



Space Critical Technologies for EU Non-Dependence

Technical Guidance Document of Horizon Europe Space Work Programme 2026

Drafted by: the General Directorate for Defence Industry and Space of the European Commission

Applicable to:

HORIZON-CL4-2026-03-SPACE-81

HORIZON-CL4-2026-03-SPACE-82

HORIZON-CL4-2026-03-SPACE-85

HORIZON-CL4-2026-03-SPACE-86



This page is intentionally left blank.



Table of contents

1	INTRODUCTION	5
2	DEFINITION OF NON-DEPENDENCE	5
2.1	Technology Readiness Level	6
3	SPACE CRITICAL EEE COMPONENTS FOR EU NON-DEPENDENCE	7
3.1	Radiation Hard FPGA on 7nm Technology	7
3.2	GaN MMICs mm-Wave Foundations (Phase A): Development and Industrialization of Semi-insulating SiC Substrate Capabilities	11
3.3	High and Very High Energy Irradiation Test Facility Market Deployment	15
4	SPACE CRITICAL EQUIPMENT FOR EU NON-DEPENDENCE	19
4.1	Space Refuelling Interface	19



Table of Acronyms

AI	Artificial Intelligence
BOL	Beginning Of Life
CPT	Coherent Population Trapping
CSAC	Chips Scale Atomic Clock
EO	Earth Observation
EOL	End of Life
FPGA	Field Programmable Gate Array
HSSL	High Speed Serial Link
JTF	Joint-Task-Force
LEO	Low Earth Orbit
LET	Linear Energy Transfer
MRAM	Magnetic Random Access Memory
N7	Technology Node 7nm
R&D	Research and Development
SEE	Single Event Effect
SiP	System in Package
TID	Total Ionizing Dose
TRL	Technology Readiness Level
TRNG	True Random Number Generator
TSN	Time-Sensitive Networking
UDSM	Ultra Deep Sub Micron



1 INTRODUCTION

In the 2019 political guidelines, the European Commission President von der Leyen underlined that “it is not too late for Europe to achieve technological sovereignty in some critical technology areas”.

The 2020 EU industrial strategy stated: “Europe’s strategic autonomy is about reducing dependence on others for things we need the most: critical materials and technologies, food, infrastructure, security and strategic areas such as Space. They also provide Europe’s industry with an opportunity to develop its own markets, products and services which boost competitiveness.”

In 2021, the European Commission has established the EU Observatory of Critical Technologies (OCT) tasked with the objective of identifying, mapping critical space and defence technologies and drafting related EU technology roadmaps. So far, the OCT has produced a number of classified documents, related to different space and defence technologies and, since 2025 also EU technology roadmaps. Information stemming from the OCT is informing this Technical Guidance Document.

The European Commission through DG-DEFIS is therefore supporting and implementing the development of critical space technologies that are strategically important for the EU.

The expected developments listed in this document are identified by the European Commission and respond to specific needs of EU Space missions (e.g. Galileo, Copernicus, EGNOS, IRIS²...).

2 DEFINITION OF NON-DEPENDENCE

In the context of this document, it is important to recall the definitions of “Independence” and of “Non-Dependence”, namely:

- “Independence” would imply that all needed space technologies are developed in Europe.
- “Non-dependence” refers to the possibility for Europe to have free, unrestricted access to any required space technology.

In particular, the following are criteria used to evaluate if a technology is considered to be part of the list of critical space technologies:

1. Items shall be of low integration level, i.e. building blocks and components (System/sub-system assembly are not included)
2. Items shall have a clearly identified function and performance target
3. Items shall be multi use and/or applications (i.e. not an enabling technology for a one-shot use)



4. Items shall be not available from a European source and for which the unrestricted availability from non-European suppliers cannot be assured
5. Critical items for which no adequate or sufficient action is on going

2.1 Technology Readiness Level

The reference TRL definition is the ISO Standard 16290 “Definition of Technology Readiness Levels (TRLs) and their criteria of assessment”.



3 Space Critical EEE Components for EU non-dependence

3.1 *Radiation Hard FPGA on 7nm Technology*

3.1.1 BACKGROUND AND OBJECTIVES:

The objective of this initiative is to **deliver a next-generation Field Programmable Gate Array (FPGA) at 7nm technology node**, consolidating EU's strategic autonomy in advanced microelectronics for space and high-performance applications. The work described herein follows from previous phases of the development undertaken in previous space projects at EU and European level, for example focused on the design of complex IP cores, the creation of a design platform, and the definition of the FPGA programmable fabric.

