Office of
Science and Technology and International

Advanced Technologies FY 2004 Projects

November 2004

U.S. Department of Energy
Office of Civilian Radioactive Waste Management
Washington, DC

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PREFACE

This booklet contains project descriptions of work performed by the Department of Energy (DOE), Office of Civilian Radioactive Waste Management (OCRWM), Office of Science and Technology and International's (OST&I) Advanced Technologies during Fiscal Year (FY) 2004. Advanced Technologies is a sub-program of OST&I's Science and Technology Program which supports the OCRWM mission to manage and dispose of high-level radioactive waste and spent nuclear fuel in a manner that protects health, safety, and the environment; enhances national and energy security; and merits public confidence. In general, the projects described will continue beyond FY 2004 assuming that the technical work remains relevant to the proposed Yucca Mountain Repository and sufficient funding is made available to the Science and Technology Program.

Project Title	Assessment of Welding Technology and Welding-Related Issues for Alloy 22 Waste Packages
OCRWM S&T Program Thrust	Advanced Technologies
Project Performers	The Ohio State University
Principal Investigator	John C. Lippold
FY 2004 Funding	$100,000

Abstract **BACKGROUND:** The closure weld and post-weld processing of Alloy 22 waste packages are important to the Yucca Mountain Project (YMP) goal to ensure that these containers will survive their design lifetime in the emplacement environment. There are numerous welding processes that can potentially be used to fabricate these containers and to make the final closure weld.

OBJECTIVES: This scoping study was designed to summarize the current "state-of-the-art" of welding process technology in the context of waste package fabrication in support of YMP.

APPROACH: In consideration of the optimum process (or processes) for completing the final closure weld, reliability, efficiency, and long-term performance were weighed more heavily than overall cost of developing or implementing the technology.

The technologies evaluated included inertial friction welding (IFW) and electron beam welding (EBW). These are both single-pass processes that will allow the final closure weld to be made in minutes rather than the hours required for arc welding processes. IFW is an extremely robust process that can produce welds of high integrity and low residual stress in Alloy 22. Although not as robust as IFW, EBW technology is mature and equipment is commercially available to achieve the weld penetration characteristics required for the closure weld. Also assessed were arc welding processes, gas tungsten arc welding and gas metal arc welding, which represent lower cost alternatives and are widely used for the fabrication of thick section stainless steels and Ni-base alloys.

BENEFITS TO OCRWM: Based on this analysis, the OCRWM Science and Technology Program prepared a competitive, multiple-award procurement for development of advanced welding techniques with potential application to future waste package closure. Initial awards will be to develop proof of principle, followed by a feasibility phase, and a third stage for actual demonstration. Depending on the confidence in successive development activities, the cost and the schedule, further down-selections may be made at each successive phase.

Project Title	High-Performance Corrosion-Resistant Coatings: A Collaborative Investigation with the Defense Advanced Research Projects Agency (DARPA)
OCRWM S&T Program Thrust	Advanced Technologies
Project Performers	Lawrence Livermore National Laboratory (LLNL), Oak Ridge National Laboratory (ORNL), Sandia National Laboratory (SNL), Nanosteel Inc. (Nanosteel), Massachusetts Institute of Technology (MIT), University of Wisconsin (Wisconsin), Naval Surface Warfare Center (NSWC), Naval Research Laboratory (NRL),Caterpillar, Case Western Reserve University (CWRU), University of California – Davis (UC-Davis)
Principal Investigators	J. Farmer (LLNL), D. J. Branagan (NanoSteel), C.A. Blue (ORNL), M.B. Beardsley (Caterpillar), L.F. Aprigliano (NSWC), R. Bayles (NRL), N. Yang (SNL), J.H. Perepezko (Wisconsin), L. Kaufman (MIT), A.H. Heuer (CWRU), E.J. Lavernia (UC – Davis)
FY 2004 Funding	$1,125,000

