

The Euratom PULSAR project

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Abstract. PULSAR (PU-238-coupled dynamic power system for Space exploration and beyond) was a research and innovation project funded by the European Commission between 2022 and 2024. The aim of this project was to establish building blocks for the development of Radioisotope Power Systems (RPS) fueled by Pu-238 with European technologies and standards. Radioisotope Power Systems (RPS) is a key enabling technology for exploration of locations hidden from the sun for prolonged periods, or of deep space, where the sun cannot deliver sufficient power to spacecrafts. This project has brought together leading stakeholders in the field of space and nuclear. PULSAR consortium includes nine partners: Tractebel (coordinator), SCK CEN, CEA, JRC, Airbus DS, ArianeGroup, UBFC, INCOTEC and ARTTIC. The paper provides a presentation of the project, the organization of the different work packages between partners, the objectives and the achievements obtained. Future prospect and expected challenges are presented based on the hypothesis assumed in PULSAR.

1 Introduction

Nuclear power is renowned for its inherently high specific power. The specific power of solar arrays is directly proportional to solar irradiance, which diminishes with the square of the distance from the sun. Over recent decades, significant advancements have been made in PV cell efficiency under low light conditions and in their resistance to space radiation at low temperatures. Despite these improvements, nuclear-powered RTGs remain superior and more attractive than solar panels and batteries when solar irradiance becomes insufficient (beyond Mars). Solar panels also face challenges during prolonged eclipses, such as the 14-day nights on the Moon or dust storms on Mars that can obscure the sun for days and deposit dust on the panels, or for high-power surface mobility applications. Consequently, nuclear power systems have been utilized for heat (Radioisotope Heater Unit or RHU) and electrical power generation (Radioisotope Power System or RPS). These systems do not rely on fission energy like terrestrial nuclear reactors but convert the heat from radioactive decay into electricity. However, RPS technology remains niche, and Europe currently lacks its own RPS solution and dedicated industrial isotope production chain for space applications. Previous ESA activities identified two radioisotopes for space mission nuclear power systems: Plutonium-238 (Pu-238) and Americium-241 (Am-241). Both are primarily produced in nuclear

reactors. Pu-238, already used as a space power source in the US and Russia, is preferred for several reasons:

- it has the highest power density (0.56 W/g for pure Pu-238), enabling a very light and compact power source.
- It emits few penetrating gamma radiations, making it relatively easy to handle.
- It has a convenient half-life of 87.7 years, suitable for all planned space missions.

Therefore, Pu-238 was chosen as the primary fuel for the PULSAR project. To address technological gaps and external dependencies, the PULSAR project aims to establish end-to-end Pu-238 production in Europe and design a dynamic RPS using a Stirling engine for higher conversion efficiency than past RTGs (Radioisotope Thermoelectric Generators).

The PULSAR consortium, led by TRACTEBEL, a Brussels-based international nuclear engineering consultancy part of the ENGIE group, includes key European nuclear and space sector actors: Belgian Nuclear Research Centre – SCK CEN, French Alternative Energies and Atomic Energy Commission – CEA, European Commission Joint Research Centre (JRC), Airbus Defence and Space, ArianeGroup; a leader in Stirling engine research, UBFC – Université Bourgogne-Franche-Comté and its affiliated Université de Franche-Comté; and two consultancies specializing in innovation and technology transfer, INCOTEC – Innovación Eficiente and ARTTIC.

This paper presents the project’s organization, scope definition through various tasks, and an overview of

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Table 1. PULSAR work package breakdown and scope.

Work Breakdown Structure	Leader
WP1 – Pu-238 production and processing	SCK CEN
WP2 – Heat source architecture and Stirling converter	CEA
WP3 – RPS engineering	TRACTEBEL
WP4 – Market assessment	INCOTEC
WP5 – Dissemination, communication & exploitation	ARTTIC
WP6 – Project management	TRACTEBEL

achievements. Future prospects and expected challenges are discussed based on PULSAR’s assumptions.

2 PULSAR overview

2.1 Scope description

PULSAR’s technical scope is divided into four work packages: Pu-238 production and processing (WP1), heat source architecture and Stirling converter (WP2), RPS engineering (WP3), and market assessment (WP4).

Two additional work packages, WP5 for Dissemination, communication, and exploitation, and WP6 for Project management, are common to Horizon Europe projects (see [Tab. 1](#)).

