Nuclear Power Systems for Space Applications

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12/05/2023

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

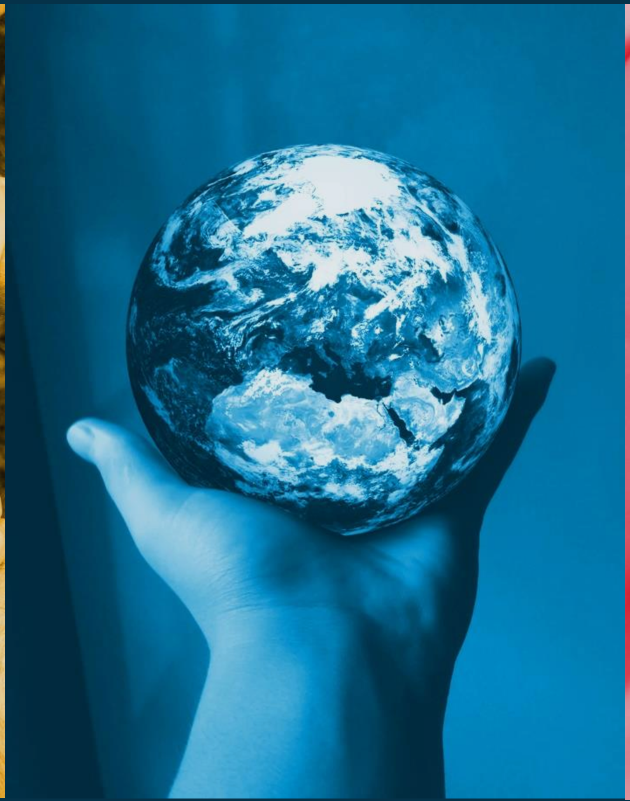
WHAT	22 Member States, 5000 employees
WHY	Exploration and use of space for exclusively peaceful purposes
WHERE	HQ in Paris, 7 sites across Europe and a spaceport in French Guiana
HOW MUCH	€6.49 billion = €12 per European per year

Who Benefits?

