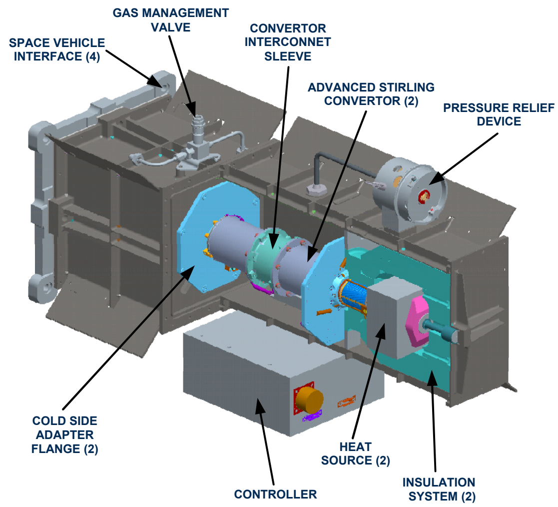
Advanced Stirling Radioisotope Generator for NASA Space Science and Exploration Missions



Courtesy of Lockheed Martin

Under the joint sponsorship of the Department of Energy (DOE) and NASA, Lockheed Martin Corporation of Valley Forge, PA, NASA Glenn Research Center (GRC) of Cleveland, OH, and Sunpower, Inc. of Athens, OH are developing a high-efficiency, 100-We (watts electric)-class Advanced Stirling Radioisotope Generator (ASRG) for potential use on future NASA Space Science and Exploration missions. The ASRG is being developed for multimission use in environments with and without atmospheres. Potential missions include providing electric power for deep space missions, surface rovers, including lunar and Mars, and stationary power generators, including lunar-distributed power and communication stations. The ASRG would provide a high-efficiency power source alternative to radioisotope thermoelectric generators (RTGs). The ASRG system efficiency of 28 to 32 percent would reduce the required amount of radioisotope by a factor of four or more compared to RTGs. This significantly reduces radioisotope cost, radiological inventory, and system cost. The ASRG also has a high specific power of 7 We/kg or greater.

Status

Lockheed Martin, under contract to DOE, is the system integration contractor for the ASRG and is now developing an ASRG engineering unit (EU). The ASRG–EU uses two opposed Advanced Stirling Convertors (ASCs), operating at a hot-end temperature of 650 °C, and is expected to produce a power of about 140 We at the beginning of the mission. Each ASC is heated by the nuclear decay of plutonium-238 fuel in a single General Purpose Heat Source (GPHS) module. ASRG–EU testing is expected to begin around December 2007.

Sunpower is developing the ASC under a NASA Research Announcement award with GRC. The convertors will be provided to DOE/Lockheed Martin as government-furnished equipment. Sunpower is also developing a higher-temperature ASC with a MarM–247 heater head and an 850 °C hot-end temperature. This increases the ASRG specific power to ~8.4 We/kg and provides increased margin with the MarM–247 material at 850 °C compared to the Inconel 718 material, used on the ASRG–EU, at 650 °C.

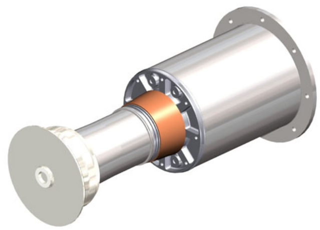
Comparison of 650 and 850 °C ASRGs

Parameter	ASRG —650 °C	ASRG —850 °C
Power per ASRG (beginning-of-life (BOL)) We	143	~ 160
Power degradation, %/yr	0.8 (power decays with fuel decay)	
Mass per ASRG, kg	20.2 *	~ 19
Dimensions, mm	Length: 725 Width: 293 Height: 410	TBD
Number of GPHS modules	2	2
Thermal power input (BOL), W	500	500
ASRG specific power, We/kg	7.0	~ 8.4
Conversion efficiency, %	28	~32
Controller	Single fault tolerant	
Operating environment	Vacuum and Mars atmosphere	
Life requirement	14 yr mission + 3 yr storage	

* Add 1.2 kg for spacecraft adapter for missions using heavy launch vehicles.

