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Role of Fabrication on Materials Compatibility in APT Target/Blanket

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ROLE OF FABRICATION ON MATERIALS COMPATIBILITY IN APT TARGET/BLANKET

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ABSTRACT

The Accelerator Production of Tritium (APT) Project is designed to produce tritium through the 3He (n,p) 3H reaction in the target/blanket system. The target/blanket system includes: a) an alloy 718 window that facilitates the passage of a high energy proton beam from the accelerator portion of the APT into the target/blanket system; b) a tungsten target where neutrons are produced by spallation of the tungsten during interactions with the high energy proton beam; c) aluminum pressure tubes that contain the 3He for tritium production and the 3H which is produced by the 3He (n,p) 3H reaction; (d) a lead blanket which moderates the spallation neutrons and also serves as a neutron multiplier; (e) stainless steel manifold that connects the aluminum pressure tubes to the tritium separation facility, and f) cooling water systems for the window, target, pressure tubes as blanket components.

The tungsten target and lead blanket components will be clad with Inconel 718 and 6061-A1 respectively, and the interior walls of the aluminum pressure tubes may require special treatments to minimize 3H losses during APT operations.

This paper summarizes several of the options associated with the fabrication of selected target/blanket components. In addition, the materials characterization technologies required to validate these components performance is presented.

The fabrication of specific components discussed in detail include the transition from the aluminum pressure tubes to the stainless steel manifold; the cladding of the lead in the blanket assembly; and the potential for weld repairs of irradiated target/blanket components. The fabrication options for clad tungsten target elements, coating the interior surfaces of the aluminum pressure tubes, and providing qualified welds for the 3He/3H and cooling water systems are outlined but not discussed in detail.

INTRODUCTION

The Accelerator Production of Tritium (APT) Project will produce tritium through the 3He (n,p) 3H reaction. The 3He gas used for tritium production will be contained in aluminum pressure tubes that will be connected to a tritium separation facility through an austenitic stainless steel manifold. The neutrons for the 3He (n,p) 3H reaction will be produced by proton induced spallation of a tungsten target. Lead blankets will be used to moderate and multiply the spallation neutrons. The high energy proton beam that induces spallation in the tungsten target will move from the accelerator portion of the APT into the target/blanket system by passing through an Inconel 718 window. Design concepts for the target/blanket components have been summarized[1] and include cladding the tungsten target elements and the lead blanket components. A schematic illustration of the target/blanket system is shown in Figure 1. The window, the tungsten target, the lead blanket, and the aluminum pressure tubes are water cooled, with heavy water being used for the target assembly.

An in depth knowledge of materials used previously in nuclear systems provides the basis for the current materials selections. The materials of construction for the target/blanket components were selected because they exhibit the appropriate neutron and proton capture cross-sections, products produced through proton-induced spallation, good heat transfer characteristics, high corrosion resistance in relatively high purity cooling water, resistance to irradiation damage and hydrogen embrittlement, and fabricability. Each of these attributes is important to the successful performance of the

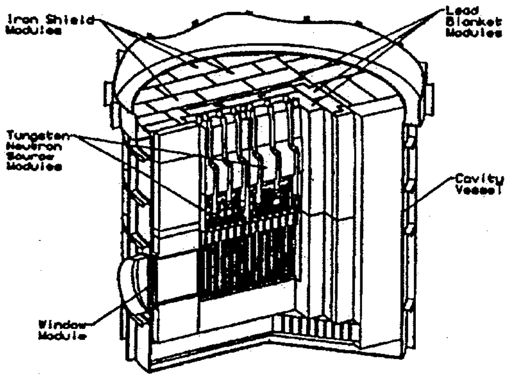

Figure 1: Schematic cross section of an APT target and blanket assembly. (Ref. 1)

target/blanket component and ultimately to the success of the APT project. Table 1 summarizes the materials selected for the target/blanket components.[2]

Table 1: Materials Selection for APT Target/Blanket (from Ref. 2)

Component	*Material*	*Basis*
Beam Entry Window	Inconel 718	LANSCE Experience; high temperature strength
Target	Tungsten	High neutron production
Target structure	316 Stainless Steel	Irradiation performance, neutronics
Decoupler Structure	6061 Aluminum Alloy	Low neutron absorption
Reflector	Lead	Neutron multiplier, low neutron absorption
Coolant tubes	6061 Aluminum Alloy	Low neutron absorption
He-3 Tubes	6061 Aluminum Alloy	Low neutron absorption

