European NPS Launch System Authorization Process

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ENDURE project & LSAP

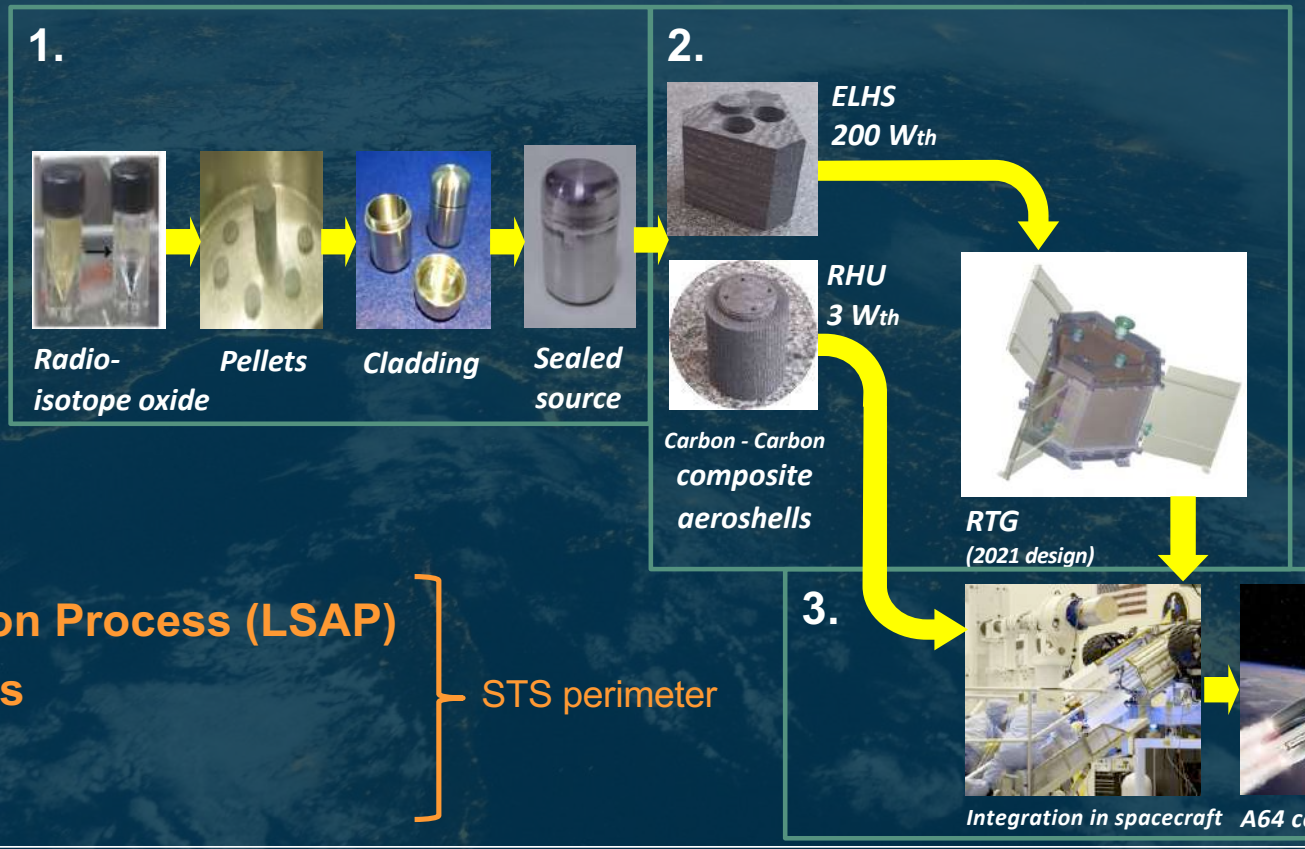
End-to-end European operational capability for RPS systems by 2031

1. Radioisotope production, pelleting & cladding
   → sealed source prod.

2. RPS system development

3. Launch Safety Authorisation Process (LSAP)
   Launch System adaptations
   Launch Range adaptations

STS perimeter



Nuclear Safety activities & LSAP – a "step-by-step" approach

The first European missions with RPS are foreseen to be launched from the Europe's spaceport in French Guiana. From 2018, preliminary Nuc. LSAP activities have contributed to the preliminary nuclear system Launch objectives and methodology in complement to the ESA safety policies and standards.

The preliminary nuclear system process (NLSAP) to authorize a NPS launch from Europe is considering "a step-by step" implementation approach (listed in order of preference and priority):

