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This paper was prepared for submittal to the Combined ANS/ASME Nuclear Energy Conference, Newport, RI, 9/16-19/90

June 1990

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U.S. DOE-AECL COOPERATIVE PROGRAM FOR DEVELOPMENT OF HIGH-LEVEL RADIOACTIVE WASTE CONTAINER FABRICATION, CLOSURE, AND INSPECTION TECHNIQUES*

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ABSTRACT

The U. S. Department of Energy (DOE) and Atomic Energy of Canada Limited (AECL) plan to initiate a cooperative research program on development of manufacturing processes for high-level radioactive waste containers. This joint program will benefit both countries in the development of processes for the fabrication, final closure in a hot-cell, and certification of the containers. Program activity objectives can be summarized as follows: (1) to support the selection of suitable container fabrication, final closure, and inspection techniques for the candidate materials and container designs that are under development or are being considered in the U. S. and Canadian repository programs; and (2) to investigate these techniques for alternate materials and/or container designs, to be determined in future optimization studies relating to long-term performance of the waste packages. The program participants will carry out this work in a conditional phased approach, and the scope of work for subsequent years will evolve subject to developments in earlier years. The overall term of this cooperative program is planned to run roughly three years.

INTRODUCTION

Researchers at the Lawrence Livermore National Laboratory (LLNL), under the auspices of the U. S. Department of Energy, are conducting research in the area of fabrication, final closure, and inspection of metallic containers for the long-term disposal of high-level radioactive waste (HLW). This work is being performed in conjunction with the proposed U. S. site at Yucca Mountain, Nevada that has been chosen for investigation of the feasibility of mined geologic permanent disposal in welded tuff. The anticipated HLW for permanent disposal will consist mostly of spent nuclear fuel from Pressurized Water Reactors (PWR) and Boiling Water Reactors (BWR).

Investigators in Canada, as part of the Canadian Nuclear Fuel Waste Management Program, are conducting similar research in the area of development of high-integrity containers for the immobilization and disposal of unprocessed used fuel in a deep geologic vault, planned for plutonic rock in the Canadian Shield. The HLW for disposal is associated with the CANDU (natural-uranium-fuelled, heavy-water-moderated and cooled) nuclear reactor fuel cycle. This paper gives the program goals and planned activities of a proposed cooperative program involving both countries.

The advantages unique to a cooperative program, as compared to an independent program, include the following:

(1) Duplication of work can be avoided, which is beneficial especially in view of current budgetary constraints that many programs are experiencing.

(2) Peer review of work by the cooperating programs allows a broader prospective for solutions to problems (cross-fertilization). International review of research may also lead more readily to public acceptance of the programs.

(3) A more "generic" container design may be developed for a broader range of anticipated and unanticipated environmental conditions. If new environmental parameters are discovered for a particular repository site, or if the repository site under investigation proves to be unsuitable for disposal of HLW, more options may be available for the adoption of container designs to other environments.

PROGRAM GOALS

The U. S. plan is to use corrosion-resistant metallic containers, in the form of thin-wall, monolithic cylinders (10-30 mm thick) with overall length of about 4.7 m and diameter of roughly 0.7 m. The metals under consideration for containers include three austenitic alloys: AISI 304L stainless steel, AISI 316L stainless steel, and Incoloy 825 (a high-nickel, iron-base alloy), and three copper-base alloys: CDA 102, CDA 613, and CDA 715. The U. S. goals for the container manufacture and certification process are to produce microstructural uniformity throughout each unit; a wrought-like homogeneous, low-residual stress microstructure with controlled composition. Any welds and/or heat affected zones generated during fabrication would be heat treated and/or mechanically worked to dissolve undesirable microstructural features. The final closure on the other hand is to be executed remotely in a highly radioactive environment, and

* Work performed under the auspices of the U.S. Department of Energy by the Lawrence Livermore National Laboratory under contract number W-7405-ENG-48.
must produce the desired features without any post-weld heat treatment or mechanical work. Activities have been underway recently to identify, assess and recommend candidate fabrication, final closure, and nondestructive evaluation (NDE) processes to accomplish and certify the above goals. The processes that will be emphasized for further detailed investigation in the proposed U.S. program are: (a) for fabrication: roll and welding plus roll extrusion, extrusion plus roll extrusion, centrifugal casting plus roll extrusion, and deep drawing; (b) for final closure: inertia welding, plasma-arc welding and electron-beam welding; (c) for NDE of the container final closure weld: ultrasonic methods for volumetric and surface inspection; and visual inspection of the overall container surface, both for remote application in a hot-cell.