However, materials selection and qualification processes frequently require compromises among the various attributes. For example, austenitic stainless steels have been the primary material of construction for tritium handling systems. This experience base, therefore, suggests the use of an austenitic stainless steel for the 3He/3H gas containment system. However, the use of austenitic stainless steels in this application would lower tritium production rates because of parasitic neutron capture. Thus, aluminum alloys were selected for the 3He/3H pressure tubes and austenitic steels for the balance of the gas handling system. In order for these materials selections, which maximize tritium production and utilize the broad base of tritium handling experience, to perform properly, an aluminum to austenitic stainless steel joint needed to be developed. This aluminum to stainless steel joint was required to be leak tight to 3He and 3H gas, be relatively resistant to corrosion by the cooling water, and provide assured mechanical integrity for the design lifetime of the system.

This paper outlines several potential fabrication challenges, in addition to the aluminum-to-stainless steel transition joint, and summarizes ongoing programs designed to address the fabrication options and provide the technical basis required to qualify the material/fabrication process for service in the APT environment.

FABRICATION REQUIREMENTS

The relatively unique requirements for the materials of construction in the target/blanket portion of the APT system led to several, fairly basic, fabrication requirements. In addition to the aluminum to stainless steel transition joint previously discussed, these requirements include the following:

1) *The cladding of high purity lead with 6061 aluminum.* Aluminum cladding is required to provide structural support to the lead and is required to minimize the release of spallation products from the lead into the cooling water. Aluminum was selected because of its low neutron capture cross section, corrosion resistance in high purity water, and excellent formability. However, the addition of aluminum to the blanket system lowers the tritium production efficiency because of parasitic loss. Therefore, the cladding should be as thin as structural considerations will allow. Additionally, the "lead containing volumes" erected by the cladding design should be completely filled with high density lead to minimize the gap between the lead and the aluminum.

This requirement for filling the lead containing volumes in the blanket modules was addressed by evaluating several fabrication techniques[3].

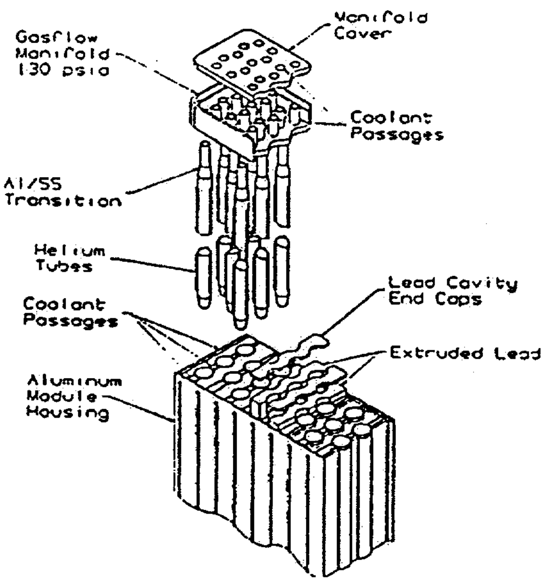

Figure 2: Typical blanket assembly (Ref. 1)

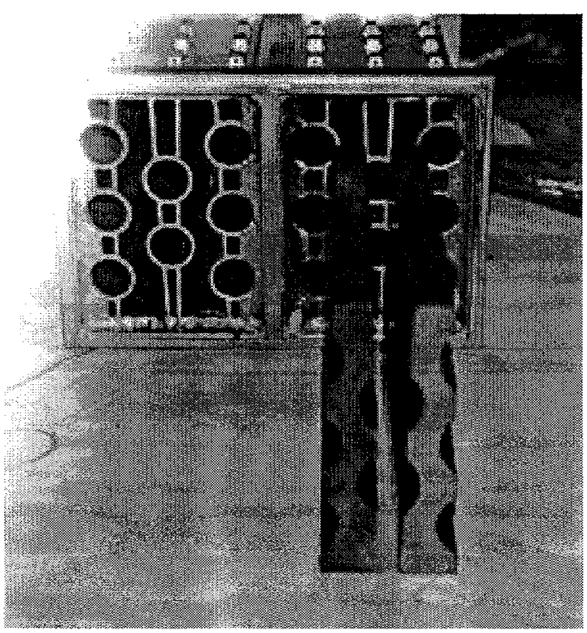

Figure 3: A small scale blanket module prepared for materials irradiation studies (Ref. 4)

2) *The ability to weld repair or modify selected portions of the target/blanket system that have been irradiated during APT service.* Many of the target/blanket components are replaceable and are designed to be removed with minimal disruption to APT operations. However, portions of the target/blanket system are designed to last for 40 years. It is highly probable that service induced degradation of the materials and/or desired system modifications will require that some of these long lifetime systems be successfully welded during their service life. Irradiation reduces the weldability of metals and alloys, primarily because of helium production and implantation in the material.

