DEMOCRITOS Demonstrators for Realization of Nuclear Electric Propulsion of the European Roadmaps MEGAHIT & DiPoP

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Abstract: The European Commission Horizon 2020 funded DEMOCRITOS project (2015-2017, see under democritos.esf.org) will be primary focused to prepare preliminary design of the ground, core and space demonstrators and their test benches for the mega-watt class nuclear electric space propulsion INPPS flagship (International Nuclear Power and Propulsion System). In addition programmatic, organizational and funding aspects for international cooperation related to INPPS realization are sketched. The new project includes partners from Europe, Russia and the Brazilian guest observer IEAv and is the follow-up of the mega-watt class nuclear electric propulsion European-Russian MEGAHIT project (www.megahit-eu.org). In Europe was already established the high power nuclear MEGAHIT and the low power nuclear (20 to 200 kW NEP) DiPoP (www.DiPoP.eu) roadmaps. Because Europe has started the implementations for INPPS flagship in the 2030-2040 timeframe, both roadmaps will be also described – from MEGAHIT the INPPS technology options, the launcher, assembly and system architecture, space mission requirements, communications and public support. In case of DiPoP it will be explained the survey of European capabilities, technical options, potential space missions and the public acceptance as well.

I. Introduction

THERE has been three European Commission funded projects for a Nuclear Electric Propulsion (NEP) enabled spacecraft in the last years: HiPER (Ref.1), DiPoP (**Di**sruptive technologies for space **Po**wer and **P**ropulsion, Ref.2) and the European-Russian MEGAHIT (**Mega**watt **Hi**ghly Efficient **T**echnologies for Space Power and Propulsion Systems for Long-duration Exploration Missions, Ref.3). Therefore in Europe the low power DiPoP (20 to 200 kW) and the high power MEGAHIT (MW class) roadmaps are available for realization. Since 2009 Russia with the Keldysh Research Centre manages scientifically in cooperation with Roskosmos, Rosatom and the Russian Academy of Sciences the transportation module with nuclear power and propulsion system (Ref.4). The finalization of dedicated ground based tests and flight test preparation for the Russian transport module is confirmed by 2018. In correlation with this tight schedule, in March 2015, the first step for MEGAHIT roadmap realization started with the European-Russian-Brazilian DEMOCRITOS (**Demo**nstrators for **C**onversion, **R**eactor, Rad**i**ator And **T**hrusters for Electric Pr**o**pulsion **S**ystems) project. DEMOCRITOS includes detailed studies of three demonstrator concepts regarding NEP – 1) DEMOCRITOS-GC the Ground Component, 2) DEMOCRITOS-CC the Core Component and 3) DEMOCRITOS-SC the Space Component. Another important aim of the European Commission funded DEMOCRITOS project is the continents wide invitation for science payload and space system technology contributions for the INPPS demonstrator mission in space. In chronological order, the next five chapters summarize the objectives respectively outputs of DiPoP (2011-2013), MEGAHIT (2013-2014), DEMOCRITOS (2015-2017) and conclusions related to programmatic aspects for INPPS realization.

II. DiPoP

DiPoP was an assessment study with recommendations and a roadmap for the European Space Policy for disruptive space power and propulsion technologies as well as their applications. For example, studied topics included space nuclear fission (electric power 30 kW to 200 kW), the rules for public acceptance, launch and operations constrains and the range of potential applications in space. Identified space applications are Mars manned (split) mission with nuclear powered infrastructure on its surface (in general planetary surface or 'space port' power generation), outer planet robotic exploration like Jupiter sample return spacecraft and Neptune orbital survey and lander mission, as well as robotic heliosphere and beyond exploration mission. Another studied emphasis was related to Near Earth Object (NEO) management. The recommended 30 kW prioritisations are 1) planetary surface power generation and usage for high power instruments and 2) small robotic exploration and NEO survey with high power radar. The recommended 200 kW prioritisations are 1) Earth threatening NEO deflection, survey and respectively mining, 2) outer planet robotic exploration and 3) large infrastructure transportation. Europe has the potential capability and interest but needs technical and infrastructure development to gain practical experiences. To reach sustainability, it is required tailored mission analysis needs and moreover short, medium and longer term R&D priorities in European Commission 'Horizon 2020' programme and at ESA. International cooperation – also with nuclear organisations – is a challenge, as well as the public acceptance management as an integral early part of any related project. Fig. 1 represents the accepted low power nuclear DiPoP roadmap for Europe.