WP1 – Pu238 production and processing

This WP addresses the key technological challenges in establishing a Pu-238 production chain in Europe. The first part focuses on designing Np-237 targets, optimizing irradiation cycles in a high-flux reactor, and the Pu separation process. The second part involves synthesizing, characterizing, and manipulating PuO₂ pellets with representative microstructure. A laser welding technique for encapsulating the pellets in their cladding is also developed. The third part covers safety assessment, licensing, and regulatory framework for the radioisotope heat source to receive launch authorization. WP1 is led by SCK CEN with support from JRC and Tractebel.

WP2 – Heat source architecture and Stirling converter

This WP develops the PULSAR radioisotope heat source architecture to meet mission operational and safety requirements and analyzes its coupling with a Stirling engine. A review of state-of-the-art heat-to-electric conversion technologies is conducted to contextualize the PULSAR proposal. Design trade-offs are assessed, and development paths are optimized. WP2 is led by CEA with contributions from UBFC and UFC.

WP3 – RPS engineering

Future space missions will include various endeavors such as observational missions, cargo transport, planetary surface exploration, sample retrieval, and in-situ resource

utilization (ISRU). The first part of this WP identifies missions that would benefit from RPS technology and defines operational and safety requirements. The second part focuses on designing the RPS, including radiator sizing, heat source integration, and Stirling engine integration. The goal is to create a comprehensive 3D model of the RPS with its engineering files (thermal, mechanical, and shielding analyses). Finally, design validity is controlled through mission system integration. WP3 is led by Tractebel with contributions from ArianeGroup and AIRBUS DS.

WP4 – Market assessment

WP4 assesses the market potential for the PULSAR solution and the developed technological components. The application of similar Stirling converters outside space applications is also evaluated. WP4 is led by INCOTEC.

WP5 – Dissemination, communication & exploitation

The primary objective of this WP is to effectively promote the innovative approach, project results, and outcomes through appropriate channels to key stakeholders, including the scientific community, industry, policymakers, and the public. The consortium also reviews the exploitation strategy to ensure optimal outcomes for all stakeholders. WP5 is led by ARTTIC.

WP6 – Project management

WP6, led by Tractebel, involves traditional project management activities, promoting partner exchanges, providing strategic decision counsel, and ensuring project progress towards objectives. WP6 also includes project governance activities with an Advisory Board comprising Euratom, ESA, ArianeGroup, Airbus, and the Belgian Federal Agency for Nuclear Control to support strategic decisions and ensure project developments meet stakeholder needs and requirements.

2.2 Project important milestones

The PULSAR research project commenced in September 2022 and concluded in October 2024.

The initial progress was reviewed during the Milestone 1 meeting in March 2023, which laid the foundation for a conceptual RPS design. Milestone 2 took place in October 2023, marking the project’s midpoint and providing an opportunity for a second iteration of the RPS design.

This project concluded with the publication of several public reports as part of the Dissemination, Communication & Exploitation activities, covering the main topics addressed throughout the project. Notably, significant public reports included one on Safety Assessment Licensing and Regulations for Europe and another on Exploitation and future valorization prospects.

A final PULSAR workshop was held on October 2024, where ESA and EURATOM – EC policymakers were invited to discuss the potential benefits for Europe in developing such independent technology (see [Fig. 1](#)).

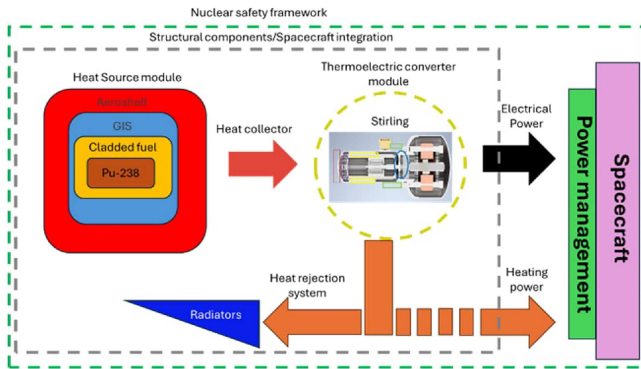


Fig. 1. Technology bricks involved in PULSAR RPS.

