U.S. Contribution to ITER Remote Handling Technology

White Paper

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1.0 Executive Summary

During the CDA and EDA phases of ITER, the U.S. contribution for remote handling technology consisted of:

- providing personnel assignments to the Joint Central Team with responsibility for remote handling R&D and design,
- developing a laser based in-vessel metrology system,
- developing and testing vacuum vessel cutting and welding equipment,
- developing the ITER Remote Handling Design Manual and the Radiation Hardness Design Manual,
- testing radiation hardened electrical connectors for remote handling, and
- design of the port assembly handling and transport systems.

Since that time, development of the metrology system continued at ORNL and precision range measurements were performed in TFTR, and elaborate mapping of plasma facing surfaces was done in NSTX. An SBIR grant is supporting development of a next-generation, reactor-relevant metrology system. In addition, ORNL has been responsible for developing all of the remote handling systems and remote maintenance designs for FIRE.

The experience gained from ITER has been applied to projects in the US that are funded and under construction. Since 1998, the Remote Systems Group at ORNL has had a major role in the development and testing of maintenance equipment for the Spallation Neutron Source (SNS). This support includes a) remote handling systems design and procurement, b) target process systems design and procurement, and c) testing critical components and operations using small-scale mockups to test tools, and full size mockups to demonstrate equipment performance and procedures. Remote Systems also provides R&D and design support to the SNS component designers to ensure compatibility with the remote handling systems, and has also developed procurement specifications for robotic manipulators, shield windows, and viewing systems, to name a few.

In addition, Remote Systems is responsible for developing the conceptual design of remote maintenance systems for a high level waste process that utilizes plasma mass separation. The Archimedes Filter Plant to be located at the Hanford Site in Washington State embodies many of the same remote handling challenges and component designs found in magnetic fusion machines like ITER.

The primary benefits derived from remote handling technology are 1) the assurance that components can be maintained, thereby leading to a high probability of meeting operational availability requirements, and 2) minimizing reactor operating costs by avoiding costly, time consuming modifications to components after operations begin. The Remote Systems Group has the experience and expertise in the area of remote handling as well as the facilities at ORNL to support ITER for developing and testing equipment and tools. This will be effectively accomplished by leveraging the experience gained from decades of related R&D and design as well as involvement in ongoing construction projects in the U.S.

2.0 ITER Remote Handling Requirements

Remote handling systems requirements interface with three areas of the overall ITER design. These interface areas are 1) test cell and hot cell facilities, 2) equipment and tools to handle and maintain the large, activated components, and 3) design support and oversight to ensure that ITER components have the features to be remotely handled and maintained. [1,2]

2.1 Facility Requirements

Design of the test cell must incorporate the requirements for component handling, lay down space, and adequate space to maneuver the large component/cask enclosures in the test cell and hot cell. The large components are the basis for designing the hot cell and determining the space and the equipment needed for refurbishment or waste disposal. The facility design will also include the arrangement and location of the remote operations control rooms where in-vessel transporters, cranes, manipulators, and remote viewing are integrated for handling and maintenance operations.

2.2 Maintenance Equipment R&D and Design

The remote maintenance equipment will consist of multi-purpose apparatus for port plug removal and for maintenance inside the vacuum vessel. In addition, the overhead crane, transport casks, various manipulators, cutting and welding tools, and end-effector tools for handling fasteners and connectors, will be used to accomplish the tasks common to many of the components in the test cell. Special purpose equipment will be designed to accomplish specific tasks for maintaining divertor cassettes, blanket modules and neutral beam injectors, to name several.

Other special purpose equipment includes the in-vessel metrology/viewing system, dust removal equipment, and a leak-check probe deployment system. In addition, there will be equipment needed for reactor disassembly and re-assembly, in particular the equipment needed for Remote Handling Class 3 maintenance, and the repair/maintenance equipment used in the hot cell.

2.3 Component Design Support

The ITER components in the test cell that are expected to require periodic repair or replacement must have provisions in their design that allows interfacing with remote handling equipment. These provisions include structural fasteners and utility connectors that are accessible and easily removed, integral lifting points for remote handling, and modular design of subsystem components that permit simple disassembly and quick installation of replacement components.

3.0 US-ITER Remote Handling Program

3.1 Previous ITER Participation

Previous U.S. participation for ITER remote handling consisted of a) providing personnel assignments to the Joint Central Team with responsibility for remote handling R&D and design, b) developing a laser based in-vessel metrology system, c) developing and testing vacuum vessel cutting and welding equipment, d) developing the ITER Remote Handling Design Manual and Radiation Hardness Design Manual, e) testing radiation hardened electrical connectors for remote handling, and f) design of the port assembly handling and transport systems. In addition, ORNL has been responsible for developing all remote handling systems and remote maintenance designs for FIRE.