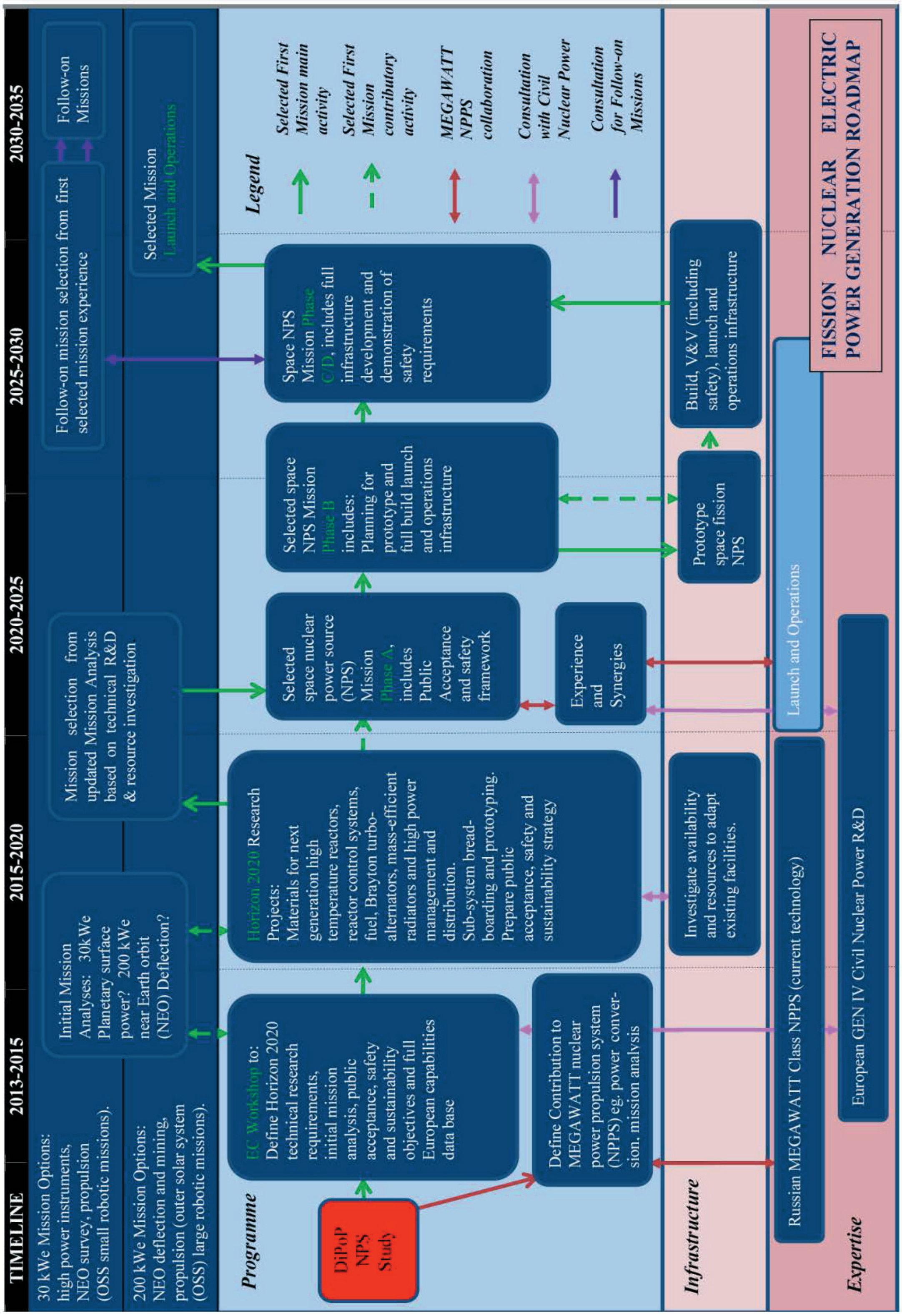

Figure1. DiPoP roadmap with mission options, programme, infrastructure and expertise developments in Europe until 2035.