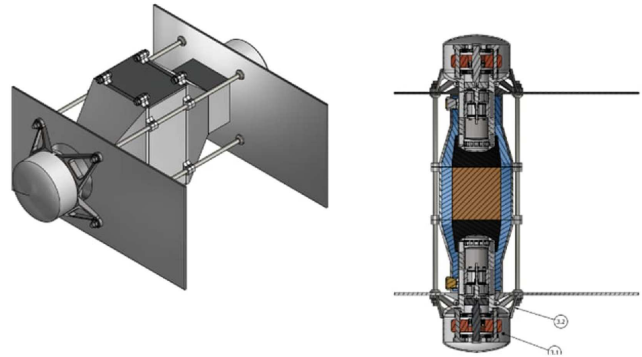


Fig. 2. PULSAR RPS 3D engineering model.

3 Project achievements on technology development

The PULSAR project has tackled all the different technology bricks and regulatory aspects of the development of a Radioisotope Power System, in particular as European know-how. A scheme of the elements involved is represented in Figure 2.

1. Heat Source (HS) module, which is further segmented in three technology bricks:
 - 1.1 Pu-238 production and processing.
 - 1.2 Cladded fuel (238-PuO₂ pellet + cladding).
 - 1.3 HS architecture (protective layers: Graphite Impact Shell, insulation and aeroshell).
2. Thermoelectric converter (stirling engine).
3. Heat rejection system (radiators).
4. Structural RPS assembly and spacecraft integration.

In addition to these technology bricks, power management distribution, control and monitoring of the power source are considered important features for the final product which need to be integrated with the spacecraft requirements. As a parallel process to the development, it is important to consider that a nuclear safety framework needs to be updated and harmonized to be able to create the opportunities to launch the RPS from European territory. PULSAR project has contributed to progress on the TRL of each technology bricks listed and on setting a comprehensive view of the nuclear safety framework.

3.1 Pu-238 production and processing

Pu-238 is the preferred radioisotope for RPS application because of its high-power density, the almost absence of penetrating gamma radiation and its relatively long half-life of 87.7 years. Even though Pu-238 is part of the Pu-isotopic vector build-up of power reactors fuel, its relative concentration with respect to the other plutonium isotopes is very small (maximum a few percentages). A concentration of at least 82.5% of Pu-238/Pu is required for an RPS. This high isotopic concentration is obtained by neutron irradiation of Np-237. A preliminary study on the feasibility of Pu-238 production in Europe funded by ESA

in 2021 proposed a roadmap for Pu-238 production [1]. Further studies are ongoing within PULSAR project to elaborate an optimized production chain.

The main steps for Heat Source Pu-238 production are:

- identification of an available Np-237 source i.e., from spent nuclear fuel streams, extraction of the nuclide, purification and increasing its concentration for easier and safer transportation.
- Manufacturing of neptunium targets, including neptunium-247/protactinium-233 separation, neptunium liquid-to-solid conversion and neptunium target fabrication.
- Neutron Irradiation of NpO₂ targets.
- Chemical reprocessing on irradiated neptunium targets, i.e., separation and purification of plutonium and neptunium from other each other and other fission products.
- PuO₂ pellets manufacturing.
- Clad the PuO₂ pellets.

3.1.1 PULSAR achievement

Within the PULSAR project, SCK CEN has achieved significant advancements towards the Pu-238 production related to the neptunium target manufacturing, their neutron irradiation and chemical reprocessing. Notably:

- optimization studies of the target geometry and irradiation conditions have been performed and several trends regarding the Pu-238 yield and the quality of the Pu vector as a function of target geometry and irradiation conditions have been identified. Two irradiation scenarios using reflector channels at BR2 have been proposed, with a calculated production rate of 418 g and 378 g of Pu-238 per year (TRL2).
- The conventional Savannah River Site (SRS) oxalate conversion route described in the open literature by US has been reproduced at laboratory-scale [2]. Moreover, modifications of the SRS oxalate conversion flow-sheet as well as more advanced conversion routes such as external gelation process to produce NpO₂ kernels have been investigated. The goal is to identify and solve challenges in designing Np targets for liquid-to-solid conversion step. Within all the studied processes, a yield between 84 and 91 wt.% was achieved and free-flowing NpO₂ materials has been obtained. This will

facilitate the further pelletization step. The PULSAR project has successfully achieved TRL3 for the neptunium conversion process.