Advanced Stirling Convertor (ASC)

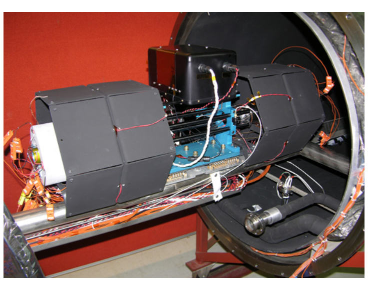
The ASC consists of a free-piston Stirling engine and an integral linear alternator that converts the piston reciprocating motion to electrical output. The ASC weighs only about 1.3 kg, has demonstrated a convertor efficiency of 38 percent at 850 °C hot-end temperature and 90 °C cold-end temperature, and has produced a maximum power output of 114 We when unlimited heat input is provided. The operating frequency is 105 Hz, and the average pressure of the helium working fluid is 3.5 MPa. Noncontacting operation is achieved with hydrostatic gas bearings, and the pressure vessel is hermetically sealed. Dual-opposed convertors are used to achieve balanced operation, and vibration levels are expected to be well below ASRG specifications based on early convertor testing.



Advanced Stirling Convertor

Extended Operation

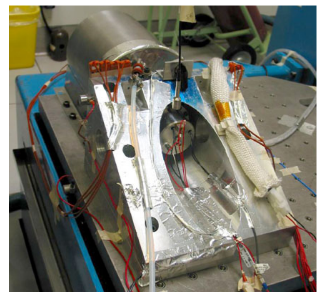
Extended operation of the ASCs is now getting underway at GRC. GRC's test facility includes six test stations for 24-hour unattended operation in air and a thermal vacuum chamber for 24-hour unattended operation, as well as other test stations for performance and controller testing. Two hermetically sealed ASCs, operating at 650 °C hot-end temperature, have begun thermal vacuum testing. They have completed over 2000 hr of testing (each convertor), including over 850 hr in thermal vacuum. Two ASCs capable of 850 °C operation have just been received from Sunpower and will soon be placed on in-air extended operation. GRC also has two pairs of convertors from Infinia Corporation of Kennewick, WA on extended testing; these were also designed to produce power from the heat of one GPHS module but use flexural bearings to achieve noncontacting operation. One convertor pair has achieved over 29,000 hr (each convertor) of testing, while the other pair has completed over 15,000 hr.



ASCs on thermal vacuum testing at GRC

Structural Dynamics and Electromagnetic Interference

An ASC recently completed structural dynamics testing at Pratt & Whitney Rocketdyne in Canoga Park, CA to evaluate robustness in a launch vibration environment. With the convertors operational, random vibrations were applied in the axial direction (direction of piston motion) and then in the lateral direction (90° to piston motion). The ASCs successfully completed tests at a Workmanship level of 6.8 grms, Flight level of 8.7 grms, Qualification level of 12.3 grms, and (Qualification + 3 dB) level of 17.5 grms. Early electromagnetic interference and electromagnetic compatibility (EMI/EMC) testing has shown the capability to meet required EMI levels and the ability for reducing EMI by shielding and/or cancellation techniques for missions requiring very low EMI.



ASC launch vibration testing

Reliability

Extensive efforts are underway to evaluate, improve, and verify the ASC and ASRG reliability. Lockheed Martin Space Systems Company of Denver, CO is leading a reliability team that also includes GRC and Sunpower. Traditional analyses include failure modes, effects, and criticality analysis (FMECA) and fault tree analysis for the convertor, controller, and system. Physics-based modeling of the convertor with probabilistic analysis is being done by GRC. The Jet Propulsion Laboratory of Pasadena, CA is also using a Defect Detention and Prevention risk management tool to support the ASC/ASRG effort. The reliability efforts draw on supporting technology work at GRC in various areas, including convertor testing, hot-end material and heater head creep testing, heater head life analysis, regenerators, magnet aging, linear alternator analysis and testing, gas bearing analysis, organics testing, and system dynamic modeling.

Further Reading

Chan, J., Wood, J.G., and Schreiber, J.G., "Development of Advanced Stirling Radioisotope Generator for Space Exploration," proceedings of *Space Technology and Applications International Forum (STAIF-2007),* edited by M.S. El-Genk, AIP Conference Proceedings 880, pp. 615-623, 2007.

Wood, J.G. et al., "Advanced Stirling Convertor (ASC) Phase III Progress Update," proceedings of *Space Technology and Applications International Forum (STAIF-2007)*, edited by M.S. El-Genk, AIP Conference Proceedings 880, pp. 313-324, 2007.

Contacts

Jeffrey Schreiber	Wayne Wong
NASA Glenn Research Center	NASA Glenn Research Center
Cleveland, OH 44135	Cleveland, OH 44135
Phone: (216) 433–6144	Phone: (216) 433–6318
Jeffrey.G.Schreiber@nasa.gov	Wayne.A.Wong@nasa.gov