INL/CON-21-61664-Revision-1

MULTI-MISSION THERMOELECTRIC GENERATOR ASSEMBLY TESTING AND LAUNCH OPERATIONS FOR MARS 2020

April 2021

Changing the World's Energy Future

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http://www.inl.gov

Prepared for the
U.S. Department of Energy
Under DOE Idaho Operations Office
Contract DE-AC07-05ID14517

Nuclear and Emerging Technologies for Space
Sponsored by Oak Ridge National Laboratory, April 26th-30th, 2021.
Available online at https://nets2021.ornl.gov

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The Space Nuclear Power and Isotope Technologies (SNPIT) division at Idaho National Laboratory (INL) fuels, performs acceptance testing, and provides spacecraft integration support of Radioisotope Power Systems (RPS) in support of National Aeronautics and Space Administration (NASA) missions. Recently the SNPIT team completed assembly, testing and launch support of the Multi-Mission Radioisotope Thermoelectric Generator (MMRTG) for the Mars 2020 Perseverance Rover mission.

I. INTRODUCTION

The production of Radioisotope Power Systems (RPS) has been an ongoing endeavor for the U.S. Department of Energy (DOE) and its predecessor agencies for the past six decades. DOE has contracted the Idaho National Laboratory (INL) to provide RPS in support of National Aeronautics and Space Administration (NASA) missions. The overall mission of the RPS program is to develop, demonstrate, and deliver compact, safe nuclear power systems and related technologies for use in remote, harsh environments (e.g., space) where more conventional electrical power sources cannot provide sufficient power. Recently the INL team completed assembly, testing and launch support of the Multi-Mission Radioisotope Thermoelectric Generator (MMRTG) for the Mars 2020 Perseverance Rover mission. The efforts described herein represent five years of preparation and execution by a 60-member team from INL.

II. ASSEMBLY

Assembly consisted of fuel assembly and preparation of the GPHS module and generator fueling whereby an MMRTG is configured to the fueled configuration.

II.A. Fuel Assembly and Preparation

A collaboration between Oakridge National Laboratory (ORNL) and Los Alamos National Laboratory (LANL) produced the fueled clads that provide the heat the MMRTG used to produce electrical power. The fueled clad is a plutonium-238 oxide pellet contained in an Iridium alloy capsule. Each fueled clad produce approximately 62-watt thermal output. INL received the fueled clads and assembled them into the graphite components that provide the primary impact protection in the remote chance of a mission incident. Two fueled clads are placed in a Graphite Impact Shell (GIS) and two GIS are placed into a General Purpose Heat Source (GPHS) module creating a heat source with approximately 250 watts thermal at the beginning mission.

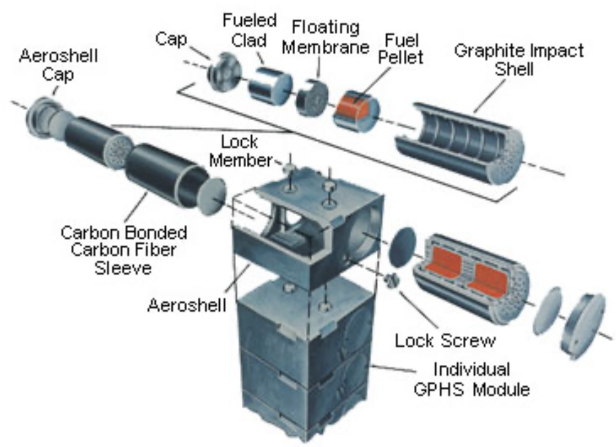

Fig. 1. GPHS module assembly [2].

Two GPHS modules were welded into each hermetically sealed can and placed on the module reduction and monitoring (MRM) system. The MRM process reduces the oxygen of the fuel by elevating the fuel temperature combined with an oxygen and carbon reaction of the graphite components. Weekly gas measurements were taken to monitor the reactant gases to determine when the fuel was reduced within specified limits. Eight completed GPHS modules were stored in four MRM cans until generator fueling began.

II.B. Generator Fueling

An unfueled MMRTG was delivered to INL as an electrically heated unit that had undergone extensive acceptance testing by the supplier team, Aerojet Rocketdyne and Teledyne Energy Systems. INL performed room temperature electrical acceptance testing to ensure the generator did not sustain any damage during shipping.

