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MARS / EUROPA INPPS Flagship High Power Space Transportation

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Abstract

This paper explicitly explains INPPS (International Nuclear Power and Propulsion System) flagship subsystems like nuclear reactor, shielding, power conversion, boom, radiators, building blocks for tanks / payload basket / PPU / cluster of electric thrusters as well as additional solar power ring electricity and real time radiation detectors. Differences between the two flagships - as high power space transportation tug - for non-human (second half of 2020th) Mars / Europa and human (2030th) Mars exploration missions are sketched.

The international studied conditions for human Mars and exploration Europa space flights are realizable by rationales for pursuing high power space transportation by INPPS due to: 1) the successful finalization of the European-Russian DEMOCRITOS and MEGAHIT projects with their three concepts of space, ground and nuclear demonstrators for INPPS realization (reached in 2017), 2) the successful ground based test of the Russian nuclear reactor with 1MW$_{el}$ plus important heat dissipation solution via droplet radiators (confirmed in 2018), 3) the space qualification of the Russian reactor until 2025 and 4) the perfect celestial constellation for a Earth-Mars/Phobos-Earth-Jupiter/Europa trajectory in 2026-2035 for most maximal INPPS flagship tests. Critical performance will be studied by parallel realizations of the ground and nuclear demonstrators of DEMOCRITOS (until 2025). The space qualification of INPPS with all subsystems including the nuclear reactor in the middle of the 2020th plus the INPPS tests for about one to two years - first in high Earth orbit robotic assembly phase of INPPS and later extended in

nearby Earth space environment flight - means a complete concepts driven approval for all applied INPPS space technologies for both Mars/Europa exploration missions by INPPS flagship.

In dependence - from the cluster of electric thrusters - the Mars/Europa INPPS payload mass is up to 18/12 tons. This very high payload mass allows to transport scientific, pure commercial and new media communication payload sections. For example, Mars and Europa payload as well as scientific payload in form of s small INPPS co-flying satellite are envisaged. The INPPS flagship missions are visionary, comparable with Apollo project and ISS with dedicated outcomes for science / technologies, international peaceful cooperation in space and additionally for commercialization plus communication from Earth to INPPS, within INPPS – means in space - and back from INPPS to Earth.

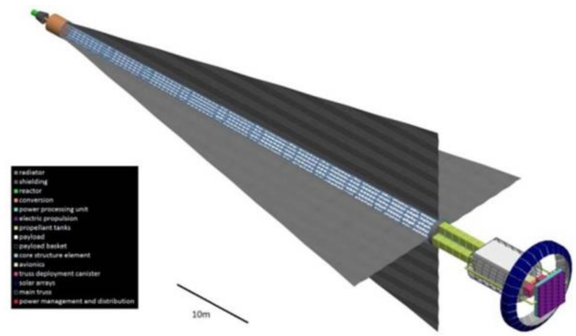
Keywords: 1) Human & Non-human High Power Space Transportation Hybrid Space Tug, 2) INPPS Flagship, 3) Nuclear Electric Propulsion, 4) Nuclear Power Source in Space, 5) Near Earth Space Environment INPPS space qualification, 6) science, commercial and communication payload to Mars & Europa by INPPS

Acronyms/Abbreviations

Artificial Intelligence (AI)
Third US human space flight program (Apollo)
High Earth Orbit (HEO)
Demonstrators for Conversion, Reactor, Radiator And Thrusters for Electric Propulsion Systems (DEMOCRITOS)
Disruptive technologies for space Power and **P**ropulsion (DiPOP)
International Nuclear Power and Propulsion System (INPPS)
International Space Station (ISS)
Megawatt Highly Efficient Technologies for Space Power and Propulsion Systems for Long-duration Exploration Missions (MEGAHIT)
Nuclear Electric Propulsion (NEP)
Nuclear Thermal Propulsion (NTP)
Near Earth Space Environment (NESE)
Nuclear Power and Propulsion System (NPPS)
Nuclear Power Source (NPS)
Power and Processing Unit (PPU)
Transport and Power Module (TPM)
Unpiloted Aerial Vehicle (UAV)
Valles Marineris Explorer (VaMEx)

1. Introduction

This paper describes the INPPS flagship as a high power space transportation tug. That includes the demonstrators, sub-systems, assembly and missions.



