



Overview of Light Weight Radioisotope Heating Unit (LWRHU) Users Guide

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Overview of Light Weight Radioisotope Heater Unit (LWRHU) User's Guide

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Idaho National Laboratory (INL) has recently compiled a user's guide for the Light Weight Radioisotope Heater Unit (LWRHU). This guide gives an overview of the LWRHU to potential users. Information and data on mass properties, dimensions, thermal loads, and interfaces are discussed.

I. INTRODUCTION

The production of radioisotope heater units has been an ongoing endeavor for the U.S. Department of Energy (DOE) and its predecessor agencies for the past six decades. The overall mission of the Radioisotope Power System (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 aren't sufficient.

This user's guide provides an overview of Light Weight Radioisotope Heater Units (LWRHU), including aspects of its physical design and performance under normal operations. This guide also identifies the planning and execution involved in launching a nuclear payload. Physical characteristics, interfaces, and environmental characteristics of the LWRHU are discussed in detail. Information relating to project management interfaces and effort are also addressed

Overall, the LWRHU User's guide document:

- Provides a general description of the physical characteristics, system interfaces, and performance characteristics of the LWRHU.
- Provides to the mission proposer sufficient detail on the LWRHU and an understanding of the interfaces and support needed to utilize in a NASA RHU enabled mission.

The information in the user's guide should help organizations proposing the use of a LWRHU to prepare a sound handling, costing, and integration narrative.

II. SCOPE

The purpose of the LWRHU User's Guide is to:

- Provide a general description of the physical characteristics and system interfaces of the Light Weight Radioisotope Heater Unit (LWRHU)
- Describe the physical and analytical models available to a mission design team
- Identify the planning and execution involved in launching a nuclear payload, including National Environmental Policy Act (NEPA) activities.

III. LWRHU OVERVIEW

The basic characteristics of an LWRHU, including the basic performance, weight, and dimension specifications, are listed in Table 1.

The LWRHU is designed to operate in planetary atmospheres and vacuum environments. While it is anticipated that performance in other atmospheres is enveloped by past mission use success on Mars and the vacuum of space, performance and material compatibility may need to be tested and understood for specific environments.

Table 1 LWRHU basic characteristics and requirements.

Parameter	LWRHU Value
Thermal output (BOM)	1.1 ± 0.03 watts
Mass (max)	42.00 grams
Plutonium oxide mass	2.66 ± 0.030 grams
Neutron emission	<7000 n/s-g ²³⁸ Pu
Surface temperature in free air	45C
Aeroshell ablation recession	50% (max)
Impact resistance on reentry (intact capsule)	49 m/s
Maximum dynamic loading	425G
Length	31.95 ± 0.05 mm
Diameter	25.95 ± 0.05 mm

Key: BOM = Beginning of Mission (at launch)

III.A. LWRHU History

RHU(s) have been used on NASA missions since the initial lunar landing. The purpose of their design was to provide heat to keep spacecraft components and systems warm in harsh cold environments throughout space without moving parts or disrupting electronic components. RHU's can be allocated where needed on spacecrafts.

Since their initial use, the RHU has been modified several times. The first RHU produced 15 Watts of thermal power and was used on Apollo 11 in 1969. That further developed into a one-watt version used on the Pioneer and Voyager programs in the 1970s. This one-watt RHU was improved to produce the same wattage but at a smaller size than its predecessor thus becoming the LWRHU (first used for the Galileo orbiter and probe in 1989).

Missions that have used the current LWRHU design are:

- Galileo – 120 LWRHUs (103 on orbiter, 17 on atmospheric probe)
- Mars Rover Sojourner Pathfinder – 3 LWRHUs
- Cassini – 117 LWRHUs (82 on orbiter, 35 on Huygens Titan probe)
- Mars Rover Spirit – 8 LWRHUs
- Mars Rover Opportunity – 8 LWRHUs

Missions that used a slightly different and older design heater unit are:

- Apollo 11 – contained two 15 Watt RHUs

- Pioneer 10 – 12 RHUs
- Pioneer 11 – 12 RHUs
- Voyager 1 – 9 RHUs
- Voyager 2 – 9 RHUs

III.B. LWRHU Description and Major Components

The heat source of the LWRHU is one fuel pellet containing ≥ 80% ²³⁸PuO₂ fuel pellet encapsulated in platinum-30 rhodium (Pt-30 Rh) alloy cladding. The cladding serves as the primary fuel containment. The clad contains a frit vent made up of a pressed and sintered disk of platinum powder. The frit vent is designed to allow for the escape of helium that is released over time from the natural decay of the plutonium dioxide fuel, thus avoiding clad distortion from excessive pressure build-up.