YOU

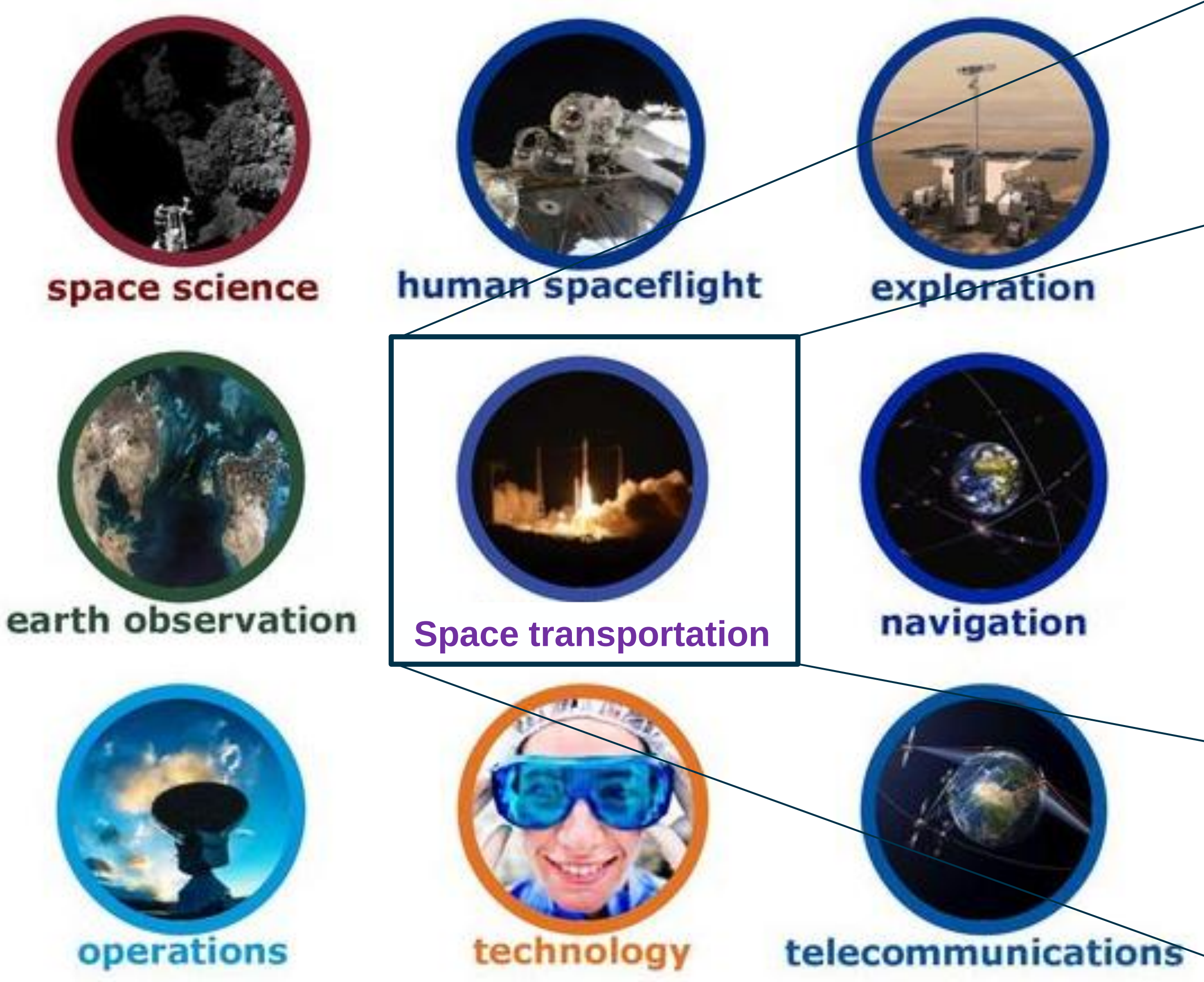
OUR ECONOMY

OUR PLANET



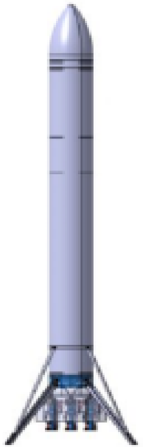
OUR FUTURE

Focus on space transportation



And more…

Introduction to FLPP of STS Future Preparation



From large demonstrators to individual technologies

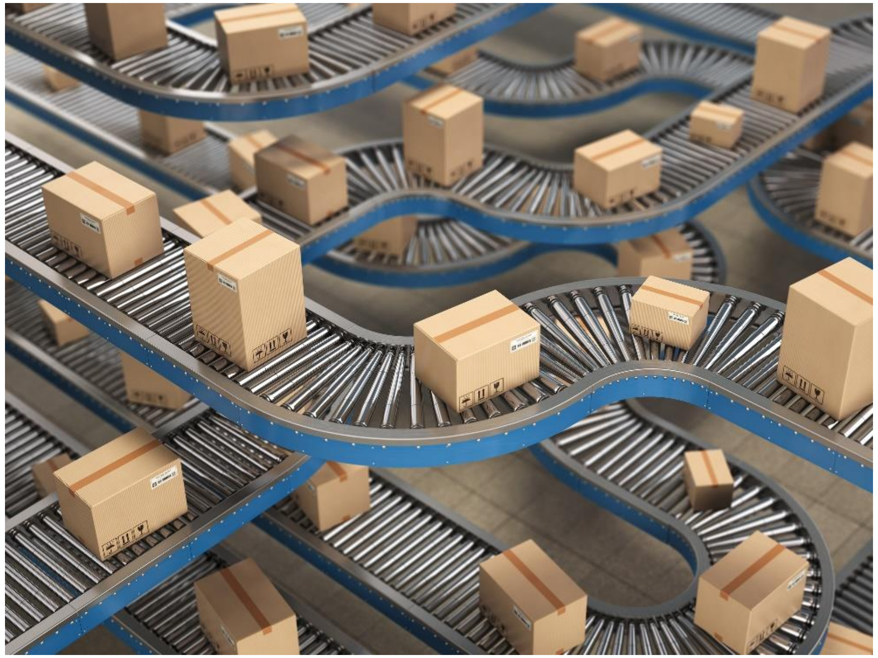
Since 2005

~200 M€ per year

End-to-end transportation	Mission oriented	Innovation oriented
Global approach to future transport with interconnected vehicles securing to-, in- and from space.	Provider of solutions for potential users (ex: Earth Observation, telecom, navigation, exploration, science and others)	Increasingly open to disruptive technologies, to co-funding schemes, to result-oriented contractual schemes

FLPP: Future Launchers Preparatory Programme
STS: Space Transporation Directorate

