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Radioisotope Power System Cask Trailer Chiller Low Heat Load Study

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SUMMARY

This report documents the study of the Radioisotope Thermoelectric Generator Transport System (RTGTS) chillers capability to transport a Radioisotope Power System (RPS) with low heat loads in the cask.

Tests of the RTGTS chillers included setting the glycol/water (coolant) temperature to a control set point of 40° and 60°F while applying heat loads ranging from 2500 to 0 W heat load. The tests performed showed that the chiller systems could handle the entire range of heat loads. However, a noise/vibration started to occur when the set point was 60°F with low heat loads.

Three recommended changes to the RTGTS chillers are recommended with varying implementation windows. The first is an operational change that can be implemented immediately. The RTGTS chillers should have a set point of 40°F when transporting an RPS less than 1500 W. The second is a short-term change (within the next two years) augmenting RPS heat by utilizing one RTGTS onboard heater (2500 W) while transporting an RPS with less than 1500 W which will also require a change to the Instrument and Data Acquisition System (IDAS) to allow monitoring and possible control of power to the onboard heaters. However, if the heater does fail during transport, no emergency actions or immediate repairs will be required due to the chillers' ability to handle low heat loads. Running a 2500 W heater when transporting low heat loads aids in prolonging the life of the chillers.

The remaining recommended long-term change is to replace the current chillers with a new portable or permanently installed chiller system in the next five to ten years. This time frame takes advantage of the proven reliability and durability of the current chillers while the new chillers are phased in and proven to the RPS program.

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FIGURES

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ACRONYMS

BTU	British Thermal Unit
HGB	Hot Gas Bypass
IDAS	Instrument and Data Acquisition System
RPS	Radioisotope Power System
RTG	Radioisotope Thermoelectric Generator
RTGTS	Radioisotope Thermoelectric Generator Transport System

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1. Scope and Brief Description

The RTGTS was originally designed for transporting the General Purpose Heat Source (GPHS) Radioisotope Thermoelectric Generators (RTG) in the 9904 casks. The RTGTS contains two chillers (a primary and backup) which are used to provide a chilled water/glycol (coolant) mixture to the cooling loops (qty 2) on each of the 9904 casks.

The cooling system was designed to remove continuous high heat loads (25,600 BTU/Hour or 7,327 Watts) making it more susceptible to component failure or operation anomalies if operated with a low heat load. The system was originally designed with a large mechanical Hot Gas Bypass (HGB) line and a much smaller electrically actuated HGB for temperature control which was modified to a single large electrically actuated HGB to increase the chillers' controllable range. The HGB diverts the hot high-pressure refrigerant around the condenser injecting it just before the evaporator effectively reducing the system efficiency and capacity. There was a concern that under extremely low heat loads the HGB would increase the compressor inlet temperature overheating the compressor windings.

A test of the chiller was conducted to determine the lowest wattage (heat load) that could be transported without additional upgrades or replacements to the chiller system. This test started applying a 2500 W heat load and incrementality stepped it down by 500 W to a 0 W heat load to simulate various RPS heat load scenarios.

2. Discussion/Analysis

Technical data could not be acquired from the vendor to perform an analytical analysis due to the age of the chillers. This report documents the results of testing the chillers at various heat loads and provides recommendations for transporting low thermal output RPS(s).

A multistep process was taken when testing the chillers. Four, 500 W heaters were installed in series in the coolant loop in line with the three permanently installed 2500 W heaters. With these heaters installed the coolant flow remained the same due to the installed automatic flow limiting K valves. Before any of the heaters were turned on, the coolant temperature was set at 40°F. Eight thermocouples were attached to various locations of the chillers which included the compressor discharge, compressor suction, top of compressor, cooled coolant, heated coolant, evaporator suction, evaporator vacuum and the HGB line. The temperatures of these locations were recorded for the duration of the test. Initially the four 500 W heaters were turned off with one of the 2500 W heaters turned on. The temperature at each tested heat load was allowed to stabilize while collecting data before the next test heat load was established. This process was completed for 2500, 2000, 1500, 1000, 500, and 0 W heat loads using combinations of heaters. Typically, it would only take the system a couple minutes for the temperatures to settle out when changing the heat load, but the system was left running at a set heat load for at least ten to fifteen minutes ensuring that the system was at equilibrium. The four 500 W heaters allowed the test to be stepped down in 500 W increments while monitoring of the system temperatures for signs of overheating. The entire process was then repeated with the coolant temperature set at 60°F. Figure 1 shows a one-minute snapshot of system temperatures stabilized with a 2500 W heat load and coolant temperature set at 40°F. Figure 2 shows the same condition with a 0 W heat load showing little temperature differences between these two heat loads. For comparison, Figures 3 and 4 show the results from the same heat loads as Figures 1 and 2 but with a coolant temperature set at 60°F.