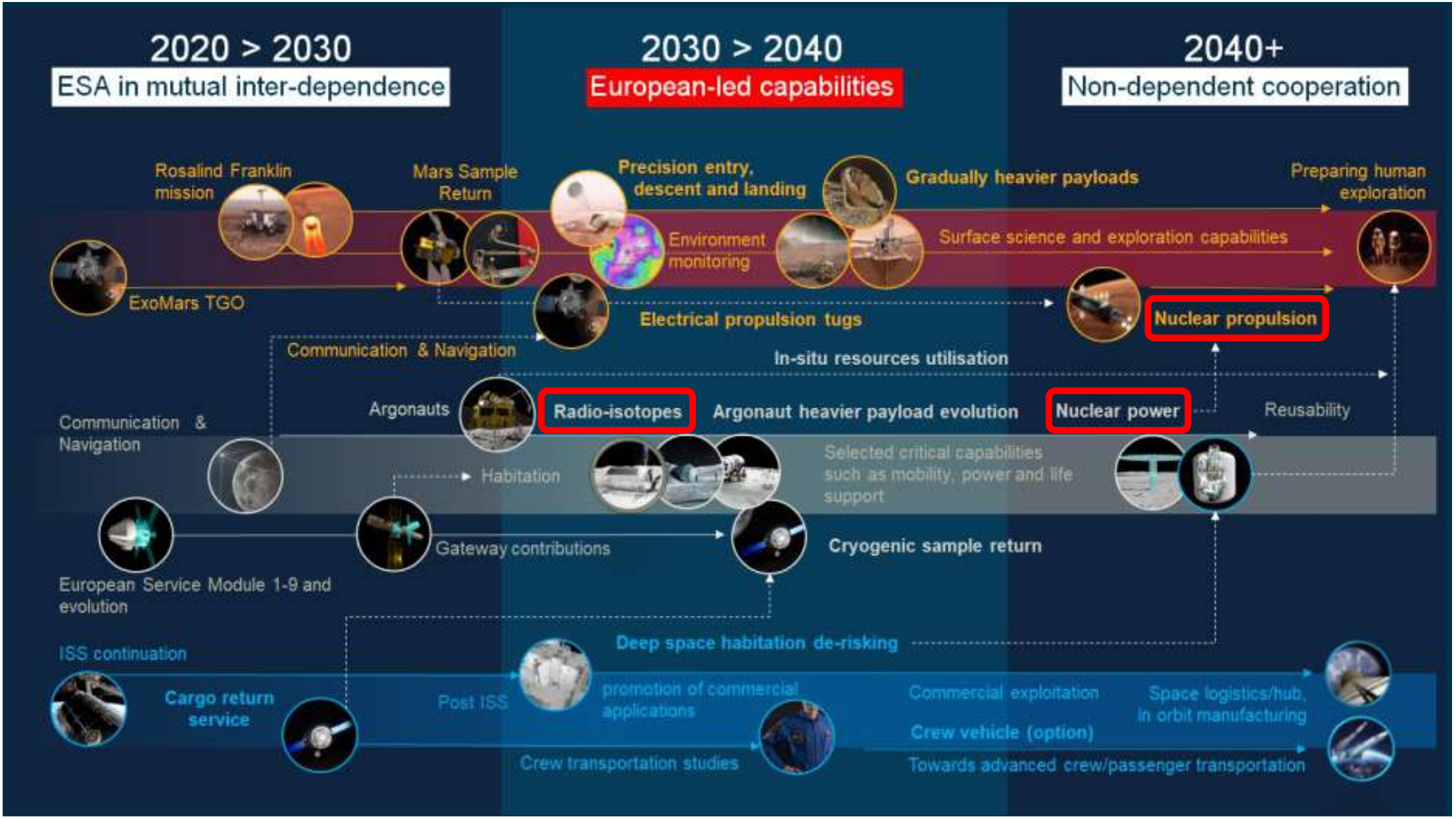
a) Development of a European **RPS** (RHU, ELHS, RTG…), based on Americium Oxide source isotope (**Am241**), aiming at delivering an end-to-end autonomous European operational capability (Ariane 6 Launcher System from CSG),

b) Use of an existing **RPS (Am241 or Pu238)** from international providers, considering NLSAP delta Nuclear Qualification activities,

c) Design/Development of a European RPS based on **Pu238 radioisotope** (European Com.-PULSAR…)

d) Evaluation of the upgrade of the French Guyana Space Centre facilities to achieve **"INB" definition**

e) Nuclear Power and Propulsion applications (*Nuclear Propulsion-U235), from ESA/HRE roadmap to be assessed – Nuclear LSAP as Key-process paving* ***Nuclear power & propulsion***


2020 > 2030
ESA in mutual inter-dependence
2030 > 2040
European-led capabilities
2040+
Non-dependent cooperation
Rosalind Franklin mission
Mars Sample Return
Precision entry, descent and landing
Gradually heavier payloads
Preparing human exploration
Environment monitoring
Surface science and exploration capabilities
ExoMars TGO
Electrical propulsion tugs
Nuclear propulsion
Communication & Navigation
In-situ resources utilisation
Argonauts
Radio-isotopes
Argonaut heavier payload evolution
Nuclear power
Reusability
Communication & Navigation
Habitation
Selected critical capabilities such as mobility, power and life support
Gateway contributions
Cryogenic sample return
European Service Module 1-9 and evolution
Deep space habitation de-risking
ISS continuation
Cargo return service
Post ISS
promotion of commercial applications
Commercial exploitation
Space logistics/hub, in orbit manufacturing
Crew vehicle (option)
Crew transportation studies
Towards advanced crew/passenger transportation

Space Nuclear Safety activities & LSAP – from 2018

LSAP initial phases from (2018), (2021) (2022)

- Building of a robust authorisation/regulatory framework with the relevant French authorities (CNES, IRSN and ASN) for missions to be launched from CSG
- Technical safety performances of all the subsystems (RPS, spacecraft LDE-PL, launcher and launch range) of a mission (system): identification of the representative Ariane-6 and mission accidental scenarios, characterisation of the accidental environments considering the accidental sequences, allocation of the NS requirements and preparation of the nuclear safety management requirement document (NSMRD) for each subsystems (Argonaut/LDE B2-C-D-E0 and “RHU STM and QM qualification”)
- From 2023: Initiation of dedicated coordination to consolidate the NS requirements for all RPS NSICs (guarantee the European NS approach launch authorisation process by preparing a robust qualification tests plan).