INL requested concurrence from the Mars 2020 mission to fuel the MMRTG approximately one-year before launch. Fueling began with placement of the generator in the Inert Atmosphere Assembly Chamber (IAAC). The electrical heat source was removed and the interior of the MMRTG was inspected. The air inside the IAAC was then replaced with argon and controlled within specified limits. GPHS modules were individually removed from MRM cans, cleaned, and inspected for damage in an adjacent inert glovebox. The GPHS modules were then transferred into the IAAC and stacked on a water-cooled fixture in preparation for fueling. Eight GPHS modules were stacked, lifted, and lowered slowly into the MMRTG to minimize thermal transients to the thermoelectrics.

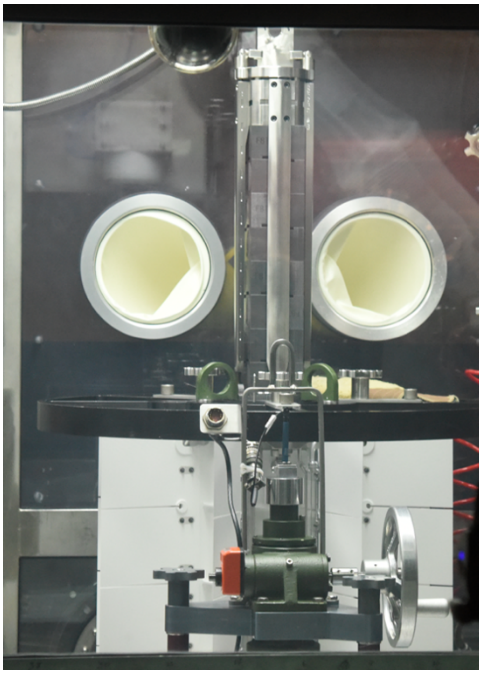

Fig. 2. GPHS module stack insertion into the MMRTG housing.

A piece of Min-K insulating material was then placed on the GPHS stack to constrain it during dynamic events such as launch, entry decent and landing. The Min-K was trimmed to a specified thickness so that when the MMRTG end cover is installed, it applies a predefined load through the Min-K to the GPHS stack thereby constraining its movement. A hose was attached to a port on the end cover allowing the argon inside the MMRTG to be removed and exchanged with helium. When the gas exchange was complete, the port was welded shut. A leak test was performed on the weld as well as the end cover seal. When the MMRTG was thermally stable, simple electrical checks were performed to verify the electrical output. The MMRTG was removed from the IAAC, radiation dose rate measurements were taken at various distances from the MMRTG, and more in-depth electrical checks were performed before transferring the MMRTG to the acceptance test stations.

III. ACCEPTANCE TESTING

Acceptance testing consisted of vibration, mass properties, and thermal vacuum tests. Electrical checks were performed between each test to ensure that the test did not cause damage to the MMRTG.

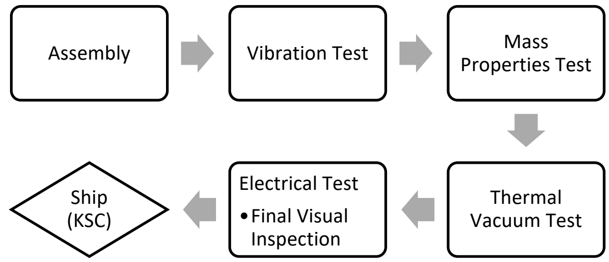

Fig. 3. INL MMRTG Assembly and Testing Flow Chart.

III.A. Vibration

The MMRTG was subjected to random spectrum and sine burst vibrational testing to verify the unit will survive the conditions experience during launch and reentry to Mars.

The MMRTG was mounted to a test fixture which incorporates accelerometers and force transducers. Accelerometers and force transducers were placed on each corner of the fixture to monitor the X, Y, and Z axis acceleration and force at the mounting end (bottom) of the MMRTG. Two triaxial response accelerometers were mounted near the fueling end (top) of the MMRTG.