The requirement for weld repair and/or modification has been or is being addressed by evaluating techniques to weld irradiated materials and by estimating the maximum helium content that can be tolerated before special weld practices are required[5].

3) *The ability to plate, or otherwise modify, the interior surface of aluminum tubes that are approximately fourteen feet long, 0.5 inches in diameter and have a wall thickness of 0.035 inches.* Tritium production in the APT system will be through neutron capture by 3He atoms contained at 150 psi in aluminum pressure tubes. The energy balances associated with the tritium production reaction are such that a fraction of the 3H produced by the 3He (n,p) 3H reaction is implanted in the wall of the pressure tubes. This implanted 3H may be retained in the tube wall, diffuse to the inner surface of the tube and be released to the 3He/3H gas environment, and/or diffuse to the outer surface of the tube and be released to the cooling water.

Experiments are in progress to evaluate the distribution of 3H that was generated during irradiation. Fabrication techniques to modify the inner surfaces of the pressure tubes and to alter the behavior of the implanted tritium and promote release to the 3He/3H gas environment are readily available if necessary. Plating with nickel or copper and surface anodization are being evaluated. Surface modification techniques, if shown to improve the release of implanted 3H to the 3He/3H gas environment, will undergo a thorough quality assurance (QA) analysis to ensure the fabrication techniques are well defined. The QA analysis shall ensure that the 3He containing tubes are fabricated in a reproducible fashion and that leak tight connections can be made to the surface of the tubes.

4) *The qualification of weld practices to minimize 3He and 3H losses from the APT system.* The target/blanket portion of the APT system will contain thousands of 3He

pressure tubes. Each pressure tube contains several similar metal welds, in addition to, an aluminum-to-stainless steel transition joint. The pressure tubes must be welded into a header and seal welded to an end fitting (Figure 4). The header will contain a variety of fabrication welds and the total 3He and/or 3H leakage from all the welds must be below a level, yet to be specified. Assurance that this maximum level is not obtained will be determined through evaluating weld process controls and post-weld examinations. Because of the very large number of welds required for the pressure tubes, verification of each individual tube weld will be different and it is anticipated, the weld process control will play a critical role in the quality assurance processes. Technologies that can be used to certify the "lack of leakage" through welds on thin walled aluminum tubes must be evaluated and demonstrated. Allowable leak rates must be defined and weld process control technologies must be established prior to the certification of required fabrication practices.

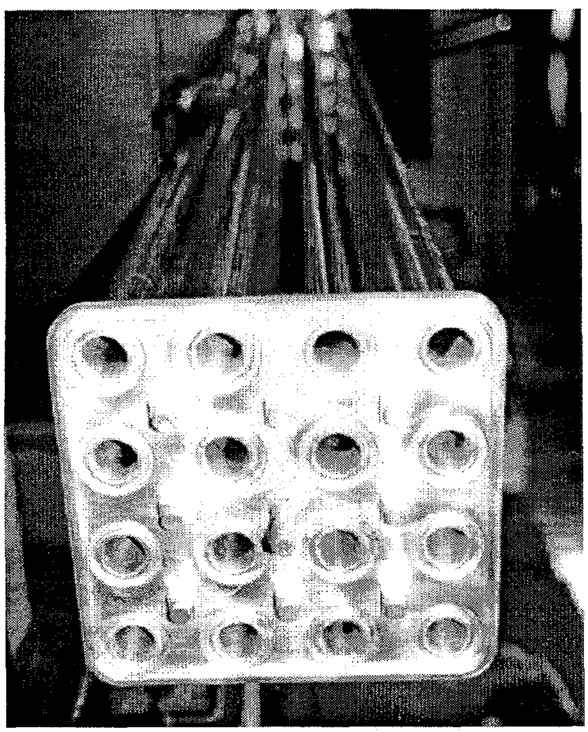

Figure 4: Partially assembled He3 manifold. (Ref. 4)