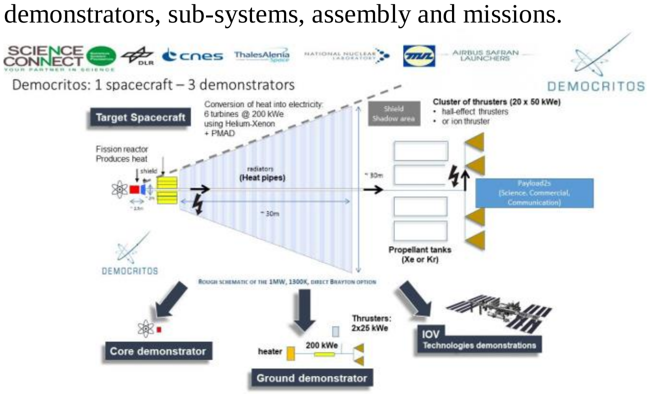


Fig. 1. Top – European-Russian DEMOCRITOS project spacecraft (INPPS) and progress beyond (see [1] to [4]): INPPS subsystems, ground, core and space demonstrators. physics and technology of functioning behind the flagship. Below - MARS-INPPS high power space transportation tug from DEMOCRITOS project with all subsystems. White: the payload basket.

Mars transportation with humans is the ultimate mission goal. The main preparation to reach the goal is the non-human mission to Mars / Phobos, return to higher Earth orbit and extension of the first INPPS flight to Jupiter / Europa: in about ten year time (see Fig. 2)!

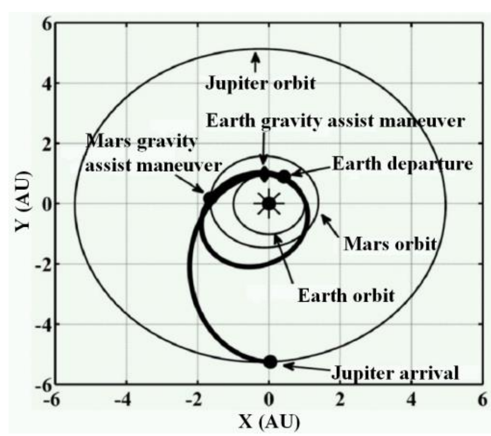


Fig.2. INPPS ten years tug flights between Earth, Mars, back to Earth and to Europa. Details of the journey [5]: HEO start 27 November 2026 (5.68 km/s), Mars arrival 15 April 2027, eleven month stay at Mars / Phobos (a long period for Mars surface payload landing (see for

example below VaMEx) and Phobos communication transponder station preparations. The Mars departure is on 15 March 2028, HEO arrival 28 December 2028 and HEO departure to Jupiter on 7 September 2031.

This nearly three years flagship orbiting at Earth allows very attractive and intensive Jupiter / Europa mission and arrival preparations – with very high payload (scientific, communication and communication) mass transport. The INPPS flight time (with the specific impulse as a parameter) to Mars and Europa for payload transport up to 18 t and 12 t are seen in Fig. 3.