- Solvent extraction in continuous process has been identified as the preferred method for separating neptunium and plutonium from fission products and from each other based on literature study. In PULSAR, distribution ratios as a function of nitric acid concentration for Np(IV), Np(V) and Np(VI) and Pu(III) and Pu(IV) with three solvents (a TBP-based solvent, N,N-diethylhexylbutyramide (DEHBA), and N,N-diethylhexylisobutyramide (DEHiBA)) were determined (TRL2).

3.2 Cladded fuel

The PuO₂ powder needs to be pressed and sintered into cylindrical pellets which can be successively cladded. The pellets production process is composed of at least two different operations:

1. granule production.
2. Pellet production.

Obtaining the right microstructure with an adequate ratio of void between the grains is important as this makes it possible to sustain the build-up of internal pressure created by the accumulation of alpha particles (helium nuclide) from Pu-238 decay. The final microstructure is the outcome of the different operations which include chemical reaction for oxalate precipitation, oxide conversion, oxygen exchange, milling processes, pressing processes, several steps of sintering with different atmospheres and temperatures. All these processing steps need to be optimized in order to reach a final pellet with the right microstructure and Theoretical Density (TD) in the range of 82–86% [3].

Plutonium oxide needs to be contained and shielded in a first layer (cladding) before being integrated in the Heat Source module. This cladding is particularly important to ensure radioprotection and to confine fines of Pu [4]. The cladded fuel must remain sealed one year after impact on Earth ground or sea following any sequential scenario, according to NASA requirements. NASA has developed its own iridium alloy (DOP26) to satisfy the safety and operational requirements. DOP26 is not available in Europe and manufacturability of such metallic alloy needs to be developed.

3.2.1 PULSAR achievement

In the PULSAR project, JRC have investigated in the Fuel and Materials Research laboratory both pellets and cladding manufacturability to develop a European know-how.

Pellet: in PULSAR the synthesis and characterization of PuO₂ pellets with representative microstructure have been investigated with Pu-239. The process to obtain pellets in the JRC facilities PuO₂ from reactor-grade plutonium with tailored microstructure and density well mimic the results obtained in the open literature by US (TRL 3).

Cladding: in PULSAR, the feasibility of using laser welding technics for the iridium encapsulation has been studied and tested in the JRC laboratories. Due to a lack of materials (DOP26 is not commercially available and iridium is very expensive), the few welding tests carried out are not sufficient to conclude on the feasibility. In addition, the composition for the iridium tested differs from that of DOP26 and may not be sufficient to produce good weld (TRL 2).

3.3 Heat source architecture

The cladded PuO₂ pellets need to be protected under additional layers in order to:

1. protect the cladded fuel in case of launch accidents (explosions, fireball, and ultimate impact on ground).
2. Protect the cladded fuel in case of atmospheric re-entry, by thermally isolating the cladding and creating an ablative barrier.

The final architecture of the Heat Source module should contain the cladded fuel and the protective layers stacked together to adapt the power request and interfaced with the thermoelectric converters in an efficient way.

3.3.1 PULSAR achievement

In PULSAR, CEA tackled the functional analysis, architecture proposal, selection of reference operating scenarios and definition of design criteria for the HS of a European RPS with Stirling converters. A preliminary design of a European RPS HS module has been proposed based on Thermal modeling (CEA) using GPHS materials and taking interfaces with RPS structures & Stirling converter into account. The re-entry ablation modeling (Ariane-Group) using SEPCARB 360 for the aeroshell have been computed.

3.4 Stirling engine

The thermoelectric converters play a crucial role for the RPS as they transform the thermal energy in electrical power available for the final user (spacecraft, rover or other devices). Thermoelectric converters for RPS can be separate in static systems and dynamic systems. Historically, RPS for space used static conversion with thermoelectric materials, which have a typical efficiency in the range 5–8%. In comparison, a Stirling engine (coupled with its electromechanical converter) could theoretically achieve much higher conversion efficiency (20%, maybe up to 40%) with a relatively high specific power (10–60 We/kg) for the anticipated power range of PULSAR RPS. A higher efficiency means that a smaller mass of radioactive material has to embark for the same useful electrical power. This is very favorable: limiting the time for production, lower source term for nuclear safety, reduced weight.

The Stirling engine operates on the principle of the temperature difference between a heat source and a heat sink. The main components of the Stirling engine are:

1. hot side chamber (called expansion volume).
2. Cold side chamber (called compression volume).
3. Piston.
4. Displacer.
5. Heat exchange interfaces.
6. Regenerator for efficient heat management.

