Contract No:

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SR18001 – Induction Heating for Tritium Storage Beds

Facility Need

Metal hydride beds used for storing hydrogen isotopes at the Savannah River Site are conductively heated and cooled to desorb and absorb gases during storage cycling. While several storage bed configurations have been utilized over the years, many achieve heating by utilizing electric cartridge heaters positioned laterally along the longest axis of the storage bed (FACE Gen 2 Beds). Others achieve heating and cooling through hot and cold nitrogen flow (Gen 1 Beds). While these beds/heating configurations are well-designed for storage cycling operations, it is unclear if they can be regenerated to operating conditions once too much helium has accumulated in them. Full regeneration of hydride beds occurs around 625 – 650 °C. It is unclear if the currently employed electric cartridge heaters in Gen 2 beds can reach these temperatures. Furthermore, since swelling can occur during routine heating operations, it is unclear if existing cartridge heaters in Gen 2 beds can be swapped for higher-power cartridges that can reach 625 – 650 °C . Similarly, nitrogen air flow (to the best of our knowledge) cannot cause Gen 1 beds to reach these temperatures. **Thus, existing Gen 1 and Gen 2 beds need to be heated through an alternative method to removal helium, so the beds can either return to normal operation or be disposed of.**

Potential Benefits

☑ Cost Reduction	☐ Defect Reduction	☐ Error Reduction	☐ Mission Diversification
☑ Mission Viability	☐ Obsolescence Solution	☑ Process Optimization	☐ Safety

Project Summary

The goal of this PDRD was to investigate if induction heating can be used for various heating processes involving hydride storage beds (e.g. regeneration, gas cycling, helium heel removal). In the original call for proposals, this PDRD fell under "Gas Processing" area of interest # 3: "Develop methods to deploy alternate ways to heat existing process equipment to minimize impact to glovebox environment."

After two years of experiments and computational modelling focused on developing induction heating methods to allow for controlled heating inside of existing storage beds using induction coils placed on the outside of the beds, we believe we have uncovered a pragmatic path to heating existing storage beds for regeneration, helium heel removal, and possibly routine gas cycling operations. Our technique involves low-frequency (< 100 Hz) induction heating through flexible solenoid coils (see Figure 1).

SR15010

Status

Started in FY18. Continued in FY 19.

Technology Readiness Level

Start of FY18:	1 - 2
End-of-FY19 Forecast:	4 - 5
End-of-FY19 Actual:	4 - 5

Financial

FY15 Project Cost:	$120,000
Cumulative Total Project Cost:	$232,000
FY19 Authorized Amount:	$120,000

Credits

Principal Investigator: Jonathan Christian
Facility Engineering Co-Lead: Zechariah Trotter
Contributors: Matthew Kesterson, Kaitlin Lawrence, Klaehn Burkes, Dean Thompson