This document sets the scope for the subsequent implementation tasks required to finalize the design, verification, prototyping, and industrialization of the 7nm FPGA device.

The scope includes the completion of **Programmable Logic (PL) architecture, integration of third-party IPs, full top-level chip integration, verification and prototyping, de-risking demonstrator and industrialization for production**. The activities cover both digital and analog integration, toolchain procurement, and foundry engagement for full mask execution.

3.1.2 WORK TO BE PERFORMED:

3.1.2.1 *PL Architecture Specification*

The PL architecture specification will finalize the design of the programmable logic subsystem, focusing on three key domains: clock distribution, power delivery, and the network-on-chip (NoC) (this latest is conditional to a demonstrated sufficient maturity level previous achieved outside this project). The clock distribution network must be designed to achieve minimal jitter and skew, providing a scalable solution across the FPGA fabric. The power architecture shall be developed to ensure robust delivery across multiple voltage domains, supporting low IR drop, power gating, and resilience for harsh space environments. The NoC topology shall be defined to guarantee high-bandwidth and low-latency interconnects, enabling efficient communication across heterogeneous regions of the FPGA.

Deliverables shall at least include detailed architectural specification documents and RTL reference models to guide subsequent integration phases.

3.1.2.2 *Integration of Third-Party IPs (Analog & Digital)*

Integration of external IP blocks is critical to enable the FPGA to meet functional and performance targets. Analog IPs such as phase-locked loops (PLLs), SerDes interfaces



shall be incorporated to support communication and timing features. Digital IPs such as PCIe, DDR memory controllers, and security modules shall also be integrated. This task will involve creating standardized wrappers and interfaces for seamless compatibility with the FPGA fabric, as well as building verification testbenches to validate the proper functioning of each IP. The outcome shall be a verified library of third-party IP cores ready for top-level assembly.

3.1.2.3 Top-Level Integration

This task covers the assembly of the FPGA's top-level design, combining the programmable fabric, NoC, and third-party IPs into a unified architecture. It will also incorporate design-for-test (DFT) and design-for-manufacturing (DFM) features to maximize yield and facilitate production testing. Reliability enhancements specific to space-grade requirements, such as radiation hardening by design (RHBD), shall also be considered.

Deliverables shall at least include the integrated top-level netlist and a complete physical design database prepared for verification and sign-off.

3.1.2.4 Verification

Verification activities shall ensure that the FPGA design operates as intended across all specified modes and conditions. Functional verification shall be carried out through simulation, formal methods, and emulation to validate correctness. Timing verification shall ensure that all performance constraints are met under process, voltage, and temperature corners. Pre-silicon validation of representative use cases shall further confirm that the device meets end-application requirements.

Reports summarizing verification coverage, regression results, and functional validation outcomes shall be provided as deliverables.

3.1.2.5 FPGA Prototyping

FPGA prototyping shall use existing programmable hardware platforms to emulate architectural features of the final 7nm device. This prototyping phase shall validate critical design choices such as interconnect bandwidth, power consumption, and configurability of the fabric. It will also serve as a risk-reduction step by identifying potential architectural or functional issues before tape-out.

Deliverables shall at least include prototype bitstreams and performance characterization results.

3.1.2.6 Digital on Top Flow

A digital-on-top (DoT) implementation flow shall be executed to integrate analog and digital blocks consistently. This methodology is expected to ensure that the digital design acts as the controlling framework, with analog macros correctly embedded and interfaced.



The flow shall also include back-annotation of parasitics and extracted views from layout, feeding them into system-level simulations for accurate performance prediction.

Deliverables shall at least include a fully assembled digital-on-top database and complete sign-off reports for functional, timing, and power compliance.

Deliverables shall at least include:

- GDSII tape-out database,
- package drawings, and
- complete PCB reference designs.

3.1.2.7 De-Risking Demonstrator Development and Testing

A dedicated de-risking demonstrator shall be developed to integrate and validate all critical IPs in a reduced, intermediate prototype ahead of the final device. This demonstrator shall be implemented as a **multi-project wafer (MPW) mask-sharing run**, allowing cost-efficient prototyping and, where possible, leveraging shared wafer space with other relevant European projects. The demonstrator shall serve as an early integration test vehicle, enabling validation of interfaces, clocking schemes, power distribution, and communication infrastructure in silicon.