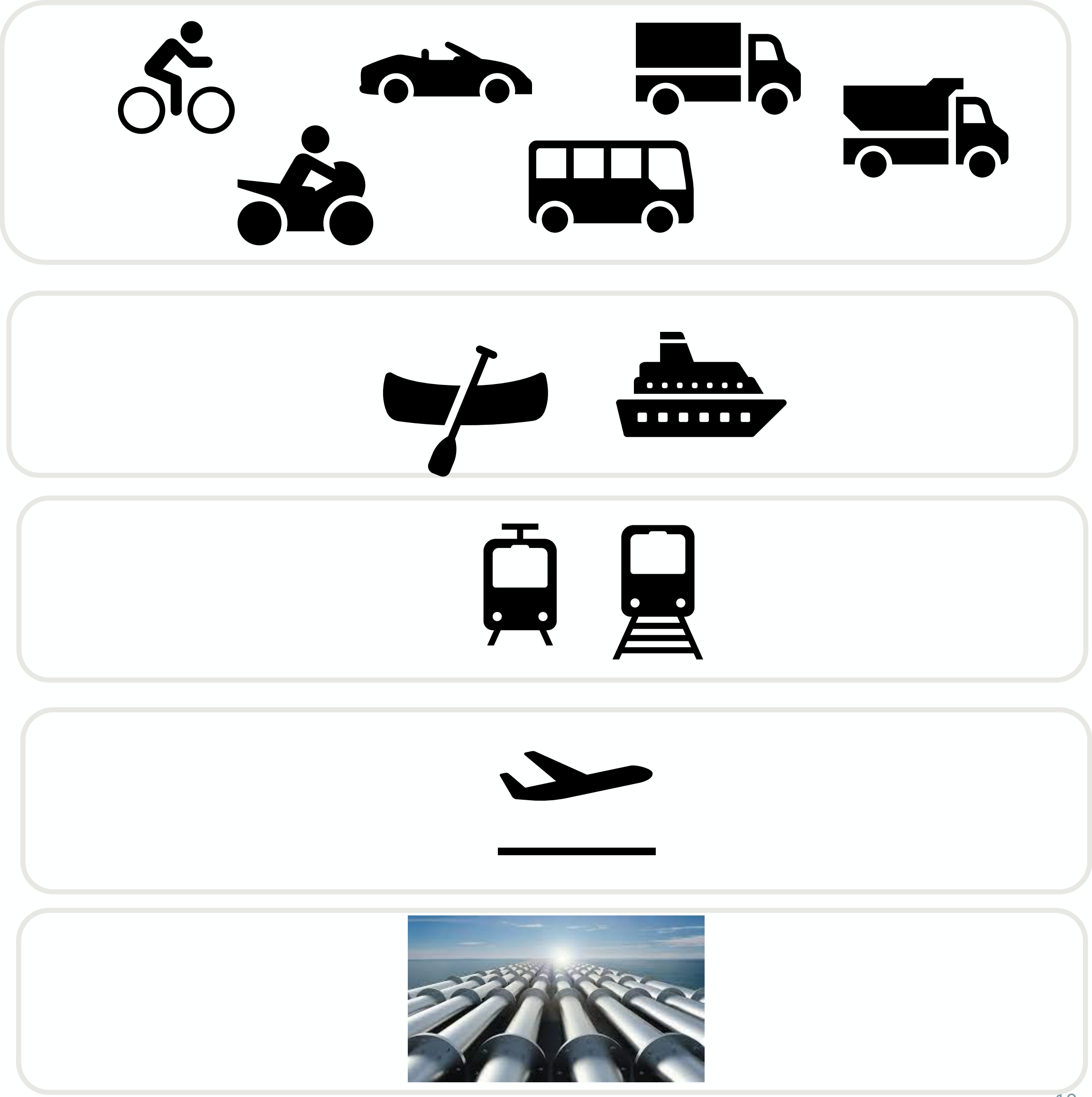
What we prepare for the future of space transportation ?



How does transport work on Earth?

What do we transport

Type of transport



Space Transportation to-, in- and from-space

European Space Agency

End-to-end transport / space logistics approach

Goal

Anticipate & prepare early to:

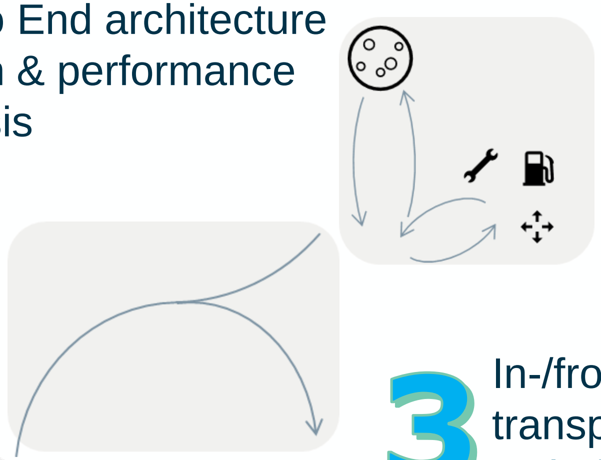
- ↓ cost
- ↓ time to market
- ↑ performance
- Enable missions
- ↓ risk
- ↓ environmental impact

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



4 In-Orbit ST services
Provided by dedicated in-space transportation vehicles (kick-stages, tugs…etc)

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

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

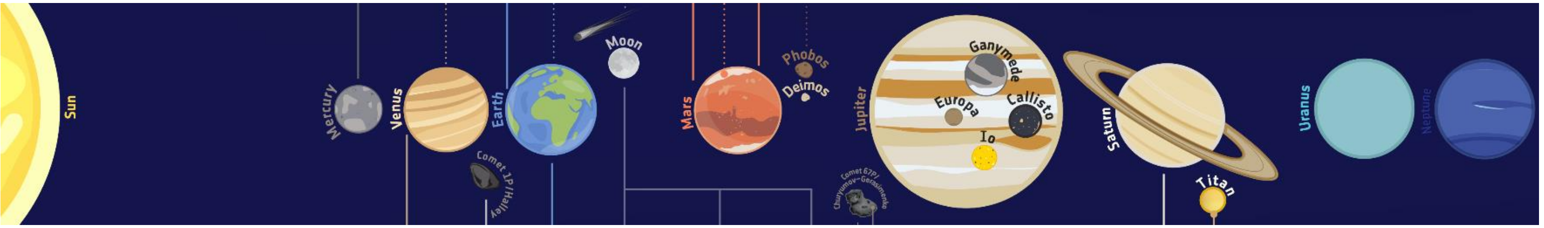
Why nuclear propulsion ?

