FINAL PROGRAM

International Workshop on the Use of Robotic Technologies at Nuclear Facilities

February 2, 2016, 1:00 p.m. – 6:00 p.m. (EST)
February 3, 2016, 9:00 a.m. – 5:30 p.m. (EST)
February 4, 2016, 9:00 a.m. – 5:00 p.m. (EST)

National Institute of Standards and Technology
Green Auditorium, Administrative Building 101
100 Bureau Drive, Gaithersburg, MD, 20899

Organizational Sponsors

NEA NUCLEAR ENERGY AGENCY

NIST

U.S.NRC UNITED STATES NUCLEAR REGULATORY COMMISSION *Protecting People and the Environment*

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Workshop Overview

The International Workshop on the Use of Robotic Technologies at Nuclear Facilities will address the use of robotic technologies at nuclear facilities during operation, emergency response, decommissioning and post-accident cleanup.

The workshop is being co-sponsored and convened by:

- U.S. Nuclear Regulatory Commission (NRC), Offices of Nuclear Regulatory Research and Nuclear Material Safety and Safeguards
- U.S. National Institute of Standards and Technology (NIST), Engineering Laboratory
- U.S. Department of Energy (DOE), Office of Environmental Management
- U.S. Department of Homeland Security (DHS), Science and Technology Directorate, Office of Standards
- United Kingdom Atomic Energy Authority (UKAEA)
- Canadian Nuclear Safety Commission (CNSC)
- Organization for Economic Cooperation and Development/ Nuclear Energy Agency (OECD/NEA)

Collaborating Standards Development Organizations include:

- American Nuclear Society (ANS)
- ASTM International
- IEEE Robotics and Automation Society

Workshop Co-Chairs:	Thomas Nicholson, NRC	Thomas.Nicholson@nrc.gov
	Andrew Szilagyi, DOE	Andrew.Szilagyi@em.doe.gov
	Adam Jacoff, NIST	adam.jacoff@nist.gov

Organizing Committee Members:

Thomas Nicholson, Don Marksberry, Anders Gilbertson, Ian Gifford, Al Csontos, Jack Parrott, Robert Bernardo, Thomas Burton and Ralph Way, U.S. Nuclear Regulatory Commission (U.S. NRC); Andrew Szilagyi, U.S. Department of Energy (DOE); Adam Jacoff and Kamel Saidi, National Institute of Standards and Technology (NIST); Laurie Judd, Longenecker & Associates; Takashi Hara, Tokyo Electric Power Corporation (TEPCO); Rob Buckingham, UK Atomic Energy Authority, Remote Applications in Challenging Environments (RACE); Philip Mattson, U.S. Department of Homeland Security; Zhao Chang Zeng, Canadian Nuclear Safety Commission; Joan Knight, Exelon Generation; Jeremy Renshaw, Electric Power Research Institute (EPRI); Chris Eason, American Nuclear Society (ANS); William Hamel, Institute of Electrical and Electronics Engineers (IEEE).

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Workshop Purpose and Objectives

The purpose of the workshop is to discuss and assess past, present and anticipated future uses of remote systems and robotic technologies in safety applications and decommissioning activities at nuclear facilities. The workshop is designed to facilitate technical exchange of lessons learned from historic nuclear applications and experiences (e.g., Three-Mile Island, Sellafield and Fukushima Daiichi), ongoing research and other relevant applications.

The workshop will also include a technical exchange of experiences and information related to the use of mobile and stationary robots in challenging environments in non-nuclear applications that are hazardous to humans, such as environments with extreme temperatures, pressures, or radiation fields or environments that are space-confined or oxygen-limited (e.g. extraterrestrial exploration, deep-sea surveys, and firefighting).

The key objectives of the workshop are to:

- **Facilitate sharing of information** between government agencies, industry and academia on the safe and reliable use of remote systems and robotic technology for monitoring, sampling and other surveillance functions for a range of environmental conditions within critical infrastructures.

- **Seek ideas and insights** on possible ways to develop remote systems and robotics to execute complex tasks for assessing structures, systems and components during post-event conditions; reporting conditions within critical infrastructures; and assuring both worker safety and facility safety performance.

- **Identify strategies** for using robotic technologies to detect, examine and recover radioactive materials such as damaged fuel rods from nuclear facilities in order to reduce exposures to workers and the public and protect the environment.

- **Identify current robotic technologies** used in non-nuclear applications that could be adapted for use in nuclear facility applications.

- **Establish realistic plans** to test both robots and their operators for a range of scenarios at nuclear facilities (e.g., construction, startup, normal operations, low power and shutdown and decommissioning).

- **Discuss the development of standards** to evaluate the performance of robots, their implementation and their integration with systems at nuclear facilities to avoid compromising the operability of safety-related plant structures, systems and components.

- **Identify ground-breaking opportunities** related to robotic technologies for the purpose of improving safety in the nuclear industry.

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Target Audience:

The workshop is intended for an audience consisting of designers, developers, operators and users of robotic technologies at nuclear facilities and other challenging and hazardous environments as well as robotics engineers from industry, academia, research institutes and government agencies.

Key Outcomes Sought:

- **Knowledge Transfer:**
  - Effective exchange of information on the current use of robotic technologies at nuclear facilities around the world.
  - A better understanding of the state of robotics and remote systems in challenging non-nuclear environments and their potential applications at nuclear facilities.
  - Introduction to existing databases or compendiums of robots and remote systems for nuclear applications.
  - Ideas and strategies for enhancing existing databases or compendiums with quantifiable and verifiable performance data.

- **Development, Testing and Evaluation Strategy:**
  - A proposed approach (or approaches) for using consensus standard test methods to assess performance to guide development, procurement and training for nuclear applications. Representative activities include:
    - Host competitions, challenges and technology incubators.
    - Identification of best-in-class contributing technologies (e.g., sensors for non-destructive evaluation, mobility platforms, manipulators, material samplers).
    - Iterate proposed solutions through validated simulations of standard test methods and mockups.
    - Conduct comprehensive testing with standard test methods to establish reliability and gain confidence in robotic performance.
    - Deploy proposed solutions into physical mockups and test beds.

- **Adoption and Implementation:**
  - A proposed end-user strategy for setting thresholds of capabilities (measured within standard test methods) necessary for deployment.
  - A proposed regulatory approach for technical review of strategies for integrating technology, standards, training and regulations to address implementation.

- **Summary of the Key Insights Drawn from Presentations and Panel Discussions**

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Workshop Registration Information and Contacts:

Workshop Registration and Logistics:

A pre-event email will be issued 3 days before the Workshop to set out details of site security procedures, parking, and related Workshop logistics.

For any other questions about the workshop, please contact the NIST Conference Coordinator, Gladys Arrisueno at 301-975-5220; gladys.arrisueno@nist.gov

Registration:

All attendees must complete and submit a registration form and pay a $71 registration fee by January 22, 2016. Access to the Auditorium will be available 1 hour before the beginning of each day of the Workshop.

To register please go to either:

International Robotic Workshop or

http://www.nist.gov/el/isd/international-workshop-on-the-use-of-robotic-technologies-at-nuclear-facilities.cfm)

Hotel Accommodations:

The official Workshop hotel is the Courtyard Gaithersburg Washingtonian Center, 204 Boardwalk Pl, Gaithersburg, MD 20878. To obtain the special Workshop rate of $154/night for nights February 1- 5, 2016, you must book your accommodation using the link BookOnline or by calling 1-800-321-2211 and referencing **Room Block: NIST Robotic Technologies Workshop** no later than **January 11, 2016.**

Hotel accommodation at the Courtyard includes shuttle service to and from the NIST Administrative Building 101 in the morning and at the close of each day. More details of the shuttle service will be provided at the hotel.

Transportation and Dining

Directions to the NIST campus plus information on local hotels, dining and site entry identification requirements can be found at http://www.nist.gov/public_affairs/visitor/index.cfm .

Please be aware that the NIST campus address (100 Bureau Drive, Gaithersburg, MD) is not recognized by most GPS systems and so you should use either "21 North Drive, Gaithersburg" or "West Diamond Avenue and Bureau Drive, Gaithersburg."

NIST provides a scheduled shuttle bus service to and from the Shady Grove metro station from 6.45 am to 6.15 pm as detailed at http://www.nist.gov/director/ofpm/upload/shuttle_schedule.pdf

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Agenda

Day 1: Tuesday, February 2, 2016

1:00 p.m. **Welcome - Howard Harary, Engineering Laboratory Director, NIST**

1:15 p.m. **Sponsors Opening Remarks**

- **Monica Regalbuto, Assistant Secretary for Environmental Management, U.S. DOE**
- **K. Steven West, Deputy Director, Office of Nuclear Regulatory Research, U.S. NRC**
- **Terry Jamieson, Vice-President of Technical Support Branch, CNSC**
- **Rob Buckingham, Director of RACE, UKAEA**
- **Philip Mattson, Director, Office of Standards, U.S. DHS**
- **Michael Siemann, Head of Radiological Protection and Radioactive Waste Management, OECD/NEA**

Moderator: Tom Nicholson, U.S. NRC

1:45 p.m. ***Session 1: Overview of Robotic Databases, Challenges and Opportunities for the Use of Robotic Technologies at Nuclear Facilities***
Co-Chairs: Andrew Szilagyi, DOE and Adam Jacoff, NIST

Session topics to be addressed:

1. What is the current state-of-the-practice in applying robotic technologies to challenges at nuclear facilities and in other hazardous environments?
2. What are the opportunities to use robotic technologies for enhanced outcomes?
3. What are the possible future uses of robotics at nuclear facilities?
4. What are the potential applications for using test methods from consensus standards to assess robotic performance in order to guide development, procurement and training?
5. What are some established or developing databases of robotic technologies and their applications and how have the databases been integrated into successful monitoring and remediation programs?