The Canadian goals are summarized in reference 5 and are similar to the U.S. goals in terms of the required microstructural uniformity of the containers. Cooperative engineering studies have been conducted over a ten-year period by Atomic Energy of Canada Limited (AECL) and Ontario Hydro Research Division (OHRD), and to date, the Canadian container development program has identified copper and ASTM Grades 2 and 12 titanium alloys as having the greatest potential to provide the required corrosion endurance for the metallic containers under the expected disposal conditions (saline ground-water environment in plutonic rock). The Canadian program developed two basic thin-wall, metallic container designs to accommodate nuclear fuel wastes associated with power production in CANDU nuclear reactors: (a) stressed-shell design in which the corrosion-resistant shell is the only structural member resisting externally applied loads, and (b) supported-shell designs in which a thinner shell of sufficient thickness to meet the corrosion allowance is internally supported by structurally supportive members, castings (e.g. lead or lead-antimony) or particulates (e.g. glass beads or sand). The overall dimensions of the stressed-shell design are roughly 0.6 m diameter x 2.5 m long, and of the supported shell designs are roughly 0.6 m diameter x 2.2 m long with thickness ranging from 6 to 30 mm. The Canadian program has emphasized the following container manufacturing processes: for container fabrication: traditional methods such as roll and welding and casting; for final closure: gas-tungsten-arc welding, gas-metal-arc welding, electron-beam welding, and resistance-heated-diffusion bonding; and for inspection: Ultrasonic methods.

**PLANNED COOPERATIVE ACTIVITIES**

The U.S. DOE-AECL cooperative program, as described in this paper, will be conducted for the mutual benefit of both countries, for the purpose of providing assistance and verification in achieving the goals that were described above. This work will be carried out using a conditional phased approach, in that the scope of work in subsequent years will evolve subject to the developments of the earlier years. This phased program will begin with an information exchange and a detailed-plan development for subsequent work.

**Phase 1. Information Development**

Phase 1 emphasis will be on development and/or exchange of information pertinent to support of selection of one or two container reference metals for the U.S. program; and primarily to accomplish container-closure welding and weld inspection in a remote environment, for the Canadian program. Collaboration will be conducted with the following hierarchy of effort: (a) literature surveys, (b) technical exchange of information developed in the programs to date, and (c) confirmatory experiments as appropriate to apply data to a specific metal; fabrication, closure and/or inspection process; or microstructural feature.

Areas of interest for the U.S. program include supportive or nonsupportive information relative to the container fabrication, final closure and closure inspection methods pertaining to planned process development investigations that are summarized in the following two tables:

**Table 1. U.S. Candidate Fabrication Processes**

<table>
<thead>
<tr>
<th>Fabrication Process</th>
<th>Container metal</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Alloy 825</td>
</tr>
<tr>
<td>Roll and welding</td>
<td>X</td>
</tr>
<tr>
<td>Roll &amp; Welding plus Roll Extrusion</td>
<td>X</td>
</tr>
<tr>
<td>Extrusion plus Roll Extrusion</td>
<td>X</td>
</tr>
<tr>
<td>Centrifugal Casting plus Roll Extrusion</td>
<td>X</td>
</tr>
<tr>
<td>Deep Drawing</td>
<td>X</td>
</tr>
</tbody>
</table>
Table 2. U. S. Candidate Closure Processes

<table>
<thead>
<tr>
<th>Closure Process</th>
<th>Container metal</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>CDA 102</td>
</tr>
<tr>
<td>Electron Beam Welding</td>
<td>X</td>
</tr>
<tr>
<td>Inertia Welding</td>
<td></td>
</tr>
<tr>
<td>Plasma Arc Welding</td>
<td></td>
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</tbody>
</table>

For container closure NDE, U. S. near-term plans include development of ultrasonics and visual inspection methods, as have been discussed above.