3.2 Development of Metrology/Viewing System

At ORNL, a frequency modulated laser range finder capable of measuring to an accuracy of 0.1 mm at 22 meters distance was under development for ITER in-vessel inspection. A prototype system was successfully tested by a) measuring various stationary objects at great distances and angles of incidence, b) mapping precise visual images under conditions of darkness, and c) measuring small motions caused by natural vibrations using the system's Doppler correction feature. The results of these tests showed that measuring the erosion of blanket and divertor components could be achieved, even under ITER operating conditions where natural vibrations in the test cell impart low frequency motion to in-vessel components. [3]

The design for the next-generation metrology system was also underway in order to meet the requirements for in-vessel inspection without impacting the operating availability of ITER. To achieve this, the system that was being designed would be capable of operating in vacuum (10^{-8} torr), withstanding radiation fields (10^{6} rad/h) and elevated temperature (200ºC), and high magnetic field (6 T). In addition, the ability to produce visual images for assessing changes to plasma facing components and inspecting for damage under natural vibration conditions was an added feature of the system. [3]

Since that time, development of the metrology system continued at ORNL and precision range measurements were performed in TFTR, and elaborate mapping of plasma facing surfaces was done in NSTX. A Phase II, SBIR grant is supporting development of the next-generation reactor-relevant metrology system. This system needs to be evaluated in a near term fusion experiment for liquid-metal flow characterization and for metrology applications in ITER or FIRE.

4.0 US-ORNL Expertise in Remote Handling Design

The U.S., through ORNL's Remote Systems Group, has participated in the Fusion Technology Program providing remote handling design support, notably for the Fusion Ignition Research Experiment (FIRE). In addition, since 1998 Remote Systems has played a major role in developing, testing, and procuring remote handling tools and equipment for the Spallation Neutron Source (SNS), and operated several full size mockups for testing various key components.

In 2002, Remote Systems was invited to develop the remote maintenance conceptual design for the Archimedes Nuclear Waste Separation System. Remote Systems is presently developing handling requirements and assessing component designs for maintainability.

The success of many of these design and testing activities is leveraged from the existing equipment in the high bay facility available to the Remote Systems Group, and from decades of previous involvement at ORNL providing support to operating facilities such as the High Flux Irradiation Reactor (HFIR), on site decommissioning for the Molten Salt Reactor Experiment (MSRE), and various military robotics programs, to name several.

4.1 Previous Fusion Experience

The Remote Systems Group is the Task Area Leader for Remote Handling Technology in the US fusion program. Through long term personnel assignments, engineering and technology support was provided to TFTR in the areas of first-wall tiles and in-vessel articulated boom-manipulator tasks, and at JET for developing the in-vessel manipulator system, remote cutting equipment, and various manipulator tools. In addition, the Remote Systems Group participated in the major national design projects, CIT, BPX, and TPX, providing remote handling systems R&D and design, design interface with component systems, and detailed cost estimates. Remote Systems is currently responsible for design and development of FIRE's remote maintenance and handling systems.

4.2 Fusion Ignition Research Experiment (FIRE)

Remote maintenance for a burning plasma experiment such as FIRE (and ITER) requires an in-vessel transporter capable of precisely handling massive components, manipulators, various tools, and viewing equipment. The ability to dexterously manipulate heavy payloads with a precision of millimeters is a requirement for components such as the 800 kg divertor module, but is beyond state-of-the-art. The technology that is needed can be leveraged from other non-fusion programs with similar requirements, applied to fusion machines like FIRE and ITER. Several non-fusion development projects at ORNL can provide the basis for meeting this requirement. [4,5,6]

4.3 Spallation Neutron Source (SNS)

Since 1998 the Remote Systems Group has had a major role developing and procuring the remote maintenance equipment for the SNS. This equipment consists of a remotely operated overhead crane, bridge-mounted servomanipulator system, through-the-wall manipulators, shield windows, cameras and various domestic and foreign-made tools needed for cutting and installing bolts and connectors. In addition, Remote Systems constructed and operates several full size mockups for testing the mercury target process system, operation of the neutron-channel shutters, and seal tests for the target, shutters, and the proton beam window. A variety of these tools under simulated remote handling conditions have been tested in the Remote Systems High Bay Facility. The results of some of these tests were the basis for modifying commercially available tools, and more importantly, identifying design changes to key SNS components such as the mercury target. [7,8]

4.4 Archimedes Waste Separation

The Remote Systems Group is developing the remote maintenance conceptual design for a nuclear waste, plasma mass separation device under development by Archimedes Nuclear Waste, LLC, San Diego, CA. Remote Systems is responsible for a) developing remote handling equipment designs for all maintenance activities in the process cell/hot cell, b) for interfacing with component engineers and facility designers to ensure that components can be repaired, replaced, or disposed of, and c) for developing equipment cost estimates and procurement schedules.