2:15 p.m. **Overview of the Testing of Robotics and their Operators for a Range of Functions and Challenges**
Adam Jacoff, NIST

2:45 p.m. **Break**

3:00 p.m. **Demonstration of Databases: From Problem Definition, to Available Robotic Technologies, to Performance Data Based on Standard Test Methods**
Ian Seed, Cogentus Consulting Ltd and Adam Jacoff, NIST

5:00 p.m. **Tour of NIST Robot Test Facility[1] for demonstration of robot testing and applications (http://www.nist.gov/el/isd/ms/roboticsbldg.cfm)**
Adam Jacoff and Kamel Saidi, NIST

6:30 p.m. **Adjourn for the day**

NIST shuttle bus will return registrants to NIST Administration Building 101 and then to Courtyard Gaithersburg for registered guests

Day 2: Wednesday, February 3, 2016

9:00 a.m. **Announcements and Agenda Review**
Andrew Szilagyi, DOE

9:10 a.m. ***Session 2: Practices, Lessons Learned and Challenges of Robot Deployment at Fukushima Daiichi***
Co-Chairs: Shinji Kawatsuma, Japan Atomic Energy Agency (JAEA) and Takashi Hara, Tokyo Electric Power Company (TEPCO)

Presentation 1: **Deployment of Robotics to Stabilize the Accident at Fukushima Daiichi NPS**
Taichiro Arahata, TEPCO

Presentation 2: **Challenges for Fuel Debris Retrieval using Robotics Technologies at Fukushima Daiichi NPS**
Yuichi Kondo, TEPCO

Presentation 3: **Startup of Naraha Remote Technology Development Center and Consideration of Deployed Robot Operation for New Standard Testing Method**
Dr. Kuniaki Kawabata, JAEA

[1] Attendees must pre-register for the tour as part of the general registration process.

10:45 a.m. Break

11:00 a.m. Presentation 4: R&D on Robots for the Decommissioning of Fukushima Daiichi NPS
Kiyoshi Oikawa, International Research Institute for Nuclear Decommissioning (IRID)

11:30 a.m. Panel 2 Discussion:

Moderator: *Shinji Kawatsuma, JAEA*
Rapporteurs: *Takashi Hara, TEPCO*
Dr. Tetsuya Kimura, Nagaoka University of Technology
Panelists: *Taichiro Arahata, TEPCO*
Yuichi Kondo, TEPCO
Dr. Kuniaki Kawabata, JAEA
Kiyoshi Oikawa, IRID

Panel questions:

1. What robotic applications have been developed and deployed to survey and assess challenging conditions within the damaged reactors and auxiliary support structures (e.g., Fukushima Daiichi)?
2. What lessons were learned in developing and applying these robotic technologies and what successes were achieved?
3. How were complex conditions and challenging environments negotiated by the adaptive robotic technologies?
4. How were cleanup objectives, including worker safety, met by using these robotic technologies?

12:00 p.m. Lunch

1:00 p.m. *Session 3: Industry and Government Experiences in Applying Robotic Technologies to Existing Challenges*
Co-Chairs: Rob Buckingham, UKAEA/RACE and Joan Knight, Exelon Generation

Presentation 1: Use of Robotics and Remote Monitoring Equipment for Reducing Dose and Risk Associated with Radiological Work at Ontario Power Generation
Joe Zic, Ontario Power Generation

Presentation 2: DOE National Laboratory Robotic System Applications for Nuclear Facilities Operations and Legacy Cleanup
Steven Tibrea, Savannah River National Laboratory

Presentation 3: Experience in Decommissioning of Nuclear Power Plants in Germany
Kenji Hara, Wälischmiller Engineering GmbH

2:30 p.m. **Break**

2:45 p.m. **Presentation 4: Robotic Handling of Legacy Nuclear Waste: BEP**
Stephen Shackleford, UK National Nuclear Laboratory

Presentation 5: The Use of Robotics at CANDU Power Plants
Jacqueline McGovern, Kinectrics Inc

Presentation 6: Use of Robotics for Dose Reduction and Efficiency Gains at U.S. Commercial Nuclear Facilities
Daren Cato, Duke Energy and Joan Knight, Exelon Generation

4:15 p.m. **Panel 3 Discussion:**
Moderators: *Rob Buckingham, UKAEA-RACE and Joan Knight, Exelon Generation*
Rapporteurs: *Ian Gifford and Steven Wessels, NRC*
Panelists: *Joe Zic, Ontario Power Generation*
Steven Tibrea, Savannah River National Laboratory
Kenji Hara, Wälischmiller Engineering GmbH
Stephen Shackleford, UK National Nuclear Laboratory
Jacqueline McGovern, Kinectrics Inc
Daren Cato, Duke Energy

Panel questions:

1. What were the project drivers that enabled your project(s) to get started?
2. What were the key elements that lead to project success?
3. How did the different parties interact: (e.g. government, regulator, operator and supplier)?
4. In your view, how could we as a community be better prepared, more coherent and ultimately more efficient?

5:30 p.m. **Adjourn for the day**

Day 3: Thursday, February 4, 2016

9:00 a.m. **Announcements and Agenda Review**
Tom Nicholson, U.S. NRC

9:10 a.m. ***Session 4: Ground-Breaking, Innovative Technologies and New Opportunities***
Co-Chairs: Laurie Judd, Longenecker & Associates and Richard Reid, EPRI

Presentation 1: Challenges and Opportunities for the Next Generation of Remote Systems and Robotics in the Decommissioning of DOE's Nuclear Facilities
Rod Rimando, DOE

Presentation 2: Snake Arm Robots for Nuclear Applications
Adam Mallion, OC Robotics

10:15 a.m. **Break**

Presentation 3: Robotics and Sensing for Nuclear Infrastructure Inspection
David Mascarenas, Los Alamos Engineering Institute

Presentation 4: RISER: 3D Contamination Mapping with a Nuclear-Capable Drone
Matt Mellor, CREATEC

Presentation 5: Developing a Suite of Remote Handling Tools for Fusion Experiments
Rob Buckingham, UKAEA-RACE

12:00 p.m **Panel 4 Discussion:**
Moderators: *Laurie Judd, Longenecker and Associates and Richard Reid, EPRI*
Panelists: *Rod Rimando, DOE*
Matt Mellor, CREATEC
Adam Mallion, OC Robotics
Rob Buckingham, UKAEA-RACE
David Mascarenas, Los Alamos Engineering Institute
*Michael Kurzeja, Exelon Corp***.**

Panel questions:

1. What can the nuclear industry do better or differently to accelerate the adoption of innovation and new technologies?
2. What are the ground-breaking, innovative technologies and new developments that are needed now to enhance the functionality and application of robotics at nuclear facilities?
3. Who has and/or who should have, the responsibility for taking these technologies from “the lab to the field” (i.e. ‘bridging the valley of death’)?
4. Are programs such as the National Robotics Initiative in the U.S., Horizon 2020 in Europe and AISP in the UK linked closely enough with industry and end users to ensure that the technology investments being made are targeted and prioritized on the ‘right’ things? If not, what should we do differently to make sure that future programs are better aligned with end user needs?

12:30 p.m **Lunch**

1:30 p.m. ***Session 5: Robotic Technology Testing, Operator Training and Certification and Regulatory Standards Development***
Co-Chairs: Phil Mattson, DHS and Tim Brooke, ASTM International

Presentation 1: Standards Development for Robotics and their Operators
Gordon Gillerman, NIST

Presentation 2: SMART Firefighting using Robotics
Casey Grant, Fire Protection Research Foundation

2:30 p.m. **Break**

2:45 p.m. **Presentation 3: Guidance on Robot Operator Certification**
Tim Brooke, ASTM International

3:15 p.m. **Panel 5 Discussion:**
Moderators: *Phil Mattson, DHS and Tim Brooke, ASTM International*
Panelists: *Gordon Gillerman, NIST*
Casey Grant, FPRF
William Hamel, IEEE RAS
Chris Eason, ANS
Dr. Tetsuya Kimura, Nagaoka University of Technology

Panel questions:

1. Where and how are robots tested?
2. Where and how are robot operators trained?
3. How can these testing and training programs be incorporated into a certification program recognized by industry and government?
4. How do industry-developed standards (e.g., ASTM International, American Society of Mechanical Engineers) gain regulatory acceptance?
5. What are the procedural and regulatory challenges that need to be addressed?

4:15 p.m. Next Steps (examples from Germany, NIST, DOE, CNSC, UKAEA, etc.)
Adam Jacoff, NIST

5:00 p.m. Workshop Adjourns

WORKSHOP ABSTRACTS

Session 1: Overview of Challenges and Opportunities for the Use of Robotic Technologies at Nuclear Facilities

Demonstration of databases from problem definition, to available robotic technologies, to performance data based on standard test methods

Laurie Judd, Longenecker & Associates and Andrew Szilagyi, DOE

The development and use of robotics and remote systems has become widespread and relatively common in many industries including aerospace, defense, oil & gas and automotive. The move towards the use of these types of systems has been driven by the need to reduce cost, improve operations and safety and to facilitate work in repetitive and/or challenging environments.

Although there are many opportunities for the use of such systems in the nuclear industry (operations, outages, D&D), there is an inherent conservatism to their implementation. However, the critical need to use remote systems at the Fukushima Daiichi plant in Japan has caused a paradigm shift in thinking about the use of remote systems.

Indeed, there are many technical challenges at nuclear facilities that require some form of remote handling expertise and equipment. In addition to the significant R&D efforts being undertaken worldwide, there are also numerous remote systems in use in multiple applications in both nuclear and non-nuclear industries. In many cases, the systems developed are customized for their given application but there are also multiple systems in use which could be applied to nuclear challenges either directly or with some minor adaptation.

In 2014, the U.S. Dept of Energy's Office of D&D and Facility Engineering supported Cogentus and NuVision Engineering to conduct a review/assessment of the current state-of-the-art of robotics and remote technologies in order to generate a baseline of what is available, what has been used where and for what applications as well as what has been successful and what hasn't.

In all, more than 1100 remote systems were identified and have been cataloged as a searchable, web-based database. Having assembled and assimilated the data, it was considered that, while many of these individual systems were customized to a single application, linking and integrating two or more systems together could address a completely different need or challenge. Such integration has never been possible in the past as there has been no such comprehensive database which contains so much information on available systems.