The efficiency of the Stirling engine depends mainly on the temperature difference between hot and cold chambers, as well as all the associated heat and friction losses. Developing a Stirling engine meets several challenges, spanning from theoretical to practical implementation. The main challenges are:

1. Heat Transfer Efficiency: achieving high-efficiency heat transfer between the engine's hot and cold chambers with the external heat source and heat sink, while minimizing thermal losses.
2. Regenerator design: the regenerator is crucial for increasing the efficiency by storing and reusing heat between the expansion and compression phases. Designing an effective regenerator that maximizes efficiency without increasing the engine complexity, cost or weight is a major challenge.
3. Material selection: the selected materials have to demonstrate high thermal resistance to withstand high temperatures at the hot head and low temperatures at the cold head. Moreover, they have to be able to withstand cyclic mechanical stresses over long periods of time.
4. Sealing and leakage: maintaining leak-tight seals in high temperature environment is fundamental to avoid loss of efficiency. The materials itself have to be impermeable to gas release.

3.4.1 PULSAR achievement

A preliminary design of a Stirling engine for space application has been elaborated by UBFC. The proof-of-concept and functional verification (TRL 3/4) have been evaluated by modelling analysis.

Two different types of simulations: in-house software (UBFC) and professional software SAGE. New arrangements for the metallic springs have been designed. The parameters used for optimal performances are:

- frequency range = 30–40 Hz.
- Pressure range = 50–70 bar.
- Cold source temperatures: 50–200°C.

3.5 RPS mechanical integration

The RPS mechanical integration starts from the definition of requirements and constraints for the space mission. It has considered the mechanical design of the RPS assembly, with sub-assemblies for integration of the Heat Source at the latest stage. The mechanical integration comprehends studies validating thermal shielding and structural design in all operating modes. Moreover, it should consider requirements for prototyping and qualification testing.

3.5.1 PULSAR achievement

In PULSAR the environmental boundaries and operative conditions have been identified. A complete 3D engineering integrating the heat source is available. The different investigation spanned:

- thermal: radiator design for heat rejection Stirling cold side to final heat sink.
- Shielding: evaluation of worker's and material's protection.
- Structural: validated resistance of RPS assembly to design conditions (pressure, loads and temperature).

3.6 RPS system integration

System integration starts with identification of a target mission in order to identify RPS electrical and mass performance requirements. In addition, environmental requirements needs to be considered. An RPS model is prepared and validated including geometry, thermal and electrical specifications. The system performances for the target mission need to be analyzed.

3.6.1 PULSAR achievement

In PULSAR, mission specification for RPS sizing and design were issued with thermal and electrical model developed for ADS systema tool. Evaluation of RPS performance were assessed in a typical lunar rover mission for various cases (moon equator and polar walk). The impact of vehicle environment on RPS performance were evaluated and cold source temperature range were identified. The model weakness and required improvements for further studies were provided.

3.7 Nuclear safety framework

The launch safety approval and licensing process is one of the precondition to a wider uptake of the PULSAR RPS, in particular due to social acceptance of nuclear devices launch. Regulations must allow the production of a radioactive material for space application, and a thorough licensing process with clearly defined safety requirements needs to be implemented, covering the manipulation, separation, handling, irradiation and extraction of Pu-238 and Np-237. Moreover, producing the clad fuel and its storage in quantity to be able to power a space mission, will require extra consideration and authorizations depending on the facilities and the countries involved. Finally, the use of Pu-238 powered RPS with a Stirling converter will require the regulation and safety referential of the European space launch site to be updated. It is therefore important to tackle the regulatory and compliance aspects from the Pu-238 production processes, through the manufacturing of the Pu-238 pellets, its clad and integration in the Heat Source module, its transportation to the launch site and up to the launch and end of the space mission. The use in the final environment, which can be the launch site and the use in space, or other environments will have

to be considered, assessed and approved. A set of nuclear safety files need to be compiled including:

- handling and manufacturing activities in dedicated processing/production facilities.
- Storage of radioactive materials in any level of the production.
- Transportation to the assembly site if necessary.
- Safety requirements at the launch site and during the space missions.