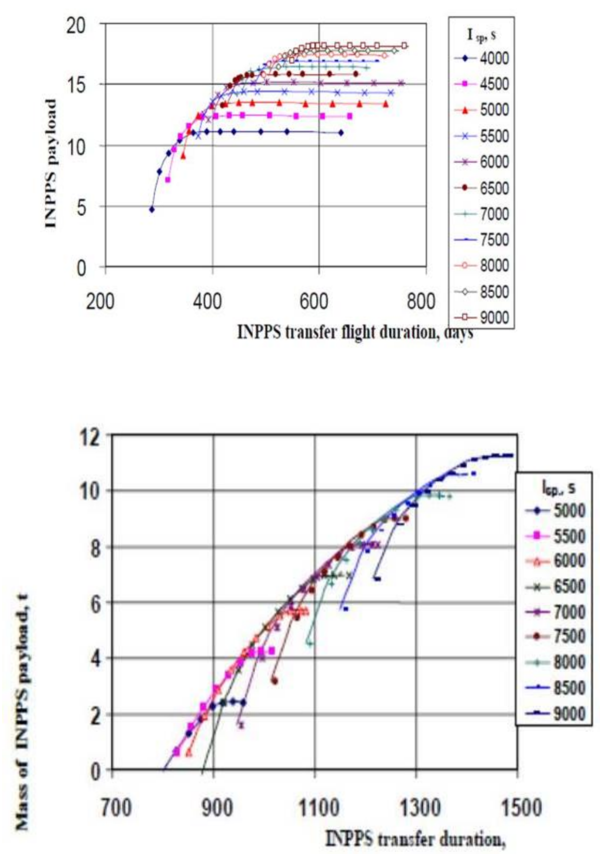


Fig. 3. MARS- and EUROPA-INPPS flagship transports (top for Mars 18 t, bottom for Europa up to 11 t) are relatively fast, but especially means several tons per flight and back! With a chemical rocket the return flight from Mars is strongly depending on Mars – Earth distance. A similar space system like INPPS but with a chemical rocket would bring to Jupiter only about 1 t payload.

The nearly two years from 2025 to HEO start at the end of 2026 covers the assembly, subsystems and space system tests in NESE. The entire Mars/Europa mission duration is in the order of the INPPS nominal ten years lifetime and ends in deep interplanetary space at Jupiter and beyond. This cruise means qualification tests under the longest, most distant, darkest and highest radiation conditions for the entire tug. Building blocks and mostly all subsystems are continuous analysed by AI with the results, that subsequent critical situation management were learned. Moreover humanoid robots in payload basket may be treated as high quality human mission analogues. In summary, the first non-human flagship transportation flight is the most maximal preparation for the save, second INPPS flagship transportation of humans to Mars.

After 2035 - the end of the first INPPS mission - all experiences will be used for the only second flagship assembly in higher Earth orbit. This second INPPS flagship will transport for the first time human to Mars and bring once more high mass payload (up to 18 t) to Mars orbit or surface.

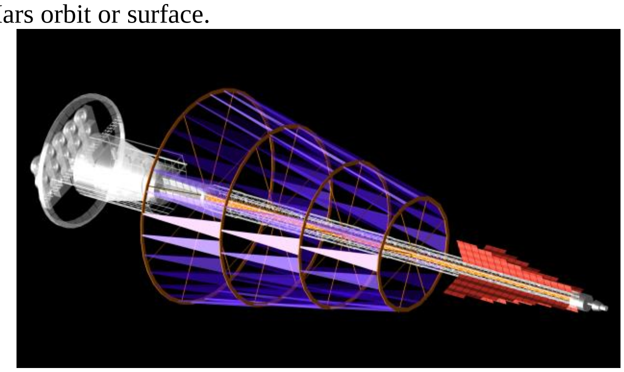


Fig. 4. INPPS flagship (for 2025 – 2035 exploration mission) with conical droplet (purple) and standard (red) radiators. Behind the droplet radiator is the payload basket (in white).

The MW class reactor for INPPS was successfully tested in Russia in 2018 and the space qualification is foreseen by 2025 [6]. This high power core fulfils the UN NPS regulations [7]. Many space organisations like ESA, NASA and more prepared probes and successfully landed on Mars, Earth moon, Titan, comet as well as on asteroids. It is time for a quality step higher: to install ESA moon village or to produce - by US kW nuclear power supply like KRUSTY experiment - on Earth moon or Mars surfaces enough power for these great infrastructures. Nuclear powered kW electricity is also necessary to penetrate into the deep ice / ocean on Jupiter Europa moon. Extra-terrestrial climate, ice and ocean research will level up significantly the understanding of terrestrial global warming.