Abstract **BACKGROUND:** Less expensive man-made materials for the proposed repository-relevant timeframes may offer cost savings for the waste package, support pallet, drip shield, ground support and invert. Alloy 22 has sufficient corrosion resistance for the construction of safe and long-lived waste packages, but is expensive. If new, relatively inexpensive, high-performance materials and processes can be found, the life-cycle costs for the proposed repository at Yucca Mountain could be dramatically reduced. A novel strategy is proposed that would use advanced high-velocity oxy-fuel (HVOF) coatings to reduce the proposed repository's life-cycle costs. These amorphous metal coatings are expected to provide comparable resistance to corrosion due to the elimination of grain boundaries. The use of the amorphous metal coatings in place of corrosion resistant metals such as Alloy 22 and Titanium Grade 7 could lead to significant cost savings. This effort is co-funded with the Defense Advanced Research Projects Agency (DARPA) because it is expected that this technology and these or similar materials developed in this effort will provide desirable benefits in naval applications. This project is also drawing on capabilities and resources at naval research laboratories for corrosion measurement.

Amorphous metals (also known as metallic glasses) must be produced with processes that can achieve very high quenching rates (> 10^6 K/sec). Historically, this has limited the production of such materials to forms such as wires, ribbons and strips. In this work, HVOF spray processing is used to produce macroscopically thick protective layers of these amorphous

materials. This is possible because this coating technique quenches the metal extremely rapidly during deposition. Amorphous metal coatings applied with HVOF promise the achievement of high performance with less expensive elemental compositions than would be otherwise be possible with conventional wrought materials. This advantage is due to the performance enhancements (strength, hardness, corrosion resistance), achieved through the elimination of grain boundaries. Furthermore, it has been shown that HVOF can produce coatings with less than 0.2% porosity and a density approaching that of comparable wrought materials. Even this small amount of non-interconnected porosity can be eliminated through the use of auxiliary processes such as high-density infrared fusing (HDIF), developed at Oak Ridge National Laboratory.

In addition to exploiting the benefits of amorphous structure, compositions must be optimized to achieve high corrosion resistance. Despite the anticipated exceptional performance, eventually components and systems made from these advanced materials may undergo degradation due to thermal aging, uniform corrosion, pitting, crevice corrosion, and microbial influenced corrosion. These issues will be examined and the data obtained will be used for accurate predictions of corrosion resistance. These results will be incorporated into integrated models that account for all relevant modes of attack.

OBJECTIVES: This project will develop corrosion-resistant thermal-spray coatings composed of high-performance alloys and amorphous metals. These materials may provide cost-effective improvements for corrosion protection of radioactive waste containers, while simultaneously providing new corrosion-resistant coatings for naval warfare applications.

APPROACH: This work is directed at the further development and optimization of HVOF coatings that will possess the corrosion resistance of high performance materials currently proposed for use, such as nickel-based Alloy 22 and titanium-based Ti Grade 7. An iterative approach including computational evaluation of alloy compositions will be used. The resultant materials promise outstanding performance on all fronts, and will be readily applied using established thermal-spray technology, augmented by new state-of-the-art post processing. Consequently, performance improvements, along with considerable cost savings, can be achieved through the replacement of more expensive corrosion-resistant bulk alloys.

BENEFITSTO OCRWM: Significant cost savings are possible, if these amorphous metal coatings can satisfactorily replace more expensive materials in the proposed Yucca Mountain Repository.

Project Title	Robotics Scoping Study to Evaluate Advances in Robotics Technologies which Support Enhanced Efficiencies for Yucca Mountain Repository Operations
OCRWM S&T Program Thrust	Advanced Technologies
Project Performers	Oak Ridge National Laboratory
Principal Investigators	Thomas W. Burgess, Mark W. Noakes, Philip T. Spampinato
FY 2004 Funding	$100,000

Abstract **BACKGROUND:** The proposed repository design baseline and associated waste processes were examined to identify where significant cost and schedule savings could accrue from implementation of robotic and remote handling technologies. The Yucca Mountain Project (YMP) previously developed a list of advanced robotics technologies for potential future investment. This preliminary list will be refined and modified based on the outcome of this study.