The Archimedes waste separation process is a high availability system that separates high level waste and low activation waste using a process based on many of the technologies developed for magnetic fusion. Hence, many of the maintenance issues are similar. These include remote handling and maintenance for the appurtenances installed in a large vacuum vessel, solenoid magnets, RF heating systems, plasma injectors, and the equivalent of plasma facing components. [9,10]

4.5 Facilities to Support Equipment Development and Mockup Tests

The Remote Systems Group has a High Bay Facility that is routinely used to support the development and testing of robotic and remote handling equipment for the Spallation Neutron Source and other ORNL projects. It measures 80'W x 140'L x 60'H, and has a 20-ton bridge-crane. In addition, there is a below-grade section, a pit area at the north end of the cell, that measures 25'W x 50'L x 30'D that is fully accessible by the overhead crane. This building is also equipped with a mast-mounted servomanipulator system, two manipulator transporters, a remote operator's control room, other manipulators and tools, and remote viewing equipment. It is ideally suited for remotely handling and testing of large scale components.

5.0 Benefits to the US Fusion Program

The US has an opportunity, through expertise in remote handling, to provide a systems engineering role that will help to ensure success of the ITER design, and to lay the foundation for US industry to provide large dollar-value remote handling equipment. Remote handling systems engineers comprise a group within a large project that literally interfaces with every subsystem that has components in the test cell. They are in a unique position to understand everyone's requirements and help provide the most maintainable component configuration, and efficient facility arrangement. These efforts could lead to lower project costs for equipment, tools, and the facility, as well as reduced operational costs later on.

Achieving availability goals for the various subsystems that make up a large, costly device like ITER is a two-sided proposition. It requires careful component designs based on subsystem-level parameters that are the responsibility of experts for the PFCs, heating, fueling, magnets, etc. And it requires incorporating a number of physical features on the components that are compatible with the remote handling equipment and tools. It is the responsibility of the remote handling specialists to ensure that design compatibility exists, and that remote handling equipment will support meeting the availability goals. In the context of the cost-value of experiment time for a complex device like ITER, it would be unacceptable not to meet these goals.

Remote handling system costs are likely to be 5-10% of the total project cost. For a device like ITER this is not a trivial amount. These include the equipment used in the test cell for removing and installing the tokamak subsystems and components, and the various equipment and tools needed in the hot cell for refurbishing components or disposing of them as waste. This represents a significant potential for US industry that specializes in this type of equipment for design, fabrication, and installation. ORNL proposes to work with industry to develop relevant, cost-effective equipment designs.

6.0 Summary

The Remote Systems Group at ORNL is in a unique position to work with the European Union and Japan to provide R&D, design and testing for the variety of remote handling equipment and tools. This is based on ORNL's previous participation in ITER for R&D, design, development, and testing of remote handling equipment, and on the current experience developing and testing remote handling systems for the Spallation Neutron Source. In addition, a high bay facility with appropriate remote handling equipment is available at ORNL for testing and development at no added cost.

References

1. "ITER Design Requirements and Guidelines Level 1," G AO GDRD 2 01-07-13 R 1.0.
2. "ITER Plant Description Document, Section 2.9 Remote Handling," G AO FDR 1 01-07-13 R1.0.
3. "Development of In-Vessel Viewing/Metrology Equipment," ITER/US/98/EV-07-07, N23 TT 11 FU R&D Activities (Task 328/329), and N23 TD 15 FU-4 Design Activities (Task D311).
4. "MFE.T4 Report Sections on Vacuum Vessel and Remote Handling Technology Assessment," T. Burgess and B. Nelson, Snowmass 2002 Fusion Energy Sciences Summer Study Report, Snowmass Village, Colorado, July 2002.
5. "Robotics Science & Technology for Burning Plasma Experiments," J. N. Herndon, T. W. Burgess, M. M. Menon, Burning Plasma Workshop II, San Diego, California, May 2001.
6. "Remote Maintenance and Cost Estimate Sections, Fusion Ignition Research Experiment Engineering Report," T. Burgess, Princeton Plasma Physics Laboratory Report No. 81 200600 Fire RPT_FT.doc, June 2000.
7. "Summary Report of Target Test Facility R&D (WBS 1.1.10)," T.W. Burgess et al, Spallation Neutron Source document, SNS –101100000-TR0003-R00, Oak Ridge National Laboratory, Oak Ridge, TN, October 2001.
8. "SNS Target Test Facility: Prototype Hg Operations and Remote Handling Tests," P.T. Spampinato, T.W. Burgess, J.B. Chesser, V.B. Graves, S.L. Schrock, ANS Embedded Topical Meeting on Accelerator Applications/Accelerator Driven Transmutation Technology and Applications '01, Reno, Nevada, Nov. 2001.
9. "Archimedes Filter Plant Remote Handling Trade Study Report," E.C. Bradley, T.W. Burgess, V.B. Graves, P.T. Spampinato, Archimedes Nuclear Waste, LLC, San Diego, CA, February 2003.
10. "Remote Maintenance System Design Description," E.C. Bradley, T.W. Burgess, V.B. Graves, P.T. Spampinato, V.K. Varma, AFP-1.9.7.3-SDD-01-Rev-0-Draft-01-Remote Handling, Archimedes Nuclear Waste, LLC, San Diego, CA, April 2003.