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THERMAL ENHANCEMENT CARTRIDGE HEATER MODIFIED (TECH MOD) TRITIUM HYDRIDE BED DEVELOPMENT. PART I – DESIGN AND FABRICATION

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The Savannah River Site (SRS) tritium facilities have used 1st generation (Gen1) $LaNi_{4.25}Al_{0.75}$ (LANA0.75) metal hydride storage beds for tritium absorption, storage, and desorption. The Gen1 design utilizes hot and cold nitrogen supplies to thermally cycle these beds. Second and 3rd generation (Gen2 and Gen3) storage bed designs include heat conducting foam and divider plates to spatially fix the hydride within the bed. For thermal cycling, the Gen2 and Gen 3 beds utilize internal electric heaters and glovebox atmosphere flow over the bed inside the bed external jacket for cooling.

The currently installed Gen1 beds require replacement due to tritium aging effects on the LANA0.75 material, and cannot be replaced with Gen2 or Gen3 beds due to different designs of these beds. At the end of service life, Gen1 bed desorption efficiencies are limited by the upper temperature of hot nitrogen supply. To increase end-of-life desorption efficiency, the Gen1 bed design was modified, and a Thermal Enhancement Cartridge Heater Modified (TECH Mod) bed was developed. Internal electric cartridge heaters in the new design to improve end-of-life desorption, and also permit in-bed tritium accountability (IBA) calibration measurements to be made without the use of process tritium. Additional enhancements implemented into the TECH Mod design are also discussed.

I. INTRODUCTION

For nearly 20 years, the Savannah River Site (SRS) Tritium Facilities have used metal hydride storage beds[1,2] with up to 12.6 kg of $LaNi_{4.25}Al_{0.75}$ (LANA0.75) for process gas absorption, storage, and desorption. The 1st generation (Gen1) storage bed design contains metal hydride with a 3 inch NPS schedule 40 pipe process vessel (PV). The Gen1 beds utilize thermal cycling with hot and cold nitrogen, inside a larger pipe vessel that contains the PV, for gas desorption and absorption.

Decay of tritium to He-3 alters the pressure-composition-temperature (PCT) properties of the LANA0.75 alloy[3] and results in reduced operating capacity forcing periodic bed replacement. Rather than replace degraded Gen1 beds with new beds, an improved bed has been designed, fabricated and cold (e.g. non-rad) tested. This paper describes the design features of a prototype Gen1 replacement. Addition of thermal enhancement cartridge heaters modified the Gen1 bed design lending to "TECH Mod" describing the improved Gen1 replacement bed design.

Second and third generation (Gen2[4] and Gen3[5]), bed designs have internal metal foam for improved heat transfer. The foam, along with solid metal divider plates, also compartmentalize and fix the hydride within the bed to prevent potential unacceptable PV wall stress when the hydride swells during gas absorption.[6] Currently, the Gen2 and Gen3 beds are not replacement options for the Gen1 beds, but their design enhancements over Gen1 beds were incorporated into the TECH Mod bed design.

II. BACKGROUND

The Gen1 bed PV is 0.91 m (3 feet) long, and shown in Figure 1 by the white material filled inner boundary. The outer boundary, with large flanged nozzles, is the jacket portion of the bed used for PV thermal swing. The process gas connection occurs through a nozzle, visible top left in Fig. 1, shared by the jacket and PV. Gen1 bed assembly steps include containment fabrication per ASME B&PV Code requirements, filling with the LANA0.75 hydride through the process gas nozzle, and a sequence of tilts and rotations is performed to evenly distribute the hydride within the bed. Final hydride distribution is verified using a borescope or radiography, as was done to generate the radiograph in Fig. 1.

After hydride leveling, the bed must be kept in the same orientation to maintain the level condition until process installation. Hydride swelling during gas absorption produces PV wall stresses that increase with level of fill. Bed tilting prior to final installation may result in hydride redistribution that may result in stresses during gas absorption that exceed ASME design limits. [6] Elimination of orientation maintenance after bed assembly would be a significant design enhancement.

Each Gen1 bed must have its own in-bed accountability (IBA) calibration curve for inventory measurements.[2] For IBA calibration curve generation, a bed is loaded with various amounts of tritium and the steady-state temperature rise of gas is measured for the gas supplied. Generation of the IBA curve for each bed requires multiple movements of large quantities of high purity tritium through the facility with both potential safety and accounting issues. Calibration without tritium would be a major improvement over the Gen1 design.

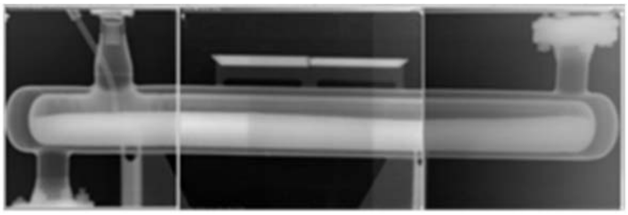

Figure 1. Typical Gen1 bed composite radiograph

When a bed containing LANA0.75 requires removal from service due to aging, the bed undergoes an extended desorption to extract gas to the extent possible. The maximum desorption temperature of the Gen1 bed is limited by the hot nitrogen supply temperature. Typically, measureable quantities of tritium remain on the bed after desorption due to insufficient heating. Extraction of the residual tritium gas is performed with several isotopic exchanges[7] before the bed is removed from the process. Elimination or reduction of the number of isotopic exchanges at the end of a bed's service life would be a significant enhancement over the Gen1 design.