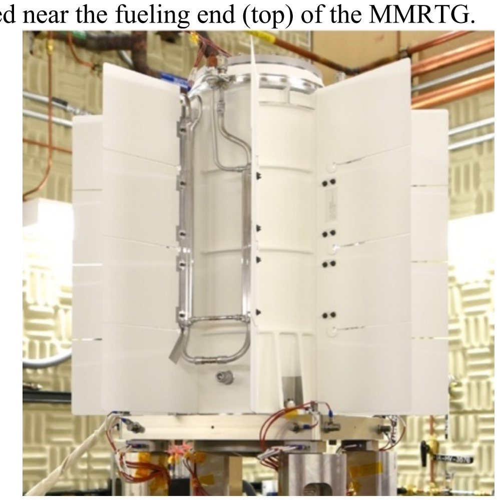

Fig. 4. MMRTG mounted on the vibration test fixture.

The data collected was compared to the MMRTG provided for Mars Science Laboratory. The data showed that the two RPS were consistent with each other.

III.B. Mass Properties

Mass properties testing started by measuring the mass of the MMRTG on a precision scale. The MMRTG was then installed on the mass properties instrument which rotates about the machine axis. A fixture precisely positions the MMRTG in two orientations to measure the composite center of gravity in the X-Y, and X-Z orientations. The measured values were provided to Teledyne Energy Systems to analytically subtract non flight components and calculate the actual center of gravity and mass moments of inertia.

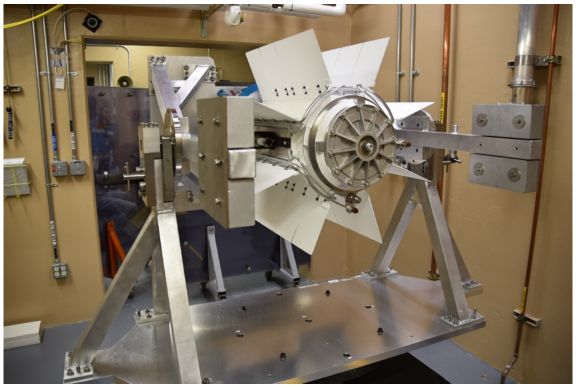

Fig. 5. MMRTG mounted on the mass properties instrument turned to measure the X-Z center of gravity.

III.C. Thermal Vacuum Testing

The MMRTG was subjected to a final power level verification where the heat transfer boundary conditions were fully controlled. This is done by testing in the INL thermal vacuum chamber where gas convection and conduction are eliminated, and radiant heat transfer is well characterized. Testing was performed to verify final power output across the generator design load voltage range. The data generated was used to validate numerical models for the life power output prediction of the fueled flight unit.

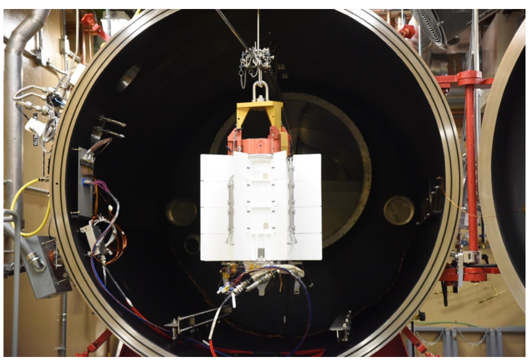

Fig. 6. MMRTG mounted inside the thermal vacuum chamber.

III.D. System Certification and Acceptance

The MMRTG was certified for flight following successful assembly and testing at INL. The flight data package included the record of assembly, radiation dose rate survey, vibration testing, mass properties testing, thermal vacuum chamber testing, electrical testing and visual inspection results. Any nonconformance that occurred during assembly and testing was documented on the certificate. The completed data package was presented to the Mars 2020 mission team for acceptance and verification of all interface requirements.

IV. LAUNCH SUPPORT OPERATIONS

After flight acceptance, the MMRTG was ready for transportation and integration with the Mars 2020 rover at Kennedy Space Center (KSC).

IV.A. Transportation

INL transported the MMRTG to KSC approximately four-months before launch. A series of pre-shipment electrical checks were performed to ensure the health of the MMRTG prior to shipment. These tests included a ground conductor resistance check, isolation resistance check (power and instrumentation circuits), and an ambient air electrical output performance test.

The MMRTG was loaded into the certified DOT type-B shipping cask (9904) after successful pre-shipment electrical checks were performed. The 9904 cask required active cooling to prevent MMRTG damage from overheating. Cooling was provided using a chilled water jacket on the exterior of the 9904 cask. Chilled water was provided by portable chillers during loading.

Fig. 7. 9904 Cask inside the RTGTS.