To mitigate external risks, it is expressly required that potential delays from other projects participating in the MPW shall not impact the schedule of this demonstrator's tape-out. The demonstrator must proceed to fabrication independently if coordination delays arise elsewhere. Furthermore, this demonstrator is expected to tape out and complete initial validation tests at least 6–8 months before the planned tape-out of the final 7nm FPGA, ensuring sufficient time to feed lessons learned into the final design.

Deliverables shall at least include:

- the GDSII database for the demonstrator,
- 1 packaged fabricated silicon representing the demonstrator, it shall be delivered to DG-DEFIS,
- bring-up and test reports,
- consolidated assessment of de-risking results highlighting any corrective actions required before the final tape-out.

3.1.2.8 Package Design

Package development shall ensure that the FPGA can operate reliably under thermal and electrical stresses, especially in space environments. The package shall be optimized for high-speed I/O routing, power delivery, and heat dissipation.

Deliverables shall at least include:

- detailed package specification and



- the final layout database ready for manufacturing.

3.1.2.9 Bring Up

Bring-up activities (of both the de-risking demonstrator and the final FPGA) shall commence once the first silicon samples are available. This will involve executing structured test plans to validate power-on sequencing, clock tree operation, configuration logic, and the proper functioning of integrated IPs. Debugging methodologies shall be applied to isolate and resolve issues, while electrical characterization will assess signal integrity and timing margins.

Deliverables shall at least consist of:

- bring-up reports,
- silicon debug logs, and
- validation databases capturing measured performance.

3.1.2.10 Place and Rout tool Development

Place and rout tool development shall focus on building low-level software components required to configure and operate the FPGA device. This shall cover programmable logic initialization, monitoring of on-chip resources, and interfacing with external systems. The action shall be essential during the prototyping and bring-up phases, enabling early functional validation.

Deliverables shall at least include:

- well-documented source code,
- integration guides, and
- test reports demonstrating compliance with FPGA functional specifications.

3.1.2.11 EDA Tools Procurement

Procurement of electronic design automation (EDA) tools is essential to support the design and verification process. This includes acquiring licenses for digital design, analog simulation, physical verification, and sign-off tools compatible with 7nm process design kits (PDKs). The tools shall be configured into a coherent design environment accessible to the project team. This activity shall achieve a fully operational EDA infrastructure validated against test designs.

3.1.2.12 Foundry Full Mask Set Execution, Tape Out, Functional Testing and Validation

The final task involves close collaboration with the foundry to prepare the **full mask set** required for device fabrication. This task is focused on the tape out of the final chip which is expected to represent the full FPGA, will all functionalities, which eventually will undertake the space qualification activities in a follow up project.



This includes performing exhaustive design sign-off checks such as design rule checking (DRC), layout versus schematic (LVS), and electrical rule checking (ERC). Once the design is validated, the foundry shall generate the mask set and initiate wafer fabrication. Finally this activity should also cover the functional testing and validation of the complete chip.

Deliverables shall at least include:

- the final mask set,
- sign-off acceptance reports,
- functional test plan and report
- 2 packaged fabricated silicon representing the final FPGA, it shall be delivered to DG-DEFIS

3.1.2.13 Requirements

The FPGA final chip should demonstrate the following major requirements:

- Clock frequency of at least 300 MHz
- Static power consumption <2W and ideally <1 W at 25 C
- Radiation robustness:
 - SEE immunity up to LET 70 MeV*cm² /mg at 125 C,
 - TID > 100 Krad (target 300 krad)
- LUTs ≥ 1.000.000 with integration density 5000 LUTs per mm²
- DSP ≥ 2000
- HSSL ≥ 112 Gb/s
- Operating temperatures
 - [-40 to 85 C] at full performance
 - [-55 to 125 C] at full functionality

3.2 GaN MMICs mm-Wave Foundations (Phase A): Development and Industrialization of Semi-insulating SiC Substrate Capabilities

3.2.1 BACKGROUND AND OBJECTIVES:

The objective of this development is to establish and industrialize a EU-based capability for the production of high-quality semi-insulating silicon carbide (SiC) substrates, targeting 100 mm and 150 mm wafer formats, to support GaN MMIC technologies for mm-Wave, space, dual-use, and high-performance applications. This effort aims to strengthen the EU's strategic autonomy in compound semiconductor materials, which are critical enablers for next-generation RF, microwave, and millimeter-wave space systems.

The work described herein represents Phase A (Foundations) of a broader GaN MMIC development technology roadmap responding to the EU Observatory of Critical Technologies and focuses on substrate material readiness, process maturity, and industrial scalability. It builds upon prior European research and pilot-scale activities in SiC crystal



growth, wafering, and characterization, and transitions these capabilities toward a stable, qualified, and industrially viable supply chain.