Areas of interest to the Canadian program will involve supporting or nonsupporting information on the following specific techniques to accomplish container-closure welding and weld inspection in a remote environment: (a) accurate and rapid seam tracking as applied to gas-tungsten-arc welding (GTAW) of titanium and electron-beam welding (EBW) of copper, with applicable NDE (especially ultrasonics and/or laser ultrasonics techniques) in a remote environment. (b) identification of specific problems anticipated for the above-mentioned techniques with problem-correction recommendations for identification and control of weld parameter sensitivity issues relative to the desired weld/heat-affected-zone (HAZ) microstructure.

**Phase 2. Technique Development**

In support of the U. S. program, phase 2 will involve more emphasis on doing a survey of anticipated metal defects, including critical flaw sizes for the reference metals, as well as for alternate metals to be identified at that time. These alternate metals may include one or two alloys from the following general alloy systems: titanium, zirconium, nickel-coppers and nickel superalloys. Detailed microstructural assessments are of interest for metal characterization in terms of details relating to long-term performance. An example is what brittle phases potentially may be produced in the weld or HAZ, and how they may affect the container postclosure performance, given the anticipated Yucca Mountain environment.

Another possible area of collaboration in support of the U. S. program for phase 2 could involve the analysis of two-metal container alternate configurations to be developed by LLNL. These microstructural analyses would relate to the feasibility of fabrication, remote closure and NDE of the designs, in terms of achieving the goals relating to long-term container performance. For example, a possible alternate container configuration could consist of two separate shells (e.g., a copper-base alloy on the outside and a nickel-base alloy on the inside).

In support of the Canadian program, phase 2 will involve identifying and comparing specific fabrication, welding, and NDE procedures for potential utilization in the Canadian container manufacturing process. As a follow-up activity to investigations performed in phase 1, welding and NDE procedures will be developed and qualified that relate to the GTAW of titanium and the EBW of copper. Of specific interest in the container fabrication area are procedures for producing container shells and closure heads from single sheets of titanium and copper utilizing such processes as deep-drawing, spin-forming or spin-casting. Other anticipated activities are microstructural analyses of all specimens produced with developed quality assurance/quality control (QA/QC) procedures, as necessary for certification of the work.

In addition, it is anticipated that the phase 2 scope for both programs will involve preparation, exchange and/or analysis of specimens for evaluation of technical implementing procedures that are under development in the other program, in the appropriate areas (fabrication, welding or NDE) for verification purposes.

**Phase 3. Prototype Testing and Technique Application**

In phase 3, collaboration will emphasize the following two major areas: (a) Application of techniques developed in phase 2 to remote operation, and (b) full-scale testing of container prototypes. Procedures/techniques will be developed as appropriate, and qualified using personnel from one program to review the other program's developments. Representative specimens will be evaluated on the basis of criteria developed by each program. This phase will culminate with the generation of a joint report providing the detailed developments of the overall cooperative program.

**OVERVIEW OF EXPECTED RESULTS**

It is anticipated that both countries will benefit from the cooperative program in general ways that have already been summarized in the introductory paragraph of this paper. The following paragraphs will attempt to identify some of the key technical areas where results may be achieved from the planned cooperative activities.

**U. S. Anticipated Results**

Assistance will be given to the U. S. container metal selection milestone in terms of development of information that
may either support or not support the U. S. decision, with appropriate recommendations for a list of alternate materials, likely including the Canadian reference titanium alloys. If necessary, confirmatory experiments may be performed in specific areas. Unanticipated environmental parameters may be identified that will assist in development of long-term container performance models. Detailed procedures/techniques may be developed to assist in confirmation testing of full-scale prototypes.

Canadian Anticipated Results

Specific problems associated with the reference Canadian closure techniques may be identified, and recommendations for problem correction may include areas such as microchemistry control of the base and/or filler-metal, and sensitivity analyses of welding parameters. Assistance will be given to the Canadian program in the development of remote applications of the reference container closure techniques. Recommendations of robotic applications may be given in the following areas: seam finding, seam tracking, data acquisition, computer control, calibration, and general process assessment. Fabrication process information developed in the U. S. program will be applied in the areas of deep drawing and extrusion, to minimize the required container weld seams. NDE developments in the U. S. program will be applied to the certification of the container closure welds. Possible techniques for examination of the copper weldments may include a combination of acoustic tomography and synthetic aperture focusing.

Through this cooperative exchange of information and resources, both countries will work more efficiently toward meeting their program goals.

REFERENCES