To illustrate the concept, a 2 day workshop was held to develop a ‘near, off-the-shelf’ solution to the challenging issue of retrieving extremely radioactive calcine wastes from silos at the DOE Idaho site. The first part of Session 1 will report on the results of the workshop as well as demonstrate the effectiveness of the database as a stand-alone tool.

In a parallel development, NIST has compiled a database of remote systems which have completed a standardized series of tests and activities conducted under controlled conditions on a series of test beds. This database enables direct and objective comparison of systems and is the starting point for the development of standardized testing of remote systems.

In the second part of Session 1, the NIST database will be introduced and ways in which both databases can be used to help end-users to identify solutions to their challenges will be discussed.

In addition, there will be discussions about the overall context within which the use of robotics and remote systems can be maximized while also paying close attention to the supporting management and implementation infrastructure such as training, certification and regulation.

Session 2: Practices, Lessons Learned and Challenges Related to Robot Deployment at Fukushima Daiichi

Presentation 1: Deployment of robotics to stabilize the accident at Fukushima Daiichi NPS

Taichiro Arahata, Tokyo Electric Power Company (TEPCO)

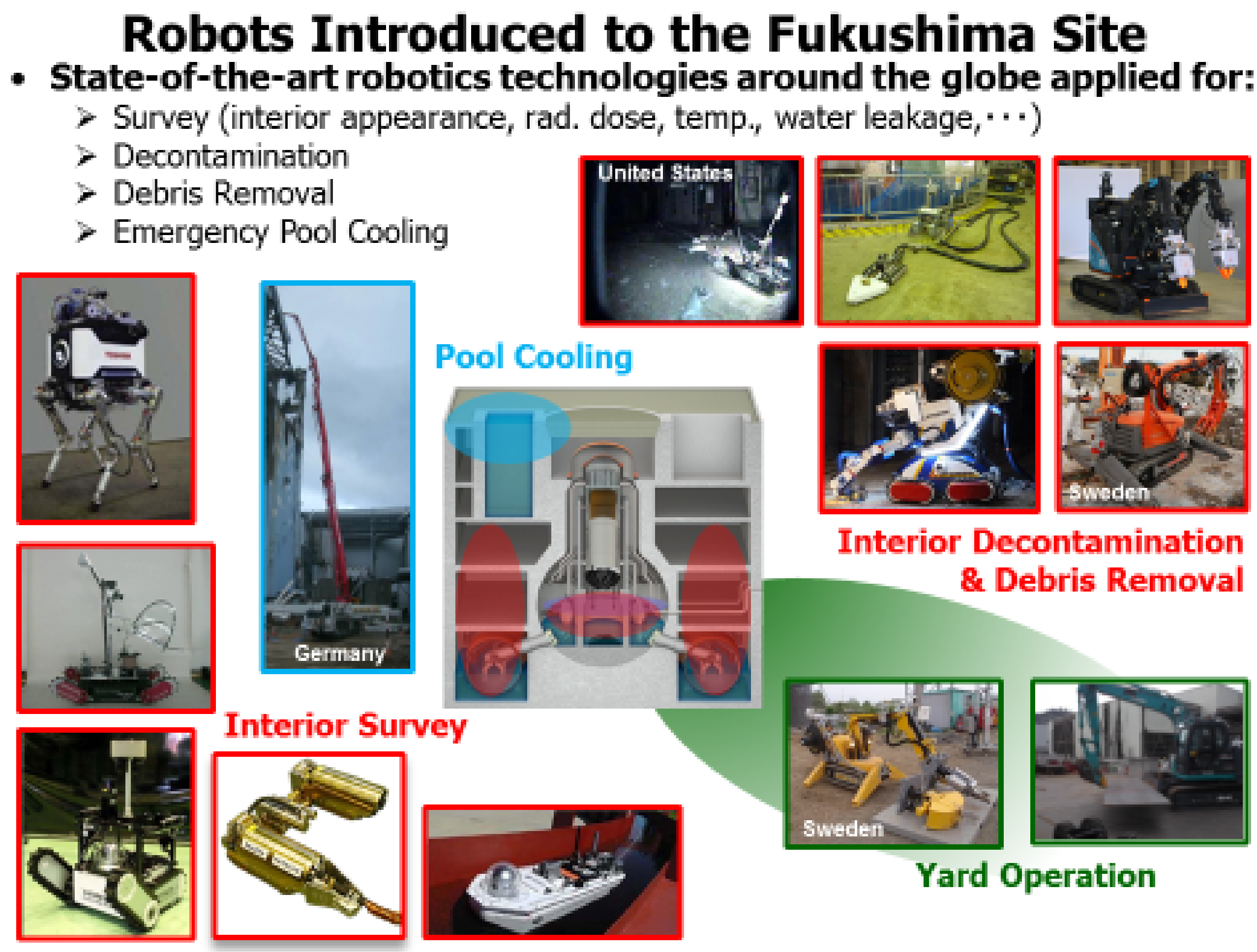
Various remote operations using robotics technologies are carried out for stabilization and cleanup of Fukushima Daiichi Nuclear Power Station.

Removal of scattered rubbles is a good example. It takes place on reactor building operating floors, in spent fuel pools and in the yards using heavy machinery such as remote operated cranes. Emergency backups for spent fuel pool cooling are satisfied by remote operated concrete pumping-up vehicles.

Focus of our discussion is given for remote operated mobile robots in missions under extremely high radiation conditions inside reactor buildings of unit 1,2 and 3, which experienced core melt. Over twenty kinds of robots have been utilized in such missions since April 17, 2011, when two PackBots of iRobot Co. were used for the first time.

Lessons learned from previous missions, information on machinery currently under development and future plans for robotics application are also included in our discussion. Additionally, topical changes in Fukushima Daiichi site since March 11, 2011 are introduced with expectation for suggestions from external parties.

Robots utilized for stabilization operations starting just after the accident till cold shutdown are introduced first. In this phase, robots are used to know environments inside reactor buildings. They took still images and motion pictures and measured data such as dose rates and temperatures. These robots performed surveys before human operations under high radiation conditions (>1Sv/h) and reduced the risk of serious troubles in the following operations such as human over exposure.



After the accident, TEPCO received several offers from external parties to use their robots for post-accident stabilization and put some of them into actual operations. Feedbacks from onsite operations were given from TEPCO to the offered parties for further development. Field of robotic operation was expanded from first floors of reactor buildings to basements (Survey Runner) and top floors (Quince) thanks to these cooperation.

These improvements provided not a small portion of contribution to achievement of cold shutdowns of the three damaged units. The obtained knowledge is also applied for development of robotics technologies in the fuel debris retrieval project.

Presentation 2: Challenges for Fuel Debris Retrieval with Robotics Technologies at Fukushima Daiichi NPS

Yuichi Kondo, Tokyo Electric Power Company (TEPCO)

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Next topic is about robotics applied for surveys and preparations for fuel debris retrieval project. Preparations such as decontamination inside reactor buildings to reduce dose rate and surveys such as examination of conditions of pressure containment vessels (PCVs) and related equipment are necessary for future planning. Robotics technology is expected to provide options for these operations. Surveys for high radiation areas such as inside PCVs cannot be carried out without remote controlled robots.

TEPCO has experiences of robotics application inside reactor buildings so far for:

- Removal of scattered rubbles
- Decontamination
- Dose rate areal distribution measurement using a gamma ray camera
- External visual examination
- Ultrasonic measurement of water level inside a suppression chamber
- PCV interior survey

Many of these experiences were obtained as a result of projects ran by International Research Institute for Nuclear Decommissioning (IRID) with a help of government funding.

Details of these robotics applications are introduced and lessons learned from the applications are discussed. User’s expectations to developers of robotics technology are also given.

Presentation 3: Startup of Naraha Remote Technology Development Center and Consideration of Deployed Robot Operation for New Standard Test Methods

Yoshihio Tsuchida, Kuniaki Kawabata, Shinji Kawatsuma
Japan Atomic Energy Agency

The Japan Atomic Energy Agency (JAEA) is a general research and development institute of nuclear in Japan and is now building Naraha Remote Technology Development Center in Naraha, Fukushima-pref. for research and develop of remote controlled technology on the decommissioning of Fukushima Daiichi Nuclear Power Station of Tokyo Electric Power Company. Naraha Remote Technology Development Center. The facility is equipped full-scale mock-up for equipment to repair/stop leakage in lower part of the PCV and test apparatus for development of remote controlled equipment and devices. Naraha Remote Technology Development Center is in partially operation and will be in full operation from Apr. 2016.

Development of Standard Test Methods (STM) for nuclear emergency response robots is one of the research theme of Naraha Remote Technology Development Center. STM for response robots are developed by the U.S. National Institute of Standards and Technology and standardized by ASTM International. STM are utilized for evaluating, purchasing and training with response robots. For instance, the Fire Department of New York City used STM for purchasing robot.

For two year after the accident occurred in Fukushima Daiichi, more than thirty robots have been deployed to the Fukushima Daiichi. In these, five robots could not return and some robots could not complete the mission because of some troubles. If the performance necessary for nuclear emergency response robots were evaluated previously, these troubles might be able to be prevented.

To clarify the functions and requirements to be evaluated for nuclear emergency response robots, it is important to analyze the objective of robot deployment and the reason for the incompletion. The functions and requirements have become clear based on the time analysis and failure analysis of nuclear emergency response robots.

From the time analysis of operation using Quince robot, more than 70% are moving time but 10% is uncertain stop. From the failure analysis, 4 out 5 failed robots are trouble related to communication for robot control.

Some STMs could be used for evaluating the function and requirements. However, additional STMs are to be developed for nuclear emergency response and Fukushima Daiichi decommissioning robots. JAEA is planning to develop the additional STM in Naraha Remote Technology Development.

Presentation 4: R&D on Robot for the Decommissioning of Fukushima Daiichi NPS

Kiyoshi Oikawa, Director, International Research Institute for Nuclear Decommissioning (IRID)

The International Research Institute for Nuclear Decommissioning (IRID) is a technology research association consisting of 18 member corporations that focus on R&D required for decommissioning the Fukushima Daiichi Nuclear Power Station (NPS). We have tied up with TEPCO's Fukushima Daiichi Decontamination and Decommissioning (D&D) Engineering Company to identify the needs of the Fukushima Daiichi site and are engaged in the integrated management on the development of various decommissioning technologies.

