Nuclear Power Systems for Space Applications

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ESA HQ Daumesnil
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Goal of this presentation

- What is ESA?
- What we prepare for the future of space transportation?
- Why nuclear propulsion?
- Why now?
What is ESA?
**We Are ESA**

**EUROPE’S GATEWAY TO SPACE**

<table>
<thead>
<tr>
<th>WHAT</th>
<th>22 Member States, 5000 employees</th>
</tr>
</thead>
<tbody>
<tr>
<td>WHY</td>
<td>Exploration and use of space for exclusively peaceful purposes</td>
</tr>
<tr>
<td>WHERE</td>
<td>HQ in Paris, 7 sites across Europe and a spaceport in French Guiana</td>
</tr>
<tr>
<td>HOW MUCH</td>
<td>€6.49 billion = €12 per European per year</td>
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Who Benefits?

YOU

OUR ECONOMY

OUR PLANET

OUR FUTURE
Focus on space transportation

- space science
- earth observation
- operations
- human spaceflight
- exploration
- navigation
- technology
- telecommunications

And more…
Introduction to FLPP of STS Future Preparation

Since 2005

~200 M€ per year

FLPP: Future Launchers Preparatory Programme
STS: Space Transportation Directorate

End-to-end transportation
Global approach to future transport with interconnected vehicles securing to-, in- and from space.

Mission oriented
Provider of solutions for potential users (ex: Earth Observation, telecom, navigation, exploration, science and others)

Innovation oriented
Increasingly open to disruptive technologies, to co-funding schemes, to result-oriented contractual schemes

From large demonstrators to individual technologies
What we prepare for the future of space transportation?
How does transport work on Earth?
Space Transportation to-, in- and from-space
End-to-end transport / space logistics approach

Goal

Anticipate & prepare early to:
• ↓ cost
• ↓ time to market
• ↑ performance
• Enable missions
• ↓ risk
• ↓ environmental impact

Space Logistics Approach

• Optimise end-to-end Transport Service in the whole value chain
• Enable multi-mission
• Ensure consistency and compatibility of new activities
• Consider new tendencies at early stage of system and techno development (ex: green, digital)

We prepare end-to-end proofs of concepts within 4 Space Logistics Blocks

1. End-to-End architecture design & performance analysis

2. Access to space
   Including Manufacturing, Assembly, Integration & testing

3. In-/from-space transportation
   Including re-entry

4. In-Orbit ST services
   Provided by dedicated in-space transportation vehicles (kick-stages, tugs...etc)
Why nuclear propulsion ?
Combine engine thrust and efficiency

With nuclear propulsion, we could have performances beyond neither solar electric propulsion or chemical propulsion can ever achieve

➢ To travel far
   *Explore where sunlight is too dim for solar energy*

➢ To travel fast
   *Reduce the transfer time*

<table>
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<tr>
<th>Solar irradiation w.r.t Earth:</th>
<th>43%</th>
<th>3.7%</th>
<th>1.1%</th>
<th>…</th>
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</thead>
<tbody>
<tr>
<td>Hohmann transfer</td>
<td>~9 Months</td>
<td></td>
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<tr>
<td>Parabolic transfer</td>
<td>&lt; 3 Months</td>
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The use of nuclear systems depends on the need

Nuclear power for space applications [4]

**ENDURE**
On-going activity

**RocketRoll**
Preliminary study

**ALUMNI**
Preliminary study


RocketRoll:
pReliminary eurOpean reCKon on nuclEar elecTric pROpuLsion for space applIcations

ALUMNI: “preliminArY eLements on nUclear therMal propulsioN for space applIcations”

RHU: Radio-isotope Heating Unit
RTG: Radio-isotope Thermoelectrical Generator
Why now ?
When there is a will, there is a way

“The restriction of ESA missions to non-nuclear sources of power severely limits the ability of the ESA Science Programme to address important scientific goals in more distant and dimly-lit regions of the Solar System […]. The Senior Committee is aware of technology developments within Europe and wish to clearly highlight that the lack of our ability to utilise such power and heat sources on future missions will continue to limit the capacity of ESA’s Science Programme.”

Final recommendations from the Voyage 2050 Senior Committee, ESA programme, 2021 [1]

Nuclear electric propulsion, nuclear thermal propulsion, nuclear vehicle and safety are identified as enabling & emerging technologies for human spaceflight & exploration

ESA technology strategy update, 2022 [2]

“The development of European nuclear space capabilities for power and propulsion is an endeavour that will require sustained commitment and substantial investment over at least two decades. Building a robust, resilient and affordable long-term European capability will not be easy but it is crucial”.

Is nuclear energy technology of the past or the future?

Google trends "Nuclear Energy"

You want to know which trend it will be?

