STATUS UPDATE FOR THE FISSION SURFACE POWER TECHNOLOGY DEMONSTRATION UNIT.

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Introduction: The Fission Power System (FPS) team is advancing FPS technology to support future human exploration and high power science missions. The FPS Initial Concept Definition[1] uses a fast-spectrum uranium dioxide reactor and a pair of fully redundant Annular Linear Induction Pumps (ALIP) to deliver heat to four 12 kW Stirling Power Conversion Units (PCU). The PCUs convert the heat to electricity and reject waste heat to four pumped water loops, which are coupled to a series of titanium-water heat-pipe-radiators (Figure 1).

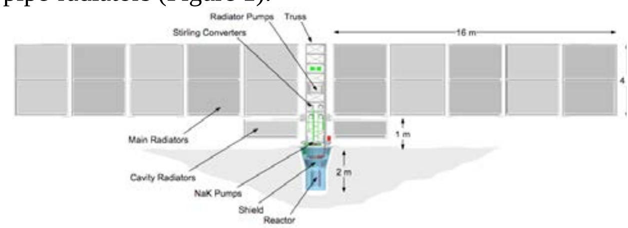

Figure 1. Fission Surface Power System

The FPS Technology Demonstration Unit (TDU) is a system level demonstration of FPS technology using an electrically heated reactor simulator, full-scale ALIP, single Stirling PCU, and a pumped water cooling system[2]. The system level TDU test will occur at GRC in a thermal vacuum environment. The goal of TDU testing is to advance the FPS Balance of Plant (BOP = non-nuclear elements) to TRL 5.

Over the past few years several component level and sub-system level tests have been completed by the FPS team. This paper summarizes those tests and describes the plan for future testing of the TDU.

Component Testing:

Annular Linear Induction Pump (ALIP)

Two ALIPs were designed and fabricated by Idaho National Labs (INL) and tested at the NASA Marshall Space Flight Center (MSFC) in their ALIP Test Circuit (ATC)[3][4]. One was designed as an FPS prototype capable of achieving relatively large flow rates, the other was a sub-scale design intended to achieve lower flow rates required for TDU testing. These tests revealed that the sub-scale ALIP was not capable of achieving the flow requirements of the TDU, so the FPS ALIP was chosen for use in the TDU.

Core Simulator

The Core Simulator was designed and fabricated by MSFC, based on a Los Alamos National Labs (LANL) reactor design[5]. NaK flow and heat transfer are mimicked by closely replicating core geometry while reactivity is mimicked using an advanced control algorithm developed by Sandia National Labs (SNL). This control scheme uses measured temperatures throughout the core to determine the thermal power that would be generated through nuclear fission.

The Core simulator was tested at MSFC in the Reactor Simulator Test Loop (RXSIM). The RXSim consists of the core simulator, core simulator control system, sub-scale ALIP, NaK-to-gas heat exchanger, and electromagnetic flow meter. While operating in constant power, power ramp, and constant temperature control modes the Core Simulator met all TDU design requirements[5]. Operating in reactivity feedback control mode caused a thermal instability that must be resolved prior to using reactivity feedback control on the TDU.

Stirling Power Conversion Unit and Controller

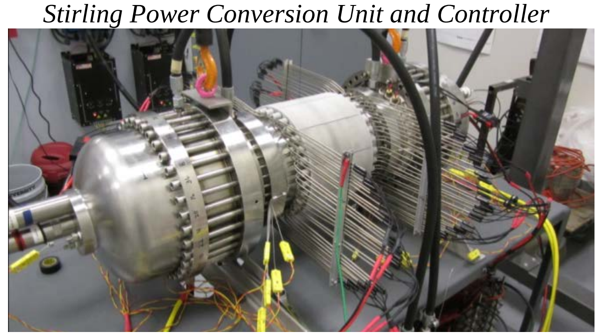

Figure 2. 12 kW Stirling PCU at Sunpower Inc.

The 12 kWe PCU (Figure 2), designed and fabricated by Sunpower Inc., is comprised of two 6 kWe free-piston Stirling convertors that are thermodynamically coupled in a dual-opposed configuration[6]. The 6 kWe free-piston engines have each been built and tested individually, and easily achieved full design power. The first test run of the fully integrated 12 kWe PCU occurred in April 2013. These tests revealed structural weakness in both the displacer spring mounting structure and the displacer dome-to-body attachment. These parts have been redesigned and fabricated and are currently being integrated into the 12 kW PCU, which will then continue extended testing. The PCU controller was previously demonstrated on a dual opposed pair of 1kW convertors and on the individual 6 kW convertors. This controller will be used to control the fully integrated 12 kW PCU during extended testing at Sunpower. The 12 kW PCU and controller are on schedule for May 2014 delivery to GRC.