In the session, I will introduce some examples of IRID's R&D activities for preparation of fuel debris retrieval that is a core operation of decommissioning. Various kinds of remote controlled equipment and robots have been developed so far for decontamination and investigation inside the reactor building.

In 2012 and 2013, we investigated the dose rate and contamination distribution at each floor of the Units 1-3. Therefore, the conditions inside the reactor buildings are still very severe. We have developed three types of remote decontamination equipment: suction/blast type, high pressure water jet type and dry ice blast type.

Submersion method is the most favorable approach from the standpoint of minimizing radioactive exposure of workers. To realize this method, whole water leakage from the PCV needs to be found and stopped. Although the point to be investigated on the PCV is very hard to access with usual vehicle, we have to have developed various remotely controlled robots for water leakage investigation.

As the most recent example, we have developed a shape changing robot that can go through a penetration to investigate the PCV to grasp the damage situation inside the PCV and also the location and condition of the fuel debris. We also developed a technology for detection of fuel debris in the reactor. Remote sensing technology utilizing cosmic ray muon is one of the methods to identify location of fuel debris.

The important process by the final stage of robot development prior to the application to Fukushima Daiichi is the evaluation in the mock-up facilities equal to the environment of the application place in the PCV. Not only examining the performance of the robot, but also training the workers to carry out the mission safely and certainly is executed sufficiently.

In the development of technologies for fuel debris retrieval, in addition to the method in which PCV is submerged, we are evaluating retrieval in the air, partial or full in air, as an applicable method. Because the status differs from unit to unit, we should consider the applicability of each method.

As the result of our R&D activities, IRID has acquired some useful outcome, but at the same time, technical challenges toward decommissioning have also becoming clearer. Based on these achievements and challenges, IRID will keep working on technology development necessary to decide the method for fuel debris retrieval in 2018 and contributing to completion of decommissioning at the earliest time.

Session 3: Industry and Government Experiences in Applying Robotic Technologies to Existing Challenges

Presentation 1: Use of Robotics and Remote Monitoring Equipment for Reducing Dose and Risk Associated with Radiological Work at Ontario Power Generation

Zic, Josip; Glover, Christopher; Thrasher, Julie; Greenland, Lindsay; Hamilton, Tony; Andrade, Angie

Ontario Power Generation (OPG) has implemented a series of robots that it uses to reduce risk and dose associated with radiological work at its stations. In particular, a series of four custom made robots were utilized to remove high activity debris from boiler drain lines at the Pickering Nuclear Generating station. During an outage on Unit 4, Radiation Protection staff identified elevated dose rates, in an Access Controlled Area under Boiler 6, of 500 rem/h (5 Sv/h) at a distance of 12” (30 cm).

Further inspections identified that the primary component of the high activities debris within the drain lines was 35 Ci of Cobalt-60. A locked restricted high radiation area was set up to control access until a plan could be developed to remove the source of the elevated dose rates. Robotics were designed and implemented to capture the high activity debris and deposit it into a shielded flask for transfer and disposal. The functions of the primary robot was to apply an ice plug on the line, cut out the portion containing the debris and then take the 1’ section of pipe to a transfer container to be placed into a shielded flask.

The primary robot was supported by a robot for performing radiological surveys and visual inspections, another robot for cutting off cladding that held insulation in place and a final multipurpose robot that assisted with insulation removal. A full scale mock-up of the high activity debris removal was performed prior to work execution. Dual 10,000 rem/h (100 Sv/h) high range detectors on the inspection robot triangulated the debris location at 2.6” (65 mm) from the bend in the drain line. The robots allowed the full execution of this work to take place remotely and with minimal dose to the robot operators and support staff.

Similar robotics have been deployed to perform high risk activities like leak searches in Access Controlled Areas of on-power units, with general dose rates in excess of 40 rem/h (0.4 Sv/h). These robots have the ability to climb stairs and are fitted with gamma detectors, PTZ inspection cameras and thermal cameras. OPG has also deployed Unmanned Aerial Vehicles (UAVs) for performing inspections of containment structures. Upcoming 2016 UAV projects include emergency response radiological surveys of the site near boundary and performing automated reactor face radiological surveys.

Presentation 2: DOE National Laboratory Robotic System Applications for Nuclear Facilities Operations and Legacy Cleanup

Steven L. Tibrea, PhD, Director, R&D Engineering, Savannah River National Laboratory, Savannah River Site, Aiken, SC

The U.S. Department of Energy Office of Environmental Management (DOE-EM) is charged to execute the safe cleanup of facilities and stabilization of material as a result of the legacy from seventy plus years of nuclear weapons development and government-sponsored nuclear energy research. Robotic and remote systems have played a key role over the years in dealing with hazardous materials. Many of the aging nuclear facilities are transitioning into an environmental legacy cleanup status requiring decontamination and decommissioning (D&D) which is ripe with applications for robotics. Robotic platforms are ideal for reducing worker fatigue, addressing technical uncertainty and minimizing both programmatic and nuclear worker risk levels. As a result, robotic systems remain an essential tool in the legacy cleanup effort of DOE-EM.

The DOE National Laboratories were pioneers in early remote manipulation and remain involved in the cutting edge of robotic systems being used in nuclear facilities in the complex today. The National Lab contributions range from early development of Master Slave Manipulators widely used in hot cells to fully autonomous robots. However, there is still a higher comfort level with systems controlled by a human (tele-operated) in nuclear facilities.

Examples of robotic technologies successfully deployed by National Labs include: Savannah River National Laboratory's Reactor Tank Inspection Program that deployed a robotic arm for Ultrasonic Testing/Magnetic Particle Testing of reactor tank walls for nondestructive examination (NDE). Oak Ridge National Laboratory's dual arm manipulator system was used for D&D of Argonne National Laboratory's CP-5 reactor and a system for waste retrieval for its Gunite tank took advantage of several remote devices. Pacific Northwest National Laboratory's Mobile Arm Retrieval System (MARS) for tank waste removal is capable of accessing the entire tank interior from a single location. Idaho National Laboratory's Yucca Mountain Waste Package Closure Project demonstrated a complete robotic system to package waste into a double (nested) canister waste package. This is just a small sample of the robotic activities through the National Laboratories that resulted in safer working conditions protecting workers from dangerous exposure.

Recent research has focused on more robust and capable robot control systems to provide for more intelligent operations potentially eliminating human errors in operation.

Less expensive standardized robotic platforms that are practically disposable and can be adapted for different missions should be a focus due to the challenges of decontaminating such devices. Another area of focus that would be beneficial for wider use in DOE facilities is standardization in robot development. This applies to both nuclear facility requirements and safety related automation controls for high consequence environments. Industry organization participation is need to promote robotics integration, technical collaboration and application standardization; e.g. American Nuclear Society, Robotics and Remote Systems Division and the American Society for Testing and Materials, International.

Gloveboxes are widely used for handling and processing nuclear material. Although this has been an effective approach in executing the DOE mission, there have been a number of contamination, hand puncture and uptake incidents from sharps in the glove box. Automating these operations would minimize or eliminate these incidents. Introducing robotics to the glovebox application will significantly reduce risk to the workers.

Facility life extension through material and structural surveillance is a perfect application for remote vehicles which can position cameras for visual inspection or a probe for NDE. All of the described uses for robotic systems contribute to worker safety by limiting human exposure and fatigue. Although there are numerous examples of successful robotic deployments in DOE facilities, robotics technology has not been fully integrated into environmental clean-up strategic planning process.

Presentation 3: Experience in Decommissioning of Nuclear Power Plants in Germany

Kenji Hara, Wälischmiller Engineering GmbH

Wälischmiller has extensive experience in various aspects of commercial decommissioning of nuclear power plants in Germany. This experience includes manually operated manipulators, semi-automatic approaches and fully robotic systems. Specific features of this experience include the use of “teach & repeat” functions and force feedback features for the operator.

Projects have included the use of simple mechanical manipulators including models A100, A200, as well as electric driven power manipulators. Examples of these are A1000 and the Telbot. Within this ability, we accomplish dry cutting, wet cutting and collecting debris up to 1000 pounds. As well as, placement and controlled packing which is essential in this of this type of exact work in high radiation environments.

To further define these capabilities, cutting can be both thermal and mechanical. Thermal technologies include laser, plasma torch and contact arc metal cutting underwater. Mechanical technologies are mainly shears, cutting discs and nibbling machines.

Specific projects where we have applied these technologies include the decommissioning of the Greifswald, Rheinsberg and Obrigheim nuclear power plants. In addition Wälischmiller has worked on decommissioning programs at Karlsruhe Reprocessing Plant. These projects were of high complexity as the internals of a reactor are very unique geometric design that requires extremely precise motion and for actual cutting. Overall, there have been seven reactors decommissioned.

Determining the tool and method appropriate for each project begins with an assessment of the customer needs, working with our technical team to select the most cost-effective, reliable and safe solution. For all projects the most important aspect begins with the ALARA concept of minimizing worker exposure during the operation. Each project is assessed for the level of robotics required for the specific task; from a small manipulator to a large fully robotic system.

Out of these experiences, we are now able to offer maintenance free, easy to decontaminate electric driven systems. The deployment mechanism for these systems can be varied, including telescopic mast, gantry system, excavator based, or on a free standing platform. We further define appropriate equipment based on necessary reach and payload. Additional analysis is to define the precision necessary, cutting forces required and special environmental requirements like corrosive acid, explosive potential and radiation levels.

The presentation will define the decision-making process and requirements for selecting the best equipment and techniques for each project. Our success in this arena stems from our commitment to understanding all aspects of the customer project and literally “seeing with the customer’s eyes”. Each and every project is different and our ability to adapt and reinvent our equipment to meet these needs is essential for success.