The final objective of the development shall be the **industrial development of an EU-based source of semi-insulating SiC substrates** addressing **100 mm and 150 mm wafer diameters**, meeting the following **technology performance goals**:

- **Resistivity:** 10^6 – 10^8 $\Omega \cdot \text{cm}$
- **Polytype:**
 - 4H-SiC (4H-polytype Silicon Carbide) and/or
 - 6H-SiC (6H-polytype Silicon Carbide)

Target material quality parameters shall include:

- **Micropipe Density (MPD):**
 - 4H-SiC: 0.5–5 MPD/cm²
 - 6H-SiC: 0.1–1 MPD/cm²
- **Dislocation Density (DD):**
 - 4H-SiC: 10^3 – 10^5 cm⁻²
 - 6H-SiC: 10^2 – 10^4 cm⁻²

3.2.2 WORK TO BE PERFORMED

3.2.2.1 *Semi-Insulating SiC Crystal Growth Development*

This task focuses on the development and optimization of bulk semi-insulating SiC crystal growth processes suitable for 4H-SiC and/or 6H-SiC polytypes. Growth techniques shall be developed and demonstrated to achieve the target resistivity range and defect density levels while enabling scalability toward 100 mm and 150 mm boule diameters.

A progressive approach shall be adopted for the acquisition and deployment of SiC crystal growth tools. The development shall initially rely on the acquisition (if not already procured and available) and operation of a single SiC growth tool, serving as the reference platform for process optimization, material qualification, and risk reduction. It shall take place within the frame of the project duration. This first tool shall enable the demonstration of core growth capabilities within EU and shall form the technological basis for subsequent industrial scaling.

Key activities shall also include dopant and compensation control, thermal gradient optimization, and polytype stability management. Process repeatability and yield metrics shall be established to support industrial production.

Deliverables shall at least include detailed growth process documentation, material characterization reports, and demonstration boules meeting target specifications.



3.2.2.2 Wafering, Polishing, and Surface Preparation

This task addresses the downstream processing of grown SiC boules into device-grade wafers. Activities shall include slicing, grinding, polishing, and cleaning processes optimized to preserve material quality and minimize surface and subsurface damage.

Surface roughness, total thickness variation (TTV), bow, warp, and edge quality shall be characterized and improved (where necessary) to meet GaN epitaxy and MMIC fabrication requirements in coordination with the final GaN device/MMIC supplier.

Deliverables shall at least include:

- 100 mm and/or 150 mm semi-insulating SiC wafers and associated metrology and surface quality reports
- 1 semi-insulating SiC substrate stemming from each growth run, taking place within the project shall be delivered to DG-DEFIS

3.2.2.3 Material Characterization and Quality Assessment

Comprehensive characterization activities shall be performed to assess electrical, structural, and crystalline properties of the SiC substrates. This includes resistivity mapping, micropipe and dislocation density measurements, polytype verification, and defect imaging.

Statistical analysis shall be conducted across wafers and batches to assess uniformity, repeatability, and readiness for industrial deployment.

Deliverables shall at least include consolidated characterization datasets, quality assessment reports, and compliance matrices against the defined performance targets.

3.2.2.4 Compatibility with GaN Epitaxy and MMIC Processes

This task ensures that the developed semi-insulating SiC substrates are compatible with downstream GaN epitaxial growth and MMIC fabrication flows. Representative GaN epitaxy runs shall be performed to evaluate surface suitability, defect propagation, and thermal and electrical behavior.

Feedback from epitaxial and device-level evaluations shall be used to refine substrate specifications and processing steps.

Deliverables shall at least include epitaxy evaluation reports and an assessment of substrate suitability for RF/mm-Wave GaN MMIC applications.



3.2.2.5 *Demonstration of Integration into the EU GaN MMIC Supply Chain*

This task aims to demonstrate the effective integration of the EU-developed semi-insulating SiC substrates into the full EU GaN MMIC supply chain, encompassing substrate manufacturing, GaN epitaxy, device fabrication, MMIC design and packaging. The objective is to validate the technical and industrial suitability of the developed SiC substrates in realistic RF/mm-Wave device applications and to benchmark their performance against non-EU reference substrates.

The supply-chain demonstration shall be conducted in a phased and progressive manner, leveraging the initial single SiC growth tool as the enabling asset for substrate production. This first demonstration phase shall validate that a fully EU supply chain can be established and operated using a limited, controlled production capacity, before any later expansion toward industrial-scale, multi-tool production lines.