The fueled capsule is placed into an assembly of three concentric, cylindrical, pyrolytic graphite insulator (PG) sleeves of increasing diameter and capped at both ends. The insulators provide protection to the fueled capsule during a re-entry by diverting the flow of heat generated at the aeroshell surface around the fueled capsule and delay the flow of this heat directly into the capsule. Thus, the temperature of the platinum-rhodium alloy cladding is maintained safely below its melting temperature. The fueled capsule and pyrolytic graphite insulator bodies are contained within a cylindrical Fine-Weave Pierced Fabric (FWPF) aeroshell and secured in place with a FWPF threaded cap. The aeroshell is the primary structural component and provides protection for the fueled capsule during re-entry and launch accident events. The FWPF aeroshell cap is screwed into the body and locked in place with a two-component, carbonaceous, bonding cement. The LWRHU has an overall diameter of 25.95 ± 0.05-mm and a length of 31.95 ± 0.05-mm. A cross-section of the LWRHU is shown in Figure 1 and Figure 2 provides the expanded view.

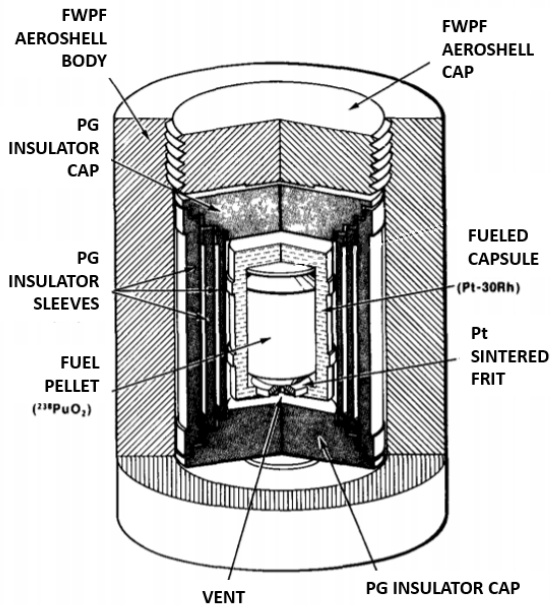


Figure 1. Cross Section Cut of LWRHU

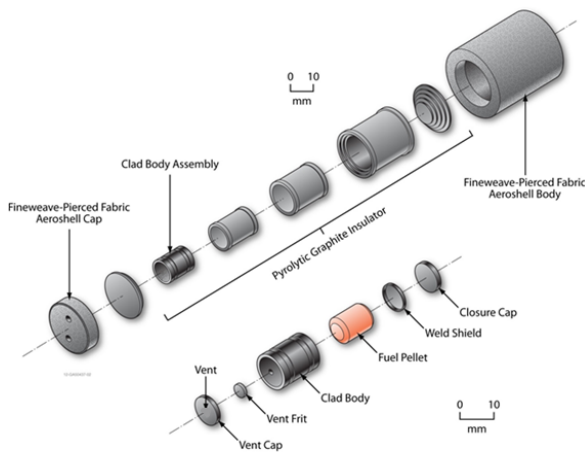


Figure 2. Expanded view of LWRHU.

III.C. System Considerations – Nominal Operations

There are operational considerations with the LWRHU. Once the LWRHU is fueled, it is thermally hot. Integration occurs at Kennedy Space Center (KSC) to accommodate mission needs with the notion that security restrictions and oversight would be in place and must be considered once the LWRHUs are integrated to the spacecraft. The LWRHU was designed to operate either in a vacuum or an atmosphere of a planet. Testing completed and/or operation in air and Mars atmosphere

have demonstrated compatibility with many known atmospheres in our solar system. However, some specific material compatibility testing may be needed depending on the mission environment.