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**

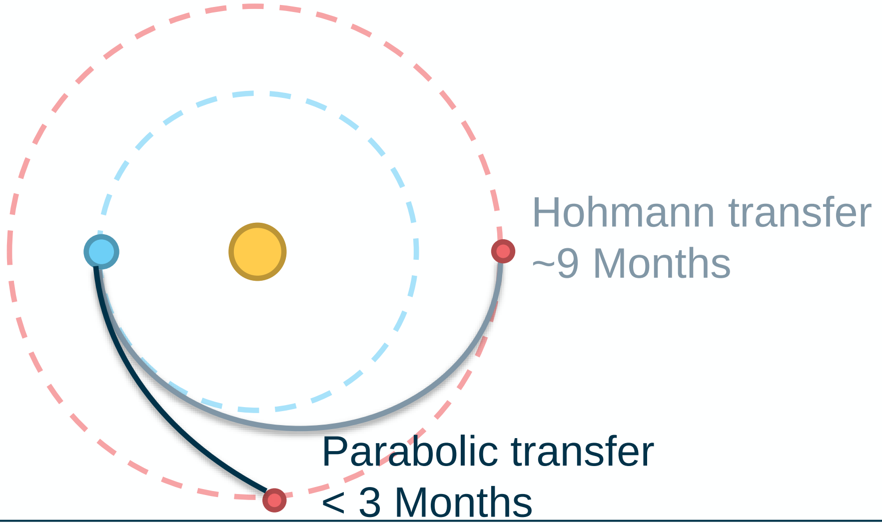
  Explore where sunlight is too dim for solar energy



Solar irradiation w.r.t Earth: 43% 3.7% 1.1% …

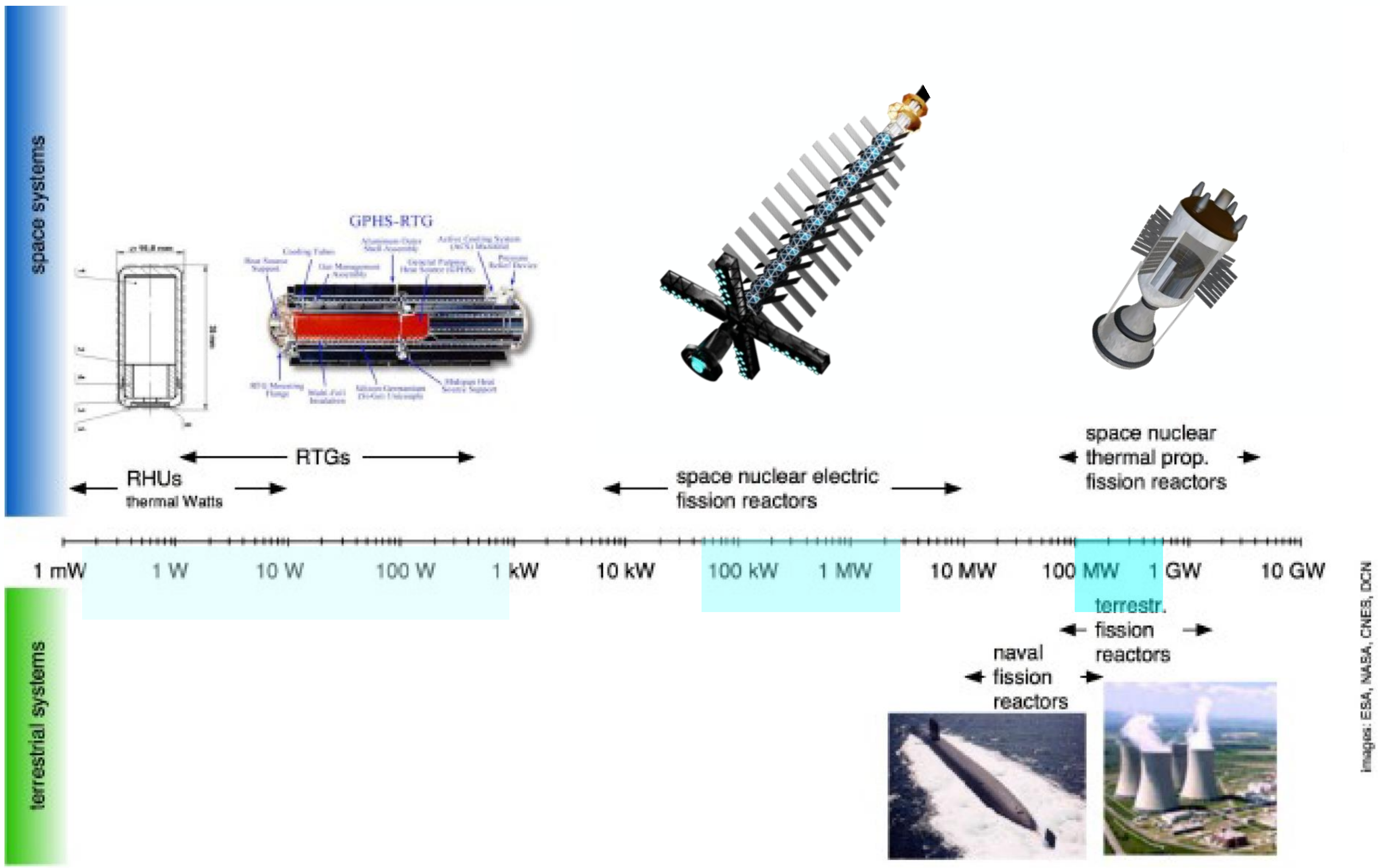
- **To travel fast**

  Reduce the transfer time



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

ENDURE: "EuropeaN Devices Using Radioisotope Energy"

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

ALUMNI: "preliminAry eLements on nUclear therMal propulsioN for space appIications"

RHU: Radio-isotope Heating Unit
RTG: Radio-isotope Thermoelectrical Generator

Why now ?

