Nuclear and Emerging Technologies for Space, American Nuclear Society Topical Meeting
Richland, WA, February 25 – February 28, 2019, available online at http://anstd.ans.org/

OVERVIEW OF THE PLUTONIUM-238 SUPPLY PROGRAM'S CERMET PRODUCTION TARGET

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The Plutonium-238 Supply Program is tasked with establishing a reliable domestic supply of ^{238}Pu to fuel radioisotope thermal generators in its crucial role of supporting future space exploitation. To meet this need, researchers at Oak Ridge National Laboratory developed a robust production target design that is used to irradiate neptunium–aluminum cermet pellets to transmute the feedstock into usable ^{238}Pu. This paper describes the target design and the innovative design features employed to improve target fabrication and assembly.

I. BACKGROUND

The U.S. Department of Energy (DOE) is responsible for fabricating radioisotope thermoelectric generators (RTGs) for the National Aeronautics and Space Administration (NASA) to use in deep space mission activities. Plutonium-238 (^{238}Pu), an unstable isotope of plutonium with a half-life of 87.7 years, undergoes an alpha decay event to form uranium-234, a reaction that also produces excess decay heat. When formed into oxide pellets, ^{238}Pu can provide a heat source for the RTG power systems. The RTG harnesses the decay heat to generate electrical power via thermoelectric conversion and ambient heat for instrumentation and space vehicles. Oak Ridge National Laboratory (ORNL), a member of the DOE laboratory system, is managing ongoing efforts to establish the ^{238}Pu Supply Program (PSP) to replenish the domestic stockpile of ^{238}Pu (Ref. 1). The PSP fabricates and assembles production targets, containing NpO_2–aluminum cermet pellets, that are irradiated in the High Flux Isotope Reactor (HFIR) to produce ^{238}Pu. The neutron transmutation path for this process is shown in Fig. 1.

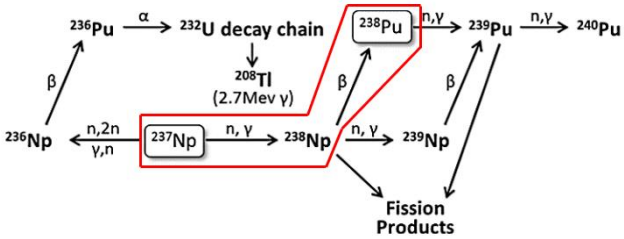

Fig. 1. Transmutation pathway for ^{237}Np to produce ^{238}Pu (Ref. 2).

Over the past 6 years, ORNL's cermet target has evolved from a research-based design to the current production design. This work describes the latest production-level capsule design.

II. CERMET PRODUCTION TARGET DESIGN

The cermet production target consists of a finned aluminum extruded tube that has aluminum–to–stainless steel bimetallic joint end terminators (Fig. 2); the latter of which were chosen to improve welding reliability. Note that the darker colored section of the transition joint seen in Fig. 2 is stainless steel and that the aluminum portion is lighter in color. The top transition joint is in the as-received condition, and the bottom joint had the aluminum flashing removed to reveal the bimetallic joint.

Fig. 2. Bimetallic transition joints – as-received condition (top) and joint with aluminum flashing removed (bottom).

A plenum space is machined into the top end terminator, referred to as the top end cap, which provides a volume to collect fission gas released from the cermet pellets during irradiation. This part is fabricated by drilling a blind hole into the top end cap, passing from the aluminum portion of the joint into the stainless steel portion. Machining such a deep blind hole can be a challenging operation but leaving a solid end on the part eliminates the use of a weld to form the plenum volume. The alternate bimetallic joint, which is referred to as the bottom transition, is machined into a tube. Both aluminum ends of the transition parts are welded to the finned aluminum extruded tube to form a target subassembly. Once in this condition, the subassembly is loaded with various internal components that include spacers, cermet pellets, dummy pellets, and a stainless steel closure plug. Figure 3 shows an image of the production target.

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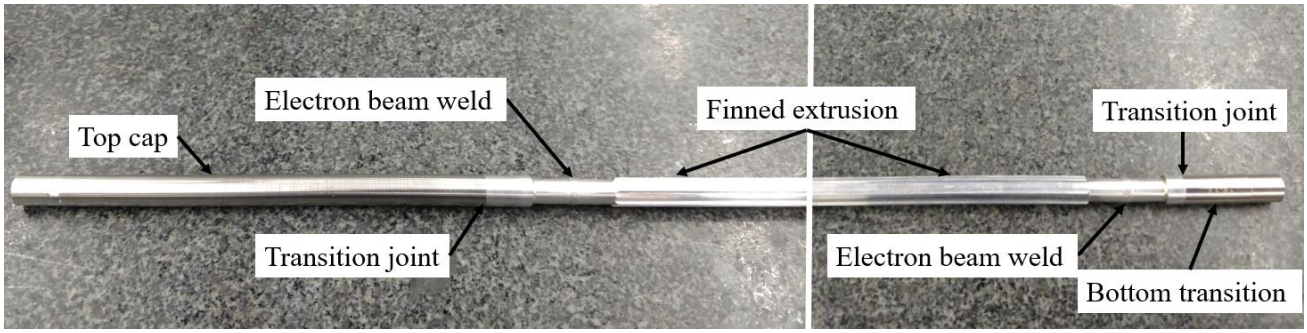

Fig. 3. Plutonium-238 Supply Program cermet production target.