Presentation 4: Robotic Handling of Legacy Nuclear Waste: BEP

Stephen Shackleford PhD, BSc(Hons) CChem, MRSC(1), Dr. Jeffrey A. Kuo, C.Eng. MIMechE(1) and Jim Harken BEng (Hons) CEng FIMechE(1) , National Nuclear Laboratory Limited(1)

The cost of decommissioning the UK's current nuclear facilities and the associated storage of waste in 2015 is circa £115 billion over the next 100 years [1]. The expected investment in new nuclear build before 2030 is circa £60 billion [2] and the cost of building and operating a geological disposal facility is circa £12 billion [3]. RAS has a significant part to play in each of these programmes with NNL estimating that for decommissioning alone, 20% of the costs of complex projects will be spent on RAS [4].

The UK robotic and nuclear industries' ability to develop and deploy Robotic and Autonomous Systems (RAS) that are able to deliver a step change in risk reduction, safety, reliability, efficiency and cost across the entire nuclear cycle: reactor operations; new nuclear build; medium and long-term waste storage; decommissioning; future reactor designs (Gen IV and SMRs). Until now, robotics has had minimal impact on the nuclear industry, however, the creation, by Sellafield Limited and the National Nuclear Laboratory (NNL) of inactive and active demonstration facilities in west Cumbria means that there is now a clear route through to deployment of robotic technology.

Sellafield is one the most challenging decommissioning environments housing 1200 buildings in 6 sq km, 200 of which hold nuclear inventory, 100 equivalent or greater than a nuclear reactor in terms of hazards and security and finally a large percentage of the ageing infrastructure is over 60 years old. Decommissioning, dismantling and waste management of nuclear infrastructure requires supporting mullti-billion pound clean-up facilities. This is a significant challenge at Sellafield but also worldwide and one which is growing in size as more plants are reaching the end of their operational lives.

The strategy chosen for individual projects varies from the hands-on approach with significant manual intervention using traditional demolition equipment at one extreme to bespoke highly engineered robotic solutions at the other. The degree of manual intervention is limited by the hazards and risks involved and in some plants are unacceptable.

Robotic remote engineering is often viewed as more expensive and less reliable than manual approaches, with significant lead times and capital expenditure. However, advances in robotics and automation in other industries offer potential benefits for future decommissioning activities, with the high probability of reducing worker exposure and other safety risks as well as reducing the schedule and costs required to complete these activities.

To that end Sellafield Limited contracted NNL to develop a robotic system for the remote handling of legacy nuclear Miscellaneous Beta Gamma Waste with commissioning of the equipment to the Box Encapsulation Plant by 2018. The project aims are:

- Accelerate and reduce the end state delivery of the Sellafield High Hazard and Risk Reduction programme.
- To utilise proven commercial ‘off the shelf’ robotic technology and develop for nuclear application.
- Prove high reliability of commercial ‘off the shelf’ robotics in nuclear environment
- Systematic approach to technical development with external LFE adopted. All low TRL research undertaken off line through UK/EU funded research.

[1] *Nuclear Provision: Explaining the Cost of Cleaning Up Britain’s Nuclear Legacy*, NDA, 2015, [2] Nuclear Industrial Vision Statement, HM Government, bis-13-629, [3] Frequently Asked Questions for Geological Disposal, NDA, 2015, [4] RAS 2020 Robotics and Autonomous Systems Strategy, Innovate UK.

Presentation 5: The Use of Robotics at CANDU Power Plants

Jacqueline McGovern, Department Manager, Inspection & Maintenance Systems, Kinectrics

The Moderator Relief Duct Inspection Equipment (MORDIE) II is an inch worm robot designed to remotely inspect 20 feet of a complex geometry duct (1.5D and 1D bends) and a secondary 2" balance line that connects to the main duct approximately 16' down. MORDIE II (hereafter referred to as MORDIE) is a delivery system with interchangeable tool heads used to inspect both these pipes/ducts. In order to ensure Foreign Material Exclusion (FME), all systems have redundancy design in and all items that enter the duct are tethered. Furthermore, an FME Bung is installed at the bottom of the duct via MORDIE to ensure no foreign material enters the system. MORDIE has a 1 ½" I.D. flexible conduit running the centre length of the tool to accommodate the FME barrier umbilical and tether. Currently, there are three tool heads for the MORDIE system:

- FME deployment module
- NDE tool head
- 2" balance line deployment module

MORDIE is used to support and position the FME bung deployment tool in the CRD. The FME
deployment module delivers the FME bung to the bottom of in the duct. The FME bung has several features including a tether and an umbilical. The umbilical accommodates the seal monitoring system and the vacuum fluid recovery system. A pneumatically powered diaphragm pump is used to continuously remove fluid (cleaning fluid or NDE couplant) that accumulates on top of the FME bung while deployed.

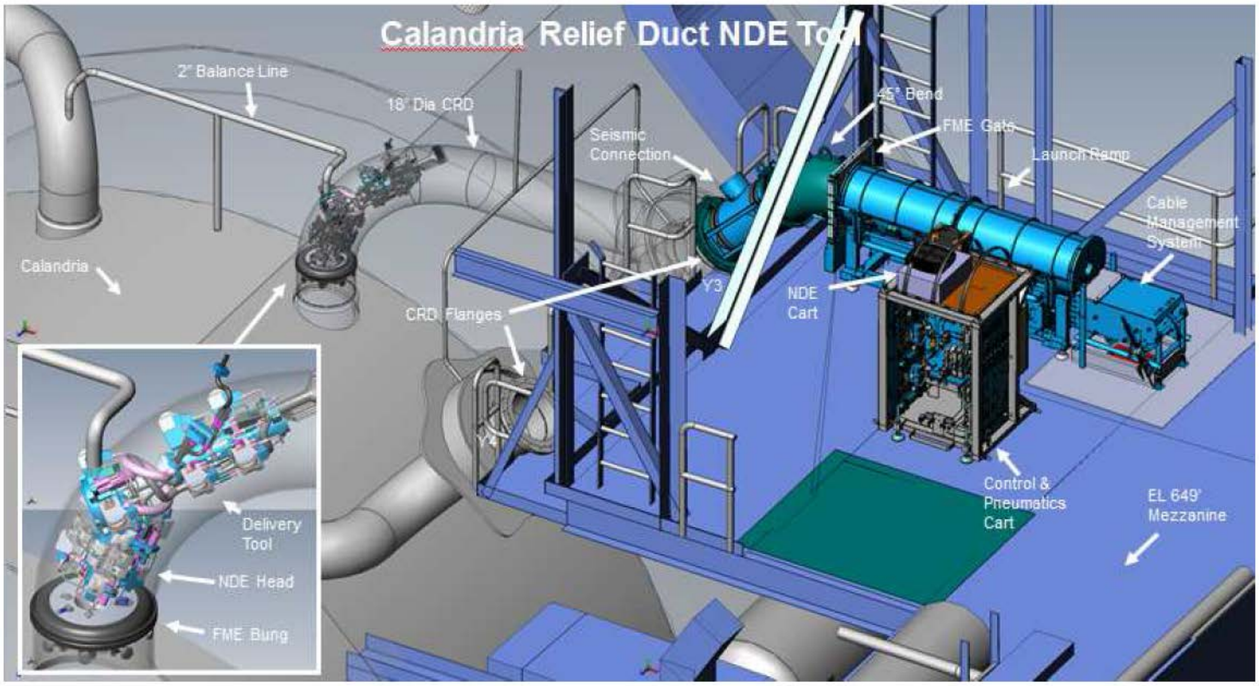
After the FME Bung is installed, MORDIE is used to support and position the NDE tool head in the duct. The NDE tool head consists of two sensors heads with a total of eight Ultrasonic (UT) and Eddy Current (ET) probes to detect and characterize potential flaws in the duct. The sensor heads are mounted on guided pneumatic actuators and can rotate to cover 370°of the duct using the delivery system rotary joint.

Once the NDE inspection of the duct is complete, the 2" balance line deployment module on MORDIE is used to deliver a secondary inspection of the 2" Balance Line with an inspection snake. The snake consists of a fiberscope camera, lighting for navigation, safety tether and two Eddy Current (EC) probe modules for NDE inspection.

MORDIE is delivered via a launch ramp that is connected to the rupture disc flange of the CRD. The back of the launch ramp incorporates the cable, tether and umbilical management system. In order to operate MORDIE with the various tool heads, the following support carts are required:

- o Power cart
- o Master control cart
- o Master control station
- o Pneumatics cart
- o Fluid cart

A layout of the entire system is shown in the image below.



MORDIE has been operational since Feb 2014 having completed hundreds of runs in the duct at the Kinectrics' full scale mock-up facility. The mock-up facility fully emulates the equipment arrange, clearances and restrictions that will be found at site. The mock-up set-up with the audio, video and breathing air system enables effective training of personnel to prevent human performance issues during site deployment.

Presentation 6: Use of Robotics for Dose Reduction and Efficiency Gains at U.S. Commercial Nuclear Facilities

Daren Cato, Remote Monitoring Lead & Robotics Program Owner, Radiation Protection, Duke Energy Robinson Plant; and Joan Knight, Innovation Director, Exelon Generation

The U.S. nuclear power industry constantly evaluates and implements cost effective technology to protect workers from the harmful effects of ionizing radiation. The intended outcomes from the deployment of robotics are to promote the As-Low-As-Reasonably-Achievable (ALARA) principle by limiting the exposure of personnel to radiological hazards and to create efficiencies in the execution of complex tasks where applicable.

Individuals from Duke Energy and Exelon Generation will provide an overview of the U.S. commercial nuclear power industry use and experience with robotic technologies. Robotics in U.S. commercial plants are used both during normal operation and during refueling and maintenance outages. Discussion will include the primary uses of robotic technologies, including carrying out various types of inspection and maintenance activities. The speakers will highlight the functionality that is needed in the various robots in use to accomplish tasks effectively, both in the more general purpose robots and specialized robotic tooling for complicated and/or very high dose tasks. In addition, the presenters will describe a number of robots currently in use for both planned and unplanned inspections, as well as for carrying out the high radiation dose tasks that must occur during normal operation. There will also be a discussion of application of some specialized robots/robotic tooling to support infrequently performed tasks, such as detailed inspection and repair of a reactor head closure flange surface. Included will be an overview of the use and experience with a robotic refuel cavity cleaning apparatus designed to operate under water. In addition, they will discuss the developments of the robotic tooling that has now been used to accomplish the infrequently performed activity of the inspection of the floor of a tank still filled with mildly-contaminated water. First hand experiences from at least two companies will be discussed, to share the challenges and learnings in the development and deployment of a number of specific applications.