The design of a spacecraft using an LWRHU must accommodate integration of the LWRHU(s). Integration configuration varies depending on mission.

III.D. LWRHU Management

The detailed roles and responsibilities of individual agencies and groups will be delineated in an interface working agreement prepared early in each project.

The nuclear launch process is established and has been successfully implemented on previous nuclear-enabled missions. Nuclear missions have added complexity that do not exist for typical NASA space-launch activities. Mission personnel should be aware of these additional activities when developing their overall plan (see Section 5.4 "Generic Notional Nuclear Launch Authorization Schedule").

III.E. Shipping the LWRHU

Upon completion of the fueling and testing sequence, the LWRHU is shipped to Kennedy Space Center (KSC) where there are two cask options: 9975 or 9516 shipping casks. The 9975 can hold up to 19 watts and is bolted for easy use. The 9516 can hold up to 500 watts and is a welded canister. Typical pre-launch arrival times vary, but a period of 4 to 6 months prior to launch allows adequate time for testing and other pre-launch activities. Once the LWRHU arrives at KSC, the cask is unloaded. The duration the LWRHU is stored at KSC is minimized as its presence will require additional resources not used at KSC to manage a DOE Category 3 Nuclear Facility.

III.F. Integration with Spacecraft

The LWRHU(s) are delivered and are stored in a safe at the Payload Hazardous Servicing Facility (PHSF) where spacecraft personnel integrate the fueled LWRHU(s) onto the spacecraft prior to encapsulation. LWRHU(s) are handled with terry cloth gloves.

Final checks will be made to ensure successful integration with the spacecraft and all systems are functioning as required. INL personnel will be responsible for nuclear material safety and security oversight at this point.

IV. LWRHU Characteristics

IV.A. Physical Characteristics

Mass properties for the LWRHU are shown in Table 2. Additional information on physical characteristics are shown in Table 1.

Table 2 LWRHU mass properties

Parameter	Value
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Mass		42.00 grams
Row name	Ixx	3.77 kg m ²
	Iyy	5.65 kg m ²
	Izz	5.65 kg m ²

IV.B. Interfaces

The LWRHU has multiple interfaces that will be mission specific. Major interfaces are shown in Figure 3. These include:

- Spacecraft interfaces
 - mechanical interface with the LWRHU
 - thermal interfaces with the LWRHU
- Space-environment interface.
 - space vacuum environment
 - radiation environment
 - thermal environment,
 - mission load environment.
- Planetary-environment interface.
 - the atmosphere
 - atmospheric pressure
 - radiation environment
 - thermal environment
 - mission load environment.
- Launch-vehicle interface.
 - atmosphere
 - atmospheric pressure
 - random vibration and quasi-static launch load environments
 - acoustic load environment
 - thermal environment.
- Ground Support Equipment.

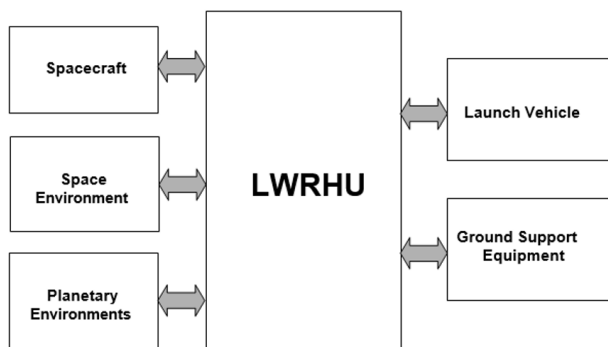


Figure 3: Diagram of LWRHU interfaces

Mounting of LWRHU on the spacecraft will be mission specific. DOE will be involved in approval of interface to ensure proper compliance. The ratio of gamma/neutron will vary based on the age of the ²³⁸Pu and date of the last purification cycle. Gamma radiation emission peaks for ²³⁸Pu about 17 years after fueling. The gamma values below are considered bounding. Neutron radiation emissions reduce with time and are considered bounding when the LWRHU is fueled.

IV.C. Environmental Characteristics

The development of LWRHU's for the Galileo mission is the basis for design requirements. All missions after Galileo have been based off this initial development work. Vibration testing and impact testing on the LWRHU's showed that they met system requirements for acceptance.