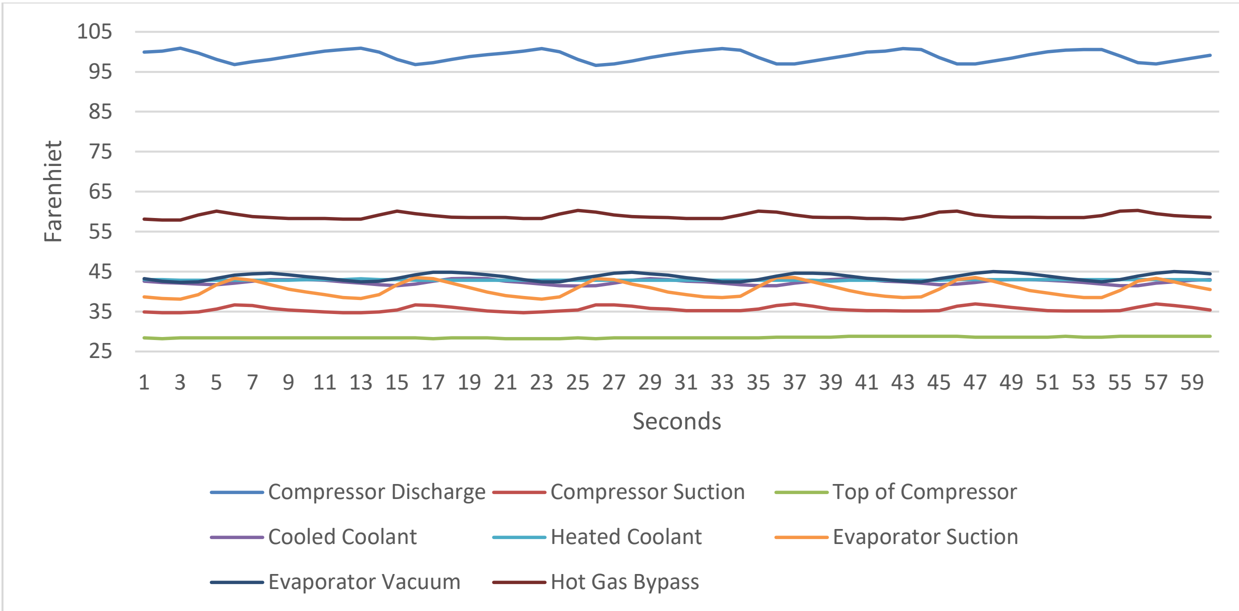

Figure 1. 40°F coolant set point with 2500 W heat load.

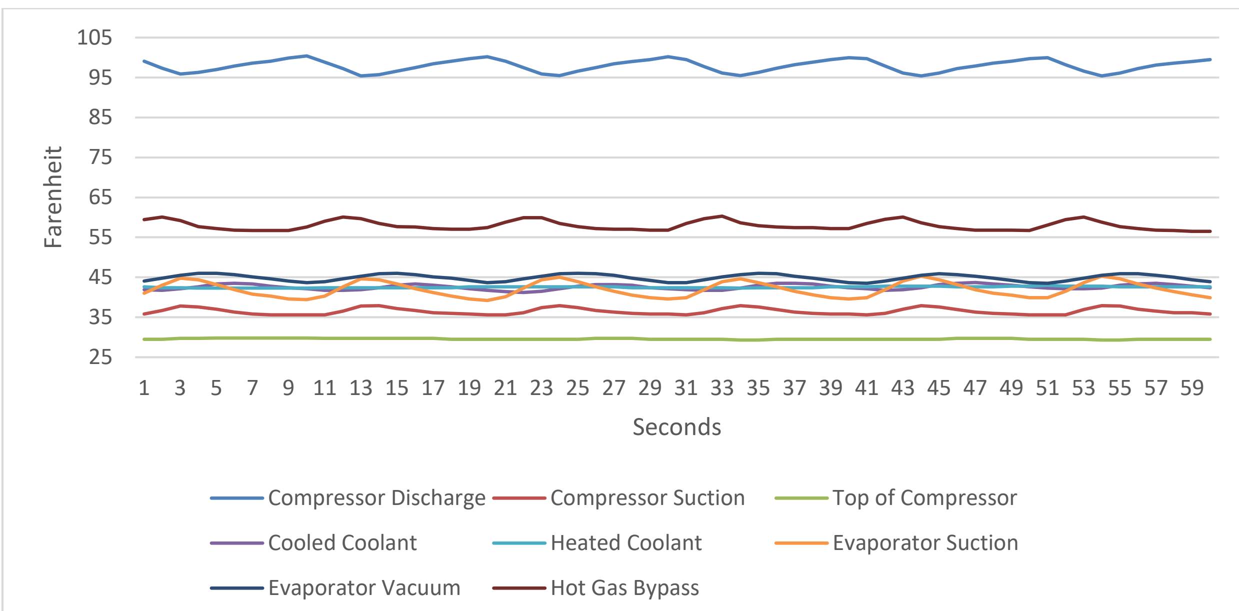

Figure 2. 40°F coolant set point with zero added heat load.