An extensive development effort ensured that the described target format was reliable, reproducible, and capable of supporting the ambitious PSP annual production requirements. Areas of development included:

- Establishment of reliable weld processes,
- Optimization of internal component design features to simplify fabrication and assembly,
- Development of a quality assurance plan for receiving and accepting fabricated parts to reduce nonconformances without negatively affecting reactor safety protocols.

The remainder of this paper describes the work performed to meet these challenges.

II.A. Establishment of Reliable Weld Processes

The primary motivation for developing bimetallic transition joints for this work was to eliminate aluminum gas tungsten arc weld (GTAW) closure welds. Earlier target development work showed that performing this type of weld in a glove box was somewhat unreliable, and failure of the closure weld generally makes the target unusable. In contrast to aluminum alloys, Korinko and Malene (Ref. 3) showed that stainless steel alloys generally have good weldability under a wide range of conditions. Producing reliable stainless steel weld joints easily in a glove box with a GTAW process proved to be somewhat trivial. However, significant development was required to demonstrate the usability of the bimetallic transition joint.

Howard, et al, (Ref. 4) previously showed how bimetallic transition joints can improve fabrication or performance of irradiation capsules in HFIR. In these earlier capsules, safety analysts assumed the bimetallic joint would fail under off-normal conditions. However, these early capsules did not contain fissile material. This overly conservative assumption could not be made for the PSP cermet production targets, and irradiation testing was required to show that the bimetallic transition joint would not degrade during target irradiation. Howard, Gallagher, and Field (Ref. 5) showed that the limiting conditions for the transition joints were consistent with the weaker base metal (i.e., the aluminum alloy portion of the transition joint).

The final challenge for implementing bimetallic transition joints into the cermet production target was to develop a joining process to make repeatable hermetic weld joints between the finned tube and the transition joints. Historically, electron beam welding was the welding technology of choice for PSP target development, because the process has excellent welding control and is performed under vacuum, which greatly reduces the potential for oxide contamination and porosity formation at the weld site. However, early electron beam welding processes tended to generate large voids on either side of the weld joint (Fig. 4). This weld joint used a metallurgically compatible aluminum alloy to produce an autogenous weld that joined the aluminum finned tube to an aluminum end cap.

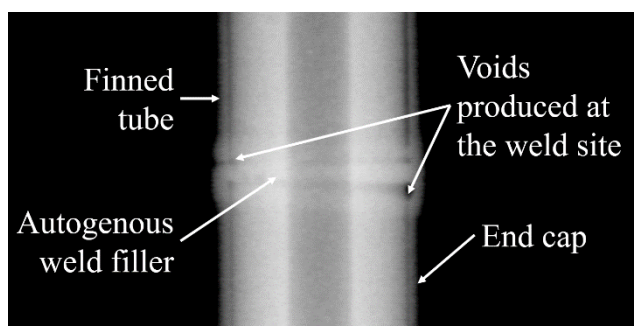

Fig. 4. Radiography of an earlier autogenous electron beam weld joint showing clear voids at the weld site.

These voids were problematic because, although the joint was hermetically sealed, the voids tended to collapse when the target underwent a required external hydrostatics collapse test, causing the target to fail. Substantial improvements to the high-voltage/high vacuum electron beam welding processes were implemented to eliminate these voids, and a subsequent weld process was qualified to support the PSP cermet production target efforts. Figure 5 shows an electron beam weld joint that was sectioned and etched to reveal weld sites (seen in dark gray) that have full wall penetration and are free of voids.

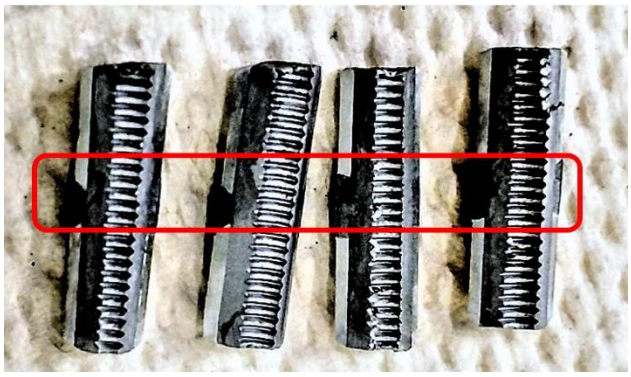

Fig. 5. Sectioned electron beam weld joint with weld site free of voids (circled in red).