This task requires considering the European legal framework and the regulations across different countries, providing a gap analysis to be able to demonstrate the compliance. Defining the nuclear safety framework is an important activity without which the RPS technology can not be developed.

3.7.1 PULSAR achievement

The PULSAR project has paved the ground on the safety assessment, licensing, and regulation of the PULSAR Heat Source. The selected design aims to comply with international safety principles and IAEA guidelines. Tractebel, ArianeGroup and JRC contributed to investigate the existing nuclear safety framework and how it should evolve to make the technology possible. The topic addressed were:

- the assessment of the handling and processing of Pu-238 in gram quantities in a nuclear laboratory [5].
- Definition of the launch phase nuclear safety requirements [6].
- Existing international and European safety regulations, licensing and gap analysis for the launch of a nuclear Heat Source from European territory [7].

ArianeGroup has defined the nuclear safety requirements for the launch phase of the PULSAR RPS and has identified the roadmap for constituting the nuclear safety demonstration in the subsequent phases of the PULSAR development.

3.8 PULSAR roadmap

The dynamics RPS fueled by Pu-238 is the assembly of the HS module containing Pu-238 with the Stirling engines. The final 3D engineering model can be seen in [Figure 2](#). Integration with the spacecraft and its avionics occurs at a later stage. The qualification of the HS module and the Stirling engine can be performed independently. Additionally, flight qualification can be conducted in two steps: an initial flight qualification without Pu-238, simulating the heat source to reduce hazards and anticipate potential issues, followed by a second flight qualification with the radioactive source. The HS module assembly will take place at the launch site. Technology development is assessed using the Technology Readiness Level (TRL) scale for space from ESA. Each high-level key objective is associated with a TRL to gauge its stage in dynamic RPS development.

The project proposal identified two main objectives to achieve higher technology maturity for PULSAR RPS:

establishing Pu-238 production capability in Europe and proving the concept of a dynamic RPS powered by Pu-238. An updated planning is proposed in [Figure 3](#), based on PULSAR assumptions. The timeline considers PULSAR achievements during the 2022–2024 project period, with subsequent steps marked as N+years, where N is the year funding becomes available. Four technology bricks (Pu-238, clad fuel, HS architecture, and Stirling engine) require consistent development, which can progress in parallel. Once the mission is identified, mechanical and system integration with the spacecraft and its power management must be designed. Concurrently, nuclear safety files must be continuously updated, and the facilities involved in fuel production and TRL qualification must be updated or designed and licensed.

In the proposed planning, considerations for each technology brick (e.g., Pu-238 production, clad fuel, HS architecture, and TEC development) are addressed. Pu-238 production is critical for the final RPS: without Pu-238 availability, the technology cannot receive final certifications. Funding to continue development at year N will allow Pu-238 production to begin within 10 years, given the assumptions in this roadmap. The development of other bricks can continue in parallel to the Pu-238 brick until TRL 6, simulating Pu-238 heat input when necessary. Afterward, obtaining Pu-238 for qualification tests is crucial. These tests should be achievable with limited amounts of Pu-238. In the PULSAR heat source design, a clad fuel pellet contains 125g of Pu-238, and a single heat source module contains 500g. Prototyping 238PuO₂ pellets with Pu-239 and simulating hot pellet production can be developed. Consolidating the HS architecture design using European-produced materials and manufacturing a Stirling engine with preliminary performance tests could be achieved in two years with continuous funding. Two additional years are needed to reach TRL 6 with performance demonstrations in relevant environments of clad fuel, HS architecture design, and Stirling engine. A critical design review (CDR) is performed after component performance assessments. The next two years can focus on performance evaluation in operational conditions to increase TRL to 7. Flight qualification tests (TRL 8) are proposed in a decoupled manner: the HS module (clad fuel + HS architecture) and the Stirling engine can be flight qualified separately to reduce risks. Once both parts are flight qualified, their design is finalized, and the HS module must be assembled with the Stirling engine at the launch pad. However, a full RPS flight qualification with Pu-238 is required, meaning flight qualification facilities must be compatible with Pu-238. With this plan, the HS module and Stirling engine development bricks would be ready for in-flight testing within 8 years, while Pu-238 production could begin and ramp up 2 years later, assuming available Np feedstock and continuous investment in PULSAR RPS development. Throughout development, licensing for increasing radioactive material use must be performed and updated by facility owners.