IV.D Planetary Protection

In free air, the LWRHU reaches a surface temperature of 45°C, so it will not reach a self-sterilizing temperature of 110°C. Additional sterilization may be required if planetary protection is required for a mission. Some methods of additional sterilization include:

- acceptance via a cement curing process (150°C for 16 hours)
- packaging and sealing LWRHUs inside sterile containers and shipping to KSC to be stored at PHSF and unpackaged and integrated into the spacecraft in a Clean Room
- sterilizing LWRHUs at KSC via heat sterilization process

IV.E Acceptance Testing

Acceptance testing of the LWRHU will verify characteristics including:

- mass
- geometry
- power
- neutron emission rate

V. Launch Safety Requirements

Activities related to launch safety requirements with a LWRHU are extensive and will not be covered in depth. A brief overview of activities, requirements, and policies related to the launch safety process follows

NASA missions planning to use a LWRHU must follow a number of NASA Procedural Requirements (NPR's) that includes:

- NPR 8580.1, "Implementing the National Environmental Policy Act and Executive Order

12114,"

- NPR 8715.3, "NASA General Safety Program Requirements,"
- NPR 8715.2, "NASA Emergency Preparedness Plan Procedural Requirements—Revalidated,"
- NPR 7120.5E, "NASA Space Flight Program and Project Management Requirements,"

Additionally, the National Environmental Policy Act (NEPA) requires all federal agencies to consider the environmental impacts of proposed actions and identify any reasonable alternatives to those actions. Compliance with the NEPA is required for all NASA activities that could result in environmental impact.

The NSPM-20 establishes three tiers of launch authorization, with each tier based on the quantity of material being launched and the mission risk. Most missions requiring a LWRHU would fall under tier 1 or tier 2 of the NSPM-20 process. Any tier of NSPM-20 requires a SAR.

VI. SIMPLIFIED PREDICTION MODELS

A simple power prediction plot was generated using the radioactive decay equation:

$$W = W_1 * e^{(-\ln(2) * (\frac{\text{Decay Period}}{\text{Pu}^{238} \text{ Half Life}}))}$$

Projections for heat output 10 and 100 years after beginning of life are seen in Figures 3 and 4.

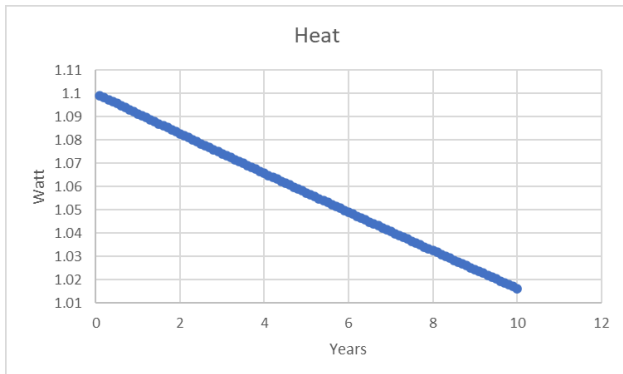


Figure 3: LWRHU Watt Output Decay Over Time (10 Years)

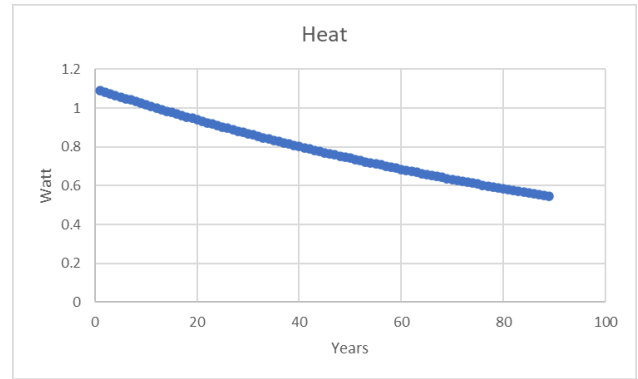


Figure 4: LWRHU Watt Output Decay Over Time (100

VII. CONCLUSIONS

INL has completed a user's guide for the LWRHU to assist potential users in mission design and scoping calculations. Information in the user's guide includes mass properties, design information, system interfaces, and launch safety. A form to request a copy of the LWRHU User's Guide can be obtained from J. Michael Newman at j.m.newman@nasa.gov.

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