Preliminary Europe Launch Safety Agreement between Agencies

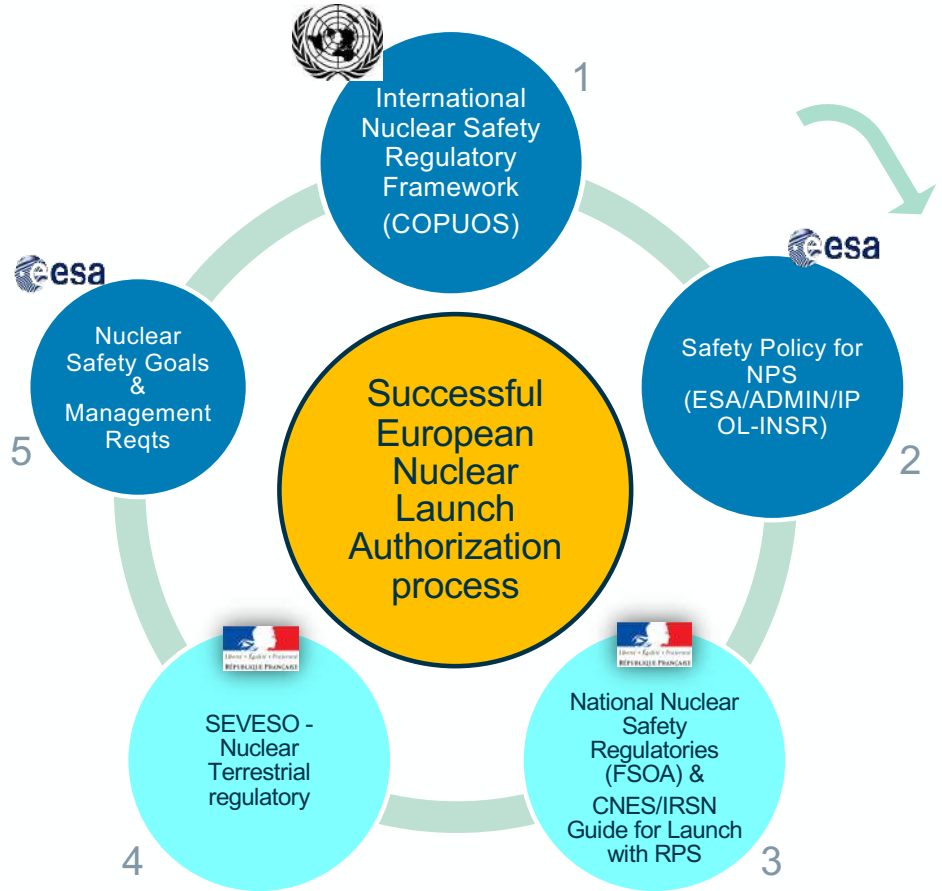
European Agencies

- esa — Overall Mission Definition (Launch & In orbit) & Programme Management
- cnes — Launch Approval from CSG up to lunar capture
- asn — Terrestrial Nuclear Authority for Establishment
- IRSN — Nuclear LSAP technical expertise for CNES

Industrial Primes industrials

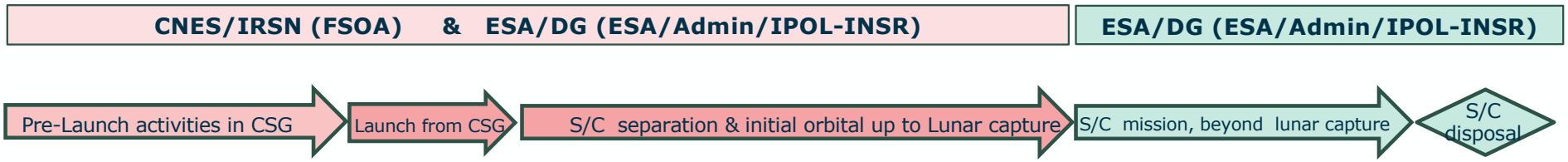
- arianeGROUP — Launcher System & Launch Complex Launch service provider
- NATIONAL NUCLEAR LABORATORY — Fuel AmOX2 and pellets provider
- UNIVERSITY OF LEICESTER — NPS Design Authority

Main European stakeholders involved in a Space Launch from French Guyana Space Centre for mission using a NPS



THE EUROPEAN SPACE AGENCY

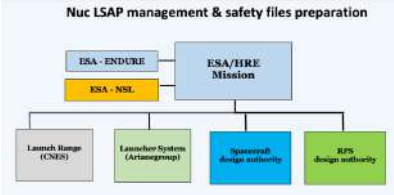
Launch Vehicle Integration & Spacecraft Missions onboarding Nuclear Power Systems (NPS)



Launch Vehicle Integration & Spacecraft Missions onboarding Nuclear Power Systems (NPS)

CNES/IRSN (FSOA) & ESA/DG (ESA/Admin/IPOL-INSR) | **ESA/DG (ESA/Admin/IPOL-INSR)**

Pre-Launch activities in CSG → Launch from CSG → S/C separation & initial orbital up to Lunar capture → S/C mission, beyond lunar capture → S/C disposal



*Definition of **Nuclear Safety Goals & Allocation of the Nuclear Objectives** (10^{-7} not to release any radioisotope to Earth for any accident with A6 or S/C)*

NSL activities to prepare **demonstration of the Space System compliance to NS Goals**

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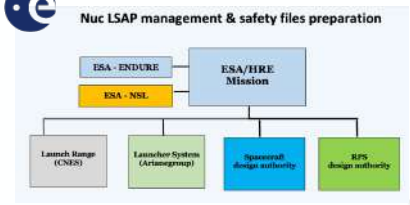
End of S/C mission (no return to Earth)