The 3He tubes are connected to the stainless steel manifold using a stainless steel/aluminum transition joint. A number of joining techniques were evaluated to fabricate this joint including explosive welding, inertial welding and brazing. Inertial welding was selected as the most promising techniques to fabricate this joint. Inertial welding is a proven solid state joining process that uses a flywheel as the kinetic energy for the heat source and a high pressure system for applying the forge force[6]. Because of the high pressure, the metal, as it becomes heated by friction is forged together with no melt zone. Hence there is no chemical change and a very narrow heat affected zone. The quality of the welds depends on the cleanliness of the weld interfaces and the process parameters used. Burst test, using helium, on inertially welded stainless steel/aluminum joints reveal that the fracture occurs in the aluminum section after yielding in an area away from the heat affected zone. Helium leak tests on the tubes with the stainless steel/aluminum show the leak rates of the welds to be less than 1.11×10^{-8} std cc/sec helium.

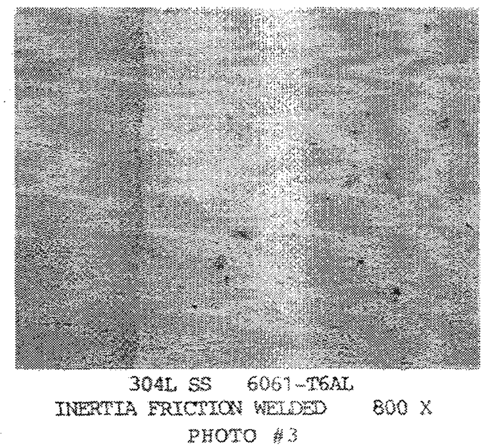

Figure 5: Metallographic cross section of interially welded stainless steel/aluminum joint. (Ref. 6)

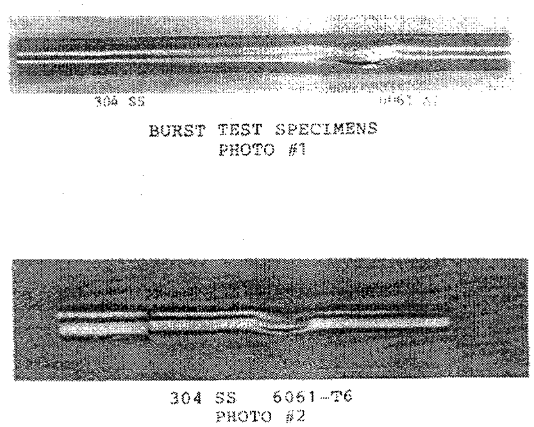

Figure 6: Burst test samples showing fracture in the aluminum section. (Ref. 6)

5) *The cladding of tungsten target elements with alloy 718 or other suitable cladding materials.* Early irradiation studies demonstrated that significant material loss accompanied the exposure of water cooled bare tungsten rods to a high energy proton beam. The material loss profile was similar to the beam profile. This loss was therefore attributed to in-beam effects on the corrosion of the tungsten. However, similar preliminary corrosion studies showed no beam effects on alloy 718 and type 304L stainless steel components, suggesting that the observed material loss in tungsten may not be solely due to beam effects on corrosion. Regardless of the cause, the irradiation studies have demonstrated that the tungsten target rods must be clad to prevent unacceptable material loss during service. This understanding of the materials/corrosion behavior led to a clad tungsten target assembly design. (Figure 7).

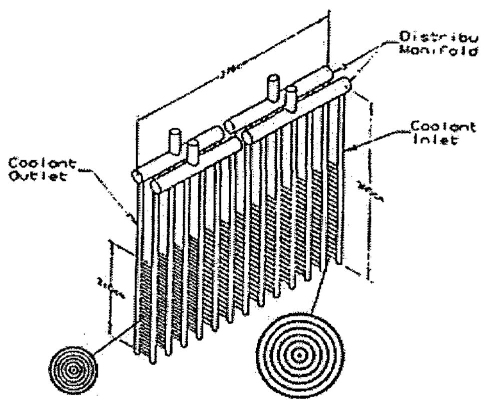

Figure 7: Target (neutron source) assembly.