Stay tuned or join the adventure…
Grazie per la votra attenzione
1. Linda J. T., Christopher S. A. and al., Voyage 2050 Final recommendations from the Voyage 2050 Senior Committee, May 2021.


Back up slides
FLPP in a nutshell …
What Does ESA Do?

ALL OF THIS IS POSSIBLE THANKS TO THE COLLABORATION OF MEMBER STATES

ESA is active across every area of the space sector

World leader in science and technology

Over 80 satellites developed, tested, and operated since 1975

More than 220 launches from Europe’s Spaceport in Kourou
Europe’s Spaceport

- European launchers lift off from **Europe’s Spaceport** in French Guiana.

- The launch range is co-funded by ESA and France and is operated by the French space agency CNES.

- The launch infrastructure for the Ariane 5, Vega and Soyuz launchers at CSG is owned by ESA, maintained and operated by Arianespace, with the support of European industry.
Space Transportation & Technology of the Future: Ariane 6 & Vega C

- **Ariane 6** – modular three-stage launcher with two configurations, using two (A62) or four boosters (A64)
- **Vega C** – evolution of Vega with increased performance and same launch service cost
- Common solid rocket motor for Ariane 6 boosters and Vega C first stage
- New governance for Ariane 6 development and exploitation allocating increased roles and responsibilities to industry
Space Rider
- An affordable, reusable, end-to-end integrated transport system offering Europe independent access to and from low Earth orbit.

Future Launchers Preparatory Programme (FLPP)
Develop competitive technologies for future launchers

Commercial Space Transportation Services and Support
ESA’s long-term vision to build economic resilience within Europe’s space transportation sector.
The tool to create commercially successful, privately funded initiatives for new space transport services.
Space Nuclear Propulsion: Terminology

- **Cassini spacecraft RTGs**
- **Russian PuO₂ 8.5W RHU: Mars 96**
- **Space modified PWR – radiator (SURE – PoliMi design)**
- **Gas-cooled – particle bed – radiator (SNPS-200; QinetiQ)**
Mission architecture study activities [4] have
➢ underlined the important role of nuclear power and propulsion systems
➢ confirmed their criticality for some mission scenarios.
Nuclear Propulsion: Performance limitations

- **Electrical Propulsion: [2, 8, 13, 22]**
  - **EP thrusters:**
    - Power/thrust: $17 \div 35\text{kWe}/\text{Newton}$
    - Very high Isp: $1'000 \div 12'000\text{s}$
    - Thrust levels: $\text{mN} \div \text{N}$
    - Beyond 100kWe: MPD-thrusters ($1 \div 100\text{N}$)
    - M3: $\approx 20\text{N} \div 400\text{N}$ thrust needed
  - Requires a Nuclear Power Source.
    - Current Telecom power bus: 25kW SEP vs Naval reactor: $\approx 500\text{MW}$
    - 1MWe reactor would give $\approx 30\text{N} \div 60\text{N}$
    - Low overall efficiency: 30-40%
    - Need of heavy radiators: 0.4-1 kW/kg
Nuclear Propulsion: Performance limitations

- **Chemical Propulsion:** [3, 5, 6, 9, 10, 21]
  - NTP thrusters:
    - Specific power for reactor: ~135 ÷ 450kWt/ton (TOPAZ)
    - High Isp: 600 ÷ 1000s (on the basis of H2)
    - Thrust levels: kN ÷ MN
    - T/W: 3 ÷ 5
    - M3 mission: 110kN (~450MWt ; 3.2ton )
  - To heat up directly propellant (NTP: nuclear thermal propulsion).
    - Turbo-fed System
    - Open reactor core – direct contact
    - Closed reactor core – indirect contact
Nuclear Propulsion: Application Overview

Legend

A Nuclear reactor produces heat that is converted into electricity which feeds ion-engines

A Nuclear reactor superheats up a reaction mass (a gas or the same nuclear fuel) that expands and hence it is ejected at high speed from a nozzle

Reverse-Rankine Electric Conversion

Gas Fed Reactor + MPD & Ion Thrusters

Gas Cooled Reactor + MPD & Ion Thrusters

Liquid Metal/Heat Pipe reactor + Hall-Effect & Ion Thrusters

Thermo-Electric Conversion

Liquid Metal + Hall-Effect Thrusters

RTG + Hall-Effect Thrusters

Reverse-Brayton and MagnetoHydroDynamic Electric Conversion

Thrust Conversion

Direct Thrust Propulsion (Fission)

Direct Thrust Propulsion (Fusion)

Generated Thrust

Required Power

kN

MW

300-500kW

50-150kW

100 W

T0+5? T0+10? T0+15? T0+20?

Year of Availability [4]