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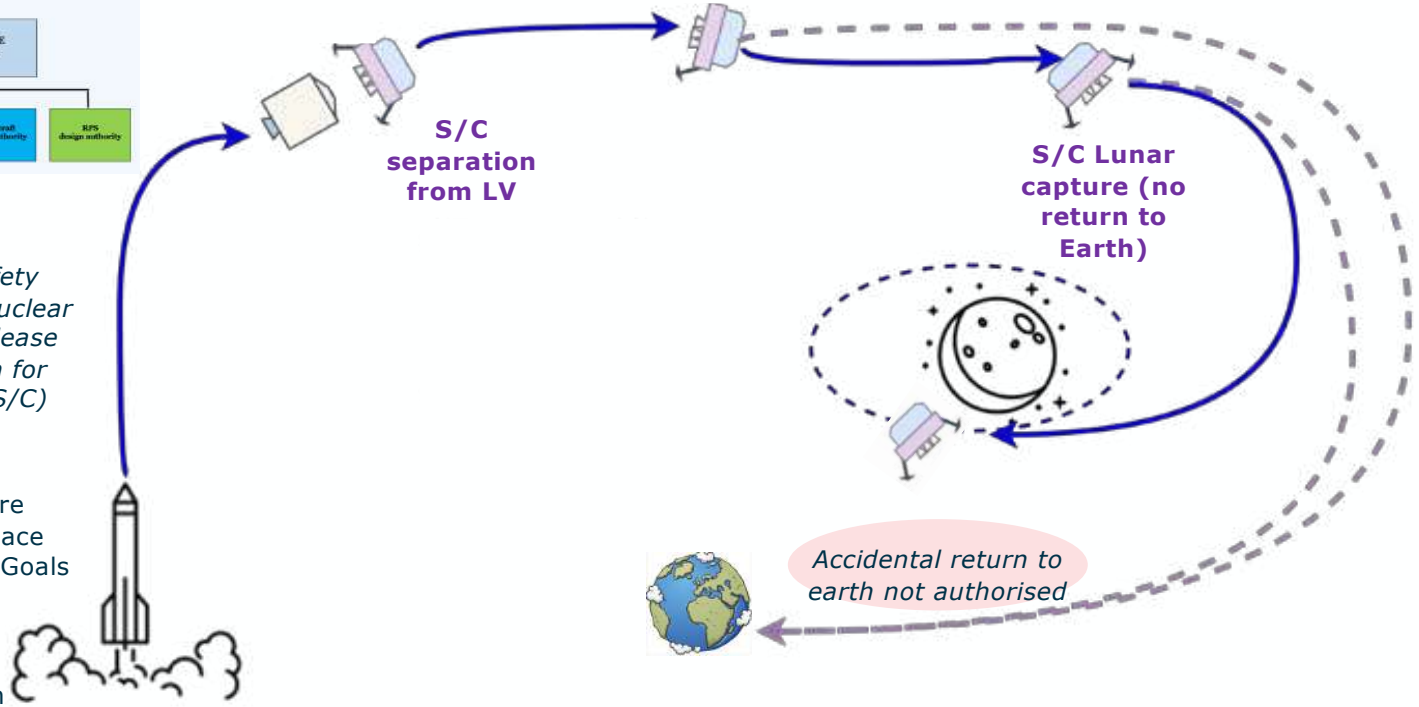
Authorisation to Launch NPS



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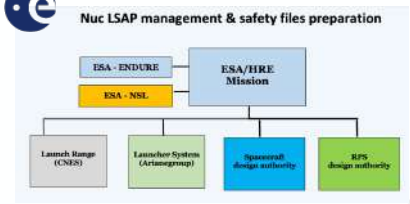

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NSL activities to prepare demonstration of the Space System compliance to NS Goals

Authorisation to Launch NPS

S/C separation from LV

S/C Lunar capture (no return to Earth)

Accidental return to earth not authorised

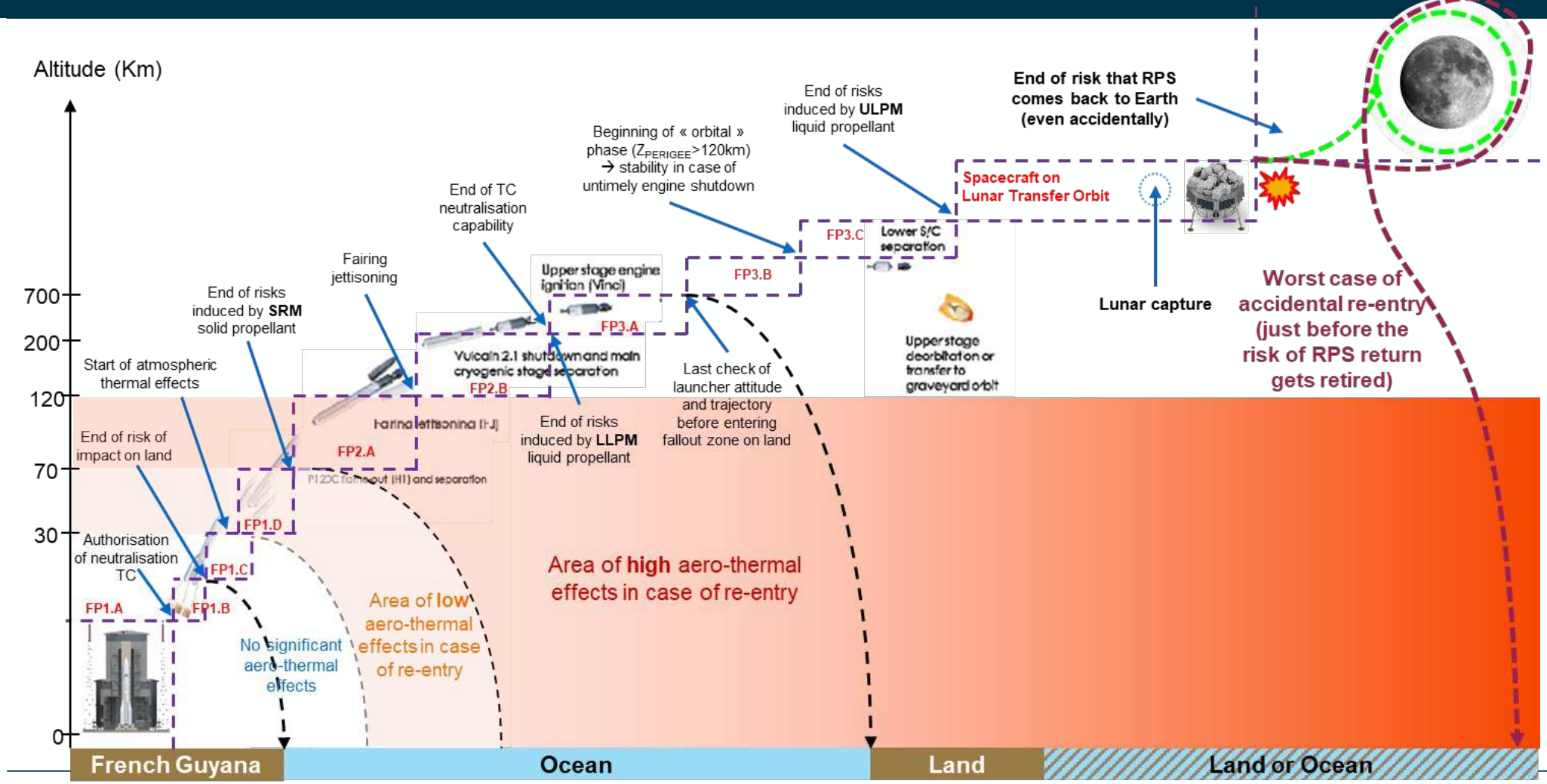
LSAP specific activities for S/C with NPS

