Concept of Operations for the Advanced Stirling Radioisotope Generator. R. L. Cataldo[1], C. A. Tatro[2], A. J. Colozza[1], X. Y. Wang[1], J. J. Rusick[1], [1]NASA Glenn Research Center, 21000 Brookpark Rd., Cleveland OH, 44135, [2]NASA Kennedy Space Center, FL, 32899

Introduction: NASA is sponsoring the development of an advanced, high efficiency radioisotope power system that can deliver four times the power compared to today's conventional thermal to electric conversion devices with the same amount of radioisotope fuel. The Department of Energy (DOE) and NASA are currently developing the Advanced Stirling Radioisotope Generator (ASRG) along with Lockheed Martin Space Systems Company, Valley Forge, PA. The first two flight units have been made available to the NASA Science Mission Directorate's Discovery Program for the Discovery 12 Announcement of Opportunity.

The ASRG is comprised of five major components; General-Purpose Heat Source (GPHS), Advanced Stirling Convertor (ASC), Generator Housing Assembly (GHA) ASC Controller Unit (ACU) and shunt dissipater unit (SDU) as shown in Figure 1. The GPHS module houses four plutonium-oxide fuel pellets within iridium clads producing approximately 62 Wt each. The alpha decay of the fuel provides the heat to two Stirling convertors. Waste heat is removed from the convertors via the case and attached fins and rejected to the environment.

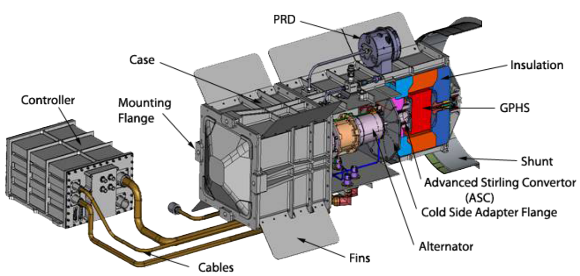

Fig. 1 ASRG cutaway.

This ASRG is significantly different than previously flown radioisotope power systems in two primary factors, i.e., the reduced heat rejection and fuel inventory. Thus a review of what potential options exists in integration protocols developed for past missions may result in different integration solutions. The ASRG is also more complex to integrate into the spacecraft in that; the controller, cables and housing are all integral components that must be mounted as one procedure. The controller must be in constant control of both ASCs once the ASRG is fueled with GPHS modules.

At the request of the Discovery 12 ASRG missions, a first cut at identifying potential launch site integration scenarios where the power source is integrated earlier in the processing flow than past missions have been assessed for technical feasibility. Future work will require further detailed assessments, including safety, hazardous propellants, etc., as the mission design becomes more mature.

Concept of Operations: In this paper, the concept of operations (conops) is defined as when the unit is fueled at the DOE's Idaho National Lab (INL). The conops phases are defined as; fueling process, flight unit testing and monitoring, storage, transportation to the launch facility, storage at the launch facility, integration to the spacecraft, spacecraft launch closeouts, countdown and launch, orbit phasing, and mission operations.

The focus here will be the integration of the ASRG to the spacecraft and mission operations. In May 2011, a down select for further Phase A study resulted in three missions being selected; InSight (Interior Exploration using Seismic Investigations, Geodesy and Heat Transfer), and two ASRG powered missions, Titan Mare Explorer (*TiME*) and Comet Hopper (CHopper). Both *TiME* and CHopper had selected 2 ASRGs to power their missions.

ASRG to S/C Integration: Prelaunch conops has focused on the potential of early integration of the ASRG power system at the Payload Hazardous Servicing Facility (PHSF). Historically, recent missions have installed the power system at the Atlas Vertical Integration Facility (VIF) via large access doors in the launch vehicle fairing section. ASRG integration at the PHSF would allow greater flexibility particularly where some components would be mounted internal to the spacecraft such as the controller, cable or ASRG itself without violating the requirement for constant electrical interconnection between the ASRG housing and controller.