While developing PULSAR RPS technology bricks, nuclear safety requirements and compliance must be addressed in parallel [7].

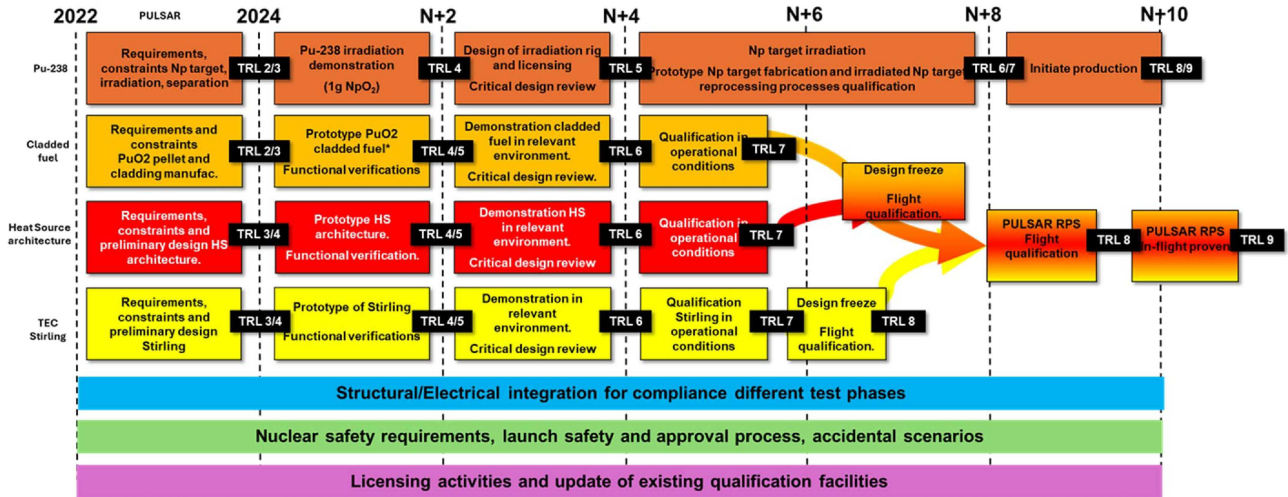


Fig. 3. – Proposed high level roadmap. * = need of Pu-238 for final qualifications.

4 Conclusions

The PULSAR project has successfully laid the foundation for the development of the first European Radioisotope Power System (RPS) fueled by Pu-238. Throughout the project, significant advancements were made in various technological areas, including the production and processing of Pu-238, the development of cladded fuel, and the design of a dynamic RPS using Stirling engines. These achievements mark a crucial step towards establishing a sustainable and independent European capability in space nuclear power systems.

Despite the progress, the project faced several challenges, particularly in the areas of nuclear safety, regulatory compliance, and the production of Pu-238. Through collaborative efforts, the consortium was able to address these challenges by optimizing target designs, improving irradiation processes, and developing robust safety frameworks. These solutions not only advanced the project's objectives but also set a precedent for future endeavors in this field.

Looking ahead, the technologies and methodologies developed during the PULSAR project hold significant promise for future space missions. The establishment of a Pu-238 production capability in Europe and the successful demonstration of a dynamic RPS provide a strong foundation for further research and development. Continued investment and collaboration will be essential to fully realize the potential of these innovations and to achieve higher technology readiness levels.

The impact of the PULSAR project extends beyond its immediate goals, offering valuable insights and advancements that can benefit a wide range of applications in space exploration and beyond. The project's success underscores the importance of international collaboration and the need for a cohesive regulatory framework to support the safe and effective use of nuclear power in space.

In conclusion, the PULSAR project represents a significant milestone in the journey towards sustainable and

efficient space exploration. The consortium's efforts have not only advanced the state of the art in RPS technology but also paved the way for future innovations that will continue to push the boundaries of what is possible in space exploration.

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Conflicts of interest

All three authors, Alessia Simonini, Nicolas Delannay, and Brieuc Spindler, certify that they have no financial conflicts of interest (e.g., consultancies, stock ownership, equity interest, patent/licensing arrangements, etc.) in connection with this article.

Data availability statement

Data associated with this article is available on <https://cordis.europa.eu/project/id/101061251>

Author contribution statement

All three authors, Alessia Simonini, Nicolas Delannay, and Brieuc Spindler, have collectively contributed to all the sections of the present article.

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