III. BED DESIGN AND FABRICATION

The TECH Mod design of a replacement for the Gen1 hydride bed was developed to include compatibility with existing hard-piped glovebox process and structural connections. Design modifications to eliminate hydride leveling, improve heat transfer, increase heating temperature for improved desorption efficiency, and IBA calibration without the use of tritium were primary TECH Mod design goals. In comparison to the Gen1 physical design features, the TECH Mod bed has different materials of construction, temperature monitoring, heat application, and PV cavity partitioning. Each of these design modifications enhances bed performance, operational efficiency and/or vessel structural capacity. Figure 2 includes a schematic of the TECHMOD bed PV design with numeric denotation of Gen1 modified features. The modifications included: 1-single central full bed length thermowell, 2-two cartridge heater heaterwells, 3-cylindrical gas filter, 4-heat transfer foam, 5-divider plates, 6-flat end cap for heaterwell and thermowell insertion, 7-heat transfer fins. The remaining discussion includes reasons and benefits for the modifications.

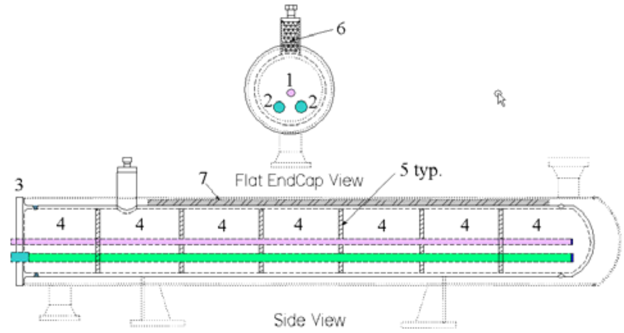

Figure 2. TECH Mod bed design

One TECH Mod design change, not enumerated in Figure 2, is the PV material of construction. The PV is the process gas containment, and, for ASME design, the material selected must account for all design loadings (e.g., pressure, temperature, hydride swelling, corrosion, embrittlement, erosion, and structural loads due to operational and external sources). Since the Gen1 PV 316L stainless steel material has an ASME maximum temperature limitation of 454ºC (850ºF), a different PV material was necessary to withstand a service end-of-life maximum desorption temperature expected to approach 800ºC (1472ºF). Review of elevated temperature strength properties, creep resistance, corrosion resistance, hydrogen embrittlement resistance, process compatibility, ease of fabrication, availability and cost was performed for several candidate alloys. Nickel alloy UNS #N06625, grade 2, was selected as the PV containment boundary material based on good performance for all qualities considered. The high strength properties of the N06625 alloy permitted the use of a thinner wall schedule 10 PV to replace the same Gen1 PV pipe. The reduced wall thickness resulted in a much greater cavity volume (TECH Mod=4.95L, Gen1=4.16L) to accommodate volume occupied by heat transfer foam, small tubes for heaters and thermocouples, and components that may improve bed performance. PV portions not required for containment were selected as nickel alloy UNS #N06600, which, despite reduced creep strength, has good high temperature performance and is compatible with N06625 and 304L stainless steel jacket materials.

After high temperature PV material selection, the addition of electrical cartridge heaters to the design was possible. Cartridge heater usage has two benefits. First, the electric heaters facilitate In-Bed Accountability (IBA) calibration data measurement without using tritium. This permits IBA testing to be performed away from the process glovebox, which is also beneficial. The second benefit is related to bed service end-of-life when bed gas inventory is removed prior to final disposition or disposal. The electric heaters permit heating to a temperature much higher than possible with the Gen1 nitrogen gas system.

Higher exposure temperature removes more gas from the bed and minimizes isotopic exchange steps required to reduce residual tritium content to acceptable levels The heaters will be placed inside two N06625 heaterwells designated by “2” in Figure 2. Bed temperature is monitored using a thermocouple that extends the full length of the PV inside a N06625 thermowell, located in the center of the PV. Note that the full bed length temperature indication of this design is superior to the Gen1 design where temperature is only monitored below the process gas nozzle. Penetration of the bed jacket and PV with the heaterwells and thermowell resulted in the need for an endcap shared by the jacket and PV to avoid differential thermal expansion problems during gas absorption/desorption cycling. Shown as “3” in Figure 2, the sharedcap is part of the primary process pressure boundary, and fabricated from N06625 material.