When there is a will, there is a way

space science

"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]

human spaceflight

exploration

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

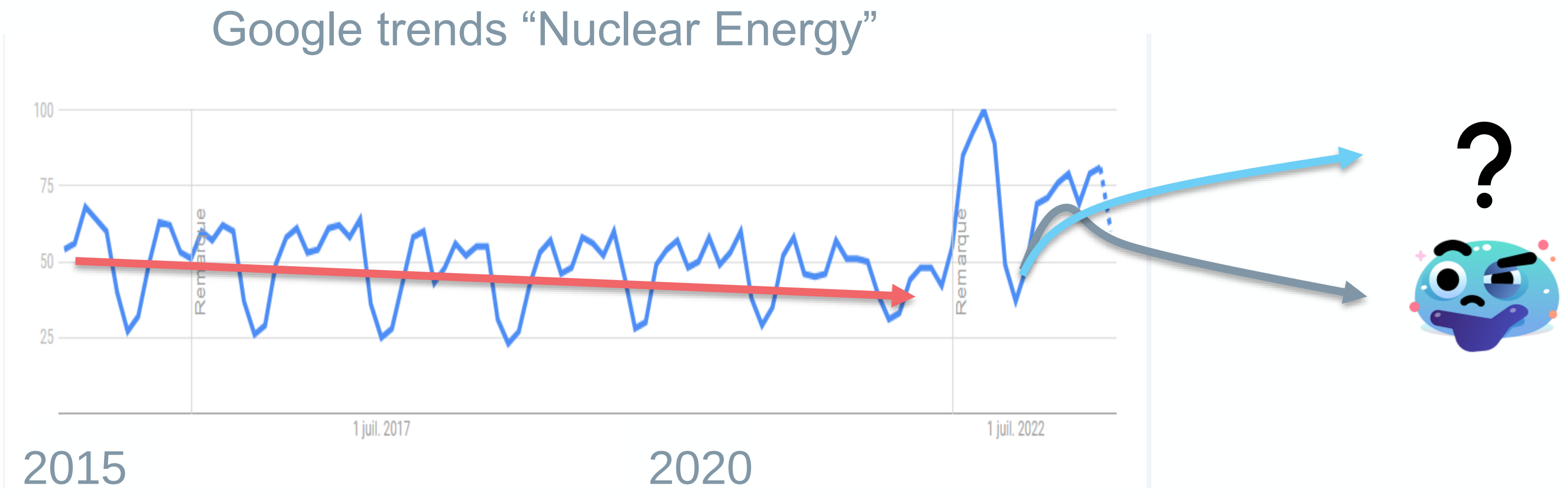
ESA technology strategy update, 2022 [2]

EUROPEAN NUCLEAR SOCIETY

"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".

European Nuclear Society, Position paper, 2022 [3]

Is nuclear energy technology of the past or the future ?



You want to know which trend it will be ?

Stay tunned or join the adventure…

Grazie per la votra attenzione

References

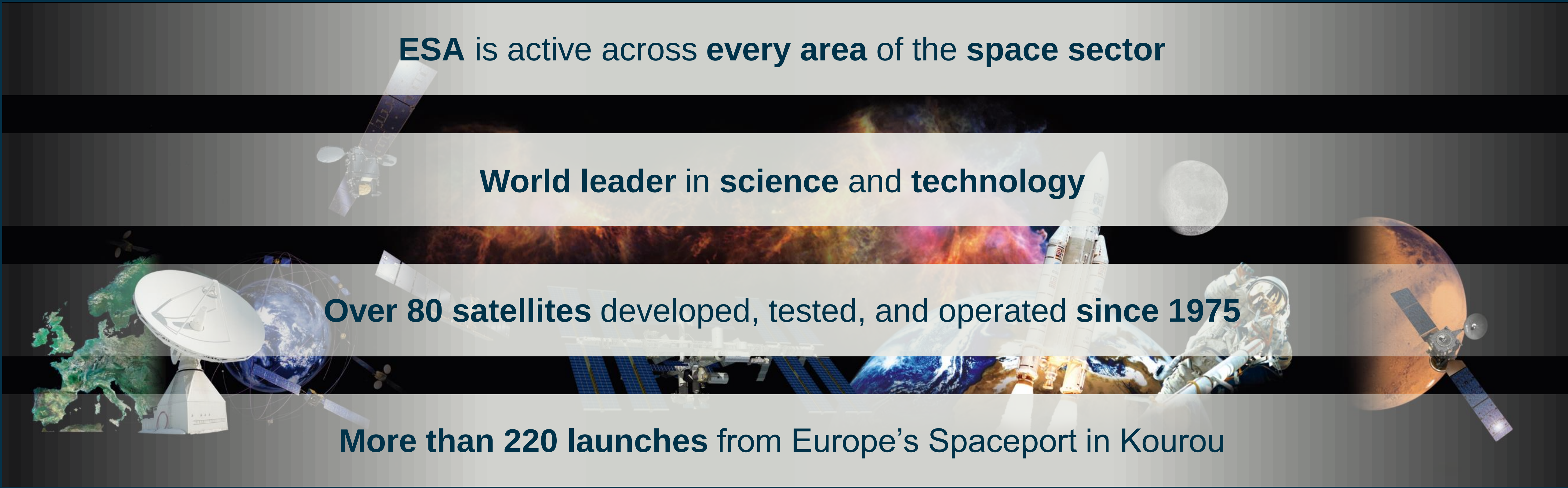
1. Linda J. T. , Christopher S. A. and al., Voyage 2050 Final recommendations from the Voyage 2050 Senior Committee, May 2021.
2. ESA, “ESA technology strategy update”, ESA-TDE-TECT-HO-2022-000464, February 2022
3. European Nuclear Society, “Nuclear Energy for Space Exploration”, Position Paper of the ENS High Scientific Council, September 2022.
4. “Summerer, L., Bruno G., and Giacinto G. "Esa’s approach to nuclear power sources for space applications." *Proceedings of ICAPP*. Vol. 13. 2007.