Session 4: Ground-Breaking, Innovative Technologies and New Opportunities

Presentation 2: Snake-arm robots for nuclear applications

Andrew Graham, Technical Director and Adam Mallion, Senior Project Manager, OC Robotics, Bristol, UK

OC Robotics is a commercial developer and manufacturer of snake-arm robots, based in Bristol, UK. OC Robotics built its first snake-arm robot in 2000 and remains the world's leading manufacturer of snake-arm robots capable of supporting themselves at full horizontal reach. OC Robotics delivered its first snake-arm robots for nuclear intervention in 2004, for a repair at Ringhals NPP in Sweden and continues to develop for and work internationally in the nuclear industry.

Snake-arm robots are typically long, slender robots, capable of being introduced into confined spaces through small apertures. In a unique motion called "nose-following", snake-arm robots are typically introduced through an aperture or cluttered space under human control, with an operator steering the tip of the snake-arm robot and controlling its forward/backward motion, using a dual joystick arrangement on a hand controller. Software control ensures that the body of the snake-arm robot follows behind the tip and minimises the arm's deviation from the path originally traced in space by the tip of the robot. This motion mode is intuitively obvious to the operator and enables snake-arm robots to be driven through small apertures, while avoiding collisions, with a minimum of effort. This type of man-in-the-loop functionality is ideally suited to ad hoc operations and operation in ill-defined spaces, for example vaults or cells with pipework for which no accurate CAD models or as-built drawings exist. The robots can also be programmed off-line to reduce operator workload during the execution of complex campaigns.

A number of types of robot have been built to satisfy different requirements. Basic statistics include: cross-sectional dimensions ranging from ½ inch to 10 inch; horizontal reach up to 14 ¾ feet and; payloads up to 44 lb at full reach. Snake-arm robots can be fitted with rigid extensions at their base to enable long penetrations to be crossed at minimal performance cost, while the articulated section of the snake-arm robot typically possesses 20 or more degrees of freedom. Conventional robots typically possess 6 or 7 degrees of freedom: the difference enables snake-arm robot arms to avoid obstacles and even to be re-positioned to accommodate moving objects while holding the end-effector stationary in space.

This presentation provides an overview of the different snake-arm robots deployed in the nuclear domain to date, the snake-arm robots being developed for new nuclear applications today (including laser cutting for decommissioning and laser welding for pipework remediation) and snake-arm robot developments for other industries which embody transferrable innovations for the nuclear industry.

Videos of some of these nuclear developments will be presented, including an application of a radiological scanning and mapping sensor system using snake-arm robot mounted sensors, laser welding to join large diameter pipes from the inside and submerged operation of a large snake-arm robot. A snake-arm robot for aerospace non-destructive evaluation and an un-tethered, mobile vehicle-based system suitable for exploring human-scale spaces will also be shown.

Presentation 3: Robotics and Sensing for Nuclear Infrastructure Inspection

David Mascarenas and Eric Flynn, Los Alamos Engineering Institute, Los Alamos, NM

One of the biggest problems facing decision makers responsible for nuclear infrastructure is ensuring that nuclear infrastructure continues to have the structural performance to safety and securely perform the functions for which they are intended. Structural integrity of nuclear infrastructure is a concern across the DOE complex. Examples of such infrastructure include the nuclear material storage tanks at the Hanford site, the Waste Isolation Pilot Plant (WIPP) and the H-canyon nuclear chemical separations plant at Savannah River. A common feature of these facilities is that they are generally not accessed by humans as a result of the dangerous levels of radiation present inside. As a result it is not possible for human inspectors to directly perform structural inspections. In the case of the Hanford tanks and H canyon the infrastructure is quite old and in many cases beyond the anticipated design life. H Canyon recently turned 60 years old and some of the tanks at Hanford site were constructed in the 1940s. WIPP is a much younger facility; however as a result of the chemical release at the site it is necessary to assess the state of the containers at the site as well as the structure itself. In the last decade great advances have been made in structural inspection technologies as well as the robotics field. However these advances have not adequately focused on the structural inspection problems of interest to the DOE because these problems are too niche to be addressed by the commercial sector.

Over the course of the last two years LANL Engineering Institute researchers have developed a number of novel, prototype tools for enabling structural inspection of nuclear facilities using robotics. These tools include a pneumatic device for remotely deploying sensor nodes from an aerial robot, a motor-driven crank-rocker linkage for performing tap-tests of infrastructure and a delta-machine-based arm for allowing aerial robots to perform repairs and remove debris that is impeding visual inspection. The LANL Engineering Institute has also invested significant effort developing new signal processing and sensing techniques. These include novel techniques for identifying structural dynamics using only imagers and techniques for rapidly measuring the thickness of plate-like structures over large areas in a stand-off manner. Both of these techniques could be deployed to inaccessible areas using robotic technology and could greatly facilitate assessing the structural performance of nuclear infrastructure.

Presentation 4: RISER: 3D Contamination Mapping with a Nuclear-Capable Drone.

Matt Mellor, Createc

In decommissioning and disaster recovery projects it is often necessary to map and quantify radioactive contamination in areas which are difficult or impossible for people to get to. This is a task is an ideal application for by robotic systems. In particular, the go-anywhere capability of drones appear to offer the promise of a generic solution. However, drones are difficult platforms to use at nuclear sites; they typically rely on GPS for stability and control, which is unreliable or absent near or inside metal clad buildings. It is also far from obvious how the data captured by a drone can be used to provide quantitative measurements of contamination. In this paper, we present RISER a drone developed specifically for building 3D contamination maps at nuclear sites.

RISER solves the access problem by using a lidar navigation system to enable stable autonomous flight in enclosed environments where GPS is unavailable. RISER is also capable of building a 3D contamination map in real-time using its on-board CZT spectrometer and centimetre-accurate positioning system; these data are combined to build a low resolution 3D image of the contamination distribution by building and solving an 'inverse problem' that relates the contamination distribution to the spatial variation in radiation intensity. Combined, these capabilities enable true eyes-off remote robotic mapping of contamination. A by-product of the system is a 3D point cloud model of the surveyed area which can be used to measure as-built or post-damage dimensions and estimate

We present the results of two demonstrations of RISER at Sellafield in the UK, the first at a partially decommissioned reprocessing plant and the second inside a chimney affected by the 1957 Windscale fire. In the reprocessing plant demonstration, indoor flight and real-time 3D mapping were demonstrated under carefully controlled conditions using a human pilot. In the chimney demonstration, access was too limited to enable a human pilot to handle more than the take-off and landing and the flight itself was handled entirely by the autopilot with waypoint navigation commands supplied by the operator.

These demonstrations show the potential for flying robots and robots with a high degree of autonomy in general to aid with decommissioning and disaster recovery.

Presentation 5: Developing a suite of remote handling tools for fusion experiments

Dr. Rob Buckingham FREng, Director UKAEA, Head of RACE (the UKAEA's centre for Remote Applications in Challenging Environments)

It is increasingly recognised within the fusion research community that remote handling will be a 'device defining driver' for a future fusion power plant.

At ITER, the global fusion research experiment that is the step before a demonstration fusion power plant, many $billions will be invested in supplying and then operating remote handling solutions.

Remote handling is needed as a direct consequence of achieving and maintaining fusion conditions. For magnetic confinement fusion (e.g. JET, ITER) these include heating the deuterium/tritium fuel mix to 200millionK under ultra high vacuum contained within a magnetic field. The fusion reaction generates 14 MeV neutrons and 3.6 MeV alpha particles that degrade and activate local materials. In-vessel remote handling systems will need to operate in kGy/hour radiation fields with zero possibility of human intervention. In concepts for a fusion power plant, beyond ITER, the equivalent of the fission fuel rod will be a tritium 'breeding blanket'. Current concepts suggest that ~50 breeding blanket sections weighing ~80 tonnes each will need to be replaced periodically during the reactor's life. These blankets also contain the primary coolant, which may be a lithium-lead eutectic, hence when removing these component it is necessary to cut and remake a series of pipe welds all to nuclear codes.

This presentation will explore three areas of remote handling technology: snake-like robot arms; cutting and welding technologies; and general-purpose inspection devices.

JET's snake-like robot arms are two horizontal planar 7 jointed booms approximately 12m in length. One carries the slave of a force feedback master-slave system that is used to conduct all necessary maintenance within the vacuum vessel. The other carries a tool chest in order to maximise the productivity of the system. In JET this system has more than 30,000 hours of operational use and in a recent campaign was used to replace the complete plasma-facing wall comprising more than 3000 individual tiles. For ITER the same device is called the Multi-Purpose Deployer. It will be longer and is expected to carry a higher payload and, because of the size of the vacuum vessel, it is a spatial device rather than planar.

Some cutting and welding has been conducted within JET, in extremis, but cutting and welding will be routine in ITER. Successful trials in 2015 of the prototype solution for cutting and welding 200mm OD stainless steel pipe using remotely delivered and operated tools show that achieving high quality welds is possible within the space constraints.

This presentation will provide a brief history of the JET Remote Handling System in recent campaigns. It will present initial results of the ITER cutting and welding trials. Finally the paper will identify two types of COTS inspection device that could be used to support remote operations. The first is a UAV and the second is a snake-like arm mounted on an untethered mobile vehicle. These were not developed specifically for the nuclear sector. Increasingly we will need to see shared investment across sectors in order to develop robust, reliable and costs effective products and services for challenging environments.

All aspects of the presentation will be supported by videos of real hardware in operation.