Potential cladding techniques include the slip fit of tungsten into cladding tubes; hot-isostatic pressing of the clad material around tungsten rods and tubes, and other techniques to promote metallurgical bonding between the tungsten and the clad material, and/or minimize the gap between the tungsten and the clad material. Metallurgical bonding would enhance heat transfer from the tungsten into the cooling water and improve the assurance that thermal hydraulic calculations would minimize actual target performance. However, if bonding is required, non-destructive inspection techniques must be developed to assess the bond quality. In addition, experimental measurements of service-induced degradation in bond quality must be assessed.

6) *The development of the technologies required to fabricate cooling water systems that may include dissimilar metal welds, a potential of corrosion induced degradation and/or irradiation induced changes in the nature of the corrosion/erosion processes.* The production of spallation neutrons and tritium in the APT target/blanket system requires heat removal from window, target and blanket components. This removal is accomplished by flowing relatively high purity water across and through components and into a heat exchanger which ultimately transfers the heat to the surrounding environment. The chemistry composition and pH of the water will be controlled to minimize corrosion of the water cooled components. Interactions among the water and the radiation environment will produce radiolysis products that may play significant roles in the corrosion processes. Water chemistry control processes are likely to involve side stream purification by ion exchange and may also involve chemical addition, hydrogen over pressurization, and/or other processes to improve water chemistry. However, stagnant areas in the cooling water systems including crevices, dead ends, under deposit areas, and other low flow areas, may cause localized alterations in water chemistry and can promote corrosion induced degradation. The cooling water systems must be designed and fabricated to minimize, if not eliminate, potential stagnant areas, especially crevices. Additionally, any bi-metallic joint must be fabricated to minimize galvanic corrosion. Fabrication practices must be coordinated with materials selection and water chemistry control practices to minimize the potential for corrosion on the cooling water systems.

The six fabrication issues outlined in this section, along with issues associated with the aluminum-to-stainless steel transition joint, illustrate the variety of fabrication and materials characterization issues associated with the APT target/blanket system. Successful focus on these issues requires knowledge of the effects of the, almost unique, mixed neutron-proton irradiation spectra on materials behavior.

An extensive materials irradiation and test program is currently underway at Los Alamos National Laboratory (LANL). This program will help develop the materials database that is required to establish and validate the technical basis for the materials selection in the APT target and blanket region. All the materials used in the target and blanket region are being irradiated in a small specimen and model component form (Figure 8) using the Los Alamos Spallation Radiation Effects Facility at the 800 MeV Los Alamos Neutron Science center (LANSCE) accelerator. The materials characterization studies include the development of mechanical and metallurgical property database in prototypic APT proton/neutron fluence and the investigation of in-beam and near-beam corrosion behavior of these materials.

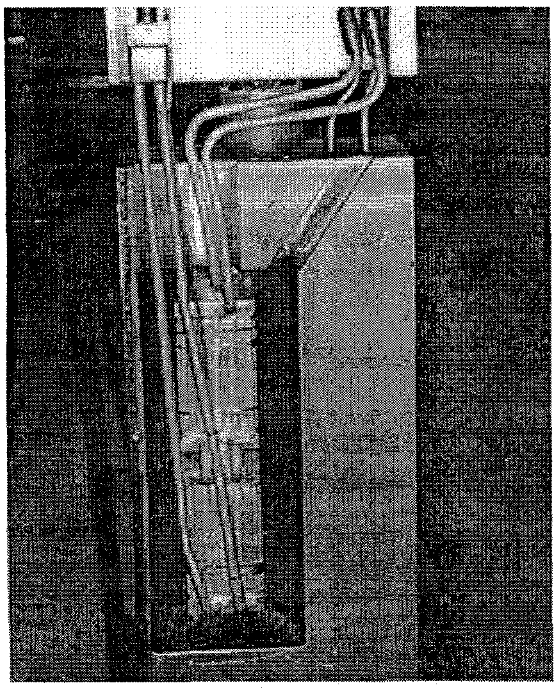

Figure 8: Photograph of a small scale prototypic blanket module prepared for irradiation in LANSCE.

SUMMARY

The tritium is produced in the APT in the target/blanket system. This paper summarizes the options and challenges associated with the fabrication of the target/blanket components and its relationship to the materials performance. The fabrication of the aluminum/lead blanket assembly, the 3He manifold including the stainless steel/aluminum joint, and the target assembly is discussed.

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