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**

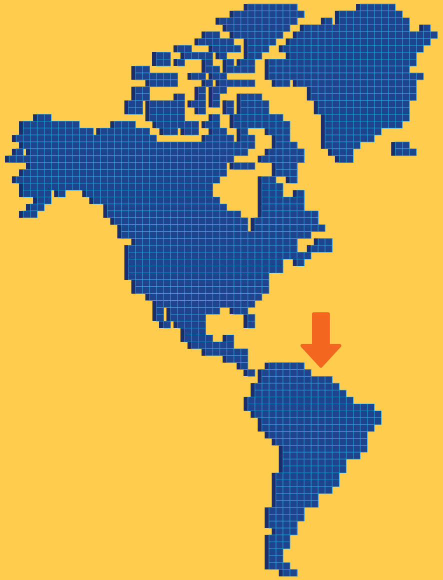
World leader in **science** and **technology**

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 Transportation & Technology of the Future

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

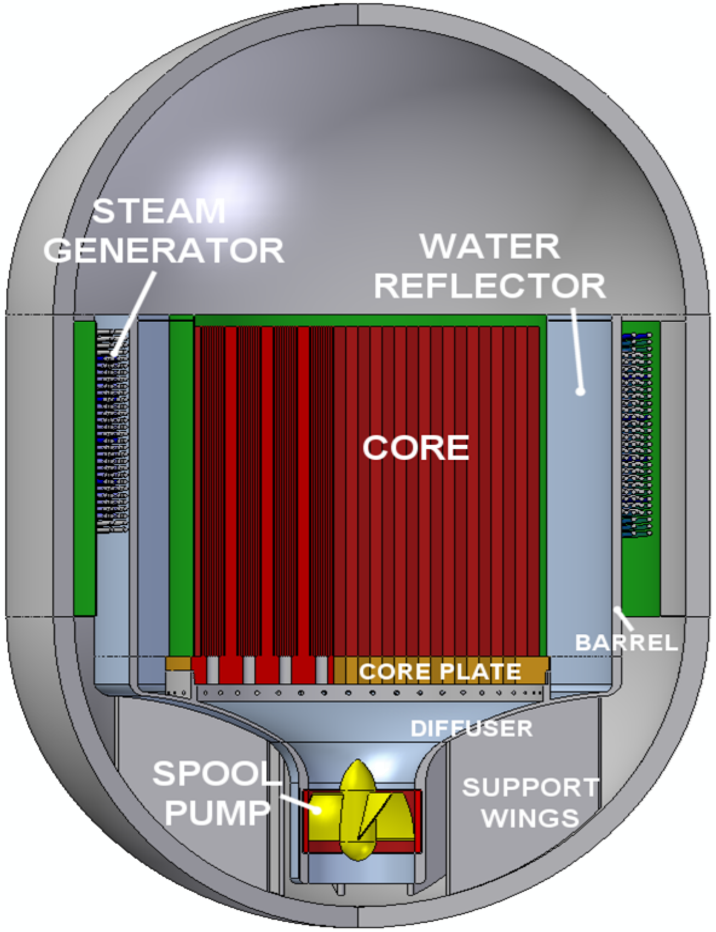
ESA’s long-term vision to build economic resilience within Europe’s space transportation sector.

The tool to create commercially successful, privately funded initiatives for new space transport services.