Perimeter of the Nuclear System activities within Nuclear LSAP

The Nuclear Safety Goals proposed for the Nuclear LSAP, apply for a launch and an orbital space mission :

- Ground operations of the launch campaign that may have impact on the nuclear safety performances, starting from NPS arrival in CSG, up to launh chronology,
- Launch operations, LV PL separation, until the moment when no more return of radioactive material back to Earth is possible even following an accident (i.e. until spacecraft lunar capture for its mission - Argonaut mission M#1),
- All operations beyond lunar capture, including operations performed by astronauts on the Moon, are excluded from the dimensioning cases through Nuclear LSAP, so far.

Accident likelihood & energetic environments evaluations



European Launch Safety Authorization Process (LSAP)

The criteria for triggering a Nuclear “LSAP process” for Launch Authorization from Europe, including radioisotope-based power systems *(including propulsion systems)* has been defined together with the French Regulators (CNES/IRSN) to consider a Space mission with RPS early 30’s.

Definition of the criteria : “Any Launch Operator intending to transport radioactive substances on-board the launch vehicle shall comply with the applicable regulations in force and, for quantities greater than 1 A2, according to Table 2 of the radioactive substance transport regulations of IAEA-SSR-6 (…)

ESA has anticipated the preparation of the Safety process and confirmed European objectives at the ESA Ministerial Council November 2022, by the ENDURE project (EuropeaN Devices Using Radioisotope Energy). Considering a launch with significant radiological hazard, dedicated LSAP and Safety Analyses shall be set-up to grant Launch Authorization :

Nuclear Safety Goals – Fundamental Objectives

Preliminary FSOA-2023, the ESA Space Policy-2018, including the International Safety framework for NPS applications in outer space : *"The fundamental safety objective of Space Mission using nuclear power source applications shall be to protect people and the environment in Earth's biosphere from potential hazards associated with relevant launch, operation and end-of-service phases of these applications. The benefits of the mission results shall be weighed against risks to people and the environment from launch, operation and end-of-service phases of the space NPS application."*

High-level Nuclear Safety requirements

A. Justification principle

Use of RPS must be justified by an analysis aiming at proving the inefficiency to use another energy source (e.g. solar panel).

B. ALARA approach

Justification that the adopted solutions minimize exposure to ionizing radiation of workers and public to the lowest reasonably achievable levels.

C. Nuclear criticality risk

The selected radioactive material, associated with the intrinsic RPS design, must not bring risk of uncontrolled nuclear chain reaction in any normal situation and in any accidental scenario.

D. Management of post-accidental situations

To limit the impact of potential accidental situations, human, material and documentary resources will be defined to inform and protect population and environment, as well as to secure radioactive materials.

Quantified Nuclear Safety goals

Situations		Radiological consequences thresholds	
Category	Likelihood range	on workers	on public / environment
Normal	**Permanent**	ALARA exposure Compliance with regulations → Maximal individual effective dose **< 6 mSv / year (0,6 Rem/Y)**	Compliance with regulations No release to the environment No exposure to ionizing radiations
Degraded	**> 10^{-2} / campaign**		
Accidental	**< 10^{-2} / campaign** and **> 10^{-5} / campaign**	ALARA exposure In any case, maximal individual effective dose **< 10 mSv / accident**	ALARA exposure Compliance with regulations → Maximal individual effective dose **< 1 mSv / year**
Aggravated accidental	**< 10^{-5} / campaign** and **> 10^{-7} / campaign**	No cliff effect ALARA exposure	
		Maximal individual effective dose **< 20 mSv / accident**	Public protection measures limited in time and space
Excluded	**< 10^{-7} / campaign**	*– Not applicable –*	

Example of nuclear safety requirement allocated to RHU

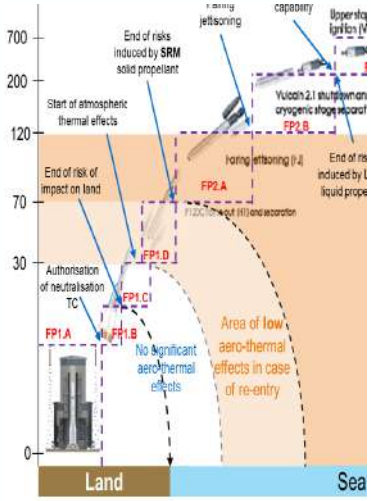
Flight Accidental scenario (RAS with a likelihood A) :

When RPS experiences the following sequence of accidental environments:

1. FIL neutralization (including shrapnel impacts),
2. Spacecraft impact on Earth's surface (French Guyana or ocean) at terminal velocity (including RPS crushing by spacecraft) after a fall starting from the end of ESR flight phase (just before ESR jettisoning)
3. Solid propellant fire or long and deep immersion in salted water

B likelihood objective : 10-3/accident

no radioactive materials get released in an air-transportable form (i.e. particles with an AED < 100 µm) during the following 100 years (TBC).