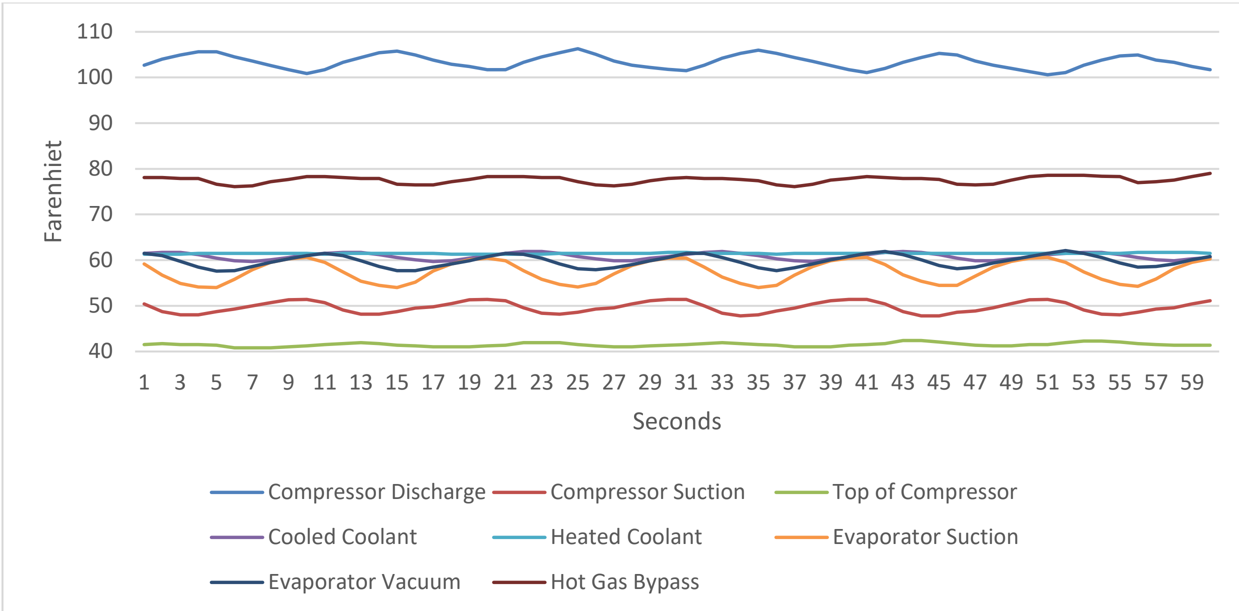

Figure 3. 60°F coolant set point with 2500 W heat load.