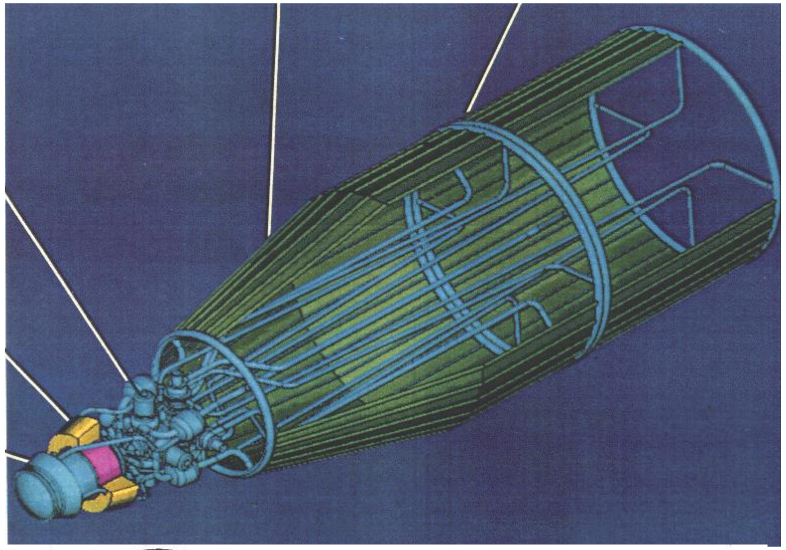
Space Nuclear Propulsion: Terminology

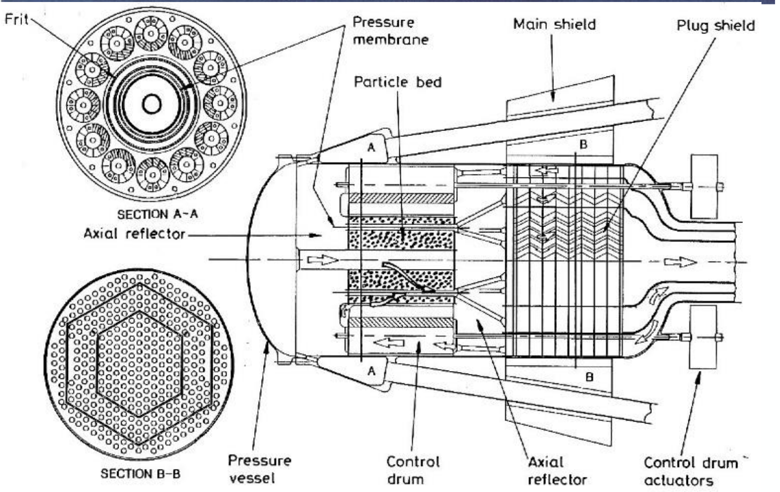
Cassini spacecraft RTGs

Russian PuO_2
8.5W RHU:
Mars 96



Space modified PWR – radiator (SURE – PoliMi design)



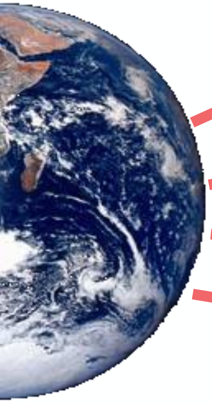


Gas-cooled – particle bed – radiator (SNPS-200; *QinetiQ*)

Space Nuclear Propulsion: Mission Enabler

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
for robotic deep space missions
- Travel time
- Mass to LEO/ launch costs

Deep Space

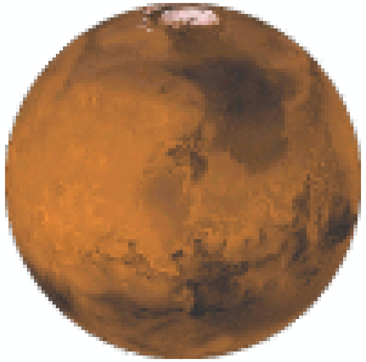
Nuclear Power
for orbit /surface ops
- Solar-independent ops
- Thermocontrol for night survival and ops

Nuclear Propulsion
for human missions to NEOs
- Mass to LEO/ launch costs

Near Earth Objects

Nuclear Power for surface ops
- Solar-independent ops
- Thermocontrol for night survival and ops

Nuclear Propulsion
for human missions to Mars
- Mass to LEO/ launch costs
- Travel time



Mars

Nuclear Power
for human surface ops
- Long-duration stays
- Long-range operations
- Redundancy

Nuclear Power for surface ops
- Solar-independent, long-duration/long-range ops
- Thermo-control for night survival and ops
- Redundancy