For example at IKI in Moscow and at DLR in Bonn / DFKI Bremen initiatives started for scientific payload related to INPPS flagship. Payload combinations for MARS-/ EUROPA-INPPS flagship is from INPPS transportation point of view possible: due to the INPPS tug return flight from Mars to higher Earth and subsequent fly to Europa. The combinations are also strategically important to explore respectively prepare for humans the transport to Mars by the second INPPS after 2035. As an example INPPS scientific payloads for Mars infrastructure and Europa moon ice and ocean research will be described below in this paper.

2. NPS for High Power Transportation and Power Supply on Celestial Bodies

In the last years, NPS were primary developed for spacecraft power supply. The US PROMETHEUS Jupiter spacecraft reactor SP-100 was foreseen with the following nominal design: 2400 kWth / 106 kWe, highly reliable thermoelectric generators with uranium nitride pellet stack clad and lithium coolant. The success full tested Russian reactor has 3500 kWth / 1000 kWel. NPS for power supply on celestial bodies - potentially used on Moon, Mars or also on Europa moon – are working in the 7 kWel – 10kWel range. Not only the power range is orders of magnitude different, but especially the NPS physics: Brayton cycle is more efficient than Stirling machines. Power by Brayton cycle is used in Russia for the reactor /conversion subsystems in the flagship. Stirling power will be delivered by the successful tested US KRUSTY system for electricity on Mars and Earth moon. KRUSTY is also applicable as power source for Europa moon ice melting. In the Brazilian Institute for Advanced Studies Stirling process was also successful tested [8]. Although the results for the Brazilian Stirling engine are preliminary they show promise as may be seen in Fig. 5.

Fig. 5. Brazilian Stirling engine nested in its text cradle and alone for better visualisation.

Fig. 6 compares these NPS research reactors with other ground based research reactors.

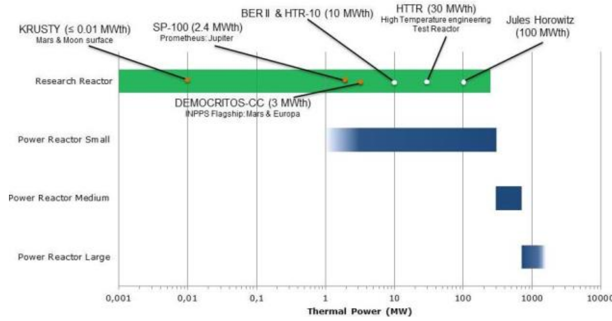


Fig. 6. All three NPS for space applications are kW to MW small research reactors. The reactors were studied in DEMOCRITOS – Core Component and falls within the spirit of IEAA safety requirements for research reactors. Ground based reactors like Berlin megacity BER II plus other Earth research reactors are also small from thermal power point of view, but with much higher power than the space reactors. For comparison medium and large power ranges for reactors are also displayed.

The Brayton cycle feasibility assessment and a preliminary concept of the turbo-alternator were studied in DEMOCRITOS for INPPS. First studies were conducted on a 1 MWe single loop and the associated turbo-alternator. Turbine inlet temperatures of 1300K and 1600K were approached and the associated efficiencies were assessed. The impact on the mass components was quantified. To reach 1 MWe power, preliminary design of the turbomachinery was carried out. Then, to meet a subscale ground demonstration of 200kWe, the reference cycle was updated and the expected changes on the turbomachinery were described. Brayton cycle was selected for conversion subsystem on INPPS.

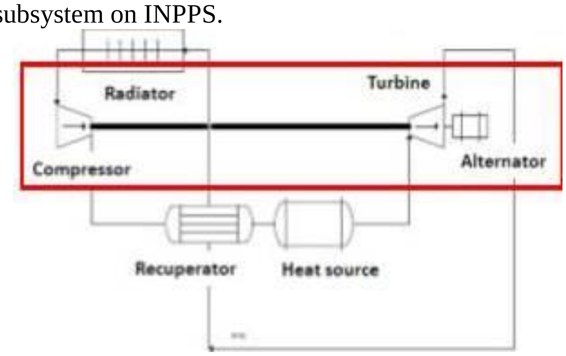


Fig. 7. Nuclear core simulator on ground - the Brayton power conversion turbo alternator will convert nuclear thermal energy into electric power for INPPS flagship electric thrusters and all other subsystems.