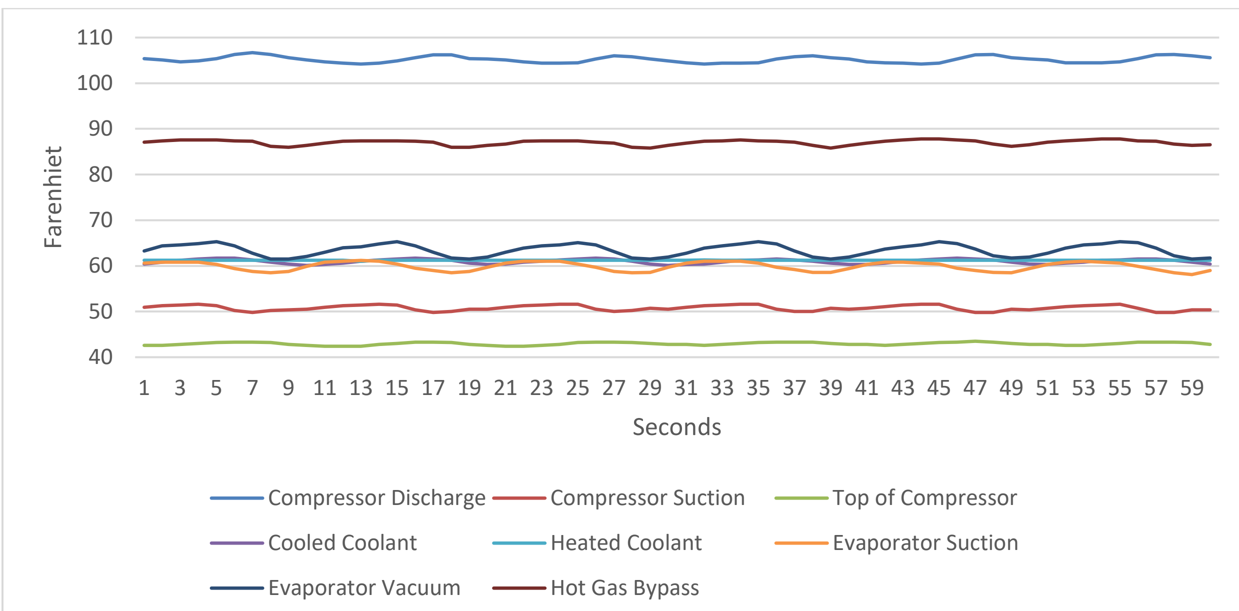

Figure 4. 60°F coolant set point with zero added heat load.

The compressor discharge temperature was closely monitored to ensure it would not exceed 200°F which was determined based on research of similar compressors. The discharged temperature of the compressor never exceeded 110°F even with no heat load; however, the HGB valve would cycle open more frequently and for longer durations compared to a 2500 W heat load. The more that the HGB cycled on, the HGB line would get hotter, reaching up to 90°F at one point. It was also noted that the temperature variations throughout the chillers would not be significant even with the HGB cycling on more frequently.

A noise/vibration was noticed every time after the HGB valve opened when the coolant set temperature was 60°F with low heat loads. It was not determined where this was occurring or why it was occurring. However, noise/vibration only occurred when vapor was present in the high-pressure liquid line, as observed through the sight glass installed on that line. This noise/vibration would gradually increase as the heat load was further decreased. When the high-pressure liquid line remained completely liquid, the noise/vibration was not present. Further investigation is needed to determine the cause and location of the noise/vibration. A coolant temperature setting no higher than 40°F is recommended while transporting heat loads of 1500 W or less.

The testing demonstrates that the chillers can handle no additional heat load with a coolant set temperature of 40°F. It is recommended to run one of the installed heaters (2500 W) if the planned 9904 cask contents contain a heat source that is at or below 1500 W. This is important because in refrigeration systems, heat plays a crucial role in maintaining functionality and preventing breakdowns. It ensures proper compressor lubrication, prevents frost buildup, aids in oil separation, avoids condensation, and facilitates efficient heat exchange. The Instrument and Data Acquisition System (IDAS) should be updated as well to allow monitoring of power to the onboard heaters and provide alarming capability if heater power is lost. However, if a 2500 W heater did fail, no emergency actions or immediate repairs would be warranted. Because of the RTGTS current configuration, these heaters could quickly be incorporated into the trailer's operation configuration when transporting low heat sources. Operating these heaters during transport would keep the cask and heat source at a reliable constant temperature and keep the chillers functioning as designed. The cost for this change is approximately $20,754 as documented in Cost Estimate Report ID: 139885. Cost breakdown is shown in Figure 5.

Activity	Cost
Design (Drawings/Software/Procedures)	$11,342
Installation/Testing	$7,593
Parts/Procurement	$1,819
Total	**$20,754**

Figure 5. Cost to install alarm system for the trailer heaters.

There have been few issues with the reliability and durability of the current aging chillers. Hence the inability to find specification sheets for parts. Additionally, the specified refrigerant (R-22) is no longer produced and is becoming more difficult to obtain. Water cooled chillers typically have a life cycle ranging from 20 to 30 years and the current chillers have close to a 30-year service life. Even though there have been relatively few problems with the chillers up to this point, it is anticipated that these chillers will eventually need to be replaced with a more modern system. It is recommended that the long-term change to replace the current chillers with a new portable or permanently installed chiller system. This time frame will take advantage of the proven reliability and durability of the current chillers while the new chillers are phased in and proven to the RPS program.

3. Conclusion

The results of the testing described above demonstrate that when the coolant on the RTGTS has a set temperature of 40°F the chillers can handle no additional heat load. However, when the coolant has a set temperature of 60°F with low heat loads a noise/vibration will start to occur. The immediate recommended change, if no additional heat is applied, is that 60°F coolant set temperature is not used with heat loads at or below 1500 W but instead have the coolant set point at 40°F. The short-term recommendation is to operate an IDAS monitored 2500 W heater if the heat load was at or below 1500 W. If the 2500 W heater was to fail during transport no emergency actions or immediate repairs would need to be conducted due to the chillers proven capacity. A long-term action to replace the chillers in the next five to ten years is recommended.