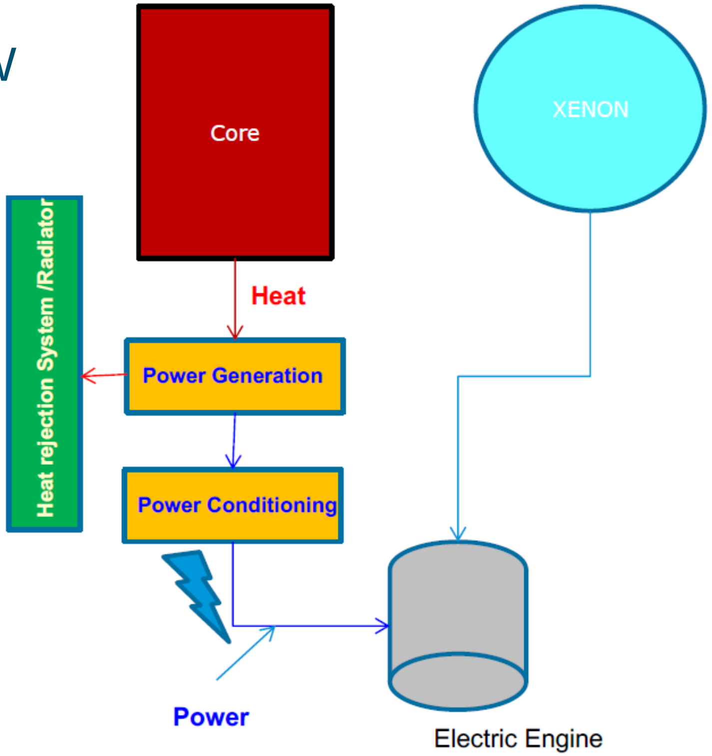
Moon

Nuclear Propulsion: Performance limitations

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

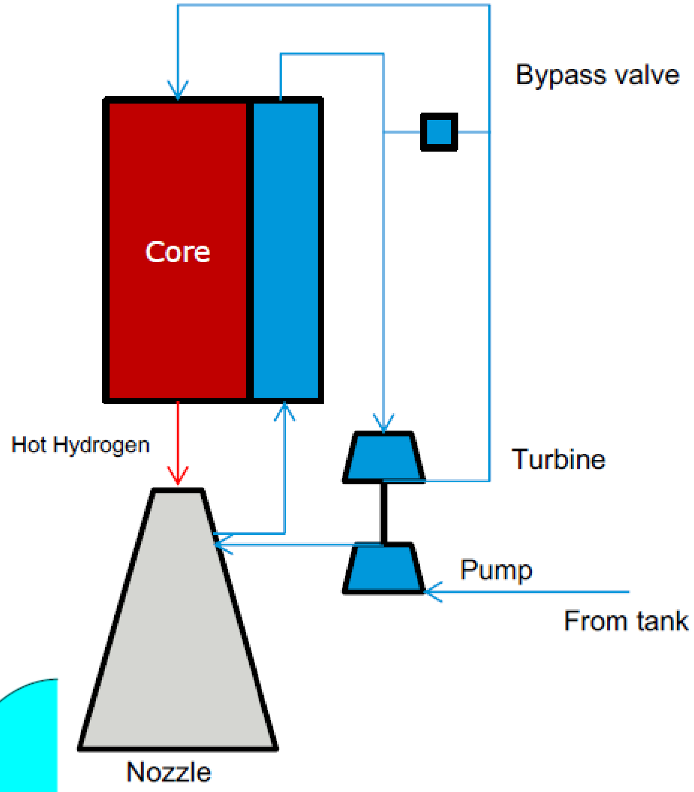
THRUSTER (Source)	*Typical Reference*	*D* (cm)	*F* (mN)	*F(R)* (mN)	I_{sp} (s)	*P* (W)	η_m (%)	η_e (%)	η (%)	C_t (W/mN)	M_t (kg)	*Stat*
Kaufman												
KERC 5 (Russia)	Gorshkov et al (1999)	5	3.9	1.5 – 6	2890	121	78	59	46	31.0	1.2	EM
T5 (UK)	Fearn and Smith (1998)	10	18	0.3 – 71	3248	463	79	78	62	25.7	1.6	F
Melco (Japan)	Ozaki et al (2000)	12	23.3	18.6 – 27.9	2897	616	80	78	62	26.4	4.9	U/Q
T6 (UK)	Wallace et al (1999)	22	150	30 – 200	3660	3870	86	82	70	25.7	6.5	EM
MESC												
XIPS-13 (USA)	Beattie et al (1993)	13	17.8	Set point	2585	439	79	69	54	24.6	5.0	F
XIPS-25 (USA)	Beattie et al (1985)	25	165	Set point	3800	4200	≈ 88	≈ 83	≈ 73	25.5	N/A	F
NSTAR (USA)	Christensen et al (1999)	30	92	19.5 – 92.7	3280	2310	84	85	71	25.1	8.3	F
Radiofrequency												
RIT-10 (Germany)	Killinger et al (2000)	10	15	5 – 25	3324	476	70	74	52	31.7	1.6	F
RIT-XT (Germany)	Leiter et al (2003)	21	100	15 – 185	4054	2570	93	83	77	25.7	N/A	EM
ESA-XX (ESA)	Bassner et al (1997)	25	200	10 – 240	3500	6800	85	85	72	34.0	N/A	EM
RIT-35 (Germany)	Groh et al (1990)	35	104	50 – 200	3193	2965	80	69	55	28.5	9.0	EM
High Frequency RF												
Muses-C (4.2 GHz) (Japan)	Kuninaka et al (2000)	12	8.1	4.3 – 8.1	2920	320	61	52	32	47.6	2.35	F
RMT (150 kHz) (Italy)	Capacci and Noci (!998)	9.5	5	2 – 8	3030	173	64	68	43	34.6	N/A	EM

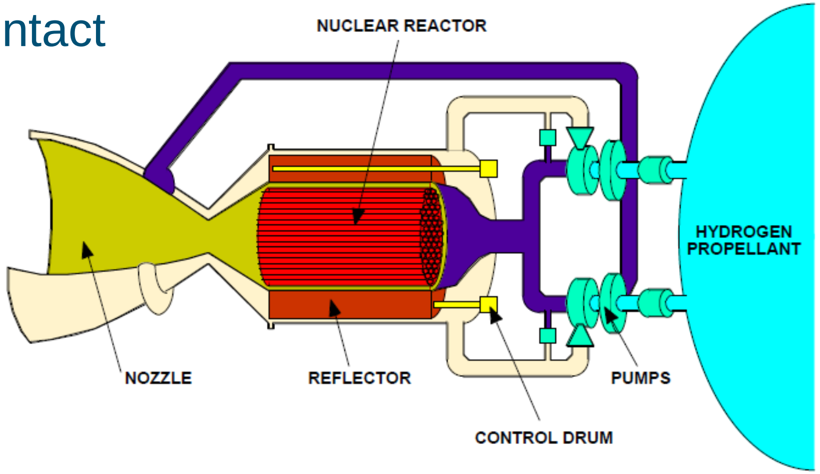
200 kW MPD thruster.
Credit: NASA



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