OBJECTIVES: The objective of this project is to perform a scoping evaluation of advances in robotics technologies to identify those mature enough to merit consideration as potential projects. The evaluation addressed the baseline robotics capabilities planned for incorporation into the current YMP repository design, including both the surface and subsurface operations. The scoping evaluation will identify where significant advantages in operating efficiencies could accrue from the deployment of any given robotics technology or approach.

APPROACH: Activities include a review of relevant existing project documentation on the current remote handling designs for surface and subsurface operations to establish the intended technology baseline. This is the foundation from which technology improvements to the baseline will be identified and analyzed for efficiency improvements.

The surface facility requirements and the procedures for handling spent nuclear fuel (SNF) casks will be examined in the context of SNF acceptance, unpacking, sorting and storage, repackaging, inspection, etc. The subsurface facility requirements and procedures will be examined in the context of transporting SNF packages to their final emplacement locations. Technologies, modifications, or other changes based on improving operating efficiencies, remote maintainability, or reduction in operator radiation exposure will be recommended.

Specific project descriptions suitable for solicitation will be generated for each of the technology areas. An overall multi-year robotics development program will be outlined that supports improved efficiencies for waste package handling, waste package and drift inspections, data collection,

incident recovery, surveillance and inspection, etc.

The final output of this project will be a robotics and remote systems technology development, multi-year road map focused on improving operational efficiency of the YMP remotely operated facilities.

BENEFITS TO OCRWM: The key benefit to OCRWM will be the development of a custom-tailored research program to assist in the future optimization of remote operations at Yucca Mountain. By increasing the throughput of SNF waste packages at the proposed Yucca Mountain repository, the potential exists for significant cost savings in parallel with facility construction costs as well as site operation costs.

Project Title	Scoping Study to Investigate Cost Effective Cementitious Materials Compatible with Yucca Mountain Repository Geochemistry
OCRWM S&T Program Thrust	Advanced Technologies
Project Performers	Oak Ridge National Laboratory (ORNL), University of Tennessee (UT), University of California-Berkeley (UC-Berkeley), MINATOM VNIIEF, Sarov
Principal Investigators	Les Dole (ORNL), Catherine Mattus (ORNL), Lee R. Riciputi (ORNL), Mostafa Fayek (UT), Lawrence M. Anovitz (UT), Don Olander (UC-Berkeley), S. Ermichev (MINATOM)*, and V.I. Shapovalov (MINATOM)* *(* funded by other programs)*
FY 2004 Funding	$100,000

Abstract

BACKGROUND: High-silica binders have a number of advantages for Yucca Mountain Project (YMP) applications. Evidence from archaeological and geological samples shows that high-silica cement binders are extremely durable. These cements, used by the Greeks and Romans, have survived for hundreds of years in hot water and for thousands of years in marine environments. As an additional benefit, high-silica binders are as strong as ordinary Portland Cement (OPC), while suppressing the formation of free calcium hydroxide that elevates the pH in OPC.

OBJECTIVES: The objective is to develop and test cost effective cementitious materials for construction of inverts, drift liners and bulkheads within the proposed Yucca Mountain (YM) repository.

APPROACH: Upon completion of the scoping study, a project may be initiated to:

1) formulate cementitious materials using high-silica hydraulic binders;
2) measure their physical and chemical properties;
3) expose combinations of these materials and waste package materials to static and flowing groundwater bracketing expected repository conditions;
4) examine both the exposed cementitious and waste package materials periodically during testing for chemical and mineralogical changes to determine reaction mechanisms and kinetics; and
5) predict the long-term performance of the material by thermodynamic and transport modeling and by comparisons with natural analogs.

These materials will be less expensive to produce, while being denser,

stronger and more durable than OPC in hot concentrated YM groundwater. Therefore, building out the repository with these cementitious materials may significantly reduce these costs and may reduce uncertainty in repository performance.

In FY 2004, a detailed Work Plan was produced based on a literature study to describe experiences with and expectations for geochemically compatible grouts and concretes for future build-out of the YMP. This includes the development of a statement of work describing the costs and schedules of research tasks that will develop and test specific cementitious formulations for the YMP and to ultimately support their acceptance and licensing.