Session 5: Robotic Technology Testing, Operator Training and Certification, and Regulatory Standards Development

No Abstracts are available at this time

Poster Session

1. Robotic Technology Research at Florida International University for the Department of Energy - Environmental Management

Dwayne McDaniel, Leonel Lagos, Hadi Fekrmandi, Anthony Abrahao, Ryan Sheffield & Erim Gokce, Applied Research Center, Florida International University

Florida International University (FIU) has a number of initiatives in the area of robotic technologies that support the mission of the Department of Energy – Environmental Management (DOE-EM) and the storage, transport and processing of high-level waste. Some of these efforts stemmed from the radioactive waste which was found in the annulus of the AY-102 double-shell tank at the Hanford. This leak has prompted the need for inspection tools that can travel in confined radioactive areas and identify the location and potential cause of the leak. To aid in this effort, FIU is investigating the development of inspection tools that are capable of gaining access to the tank secondary containment and provide live video feedback. The effort has led to the development of two inspection tools; a magnetic wheeled miniature motorized rover that will travel through the refractory cooling channels under the primary tank and a pneumatic pipe crawler that will inspect the air supply lines leading to the central plenum of the tank.

The magnetic wheeled miniature tool is a remote controlled rover with four wheels directly driven by independent micro DC motors. The tool is being designed for highly radioactive environments, with no embedded electronics in the rover with the exception of the camera. The inspection tool will be required to enter a refractory channel at the edge of the primary tank and travel through a maze of channels to reach the central plenum. The path includes approximately 40 feet of channels with cross sections as small as 1.5 inches by 1.5 inches and four 90° turns. Additional challenges are related to debris in the channels from the aging refractory pad. To avoid the debris, the device will travel upside down magnetically attached to the bottom of the primary tank. If successful, the tool will be able to provide visual information regarding the conditions of the tank floor and refractory pad and potentially pinpoint the location of the leak. Current bench scale testing has demonstrated that the tool can navigate through the first 17 feet of channel, but slight design modifications will be needed to make the turns.

The pneumatic pipe crawler is a worm type robot with a modular design, composed of interchangeable cylindrical modules connected with flexible links. The design is an evolution of previous peristaltic crawlers developed at FIU and uses pneumatic actuators to emulate the contractions of the peristaltic movements, which is suitable for highly radioactive environments by not requiring embedded electronics. The crawler also has a camera which will supply visual information regarding the air supply lines and the central plenum. To reach the central plenum, the crawler will have to travel through approximately 100 feet of piping including three and four inch diameter pipes and traverse through vertical risers, elbows and reducers. Bench scales tests have demonstrated the crawler's ability to navigate through the necessary pipeline geometries. Future efforts will focus on enhancing the inspection capabilities of both the crawler and the miniature rover, by integrating various sensors into the devices.

2. Current Status of a U.S.-Korea Collaboration on Development of Enhanced Telerobotic Operation Method

Young Soo Park, Argonne National Laboratory

This work introduces a U.S.-Korea collaboration in-progress for R&RS technology development for D&D. It leverages the lessons learned from a previous experience of deploying robotic systems for nuclear reactor D&D and subsequent technology enhancements in DOE-EM.

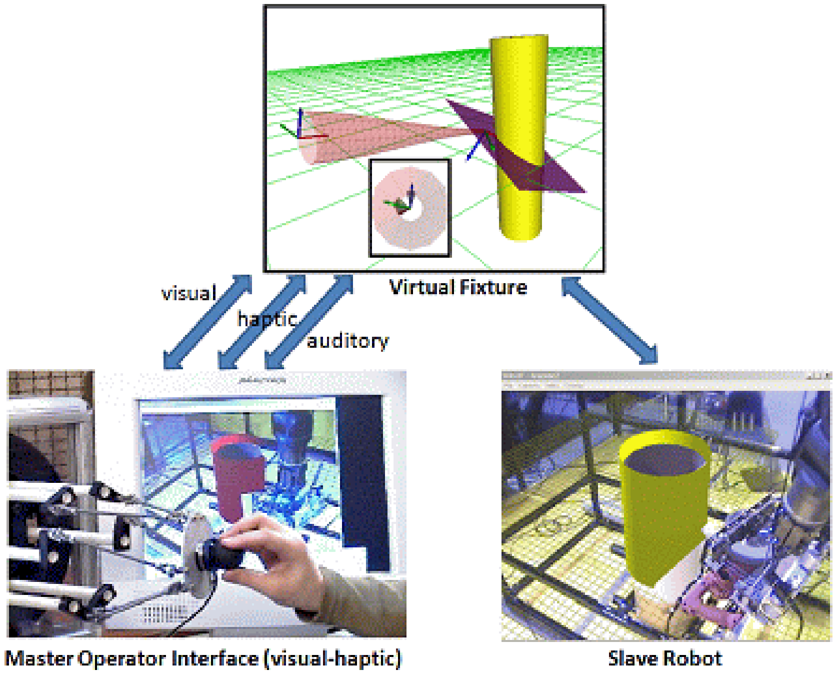
In South Korea and the United States, there is imminent potential liability for decontaminating and decommissioning (D&D) life-ended nuclear reactors and facilities. For dismantling tasks in high-radiation and -contamination areas, use of robotic and remote systems (R&RS) are expected to replace human from the hazardous environment and to improve task performance by borrowing precision and physical strength of robots.

Traditionally the development in R&RS has been focused on enhancing force reflection or adding autonomy. However, practical experience in deployment indicated the pitfalls of such approaches. To achieve high level of autonomy generally require complex robots which are vulnerable to costly breakdown and maintenance. On the other hand, operating the robot with manual teleoperation is difficult, inefficient and imprecise for complex tasks in unstructured environment. To overcome such difficulties, an enhanced form of teleoperation, namely 'telecollaboration', is proposed. Instead of pursuing autonomy or dexterous force reflection, the proposed teleoperation method is focused on enhancing the operator interface with augmented reality. This enhanced teleoperation method makes it suitable for application to simple equipment while still achieving enhanced performance of teleoperation – efficiency and precision. The development addresses three main components: implementation of multi-modal virtual fixtures, 3D environmental sensing and reconstruction and testbed implementation with a prototype robot.

Multi-modal Virtual Fixtures: Virtual fixture is by definition 'artificially generated geometric surface overlaid on human operator's perceptual domain in such a way to guide teleoperation". As depicted in the figure below, virtual fixtures lies between and interacts with the master and slave parts of a teleoperation control system, in such a way to provide motion guidance or define forbidden regions. Introduction of virtual fixtures in teleoperation enhances control stability as well as operation performance. Key technologies are presented for generation of virtual geometry and visual-haptic augmentation (i.e. display onto operator percept).

3D Environmental Sensing and Reconstruction: The application of VF in many D&D operations is characterized by contact manipulation. However, a key assumption and bottleneck in this method is the lack of a technology basis for environmental perception, i.e., environmental sensing and reconstruction. The current state-of-the-art environmental perception technology is geared toward mobile robot navigation and thus is inadequate for such robot manipulation applications, mainly due to insufficient accuracy, precision and processing speed. To this end, an improved 3D sending method is developed with improvements in accuracy of 3D scene reconstruction and reliability of tracking moving objects. This work addresses the development of such a perception basis and the conceptual demonstration of its applicability for enhanced teleoperation.

Conceptual Demonstration with Prototype Robot: The component technologies of VF and 3D sensing are integrated into a testbed robot system for conceptual demonstration and improvement. In the subsequent years the collaboration will lead to porting the technology onto a D&D robot system being developed at KAERI.



3. Experience of Deployed Confined Sluicing/Scarification and Potential Applications at The Hanford Site

Michael Rinker, Pacific Northwest National Laboratory; Karthik Subramanian, Chief Technology Officer, Washington River Protection Solutions; Dr. Barry Burks, Vice Chancellor for Research and Economic Development at North Carolina Agricultural and Technical State University (previously Senior Technical Researcher, Oak Ridge National Laboratory)

This paper and presentation provides an overview of scarifier technology that was developed and deployed with a robotic arm and a remotely operated vehicle at the Oak Ridge Gunite And Associated Tanks in the 1990's and early 2000's. Additionally, it addresses the potential modifications and integration of the technology with the Mobile Arm Retrieval System currently in operations at the Hanford Site.

Scarifying end-effectors were developed in the 1990's by the Pacifica Northwest National Laboratory resulting in a Confined Sluicing End Effector that was tested, integrated and deployed in the by the Oak Ridge National Laboratory to successfully remove remaining sludge wastes and heels in the Gunite And Associated Tanks at the

Oak Ridge Reservation. Lessons learned were collected and documented at the end of the retrieval activities.

The Hanford Site has been operating the Mobile Arm Retrieval System (MARS) to remove residual nuclear waste from the Single Shell Tanks in the C Tank Farm. Lessons learned to date for the use of the MARS have been collected and one of the potential improvements for retrieval at Hanford under consideration is the use of scarifying technology that would be integrated with MARS.

4. Remote Robotics for Material Handling, Welding and Inspection of Yucca Mountain Storage Canisters

Kevin Croft and Tim McJunkin, Idaho National Laboratory

The Yucca Mountain Waste Package Closure Project exemplifies the challenges and possibilities of remote systems and robotics in difficult environments.

The Industrial and Hot Cell Robotics program develops innovative systems and sensors that enable industrial processes, such as welding and inspections in hot cells and other challenging conditions. INL industrial robotic researchers are adept at guiding projects from conceptual design to fully functional demonstration prototypes and facilities, to commercial readiness. The program dates to 1978 when it started as a welding inspection group. By 1980, it was conducting welding robotic research for the U.S. Navy.

Today, INL's industrial robotics team is known internationally for its welding and inspection research and innovations. It has developed methods to test welds on the spot, allowing workers to correct flaws immediately and complete projects faster. The team has patented many of its inventions. It also has worked on several major projects, including current inspection of welds for an oil and gas pipeline company from Italy, a welding and inspection system for the Department of Energy's National Spent Nuclear Fuels program and remote waste-handling systems for the Yucca Mountain nuclear waste repository.