The radiators in Fig. 7 are standard and droplet radiators. Both are space qualified (see also Fig. 8). The higher temperature dissipation (located more nearby to the conversion / shielding / reactor subsystems) is still performed by 'classical' / standard radiators. In Fig. 4 the suggestion is, that the droplet radiators form a hollow-cone (it looks like an attractive umbrella-like layout) and are mounted behind the ‘classical’ radiator part), which matches exactly the shadow-cone of the radiation shielding of the Mars INPPS. In this way the maximal surface of droplet radiators is available and in addition the droplet radiator temperature profile is uniform in azimuthal direction along the flagship main axis.

Droplet radiators are best suited for the lower temperature end of the heat dissipation. The ‘classical’ radiators are still connected directly to the conversion/shielding/reactor subsystems and give the then cooler cooling oil to the droplet radiators. Droplet radiators are space qualified (see Fig. 8), but would need larger scale test on ISS or on a dedicated space platform.

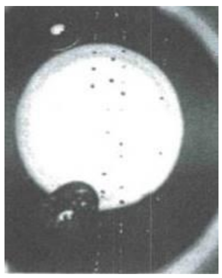


Fig. 8. Image of oil droplets in a Russian droplet radiator in LEO.

3. INPPS payloads: Mars VaMEx and Europa TRIPLE

The Valles Marineris on Mars is the largest known canyon in the solar system. With a length of about 4000 km, width of up to 800 km and a depth of about 10 km this canyon is of highest interest for water can physically exist there even in its liquid state. However, due to its vast dimensions a sustainable exploration of the Valles Marineris requires a complex and fast mobile system. The INPPS’s huge payload capacity of up to 18 tons offers a unique opportunity for such a heavy weight exploration system, as e.g. the VaMEx mission concept is designed. As a heterogeneous swarm the VaMEx system consists of rovers, hominid robots, special designed UAV’s and a mobile base station.

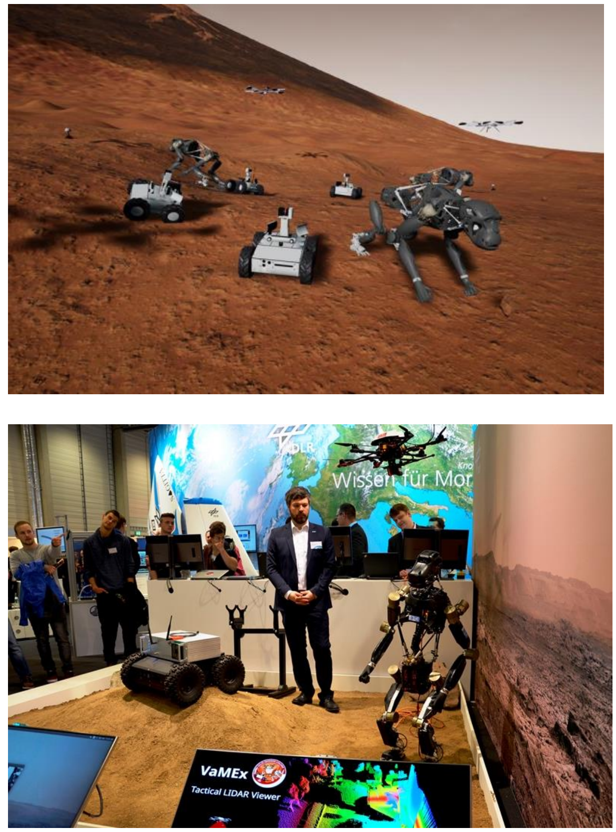


Fig. 9. Top - VaMEx multiple swarm units foreseen to be deployed on Mars surface. Bottom - VaMEx at DLR exhibition booth during ILA 2016 in Berlin.

Started in 2012 the ‘VaMEx – Valles Marineris Explorer’ [9] has become an ongoing concept study and project line for a systematic development of key technologies to enable a future VaMEx space mission. Required technologies are e.g. artificial intelligence for high degrees of freedom robots, capability for autonomous operations, and reliable system stability over a long mission time, cooperative swarm behaviour and redundant and reliable navigation capability.