Representative GaN MMIC designs shall be defined, implemented, and evaluated using the EU-developed SiC substrates. At minimum, the following MMICs are suggested to be designed and fabricated:

- 1 Power Amplifier (PA), and
- 1 Low Noise Amplifier (LNA),

targeting representative frequency bands (e.g. X, Ku, Ka-band) relevant to space, dual-use high-performance applications. Alternative demonstrators are not excluded however, rational and justification shall be given in the proposal.

The MMIC designs shall be developed by EU MMIC design entities and fabricated by EU GaN manufacturers, ensuring that the complete supply chain, excluding the benchmark substrate, is EU based. The same MMIC designs, process flows, epitaxial structures, and packaging approaches shall be reused on a non-EU semi-insulating SiC substrate of comparable specification to enable a fair and controlled comparison.

Electrical, RF, thermal, and reliability-relevant performance metrics shall be measured and compared, including but not limited to output power, gain, noise figure, efficiency, linearity, thermal resistance, and basic reliability. The comparison shall assess the impact of the EU-developed SiC substrate on device and circuit-level performance, as well as manufacturing robustness.

Deliverables shall at least include:

- MMIC design documentation for the PA and LNA
- 1 fabricated PA and LNA MMICs die using EU-developed SiC substrates, it shall be delivered to DG-DEFIS
- 1 fabricated reference PA and LNA MMICs die using non-EU SiC substrates, it shall be delivered to DG-DEFIS
- comparative measurement and characterization reports
- a consolidated assessment of supply-chain integration, performance benchmarking, and industrial readiness



3.2.2.6 Pilot Production and Industrial Scaling

This task focuses on transitioning the developed processes toward pilot-scale industrial production. Activities shall include scaling crystal growth and wafering processes, defining process control methodologies, and establishing key performance indicators (KPIs) for yield, throughput, and cost. Supply chain considerations, including raw material sourcing and equipment readiness, shall also be addressed.

Based on the results obtained with the first SiC growth tool, this task shall define the technical, logistical, and investment requirements for extending the substrate production capability to multiple growth tools, enabling higher throughput, improved redundancy, and cost optimization. Multi-tool deployment shall be planned within this phase under the condition that positive results are achieved in the previous phase based on a single growth tool.

Deliverables shall at least include pilot production wafers, industrial readiness assessments, market analysis and scalability reports.

The described development activity is expected to be sized in line with the EU financial contribution defined by the Call, or higher if additional investment will be raised. However, if a reduced number of activities and/or limited number of growth tools will be procured, the proposal should explain the case, the rationale as well as reflect it in a request for a lower amount of EU budget contribution.

3.3 High and Very High Energy Irradiation Test Facility Market Deployment

3.3.1 BACKGROUND AND OBJECTIVES

The objective of this development is to establish a next-generation very high energy radiation test facility in Europe for irradiation testing of Electronic, Electrical, and Electromechanical (EEE) components, consolidating EU strategic autonomy in space radiation qualification. The work described herein follows previous European developments in heavy-ion irradiation, and it aims to extend capabilities to provide routine, high-energy, multi-ion species testing with increased beam time and broader industrial and institutional access.

This document sets the scope for the subsequent implementation tasks required to design, commission, and operate a fully functional facility capable of delivering **70 MeV/n to ~1 GeV/n** (ideally up to 5 GeV/n) ion irradiation, for at least 4 different ion species sufficiently different in mass, and jointly providing typical LET ranges necessary for radiation effects testing (e.g. 0.5 to 60 MeVcm²/mg), and, where feasible protons, with applications in SEE, SEL, and displacement damage testing. The facility shall enable in-air testing of components and boards, and integrate beam diagnostics, control systems, and booking platforms for user access.



The facility shall be open and accessible to EU and non-EU space stakeholders. Nevertheless, in case the amount of beam time requested exceeds the available beam time, allocation shall **prioritize EU-based stakeholders**. Requests from non-EU stakeholders shall be analyzed on an ad-hoc basis, considering the remaining available beam time. This prioritization scheme shall be reflected in the proposal, implemented in the operational procedures, and enforced through governance mechanisms.

In addition, an enhanced prioritization scheme shall be implemented to provide **fast-track access to irradiation tests** that are directly supporting the implementation, qualification, or risk mitigation of **EU institutional space missions and programmes (e.g. Galileo, Copernicus, IRIS²)**. Such requests, when submitted by EU-based stakeholders or EU institutional actors, shall be given preferential scheduling within the available operational windows, subject to technical feasibility and safety constraints.