II.B. Optimization of Internal Component Design Features to Simplify Fabrication and Assembly

Internal components of the cermet production target have specific functions to ensure proper irradiation performance and post-irradiation processing. Component optimization is then constrained to prevent negative impacts on cermet pellet performance, which includes ^{238}Pu production rates, thermal boundary conditions, target containment integrity, and several other criteria. An obvious concept for optimization was to minimize the geometric complexity of parts to simplify machining. This approach was used when designing spacers and weld joint geometries; these components have simple tubular geometries by design. However, the dummy pellet specifically ensures that the active pellet length does not apply axial stress beyond the relatively strong finned tube, as well as provides a visual feature to designate a cutting location for post-irradiation processing. Therefore, the part was optimized to be a simple tube with a rounded notch at the center of the part. This notch feature provides a recess that allows the finned tube to neck down without compromising the tube integrity. Given that the dummy pellets were located on either side of the pellet stack, these features lock the pellet stack in place within the finned tube region of the target while also providing a clear feature for post-irradiation cutting (Fig. 6).

Fig. 6. Collapsed finned tube with visible dummy pellet recess.

II.C. Development of a Quality Assurance Plan for Receiving and Accepting Fabricated Parts to Reduce Nonconformances without Negatively Affecting Reactor Safety Protocols

A fundamental component of a successful production process is an adequate quality assurance plan. This generally includes processes for performing dimensional inspection, establishing various acceptance criteria, etc. For a target to be accepted for irradiation in HFIR, a detailed package must be generated to demonstrate that various safety requirements are met and documented in accordance with the American Society of Mechanical Engineers Nuclear Quality Assurance (NQA-1) program. Given that ORNL is a research institution that is not well poised to fabricate and weld targets on a production scale, outside vendors are relied on to perform these duties. Thus, appropriate processes for receipt inspection and vendor qualification are required to ensure that reactor safety protocols are met.

Historically, as part of fulfilling these requirements, the generic approach to receiving parts fabricated by outside vendors was to perform full inspection of all machined dimensions on all parts. Again, the volume of parts was generally not commensurate to that of a production facility, making this approach palatable to sponsor programs. This is not the case for the PSP, so a less orthodox approach was needed to ensure success.

The process established for the PSP dictated that dimensional inspection would be separated into safety-critical and design-critical dimensions. Generally, design-critical dimensions greatly outnumber safety-critical dimensions. Also, the former set can be verified over the course of the target assembly process, or by fit-up testing, whereas the later set must be formally inspected and documented by qualified inspectors. By creating a distinction between these two types of dimensions, the PSP can expedite the receipt inspection and dimensional inspection process by formally inspecting a small subset of safety dimensions, while proceduralizing the fit-up testing for the design-critical set. This approach also reduces the number of nonconforming parts, which improves the process for accepting parts while not reducing the overall effectiveness of the quality assurance program.

This plan was implemented by the PSP earlier in FY 2018. The target fabrication team was tasked with producing 63 targets divided into two sets; the initial 35 targets used the conventional “full inspection” approach, and the latter 28 targets employed the modernized inspection/acceptance approach. The first set had nonconformances on virtually all targets, whereas the second set had none, although both sets were functionally equivalent.

III. CONCLUSIONS

The ^{238}Pu Supply Program managed by Oak Ridge National Laboratory has established a robust cermet production target design. This irradiation vehicle includes many advanced welding and design features that ensure fabrication, assembly, and weldability of the target. ORNL also has instituted a modern quality assurance program for accepting and inspecting target components. The program has improved the receipt inspection and target fabrication processes resulting in a reduction of the number of nonconformances to zero for the latest assembly campaign. Furthermore, these design improvements have reduced part fabrication time and target loading time, thereby improving the overall efficiency of the PSP production facility. These efforts show real progress for the PSP and demonstrate its ability to replenish domestic ^{238}Pu stockpiles at prescribed annual rates to support future space exploration.

ACKNOWLEDGMENTS

The author would like to acknowledge Roger Miller, Alan Frederick, Doug Kyle, and Dan Mobley for their invaluable assistance in weld development for this work. Funding for this program is provided by the National Aeronautics and Space Administration through the U.S. Department of Energy, Office of Nuclear Energy.

A portion of this research used resources at the High Flux Isotope Reactor, a DOE Office of Science User Facility operated by Oak Ridge National Laboratory.

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