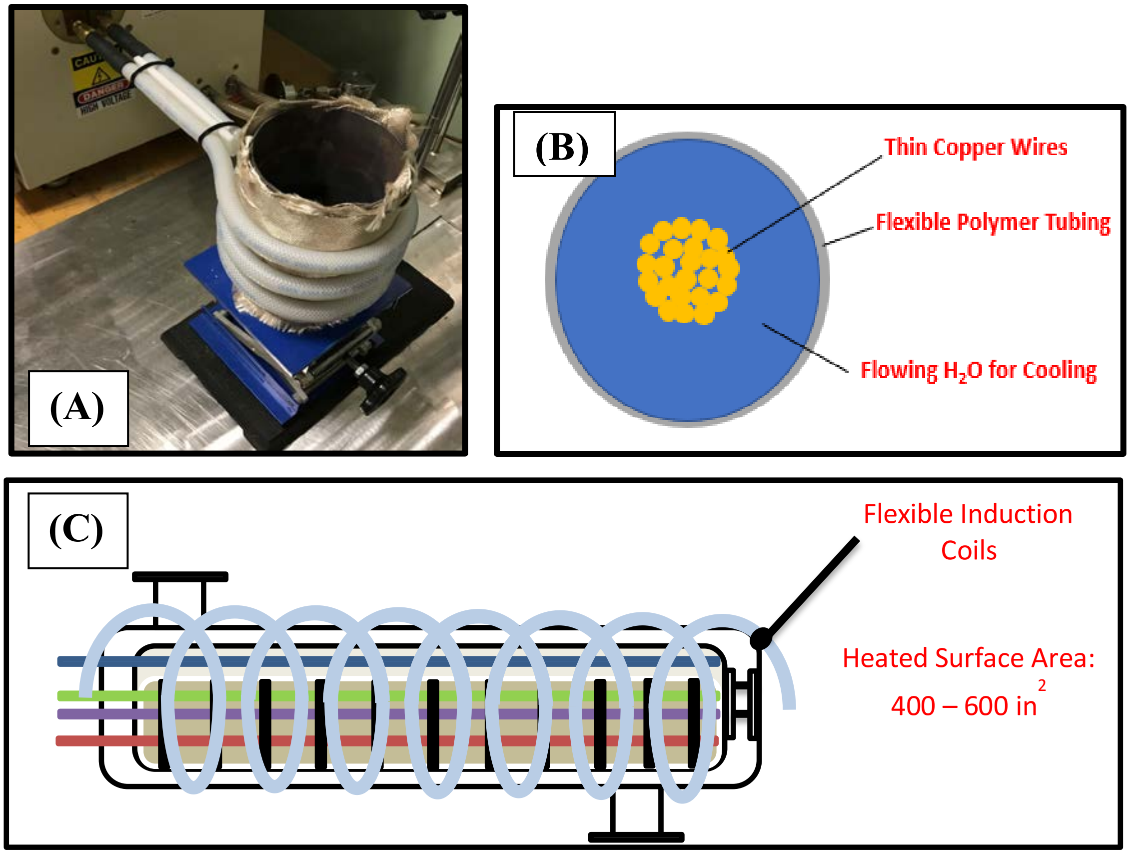

Figure 1. Flexible induction coils allow existing tritium storage beds to be conveniently set up for induction heating. (A) A flexible induction heating coil is used in heating experiments on a Sch. 10, 4" OD, 304/304L stainless steel pipe (similar to the outer jacket used in both Gen 1 and Gen 2 storage beds). (B) Graphic showing the cross-section of a flexible induction coil (C) Graphic showing how a flexible solenoid coil could be positioned on the outside of a tritium storage bed. Because the coil can cover the entire outer surface of the storage bed, the surface area that can be heated is large compared to beds that utilize cartridge heaters.

Although induction heating is energy efficient and fast, heating typically occurs at the surface closest to the induction coils. This surface heating, known as the "skin effect", manifests in both high and middle alternating frequency ranges. A major downside of surface-heating tritium storage beds is that surface temperatures would likely need to be significantly higher than 625 – 650 ^{o}C for the center of a storage bed to reach these temperatures. Prolonged heating of stainless steel above 700 ^{o}C can induce unfavorable changes that could disqualify a storage bed's outer jacket and process vessel from being used for tritium operations.

To deliver induction heating to the center of storage beds - near LANA and heat-transfer foam – it is necessary to apply very low AC frequencies. At frequencies less than or equal to 100 Hz, the penetration depth of the induction heating is significantly increased. Thus, solenoid induction coils placed on the outside of a tritium storage vessel can be used to deliver significant heat to the center of the bed to induce gas desorption and regeneration. This form of targeted heating should prevent any metal components in a storage bed from exceeding a temperature at which they are disqualified for use in tritium operations. Furthermore, because induction heating is so rapid, and the heat source (the coils) is not actually hot, the central components of a storage bed could be heated and cooled very quickly, thus limiting potential material changes that can manifest due to prolonged heating at high temperatures.

Unfortunately, low-frequency induction power supplies are not commonplace. Thus, we have been unable to experimentally validate our computational findings so far. However, we have performed numerous preliminary experiments at higher frequencies and we have rigorously modelled our low-frequency approach using Multiphysics software (see Figure 2). At the end of FY19 we began working with several vendors to determine if a low-frequency power supply could be developed to mimic our computational results. After some searching, the engineering team at Inductotherm Corp. ran independent evaluations and simulations based on generalized information that was provided to them, and they deemed it feasible to build a power supply to meet the criteria outlined in our simulations. Their 50-kW instrument can deliver AC frequencies of 60 – 100 Hz and has been quoted at $ 100 k. As of 9/20/2019, we are awaiting a quote from one other company.