The main task of VaMEx is nothing less than the enabling of an intensive exploration of the huge canyon system Valles Marineris on Mars, searching there for spots of wet soil and even puddles of liquid water at the bottom of the about 10 km deep valley and aiming for the detection of former or even present life forms. For achieving this ambitious goal, a heterogeneous drone swarm is utilized. The swarm consists of several rather small rovers (Sojourner size), hominid robots (child size) and unpiloted aerial vehicles specially designed for flying within the very thin Martian atmosphere. The swarm operates autonomously to a high degree; while for the UAVs full autonomous operation is required. The individual drones operate in a cooperative manner and enable stable communication links even in very rough terrain. Since each type of robot has at least one substitute, within the swarm redundancy is given. The swarm drones are equipped with various sensors, as camera systems for visual navigation [10], supported by radio navigation and further support by a space segment consisting of CubeSats or Nanosats in orbit [11]. Operations on the ground can be controlled by terrestrial remote control and in case of danger by the implemented swarm artificial intelligence itself in real time.

In 2020 the third phase of developments for VaMEx starts, and in 2022/2023 a first combined field test is planned in order to demonstrate and validate the overall capability of the VaMEx swarm in a terrestrial analogue field test. If this field test will show convincing results, the Valles Marineris Explorer could be an ideal payload candidate for both INPPS flagship missions to Mars (the non-human and human ones).

In addition, navigation of the VaMEx multiple swarm shall be supported by several CubeSats or Nanosats deployed into Martian orbit.

A complex system like VaMEx (with an assumed total weight of all components of about 8 t) requires the large payload capacity of great launcher. From launcher point of view VaMEx may already transported by the first non-human INPPS flagship mission to Mars. VaMEx, as the potential INPPS payload candidate of DLR consists of various individual components and drones that can be launched from Earth in several independent steps and being implemented to the payload basket of the INPPS flagship. As soon as the INPPS reaches Mars (already after 2025), its first target destination, the complete VaMEx system can be dropped at once to land at the surface (mobile lander with drone swarm) or being released into orbit (navigation satellites), respectively. A modular virtual testbed for multimodal autonomous planetary missions, called VaMEx-VTB is explained at IAC DC 2019 [12].

TRIPLE is an idea for a potential payload candidate from Germany for EUROPA-INPPS consists – for example – of an ice melting probe with integrated nanoAUV payload (see Fig. 10). TRIPLE would need power supply, as it is available by KRUSTY.

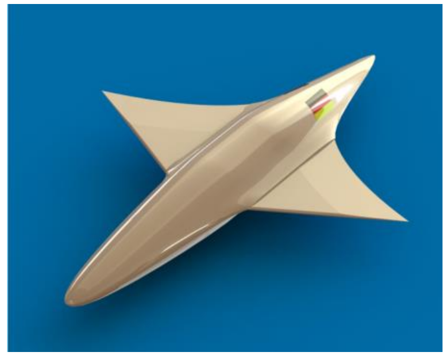


Fig. 10. Concept proposal of nanoAUV for Europa moon ocean and ice research.

4. Realizable Conclusions and Outlook

All papers at IAC DC and the MW reactor test confirmation in Russia (see in [2] to [7]) summarized the remarkable progress in INPPS preparation for flight qualification after 2025. Therefore payload studies for MARS-/EUROPA INPPS high power and heavy space transportation to Mars and Europa were sketched. Insofar, in addition to a 'High Power Space Transportation' program (which will be necessary to realize – in parallel the core, ground and space demonstrator concepts of DEMOCRITOS – in the next years) concerted actions for science payload decisions are desired. Because efforts are urgent necessary to combine the INPPS flagship system and subsystems progress with high quality scientific payload involvement like VaMEx and others.

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In memory for Hartwig Bischoff (†), who was a colleague and friend. He was in charge for NEP at European Commission and initiated and strongly supported the three European Commission funded projects for INPPS flagship.

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