3.3.2 WORK TO BE PERFORMED

3.3.2.1 *Beamline Architecture Specification*

The beamline architecture specification shall define the design of the facility's irradiation lines, including beam transport, optics, focusing, and energy selection. Key aspects include energy range (70 MeV/n to ~1 GeV/n, ideally up to 5 GeV/n) for at least 4 different ion species (sufficiently different in mass, and jointly providing typical LET ranges necessary for radiation effects testing e.g. 0.5 to 60 MeVcm²/mg), and where feasible protons, beam uniformity control, and integration with irradiation stations. The facility shall be designed to ensure the availability of at least 2200 hours of beam time per year, offered in at least two distinct operational time windows during the year (e.g. spring and autumn), providing predictable and reliable access for users.

Deliverables shall at least include:

- Detailed beamline layout and optics simulations
- Operational planning documents and beamline specifications
- Energy and LET profiles for all ion species

3.3.2.2 *Multi-Species Ion Capability*

This task covers the integration of multiple ion species to replicate space radiation environments. It shall include the development of source and extraction systems for 4 different ion species, and where feasible protons, along with fast switching mechanisms to allow efficient transitions between ion species during operations. LET and energy calibration for each species shall be performed at the irradiation target. The inclusion of protons is considered an aspirational objective and shall be pursued on a best-effort basis; accordingly, the proposal is expected to address this optional requirement by clearly outlining the planned approach, feasibility, and limitations associated with proton implementation.

Deliverables shall at least include:

- Verified ion source and beamline designs for all species



- Characterized LET and depth-dose profiles at target locations
- Documentation of ion switching procedures and expected performance

3.3.2.3 Top-Level Facility Integration

This task covers the assembly of all subsystems into a fully operational facility, including irradiation stations, beamline optics, control systems, diagnostics, and safety interlocks. The integration shall include an online interface through which end users can request access to the facility, submit and manage irradiation test requests, schedule beam time, and interface with the systems used for operating the beam and performing the actual testing. The facility and all interfaces, including the access request and operational interfaces, shall clearly display the EU flag and state that this capability has been developed via the EU Space R&D programme and actions on critical space technologies to support EU strategic non-dependence.

Deliverables shall at least include:

- Integrated facility schematics

3.3.2.4 Verification and Commissioning

Verification and commissioning activities shall ensure that the facility operates within specified parameters. Functional tests shall include beam energy, LET, flux, uniformity, and irradiation environment checks. The verification shall also confirm correct implementation of the EU-prioritized beam-time allocation scheme and full functionality of the online access and operational interfaces.

Deliverables shall at least include:

- Commissioning reports with beam energy, LET, and uniformity verification
- Operational validation and user interfaces
- Documentation of beam scheduling and prioritization mechanisms

3.3.2.5 Control Software and User Interface Development

Control software shall provide real-time monitoring of beam energy, ion species, intensity, and uniformity. An integrated online interface shall be developed enabling end users to request access, submit test plans, schedule experiments, and monitor irradiation parameters during testing. All interfaces (including GUIs) shall clearly display the EU flag and indicate that the facility has been developed under the EU Space R&D programme addressing critical space technologies and European non-dependence. Attention should be given in ensuring that the public interfaces will be secured from potential cyber-attacks, especially for preventing malicious actions aiming at accessing data results.

Deliverables shall at least describe:

- Control software with monitoring and logging capabilities
- Public-facing access and booking interface



3.3.2.6 Safety and Radiation Protection

Safety activities include shielding design, interlocks, and radiation monitoring to protect personnel and the facility. Safety procedures shall be compatible with routine industrial operation and multiple user campaigns per year.

Deliverables shall at least include:

- Safety assessment reports and shielding validation
- Operational safety manuals
- Radiation protection verification data

3.3.2.7 Facility Operation and Maintenance Planning

Operational planning shall define scheduling of beam time, maintenance cycles, and user support. The operational model shall ensure delivery of at least 2200 h/year of beam time, split into at least two operational windows, while minimizing downtime during these periods to prioritize EU user access.

Deliverables shall at least include:

- Operational manual and maintenance schedules
- Beam-time allocation and user support procedures

3.3.2.8 Demonstration Test Campaigns

To demonstrate the full functionality, maturity, and operational readiness of the facility, two representative irradiation test campaigns shall be executed during the project lifetime. These campaigns shall involve complex and dense EEE components representative of modern space hardware, such as advanced processors, FPGAs, system-in-package devices, or high-density electronic boards.