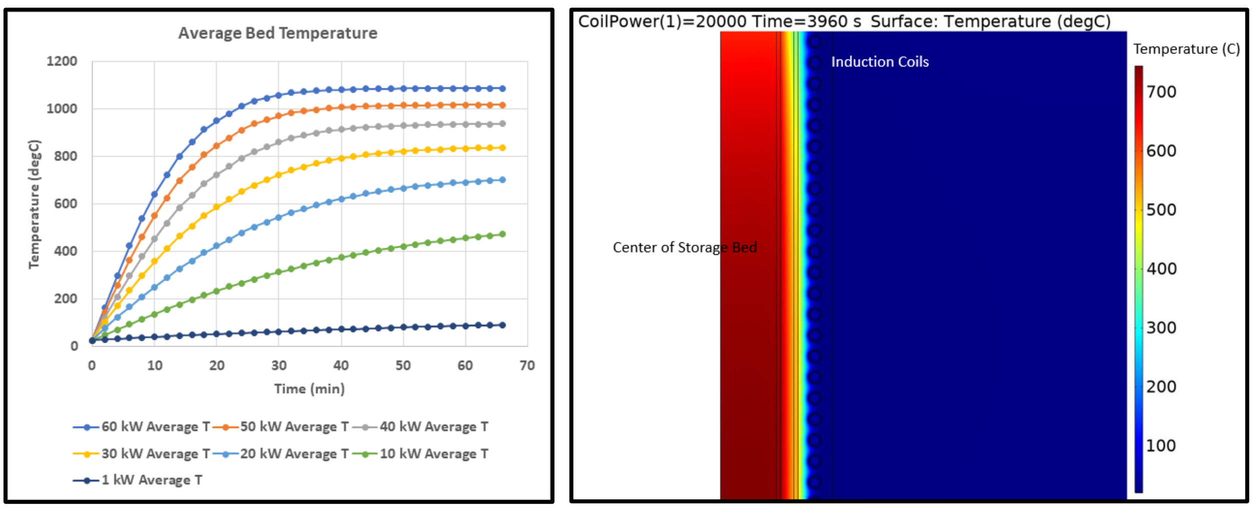

Figure 2. LEFT: Average temperatures of the center of a full-scale storage bed were modelled and are plotted as a function of time and various induction powers. The employed induction frequency was 80 Hz. Steady-state temperatures are reached within 40 – 60 minutes for all power levels. **RIGHT:** Cross-section of a full-scale storage bed after 66 minutes of heating at 20 kW and 80 Hz induction. The low-frequency can deliver impressive heating directly to the center of the storage bed, thus preventing the outer bed components from becoming so hot that they can no longer be used in a tritium facility.

In summary, induction heating is both rapid and energy efficient. The technique has large utility and can be performed using flexible coils operating at a specific frequency to deliver induction heat at a specific location within a complex component thereby allowing for a variety of applications. In two years, our PDRD has progressed from feasibility determination to technology development; we have submitted an invention disclosure that details our progress. Future work should focus on evaluating site-specific heating of a storage bed using a low frequency induction heating system with a flexible induction coil that can be easily tailored to fit complex geometries.

Milestones/Findings/Accomplishments

Project Milestone	Expected End	Actual End
Computationally evaluate different storage bed and induction heating coil configurations and material types	2/28/19	2/1/19
Extensive low-frequency modeling of existing storage beds	5/31/19	6/3/19
Design novel heating configuration and evaluate vendors to provide necessary equipment	9/1/19	9/20/19
Submit year-end report/project summary	9/27/19	9/23/19

Future Work

1. Procure and install a low-frequency induction power supply (20– 24 weeks)
2. Perform preliminary testing and diagnostics on low-frequency instrument (6 – 12 weeks)
    a. Tests will include heating experiments using infrared radiometry to evaluate heating of simplified storage bed components (i.e. stainless-steel pipes assembled in a similar configuration to a storage bed but without welds)
3. Perform heating tests using a full-scale storage bed (6 – 12 weeks)