *Training Simulator (ANL, Novatech)*: This task involves the development of a training simulator designed to help operators acquire robot operational skills, become familiar with the operational procedures, and practice execution of task operation scenarios. The mixed-reality simulator will support practice with both hardware and virtual-reality components. The training simulator will be used for training the site contractor workers, and to achieve this goal, we will construct a new set of mixed- reality telerobotic station for training system will be constructed specifically for operators at ORNL. This task will be carried out in collaboration with Novatech through a subcontract to leverage its industry-grade experience in training simulator technology applied to a wide range of domain areas including the nuclear sector.

11.4. *Tele-autonomy (ANL, NIU, KAIST)*: Once proven, verified, and practiced, robotic operations can be executed. While fully manual teleoperation serves as the baseline approach, tele-autonomous operation, combining automation and manual operation, offers a more efficient and reliable approach in partially structured task environments. In practice, tele-autonomy can be achieved by blending robot's autonomous motor behaviors with manual teleoperation. The autonomous robotic behaviors may take the form of virtual fixtures, motion primitives, and/or task sequences. These autonomous behaviors will be combined with teleoperated motion within the robotic architecture. The collaborative task will be undertaken in partnership with ANL, NIU and KAIST.

The MR-ONS aims to deliver a high-quality, real-time mixed-reality environment by

seamlessly integrating virtual- and augmented-reality with hardware control capabilities. This integration is designed to enhance the efficiency and reliability of the robotic hot-cell systems, particularly in unstructured and semi-structured task environments.

Task 12: System Integration, Training, and On-site Demonstration

This task entails the system integration, provision of operator training, and on-site demonstration.

12.1. *Robotic Workcell Systems Integration (ANL, ORNL)*: This task addresses the integration of the robotic workcell components – dual-arm robot, grippers, workcell frame, remote handling devices, camera systems, and teleoperator station – for integrated system operation test at ORNL's remote systems test facility. A thorough test will be performed to verify the correct operations of all the parts and integrated systems under all deployment operations scenarios, followed by systems upgrades and modifications.

12.2. *Operator Training Program (ANL, ORNL, UCOR)*: This task involves the provision of training programs for the site workers on robotic and remote systems operations for the waste handling operations scenarios. The training may determine changes that have to be made to the workcell design and that will be incorporated before it gets transferred for deployment. The training program will utilize the mixed-reality robotic training system developed in the previous task 11. The operator training program will be provided throughout the phase 2 project period.

12.3. *On-site Technology Demonstration (ANL, ORNL, UCOR)*: This task involves the on-site demonstration of deployment of the robotic workcell system for waste handling operations in the ORNL B3517 facility. This task will also involve close collaboration with the site contractor, UCOR, for facility entrance facilitation, and site preparation. Before the workcell is transferred, we have to identify the utility connections available in B3517 highbay and make changes to the workcell to adapt to B3517 utilities. Rigging and transferring the workcell from B7603 to B3517 will need to be coordinated with ORNL/UCOR riggers. Since the operator will be in another room, the electrical, video, and other connections need to be extended to this area. A functional test needs to be performed once the workcell has been moved before actual operation commences. UCOR will also provide the manpower, scheduling and engineering support throughout the technology demonstration.

During the operation, both ORNL and ANL staff may be required to help with any problems that the operators may face during the actual operation.

Task 13: Phase 2 Summary Report (All)

In this task, Phase 2 participants will provide a summary report on their development, and ANL will integrate them into a combined report including integration and test results. As noted in Task 8, the task requirements will be collaboratively developed by the Team with information provided by UCOR based on ORNL site cleanup mission needs and objectives.

Phase 3: Technology Adaptation for Broad Acceptance by Various EM Sites

Phase 3 activity will focus on technology adaptation and maintenance, which include the following tasks:

Task 14: Technology adaptation and maintenance for test site: Based on the findings in the initial site deployment in phase 2, subsequent activities will be directed to further technology adaptation and maintenance to meet the needs at the test site. This task will lead to technology maturity level of TRL 8.

Task 15: Task 15: Technology adaptation for other site applications: This task will involve an assessment to adapt new robots with different capacities, modification of hotbox structures, tools, and digital twin platform for other task sets at other DOE-EM sites.