Each test campaign shall be structured to include both internally conducted experiments performed by the project consortium and externally proposed experiments submitted by end users. External experiments shall be selected through an open call mechanism managed via the facility's online access platform.

An internal experiment selection board shall be established within the project consortium to evaluate, prioritize, and select external experiment proposals based on technical relevance, feasibility, safety, alignment with project objectives, and available beam time. The European Commission shall be part of this selection board, and shall have the final decision authority for experiments submitted by non-EU end users.

The test campaigns shall validate high-energy penetration (including heavy ions), beam uniformity, in-air testing capability, operational interfaces, user workflows (from access request to data delivery), and governance procedures related to user access and prioritization.

Deliverables shall at least include:

- Test plans and descriptions of EEE components for both campaigns
- Irradiation reports including beam conditions, LET, dosimetry, and test results

3.3.2.9 REQUIREMENTS

The very high energy test facility shall meet the following major requirements:

- Energy range: 70 MeV/n to ~1 GeV/n (ideally up to 5 GeV/n) for at least 4 different ion species sufficiently different in mass, and jointly providing typical LET ranges necessary for radiation effects testing (e.g. 0.5 to 60 MeVcm²/mg), and where feasible protons
- The facility shall demonstrate the capability to reach at least 100 MeV/n not only for light ions, but also for heavy ions, i.e. lead or heavier, in conditions suitable for EEE space radiation testing.
- In principle, the facility shall be capable of reaching energies up to approximately 1 GeV/n (ideally up to 5 GeV/n) for the various ion species. At these very high energies, the available beam time is expected to be limited to approximately 300 h/year. This capability, including the incorporation of additional ion species and fast switching between them, shall be considered as part of the project scope.
- Beam time availability: at least 2200 h/year, split into at least two operational windows per year (e.g. spring and autumn)
- Beam uniformity: $\pm 10\%$ standard; $\pm 5\%$ where required
- Operational environment: in-air testing
- Multi-species capability with reproducible LET profiles and fast switching
- User access: open to EU and non-EU stakeholders, with prioritization of EU-based stakeholders when requested beam time exceeds availability; non-EU requests subject to ad-hoc evaluation and governance approval
- Control and booking platform: online interface for access requests, scheduling, beam operation and monitoring, clearly displaying the EU flag and indicating development via the EU Space R&D programme and actions on critical space technologies for European strategic non-dependence
- Demonstration: successful execution of two irradiation test campaigns combining internal consortium experiments and externally selected user experiments, governed by an internal selection board including the European Commission
- Safety and radiation protection: fully compliant with European regulations

4 Space Critical Equipment for EU non-dependence

4.1 Space Refuelling Interface

4.1.1 BACKGROUND AND OBJECTIVES

Development and maturation, up to flight readiness, of a Refuelling Interface allowing the transfer of multiple propellants (incl. for Electric Propulsion) and compatible with the use cases and demonstrations targeted by the *EU ISOS4I Pilot Mission* (more info in the [ISOS guidance document issued for the call topics 2025](#)), therefore the guidance document for the



ISOS Pilot Mission, derived in close collaboration with the ISOS Pilot Mission Advisory Group, and published on the EU funding and tenders portal).

The interface may also combine functions, for instance docking, to ensure a stable connection between servicer and client or fuel module and a platform, however the main design drivers should be the compactness of the solution (mass, volume), the achievement of minimal leakage performance and compatibility with the widest possible range of use-cases.

As indicated in the 2026 Work Programme, the proposal shall target a final Technology Readiness Level (TRL) equal to or higher than 5. In this context, the consortium is expected to build upon technology maturation levels already available within the EU, taking into account ongoing development activities supported by EU programmes (e.g. ISOS-related actions under the HE WP 2025 EU Space call) as well as other relevant European and national programmes, provided that the entire supply chain is compatible with the EU27, including Norway and Iceland.

Accordingly, the proposed technical solutions shall coherently develop advancements beyond the maturation levels targeted by ongoing projects, and therefore these advancements are ultimately expected to be demonstrated through space-relevant evaluation and system-level qualification activities, aiming at compatibility with **TRL 7**.