The SRNL Gen2 and Gen3 bed designs use heat conducting aluminum foam inside the PV to improve heat transfer rates and reduced cycle time. As indicated by “4” in Fig. 2, the TECH Mod design utilizes foam between “5” divider plates to create cells within the PV cavity. The Gen2 and Gen3 designs utilized solid metal divider plates to create cells of hydride within the bed rather than a single large hydride mass as present in the Gen1 PV open cavity design. Process gas communication between cells was achieved by using a single porous metal filter tube to penetrate through all cells. The TECH Mod bed uses porous metal divider plates to permit free gas flow between cells, and remove the need for the bed length filter tube. The combined use of divider plates with foam eliminates the post fill leveling step, as the divider plates, while porous to permit gas flow through the plates, serve as solid partitions against hydride migration between cells. The 3-dimensional foam porosity effectively fixes the hydride in the as-filled condition to also eliminate leveling with orientation maintenance. In contrast to the Gen2 and Gen3 aluminum foam, copper foam with a melting point of 1080ºC (1980ºF) was used based on a maximum end-of-life temperature in excess of the aluminum melting point of 660ºC (1220ºF).

The final TECH Mod design was a combination of improvements based previous bed experience data, and re-engineering to meet new design limits. For design verification, and process verification, a prototype TECH Mod PV was fabricated as shown in Fig. 3. For performance testing purposes, PV fins and surrounding jacket pipe with mounting legs were omitted, as these features did not require demonstration. Fabrication of the prototype included full weld inspection with radiography, and dye-penetrant testing per ASME requirements. Bed item fabrication and joining of the different alloys was completed without difficulty.

Figure 3. As-built prototype without jacket

Addition of bed internals and hydride was completed after component fabrication and testing. During addition of the internals, the flat end cap was the only PV pressure boundary item not present. Internal items were installed through the top cap opening of a vertically mounted PV, with the thermowell and heaterwell tubes placed in the PV cavity after filling the round PV head with foam. The tubes served as guides for holes in the foam and divider plates. Each cell was assembled by adding foam, pouring in a pre-measured quantity of hydride, exciting the PV with a rubber mallet to get the hydride into the foam, and addition of a divider plate to complete the cell. The foam, dividers and tubes were fabricated to have a 0.05-0.10 inch interface gap to ensure easy fit-up during assembly. After the bed internal assembly was complete, the flat end cap was welded in place, and the bed subjected to pneumatic testing per ASME. Prior to activation of the hydride, a set of radiographs was collected for the bed to serve as a record of hydride position in the cells.

IV. RESULTS

The pursuit of a replacement for a Gen1 tritium storage bed, has resulted in the “TECH Mod” design which has significant design improvements related to installation, operation and final disposition. Major changes including materials of construction, heating method, temperature monitoring, and heat transfer features have been fabricated and successfully tested. The resulting design serves as a direct replacement for existing Gen1 beds, and has significant additional capability due to increased design limits and pre/post-operational flexibility. All improvement goals related to elimination of hydride leveling, elimination of tritium based IBA calibration, and higher temperature end of service life desorption to reduce isotopic exchange have all been met to establish the final TECH Mod design. Performance testing of the prototype bed has been completed and documented separately [Ref. 9].

V. DISCUSSION

While not originally an intended function of divider plates and foam, hydride fixity in the as-installed position is a significant improvement over the Gen1 bed. Figure 4 shows two radiographs taken more than one year apart with the PV oriented such that gravity acted from the rounded cap toward the flat cap, or down in the figure. The left PV image was generated immediately after assembly. The right PV image was taken after operational testing more than a year later. Each PV image in figure 4 resulted from connection of 3 x-ray film pieces. Both images are shown with inverted contrast to accentuate the position of the hydride material. While not readily apparent from the small figures, the light/dark PV in-cell boundaries correlate to hydride position and are nearly identical for the two images, indicating that hydride movement was insignificant. It should be noted that the light and dark areas do not indicate complete volume fill or void space. The radiographic images show light/dark contrast based on differences in density. Light areas indicate lower density, and dark areas greater hydride density. The shape of the light dark areas is consistent with the pouring of material along one side of the PV during assembly resulting in a greater density along the pour side and upper portion of the cells due to filling in the opposite vertical orientation. The light/dark boundary shows how the 3-dimensional cell structure of the foam supports the hydride against gravity, and essentially locks it in place. Additional radiographs showed no agglomeration of hydride between the process nozzle and tube filter, and the 0.05-0.10 inch clearance used at interface locations (e.g., between divider plates and PV) was sufficiently small to minimize movement of hydride between cells.

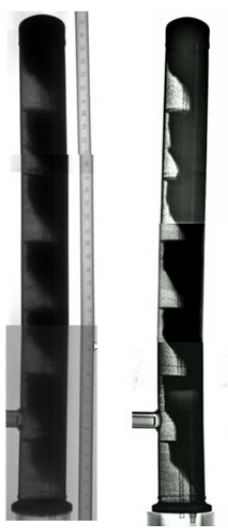

Figure 4. TECH MOD radiographs before (left) and after (right) activation

VI. CONCLUSIONS

The TECH Mod hydride bed design replaces currently installed Gen1 beds without any modification to facility operating equipment or services. The new design is superior to Gen1 in regard to handling flexibility, calibration, and final disposition. Technical attributes and cost justify facility implementation of the TECH Mod beds for replacement of Gen1 beds.

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