Flight Aggravated Accidental scenario (RAS with a likelihood A') :

When RPS experiences the following sequence of accidental environments:

1. Blast wave and fireball due to FIL neutralization
2. Spacecraft impact on Earth's surface (land or ocean) at terminal velocity (including RPS crushing by spacecraft) after a fall starting from the end of ESR flight (just before ESR jettisoning)
3. Spacecraft MON/MMH explosion and helium tanks bursts (including shrapnel impacts) at Earth's impact
4. Solid propellant fire or long and deep immersion in salted water

the release of radioactive materials in an air-transportable form (i.e. particles with an AED < 100µm) shall not result in radiological consequences that exceed the thresholds defined by nuclear safety goals for aggravated accidental situations.

B' likelihood objective : 10-2/accident

Note: In a preliminary approach, the upper threshold to be met for radiological consequences on public in an aggravated accidental situation can be set at 10 mSv on 1 year.

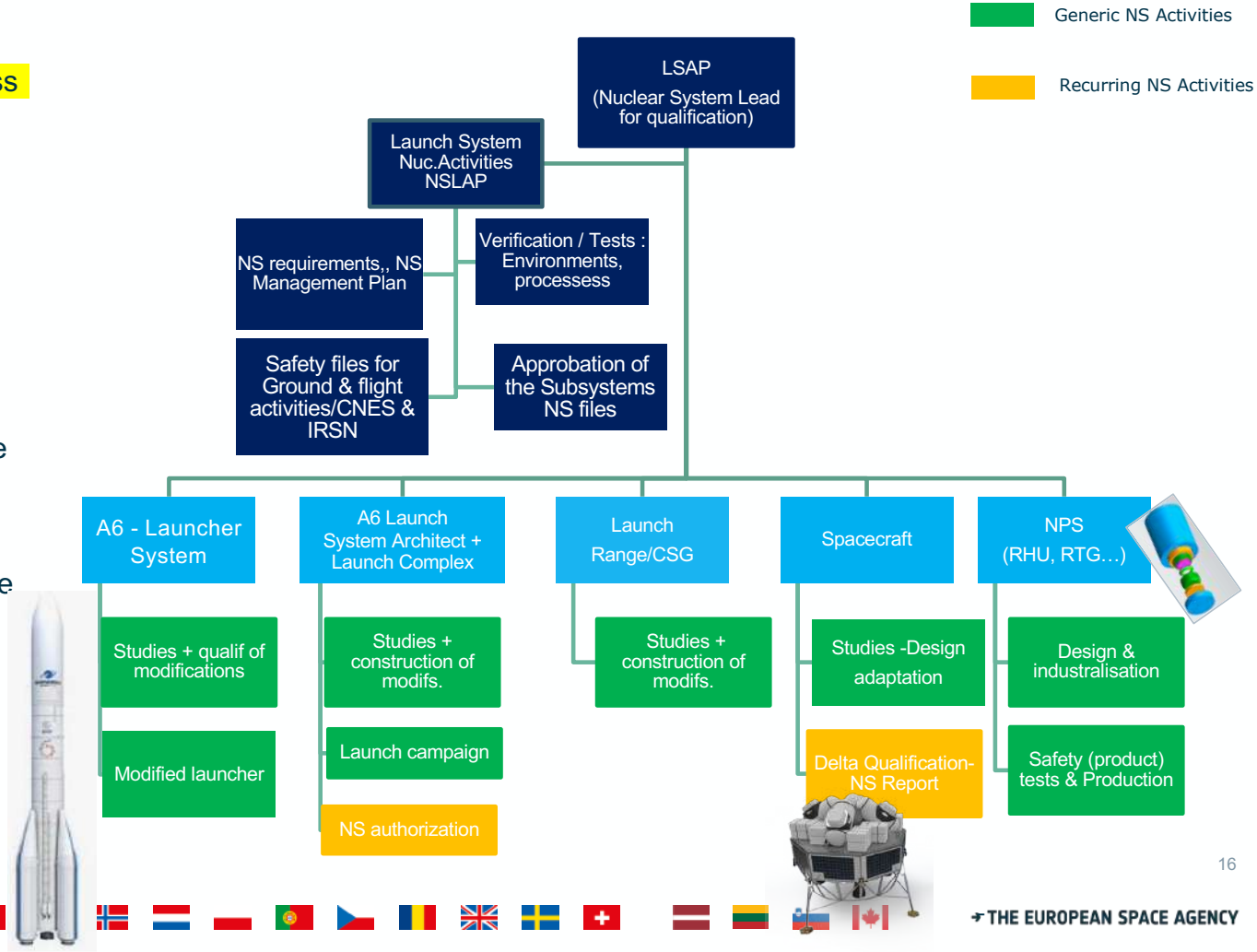
To respect the NSG,
each RAS of the PRA, must comply the criteria

Requirement of **RAS probability of occurrence** **X** Requirement of **probability that mitigation barriers does not withstand** accidental sequence **< 10^{-7} / launch campaign**