Yucca Mountain Waste Package Closure Project - The Industrial Robotics group developed the Yucca system to demonstrate the processes required to weld and inspect welds on a waste package (a waste package is 20 feet tall and 7 feet in diameter with a stainless steel lid inside a nickel-based alloy canister with a separate lid). Development included identifying the necessary robotics to complete the task with a variety of weld configurations in the high radiation environment. The team used mostly commercial off-the-shelf equipment to complete the welding, inspection, and repair, as well as developing custom designed solutions as needed. The team then successfully demonstrated the project in March 2009 at its Idaho Falls facility. The Yucca Mountain Closure Project showcases many of the team's research specialties – welding, repair, non-destructive examination and robotics in remote, semi-autonomous applications where direct human involvement is hazardous (the system is designed so operators can monitor it from a remote control room). It applied the team's capability of creating a coherent real-time control system with diverse computational and robotic components to a complex task. Custom air-cooled welding torch, weld repair tools, and phased array ultrasonic and eddy current inspection probes are among its accomplishments.

Robotics -The company in charge of the Yucca project gave the INL team challenging requirements, including developing two radiation-hardened robots and a bearing to transport them, comprising in total a 13 degree-of-freedom (DOF) integrated robotic system. The team designed four tools and support equipment, to reside on a remote removable storage tray which could be remotely picked up and removed for servicing when needed. The tools are a combination of commercially available components and custom pieces that enable the robot to handle and utilize the tools as necessary. The custom integration software merged teach-pendant-taught trajectories with software-generated trajectories to meet the requirement of an offset and tilted WP. Trajectories were generated using INL algorithms and a laser profiling seam tracker to position tools.

Welding -The welding system is comprised of one air-cooled gas tungsten arc welder on each robot. Wire is fed from two spools depending on the material needed for the weld (316 Stainless inner lid, and C-22 alloy for the outer corrosion barrier). Support for tasks like adjusting the tungsten stick-out or gas cup height, or for switching a spent tungsten for a freshly sharpened one, are handled automatically and remotely on the tool tray. The system also incorporates arc-viewing cameras and controllable actuators to allow the welder to make small adjustments to perfect the weld process from the remote operator stations. Data collected from a laser profilometer is used to adjust wire feed rate to ensure consistent fill volume and appropriate crown height on a finished weld. Tools were also developed to grind and inspect flaws detected during inspection.

Inspection and Repair -The Industrial Robotics team incorporated phased array-ultrasonic and array-eddy-current- imaging technology to inspect the welds and seals on the canisters minutes after they are completed. Pass-by-pass inspection of the welds allows the operator to correct any flaws or cracks immediately, reducing the time it takes to package the waste. Commercial transducers are designed into custom probes to position the sensor so when deployed by the robot, it will correctly juxtapose it to the weld. INL-developed software generated the timing patterns to steer and focus ultrasound at the weld. When defects are detected, a removal tool mentioned above grinds flawed welds in a controlled geometry that can be re-inspected with a probe and welded with the same process as before.

It was also necessary to verify calibration on remote inspection hardware, and for this, a calibration block was incorporated into the removable tool tray. This enabled pre-inspection and post-inspection calibration scans to verify that data collected during scans was reliable.

Glove-Box Friendly -The envelope of the entire tool holder was constrained to allow servicing of the tool tray in a glove box if necessary. The challenges presented by restricted footprint required custom and sophisticated design and engineering.

Remote Material Handling - Also integrated into the system was a 4 DOF robotic material handler used to handle a variety of large tools for waste package closure, as well as handling necessary components of the welding system, such as the waste package grounding fixture.

The process included remote receipt of canister lids from outside the cell via a linear conveyor, delivery of the waste package lid was accomplished by this 4 DOF gantry robot.

This system was also responsible for robotic placement of the custom designed tool responsible for expansion of a welded spread ring on the inner canister, including automatic reacquisition by the robot, subsequent to tool movement after expansion of the ring. Because the system included the ability to remotely repair welds it was necessary to develop and deploy a tool to remotely clean the waste package after grinding, also deployed by the 4 DOF robot.

It was also necessary to remotely evacuate and purge the inner canister with an inert gas. This custom designed tool was placed in position via the 4-DOF robot. The second lid was then robotically brought into the cell, moved to the canister/weld area and placed on the outer canister.

Following successful welding, a weld burnishing tool was robotically placed on the canister and burnishing of the exterior weld completed. This tool also was custom designed to enable operation in a high radiation environment, and under the constraints necessary for waste package closure.

Remote Process Visualization -Remote processes for the system required human visualization, and for this system a system of many cameras was utilized to enable an operator at a given workstation to see into the cell from a variety of angles. Because the system is large it was necessary to incorporate several remotely controllable pan/tilt/zoom (PTZ) cameras, as well as several cameras on individual robotically deployed tools. These cameras allowed the operator to confirm visually that the system components had correctly functioned.

Conclusion -The system was successfully demonstrated to DOE and a number of other interested entities during a comprehensive week-long demonstration in Idaho Falls, Idaho. A 6 minute video is available for viewing an abbreviated operation of the system.

References -

C. I. Nichol, D. P. Pace, E. D. Larsen, T. R. McJunkin, D. E. Clark, M. L. Clark, K. L. Skinner, A. D. Watkins, H. B. Smartt, “Yucca Mountain Waste Package Closure System Robotic Welding and Inspection System”, Nuclear Technology, Vol. 176, ppg. 138-146, October, 2011

K. Skinner, G. Housley, C. Shelton-Davis, “Waste Package Closure System”, Nuclear Technology, Vol. 176, ppg. 296-308, October, 2011

Nichol, McJunkin, Clark, Larsen "Remote Robotic Fabrication: Case Studies in Architecture Resilience" AWS National Robotic Arc Welding Conference, Milwaukee, WI., May 23-25, 2011.

Nichol, C.I., “Telepresence System for Nuclear Industrial Processes” American Nuclear Society Winter Meeting 2009, Washington D.C., Nov. 19, 2009.

H. B. Smartt, D. P. Pace, E. D. Larsen, T. R. McJunkin, C. I. Nichol, K. L. Skinner, M. L. Clark, and T. G. Kaser, "Robotic Welding and Inspection System," in 8th International Conference on Trends in Welding Research, Pine Mountain, GA, 2008.

5. Anthropomorphic Operations Inside PIE Hot Cells

Kevin M. Croft, Idaho National Laboratory

The objective of this work is to enhance the remote manipulation capabilities in the execution of post irradiation examination (PIE) processes and to reduce the overall costs of a facility. A system for sample manipulation consisting of combined 3-D vision and haptic (force-feedback) arm/hand systems will dramatically enhance PIE processes.

Current PIE technologies and capabilities, throughout the DOE complex, are limited by radiological dose or contamination control requirements. Currently, hostile hot cell environments are mitigated by the use of thick shielded windows and tele-manipulators which allow for viewing and handling radiological objects while being protected from associated biological effects. However, shielded windows are large, heavy, fragile, limit/distort available views and are very expensive to purchase (@ approximately $12/in^3$), install and maintain. Traditional master-slave manipulators (MSMs) are extremely expensive (at an average of $400K per pair, purchase price), to install and are maintenance-intensive. Compared with the humans that operate them, MSMs have relatively limited motion, making some tasks to be performed with these devices extremely time consuming and/or impossible.

An electro-mechanical haptic arm/hand (anthropomorphic) system would allow a user to fully utilize the natural dexterity and force sensations within their hand(s) when performing remote manipulation tasks, automate some tasks and perform some tasks with enhanced performance and ease. Implementation of 3-D vision technology would provide a user with enhanced (close up) appreciation and capability relative to tasks being executed. The very minimal cell wall penetration(s) required by such a combined system would greatly facilitate its application into large cells, portable cells and transfer ports (to name a few) with minimal, if any, existing facility modifications. Implementation into new facilities could potentially make the overall facility costs less.

Making these systems tolerant to the hostile environment is a technical challenge that needs to be met, as well as the development of the anthropomorphic capabilities of and electric robot (servo-hydraulic systems exist, but the hydraulic component is not typically friendly to hot cell environments).

6. Automation and Robotics Applications for Nuclear Material Processing at LANL

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There are a number of challenges to effective automation for nuclear material processing in a glovebox environment. Some challenges include limited access, inert atmospheres, particulate contamination, radiation sources and corrosive chemical operations. These challenges along with the lack of uniformity in a laboratory environment (i.e. most automated systems tend to be one-of-a-kind) have hindered the development of highly automated systems for nuclear material processing in a glovebox environment. Nonetheless, as computers and automated systems have become more prevalent, automation has been gradually applied in glovebox environments. This talk presents several examples where robotics and/or automation has been or soon will be deployed for nuclear material processing in a glovebox environment. Specifically, this talk presents automation that has been developed for the ARIES program, for cleaning spherical containment vessels, for power supply dismantlement and for several other glovebox lines. In addition to application examples, challenges to successful implementation are also discussed.

7. Inspection Technology Application Concepts for Detection of Hidden Corrosion in Double Shell Tank Floors

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Double-shell waste storage tanks located at the Hanford site in Washington state store millions of gallons of hazardous chemical waste. To monitor their condition and ensure continued viability, these tanks are inspected periodically through a comprehensive integrity program. Tank configuration variations and construction conditions present several access challenges that will need to be overcome in the future. In 2012, the first leak in a double-shell tank at Hanford was discovered and the failure was observed to be from the primary tank bottom. The exact failure location and damage mechanism are both still undetermined. Further reviews of original construction records assessed the extent to which the other double-shell tanks in the system had similar as-built characteristics. Up to this point, inspection data has only provided information to engineers about the condition of the tank sidewalls and yielded no early warning as to the potential for double-shell tank bottom failure. As a result of this discovered integrity monitoring weakness, primary tank bottom failure, and follow-up construction research, a key improvement needs to be made to the integrity program that would add the capability to inspect the primary tank bottom of double-shell tanks.

Various types of inspection processes will be discussed in this paper including visual, ultrasonic, electromagnetic, and infrared. Inspection access to the primary tank bottom using these techniques is limited to channels in an insulating concrete pad that the tanks rest on. Using this approach will require small robots that can be inserted from the risers on top of the tank. Another approach being reviewed is the use of guided waves that could be propagated from the side walls of the tank. This process will also require robotics to install the sensors on the tank wall which must occur in the double shell tank annulus space which is approximately 30 inches wide. Concepts for all inspection methods will be discussed in the paper.