Sub-System Testing

Cold-End Sub-System

The original intent of the TDU was to achieve TRL 6 by demonstrating the full BOP, including prototypic radiators and water pump, in a thermal vacuum environment. However, budget cuts have reduced the scope of the TDU, eliminating radiators, and limiting it to achieving TRL 5. TDU radiators have been replaced with a convective Waste Heat Exchanger (WHX), which uses ambient air to provide cooling. GRC and Advanced Cooling Technologies (ACT) have put some effort into developing affordable radiator designs through the Small Business Innovation Research (SBIR) program which could be used in follow-on testing to return the TDU to a TRL 6 demonstration[7]. However, follow on testing is currently unfunded.

During TDU testing this waste heat will be dissipated to the Facility Cooling System (FCS) which consists of a Commercial-Off-The-Shelf (COTS) canned water pump (in thermal vacuum), convective WHX (outside of thermal vacuum), volume accumulator, and all associated instrumentation. Cold-End sub-system testing was completed in February 2013, showing that the water pump met performance requirements in a thermal vacuum environment, through the entire range of TDU operating conditions. It also provided the first verification of both operational and emergency procedures prior to introducing NaK to the system and integrating high value hardware.

Hot-End Sub-System

The hot-end sub-system consists of the Core Simulator, Core Simulator controller, ALIP, electromagnetic flow meter, differential pressure flow meter, lower reservoir, volume accumulator, fill & drain system, and all associated instrumentation. Hot-End Sub-System is currently being assembled with testing scheduled to begin in April 2014. This test will mark the first time that GRC has tested a pumped NaK loop and will pave the way for TDU testing in June 2014. During hot-end sub-system testing the cold-end sub-system will be offline to remove the possibility of NaK-Water reactions in the event of a NaK leak. Testing will verify component functionality and performance in high vacuum, verify stress models on structure and piping, and validate operational and emergency procedures prior to introducing the Stirling engines into the loop.

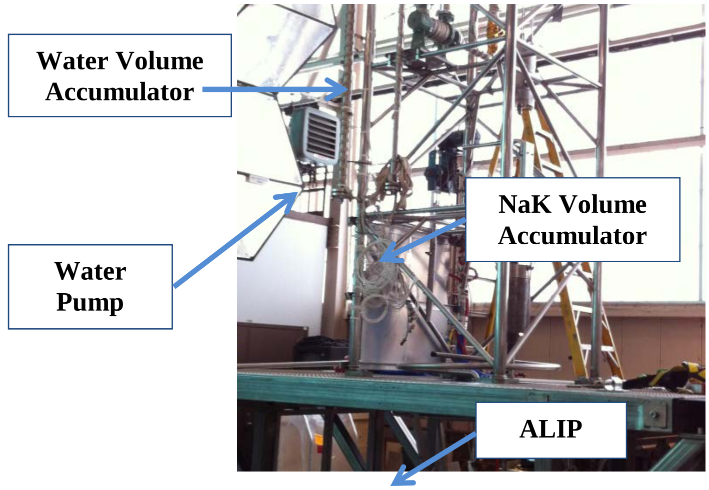

Figure 3. TDU Hot-End and Cold-End Sub-Systems being assembled at GRC

Conclusions: The FPS TDU is a non-nuclear demonstration of a Fission Power System in thermal vacuum. Component level testing has been completed on the Core Simulator. Component level testing of the 12 kW Stirling PCU is nearing completion and the PCU is on schedule for April delivery to GRC. The Cold-end subsystem was successfully tested in February 2013. The hot-end sub-system is currently being assembled and is on schedule for testing in April 2014. PCU integration into the TDU is scheduled for May 2014. TDU is scheduled to begin in July 2014 and conclude in September 2014. A successful TDU test will result in FPS technology being elevated to TRL 5, with the possibility of demonstrating TRL 6 in follow on testing.

Core Simulator

References:

[1] Fission Surface Power Team, (2010) NASA/TM – 216772. [2] Mason, L. (2011) NASA/TM – 217100 [3] Polzin, K. (2010) NASA/TP - 216430 [4] Polzin, K. (2013) NASA/TP – 217487 [5] Godfroy, T. (2011) NETS Paper 3508 [6] Stanley, J. (2013) NETS paper 6753 [7] Briggs, M. (2012) NETS Paper 3031