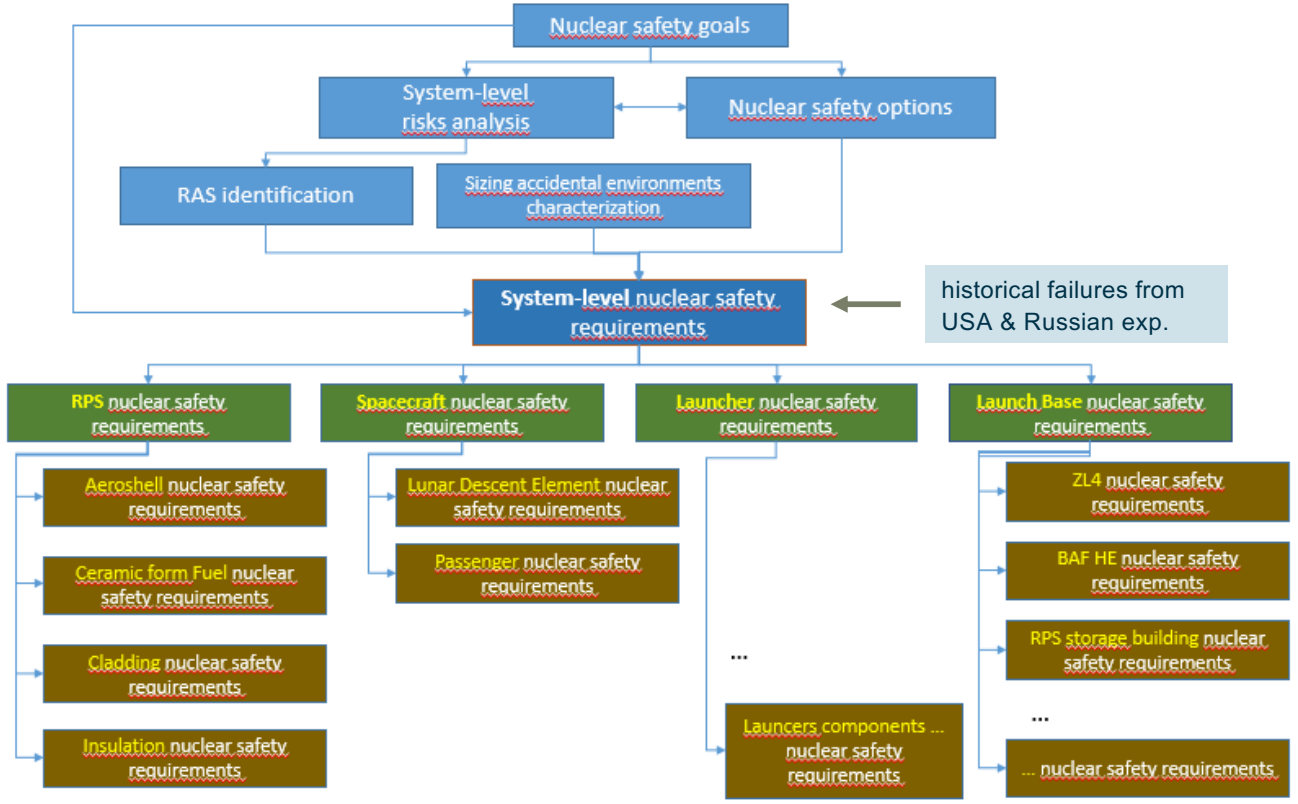
Structuration of the Generic NS activities for Ariane 6/Arg. Launch ref.

NSLAP - Launch System activities build-up for **a first European Launch,** as Generic Nuclear Safety process with CNES/IRSN :

1. End-To-End management of Nuclear safety demonstration and preparation of safety files (Ground Segment & Flight Segment),
2. Launcher and Launch base adaptations : limited yet robust for subsequent missions,
3. NPS Design/Testing/product. as main system for the safety demonstration,
4. Spacecraft impact to be optimized through early adoption of safety Options/Requirements (first possible mission being Argonaut M#1).