BENEFITS TO OCRWM: Based on the outcome of the scoping study, a project may be initiated to develop and test cost effective cementitious materials for construction of YMP inverts, drift liners and bulkheads. While being compatible with YMP repository systems, these materials will be less expensive to produce, and as strong and more durable than OPC.

Project Title	Studies of Advanced Welding Techniques for Nuclear Waste Containment
OCRWM S&T Program Thrust	Advanced Technologies
Project Performers	Lawrence Livermore National Laboratory
Principal Investigator	Frank Wong
FY 2004 Funding	$390,000

Abstract **BACKGROUND:** The current YMP waste package design employs gas tungsten arc welding (GTAW) in fabricating the waste package for the Ni-Cr-Mo alloy, Alloy 22, outer barrier and 316NG inner shell. While GTAW is widely used in industry for many applications, it requires multiple weld passes (e.g., ~8 passes are required for the Alloy 22 outer barrier), which will produce weld distortions and regions of tensile residual stresses at the surface. By comparison, single-pass welding methods inherently use lower heat input which results in lower levels of weld distortion and also narrower regions of residual stresses at the weld.

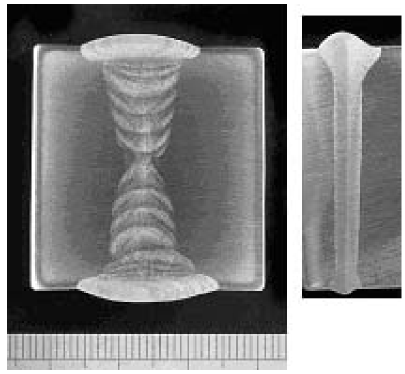
Electron beam (EB) welding is also widely used in industry and typically results in faster welding times (as it is a single-pass method) and a more favorable distribution of residual stresses. However, conventional EB welding usually requires the work piece to be contained in a good vacuum environment during welding. A vendor has developed a Reduced Pressure Electron Beam (RPEB) welding process which allows EB welding in a reduced pressure environment (≤ 1 mbar) achieved by local sealing and pumping. The RPEB method has been used by SKB (Swedish nuclear waste program) in their waste package mockup program (~40 canister mockups fabricated with RPEB welding since 1992).

OBJECTIVES: To explore the use of advanced welding techniques, such as Reduced Pressure Electron Beam Welding, for potential cost savings in fabrication of YMP waste packages.

APPROACH: If such a single-pass welding technique could be used in fabricating the YMP waste packages, potential cost savings would be significant and would primarily result from:

- Elimination of weld filler metal;
- Faster welding times;
- Elimination of plate overstock;
- Reduced machining times; and
- More favorable distribution of residual stresses.

A comparison of GTAW and RPEB welds in Ni-Cr-Mo-W alloys is shown below.



Multi-Pass GTAW (Left) and Single-Pass RPEB (Right) Welds in Ni-Cr-Mo Alloys of Comparable Thickness

In order to evaluate the use of RPEB welding for waste package fabrication, a comprehensive comparison of GTAW and RPEB welding on waste package alloys will be conducted. This comparison will focus on long-term materials performance factors most relevant to the YMP application: corrosion, metallurgical stability, and as-welded residual stresses. An iterative process will be used to optimize the RPEB welding parameters for this application. The goal is to demonstrate that the resulting RPEB welds have equal or better long-term materials performance as GTA welds for the YMP application. Having attained this goal, a full diameter, one-quarter length scale waste package mockup of the Alloy 22 outer barrier will be fabricated with RPEB welding.

BENEFITS TO OCRWM: The use of RPEB welding for waste package fabrication would provide the following benefits to the OCRWM program:

1) significant cost savings in waste package manufacturing;

2) equal or better materials performance in terms of corrosion, metallurgical stability, and as-welded residual stress; and

3) increased repeatability and reliability in waste package welding due its single-pass nature.