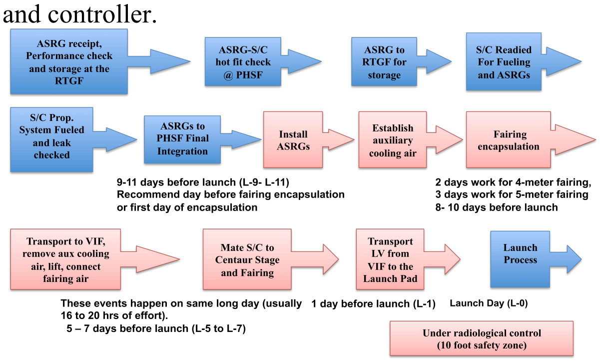

Fig. 2 Spacecraft Process Flow at the PHSF

Figure 2 shows a notional process flow for integration to the spacecraft, fairing encapsulation, transport to the VIF and launch pad.

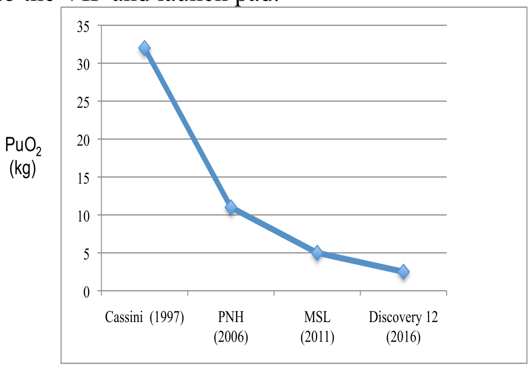

Fig. 3 Plutonium Required for Different Missions

Since the amount of plutonium used with the ASRG's is much lower compared to recent past missions as shown in Fig. 3, this option was considered to be reassessable in trading the complexity of integrating through a fairing door(s) at the VIF and potentially a less complex integration at the PHSF with the additional safety and security contraints applied earlier in the launch operations phase.

A radiation assessment of fluence lines for the ASRG GPHS units was performed by the KSC Health Physics and Radiological Protection Officer and arrived at a safety perimeter of a 10-foot radius for Launch Site Operations. The previous missions shown in Fig. 2 had a significantly larger safety zone. ASRG integration earlier in the spacecraft processing flow becomes more promising since launch vehicle fairing encapsulation at the PHSF and Centaur/Atlas preparation at the VIF could be done less constrained with this smaller safety zone for the ASRG.

Another consideration is to maintain the ASRGs within temperature limits during and after spacecraft integration. The spacecraft thermal environment is controlled during prelaunch activity, maintained during ground transport, and controlled after mate to the launch vehicle. Sufficient gas flow is provided to maintain the ASRG within temperature limits once the payload is encapsulated by the fairing. The thermal environment is also controlled in the PHSF and natural convection, or floor fans if needed, would maintain the ASRGs prior to connection of the active cooling supply. If the ASRGs were to be encapsulated internal to the spacecraft, localized spot cooling would most likely be required.

However, during the approximate one-hour lift at the VIF, active cooling is not provided as standard services, but could be provided if necessary. A thermal assessment was performed to determine the maximum temperature rise of the fairing volume with two ASRGs mounted on the spacecraft during a typical early morning lift sequence without active cooling. The worst case scenario, sunny no wind and two ASRGs (1000 Wt), was considered in the analysis. The temperature results are shown in Table 1 and show that the magnet temperature is maintained within the limit (120 C) even for the worst case.

Table 1 Thermal analysis results

	Sun, No wind
GPHS (Wt)	1000
T shroud(C)	36
T air inside shroud(C)	38
T ASRG housing(C)	83
T magnet (C)	111

Summary: A path forward has been identified with the potential for early ASRG and spacecraft integration. A reduced radiological worker safety zone and less thermal energy involved allow an opportunity for a new assessment in the established process for RPS missions. The KSC facilities and Atlas support equipment already in place allows the ASRG to be maintained within temperature limits. Details of the radiation and thermal analysis will be presented in the final paper.

Future work: Further safety analyses and assessment are required for the new process steps not currently in established protocols, which were beyond the scope of this work. NASA, the Mission - TiME or CHopper, Range Safety, INL, DOE, and LV Contractor must work together to develop final integration approach based on the final spacecraft configuration.