The cask with MMRTG was loaded into the Radioisotope Thermoelectric Generator Trailer System (RTGTS), a specially designed transportation trailer to support the transport of a loaded 9904 cask. A team of INL employees followed the RTGTS during transport to provide monitoring support and response to out of tolerance conditions.

The 9904 cask was unloaded at KSC and the MMRTG removed at KSC. Post-shipment health checks were compared to the pre-shipment health checks to ensure no damage occurred during shipment.

IV.B. Integration

The flight mechanical and electrical adapters were installed onto the MMRTG three months prior to the launch. INL conducted integrated operations with Jet Propulsion Laboratory (JPL) personnel to install the flight hardware, which provides the mechanical and electrical interface between the MMRTG and the Mars 2020 rover.

The hot-fit check, a mission risk reduction operation, was performed three-months in advance of launch.

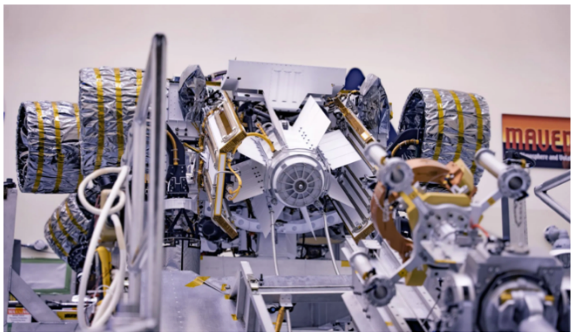

Fig. 8. MMRTG hot-fit check to Mars 2020 rover.

The hot-fit check was the first electrical and mechanical mating of the fueled MMRTG to the Mars 2020 rover and is a key milestone in the overall mission integration workflow. INL was responsible for delivering the MMRTG and supporting the electrical and mechanical integration at the Payload Hazardous Servicing Facility (PHSF) at KSC. JPL performed several integrated functional tests after the MMRTG was mechanically and electrically mated. The MMRTG was de-mated from the rover after testing was completed and stored until final integration at the Vertical Integration Facility (VIF).

The MMRTG was transported to the VIF ten-days before launch. INL and JPL worked together to perform mechanical and electrical integration.

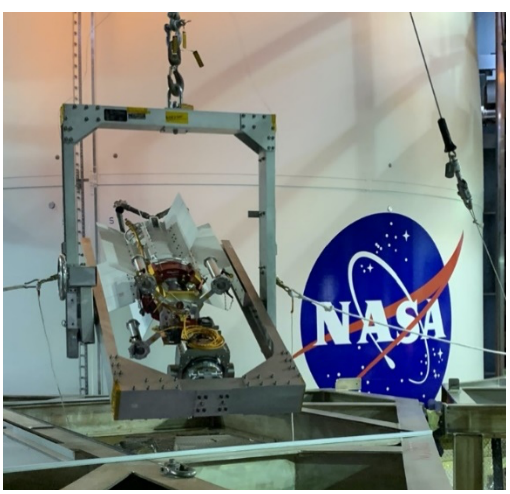

Fig. 9. Final MMRTG integration operations to the Mars 2020 Perseverance Rover at the VIF.

II. CONCLUSIONS

The MMRTG for the Mars 2020 rover was the second MMRTG assembled, tested, and integrated. There were several challenges that the INL, Aerojet Rocketdyne and Teledyne Energy System team had to systematically work through to support launch of the Mars 2020 rover.

The Mars 2020 Perseverance Rover, aboard an Atlas V-541 rocket, was launched from Launch Complex 41 located at the Cape Canaveral Air Force Station (CCAFS) in Florida on July 30th, 2020. INL played a key role in the successful launch of the rover through execution of the MMRTG mechanical and electrical integration operations with JPL mission system integrators and NASA's launch service program organization.

ACKNOWLEDGMENTS

The authors would like to acknowledge Dr. Stephen Johnson and Ms. Kelly Lively from Idaho National Laboratory for their leadership in assembly, testing, and launch operations for the MMRTG. The authors also would like to acknowledge Bill Otting and Andrew Lane from Aerojet Rocketdyne and Josh Wojcik from Teledyne Energy Systems for their technical support fueling and testing the MMRTG. The authors also acknowledge the efforts of Oakridge National Laboratory and Los Alamos National Laboratory for supplying the fueled clads. This work was funded through Department of Energy contract DE-AC07-05ID14517.

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