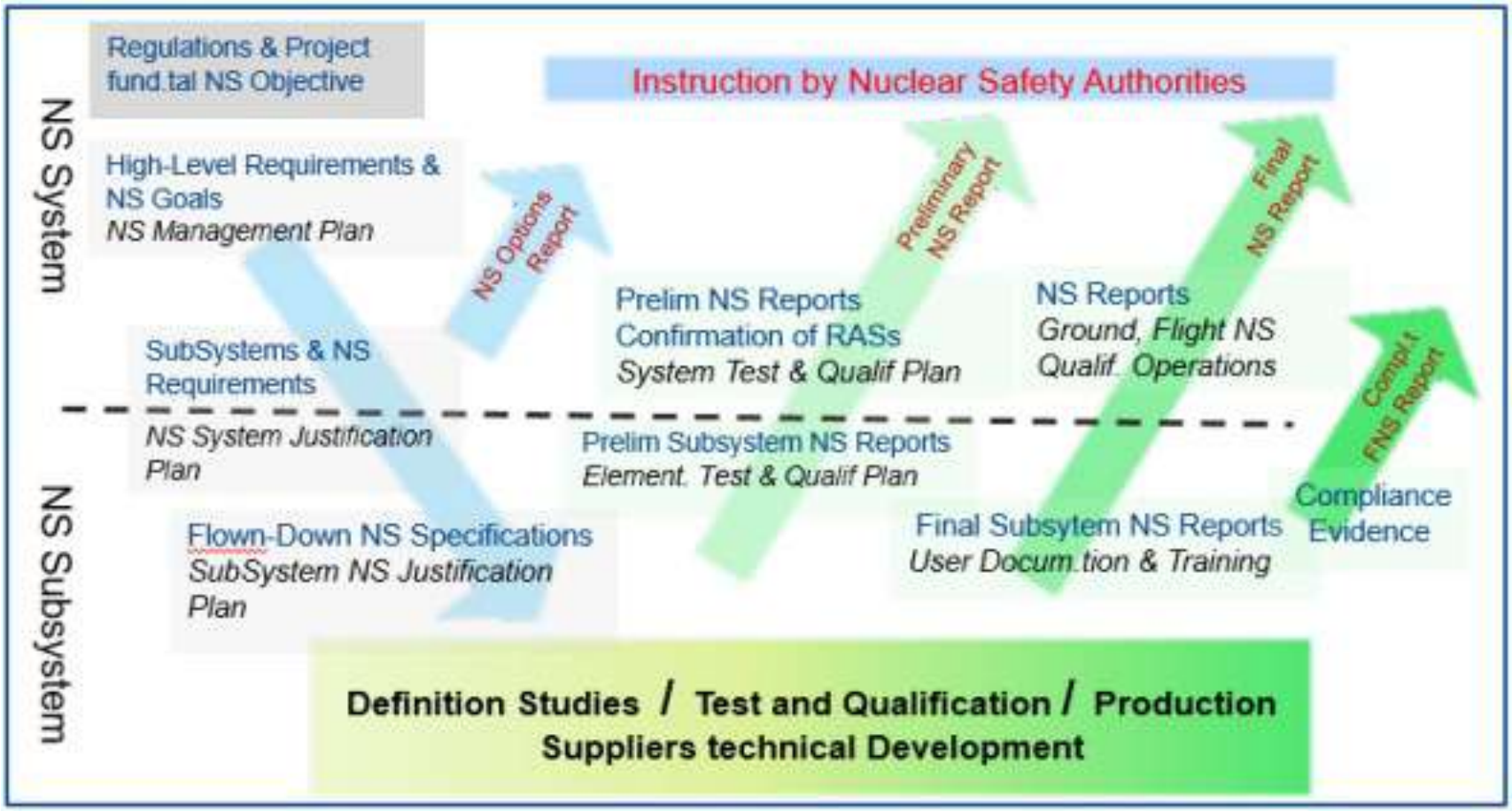


Subsystems flowdown Rq. towards NSICs characterization



NEP Nuclear Safety requirement → NEP NS Important Component or other item important for NS → Key Characteristics (KC) affected to each of the NSIC → Defined Requirements (DR) for each KC → Proof of demonstration & Source

Nuclear System management Process – justifications flux



Launch System Authorisation Process (LSAP) – Framework, System Activities Management & Organisation

United Nations – International Atomic Energy Agency (IAEA)

Principles relevant to the Use of Nuclear Power Sources In Outer Space

Principles to be translated into national laws

United States

National Security President Memorandum #20

NSPM-20

France

French Space Operations Act

(updating in progress)

CNES & Institut de Radioprotection et de Sûreté Nucléaire (IRSN)

ESA

ESA safety policy

on the use of nuclear power sources

ESA/ADMIN/IPOL-INSR(2018)1

Defines roles & responsibilities for
- Programmes & TEC Directors
- ESA Independent Safety Office (TEC-QI)

PHASES	**Applicable to the ground phase, launch phase and orbital phase up to lunar capture**	**Applicable to all phases from ground up to the end of the spacecraft mission**

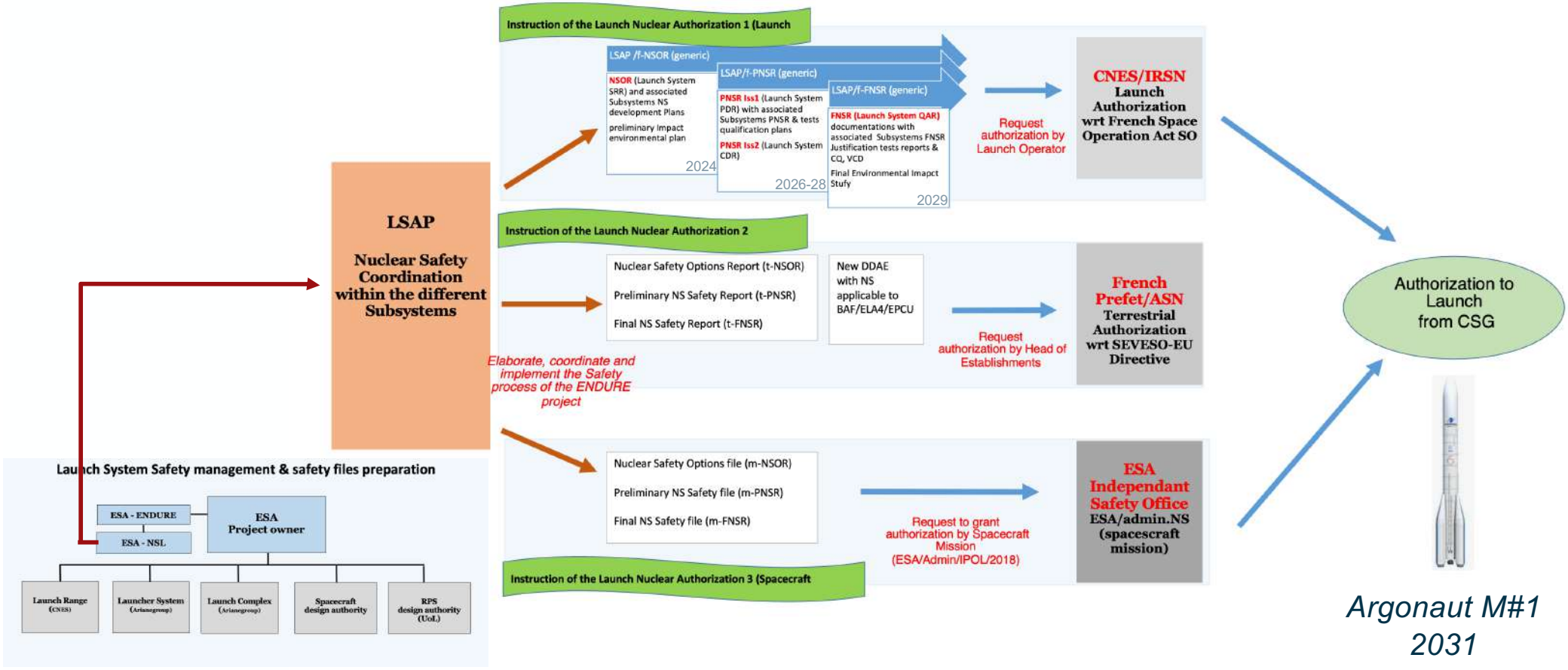
COMPONENTS	**Launch Range**	**Launcher System**	**Spacecraft**	**RPS**

⇨ **ESA Trans-Directorates activity (HRE, TEC, STS and SCI in due time) to define the Nuclear System Goals and allocate the resulting nuclear objectives to all four involved components: Options identification & trade-offs, design choices…**

⇨ **Strong interface with CNES and Institut de Radioprotection et Sûreté Nucléaire (IRSN) supporting it with its technical expertise and ESA Programs & Primes**

CONCLUSION

Nuclear LSAP logic & authorizations for European Launch



Argonaut M#1
2031