Such technology adaptation and maintenance will result in further technology maturation, which will result in continued use and broader acceptance by the EM site users.

Appendix B.9

The identification of fee risk ownership for both the Government and the Contractor is set forth below.

Subtask 4-3 Fee Risk Ownership				
Risk ID	**Title**	**Statement of Event**	**Type**	**Owner**
TO-4-03	Ineffective Execution	If project management execution is not effective, in that other DOE program offices contractors or EM prime contractors, or other agreements established under Memorandum of Agreement(s) cannot fulfill DOE's commitments to UCOR, then task order schedule and cost performance may be impacted.	Risk	DOE
TO-4-04	Changes in Security Requirements	If federal security requirements change, then task order cost and schedule performance may be impacted.	Risk/ Opportunity	DOE
TO-4-05	Transportation Interruption	If another DOE prime contractor causes a waste transportation event on the reservation (e.g., spread of contamination) that results in a shutdown of waste transportation, it could impact task order cost and schedule performance.	Risk	DOE
TO-4-07	Designated Landfills Unavailable	If waste disposal facilities are not available when needed for waste disposal (e.g., due to unforeseen circumstance such as temporary closure due to violations by another DOE prime contractor or significant weather event) then there could be an impact on waste generation forecast cost performance.	Risk	DOE

Subtask 4-3 Fee Risk Ownership				
Risk ID	**Title**	**Statement of Event**	**Type**	**Owner**
TO-4-09	Unexpected Hazards/Conditions (Differing site conditions)	If differing conditions are encountered that could not have been reasonably foreseen, then there could be an impact on task order schedule and cost performance.	Risk	DOE
TO-4-12	Regulatory Approval Delayed/ Additional Requirements Added	If regulators takes longer than the prescribed/planned protocols to approve regulatory documents, or impose additional requirements, then task order performance may be impacted.	Risk	DOE
TO-4-14	Delays in internal/external DOE review/approval of required documents	If DOE takes longer than planned to review/approve documents, due to reasons other than document quality, then task order cost and schedule may be impacted. Documents may include DOE O 413.3B, Contract Award, Design documents, regulatory documents, waste handling plans, project management plans, etc.	Risk	DOE
TO-4-16	Change in ES&H Requirements - DOE Initiated	If DOE initiates a change to ES&H requirements, then task order cost and schedule performance may be impacted.	Risk/ Opportunity	DOE
TO-4-18	Extreme Weather	If an extreme weather event occurs (e.g., rain, heat, cold/snow, high winds/tornado, earthquake), then task order cost, schedule or technical performance may be impacted.	Risk	DOE
TO-4-20	Industrial Accidents	If an industrial accident by another DOE prime contractor, occurs that results in a temporary shutdown of field activities, then there may be impacts to task order cost and schedule performance.	Risk	DOE

Subtask 4-3 Fee Risk Ownership				
Risk ID	**Title**	**Statement of Event**	**Type**	**Owner**
TO-4-26	Supply Chain - Material/Equipment Availability - Non-foreseeable	If unforeseeable supply chain issues impact material/equipment availability or lead times, then task order cost and schedule may be impacted.	Risk	DOE
TO-4-31	Contaminated Equipment Not Releasable - Non-foreseeable	If release conditions cannot be met due to unforeseeable and unpreventable conditions, then non-government equipment may need to be dispositioned and purchased by DOE.	Risk/ Opportunity	DOE
TO-4-33	Change in Mission or Policy - DOE Initiated	If DOE initiates mission or policy requirements change, then task order cost and schedule performance may be impacted. Includes other than ES&H related, for example - cyber security.	Risk/ Opportunity	DOE
TO-4-35	NHPA Impacts Non-foreseeable	If National Historic Preservation Act (NHPA) reviews by the Tennessee State Historic Preservation Officer (SHPO) or the Council take longer than the Historic Preservation Plan (HPP) prescribed protocols, such as the Section 106 Recordation, Interpretation and Documentation for the demolition of a facility, or there is disagreement with the recommended interpretive effort then task order performance may be impacted, may require additional efforts.	Risk	DOE
TO-4-37	Change Waste Generation Forecast - DOE Initiated	If DOE initiates a change impacting WGF, then task order cost performance may be impacted.	Risk	DOE