4.1.2 WORK TO BE PERFORMED

It is expected that the work performed will consist of the following parts:

4.1.2.1 Space qualification and industrialisation of one of the technical solutions considered by the projects awarded in the WP2025 ISOS topics ensuring a fully European supply chain and technological non-dependence

This implies selecting one refuelling interface concept already considered and under development under one or more of the projects awarded by the WP2025 ISOS topics. The proposal should very clearly describe the link to these ISOS project(s) and provide evidence that the solution proposed for qualification and industrialisation is considered in the ISOS project(s). Therefore, the specific focus should be to bring it from a prototype or breadboard level to a fully space-qualified product. In practice, this includes detailed design consolidation, materials and process selection compliant with space standards, qualification testing (mechanical, thermal, vacuum, contamination), and adapting the design for repeatable manufacturing. A key expectation is that the full supply chain (components, materials, manufacturing, testing) is based in EU, ensuring technological non-dependence and readiness for industrial production.

4.1.2.2 Elaboration of addressed use cases

The development must clearly define and justify the operational scenarios in which the refuelling interface will be used, both as a standalone product addressing a variety of ISOS



use cases and ultimately in the context of the ISOS4I Pilot Mission. This includes identifying the relevant spacecraft and infrastructure elements (e.g. client satellites, fuel depots, logistic elements, etc.), mission orbits (LEO, MEO, GEO), propellant types (liquid, gaseous, green), and operational concepts (e.g., robotic refuelling, modular replacement, docking-assisted transfer).

4.1.2.3 Concrete implementation roadmap for inclusion in the ISOS4I Pilot Mission

This requires producing a realistic and detailed plan showing how the refuelling interface will be integrated into the ISOS4I Pilot Mission. The roadmap should cover technical milestones, qualification steps, interfaces with other mission components and technological developments, schedules, risks, and responsibilities. Close coordination with the ISOS Coordination and Support Action (CSA) is expected to ensure alignment with mission constraints, interfaces, and overall system architecture.

4.1.2.4 Extensive ground testing in a representative environment

The project is expected to carry out a comprehensive test campaign that simulates the environmental and operational conditions of space. This includes vacuum, thermal cycling, exposure to different pressure ranges up to and beyond requirements of applicable missions, and demonstrations with different propellants. Testing must demonstrate reliable operation across conditions, validate sealing and leakage performance, and confirm mechanical and functional robustness. More specifically, the following shall be achieved:

- **Demonstration with different propellant types and under varying conditions**
Therefore, testing the interface with multiple liquid and gaseous propellants (including green propellants and electric propulsion propellants), under different pressures and temperatures, to prove broad compatibility and performance stability.
- **Demonstration of possible combination of functions (e.g., docking)**
If the interface combines refuelling with other functions, such as docking or mechanical capture, these combined operations must be demonstrated to work reliably together, without degrading refuelling performance or safety. Moreover, all functions (for instance docking if applicable) shall be tested and demonstrated under representative environment conditions.
- **Reliability testing and lifetime extraction**
The interface must undergo repeated connection, disconnection, and refuelling cycles to assess wear, degradation, and failure modes. From these tests, lifetime models and reliability metrics are expected to be derived, ultimately showing compatibility with ISOS pilot mission applicable component duration and operational needs.
- **Possible integration in ground testing for call HORIZON-CL4-2027-SPACE-03-21**
The project should be fully prepared to align or integrate its testing activities with parallel Horizon Europe ground demonstrations, where relevant. This requires coordination with the ISOS CSA and other consortia (primarily the project expected



to be funded under HORIZON-CL4-2027-SPACE-03-21) to ensure technical compatibility, efficient use of shared test facilities and a high impact integrated demonstrator.

4.1.2.5 *Demonstration of production scalability aiming at a marketable product*

Beyond technical performance, the development must show that the refuelling interface can be manufactured at scale with consistent quality and reasonable cost. This includes defining manufacturing processes, identifying critical components and suppliers, assessing production bottlenecks, and demonstrating that the design is suitable for series production rather than one-off demonstrators, ultimately supporting commercial deployment.

Deliverables shall at least include:

- Test plans
- Test reports
- Roadmap for integration in the ISOS4I Pilot Mission
- Proposal to ISOS CSA for integration in the ground testing for call HORIZON-CL4-2027-SPACE-03-21
- Production scalability report
- Use case elaboration with identification of applicable missions, market analysis and business case

4.1.3 REQUIREMENTS

The refuelling interface shall meet the following minimum requirements:

Types of Propellant	Liquid and gaseous (including green)
Pressure	At least up to 200 bar
Operating Temperature	As wide as possible, compatibility with LEO/MEO/GEO environments
Leakage	Minimal leakage demonstrated for different operating pressures/propellant types
Design	Compact, lightweight



END