III. MEGAHIT

As a completion to the low power nuclear DiPoP roadmap, the MEGAHIT project delivered the high power nuclear roadmap (for more MEGAHIT roadmap details see in Ref. 3). MEGAHIT project envisaged the creation of 1 MW class nuclear electric spacecraft – the INPPS flagship. The project has foreseen a mission launch after 2030. The key characteristics of the INPPS are (see Fig. 2)

- 30 m or greater spacecraft length,
- an estimated radiator area of 1000 m^2,
- final spacecraft mass of 40 t,
- electric propulsion system specific impulse range ~ 3000 to 8000 seconds,
- a nuclear reactor to achieve power at a high level (>1 MW),
- robotic assembly and departure from a sufficiently high orbit (800 km or higher for safety considerations),
- a space system that can function five years in full power on a total lifetime of ten years and
- the reactor shall remain subcritical at all times during launch, even in case of a launch failure.

Especially during the technology development phases of the flagship the economic benefits for nations on different continents will enable the project to go ahead internationally too. Fig. 3 displays the INPPS general architecture and the spacecraft subsystems.

The MEGAHIT roadmap intended the highlights of development steps, identified the main technology and co-development issues that such an endeavour will face. The foreseen reactor powering the MEGAHIT spacecraft may be a compact, fast spectrum reactor. The options with the highest technology readiness level (TRL) are either a direct cycle He-Xe gas-cooled reactor with epithermal to fast spectrum and core outlet temperature of 1300K or an indirect cycle Lithium liquid metal-cooled reactor with fast spectrum with core outlet temperature 1350K. The co-development opportunities for the reactor are related towards high temperature material and studies respectively simulations for ten years lifetime operation in space environment.

MEGAHIT flagship contains a turbine, which is able to sustain operation for five to ten years with non-oxidising gaz at 1300K or higher to convert the reactor power to electricity. Turbine bearings with warranted operation lifetimes between five to ten years (without maintenance) will also be a co-development issue. On the different participating continents turbine technology developments are applicable in their aeronautics, non-space advanced materials industry outside nuclear industry.

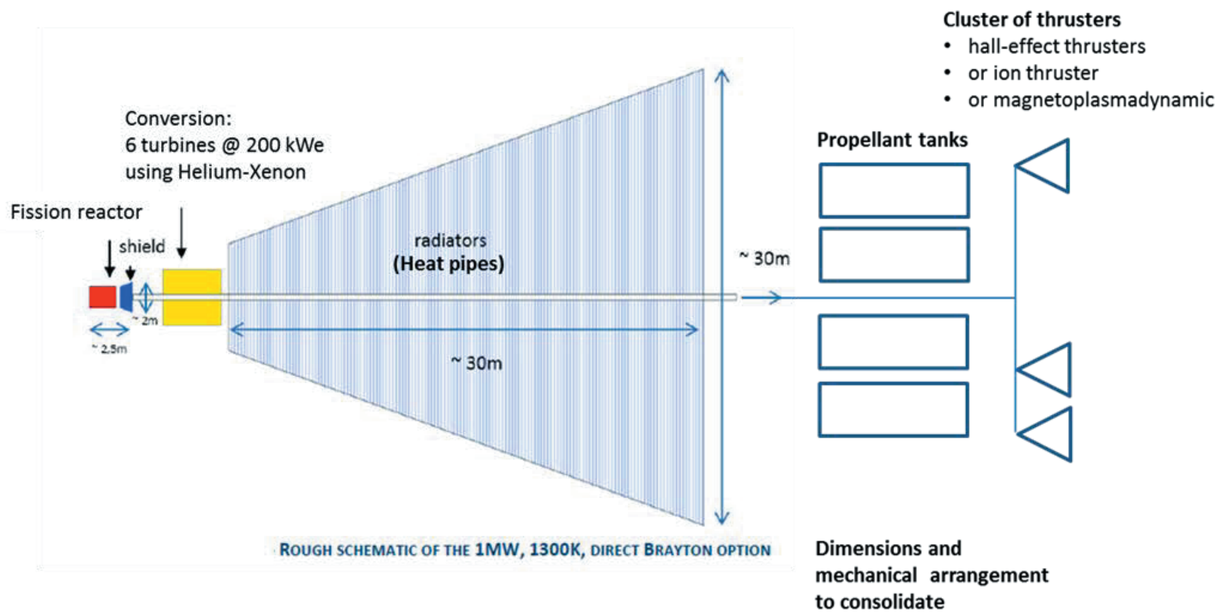

Figure 2. Concept drawing of MEGAHIT NEP spacecraft to present an idea of the dimensions and magnitude of space subsystems for the INPPS flagship.

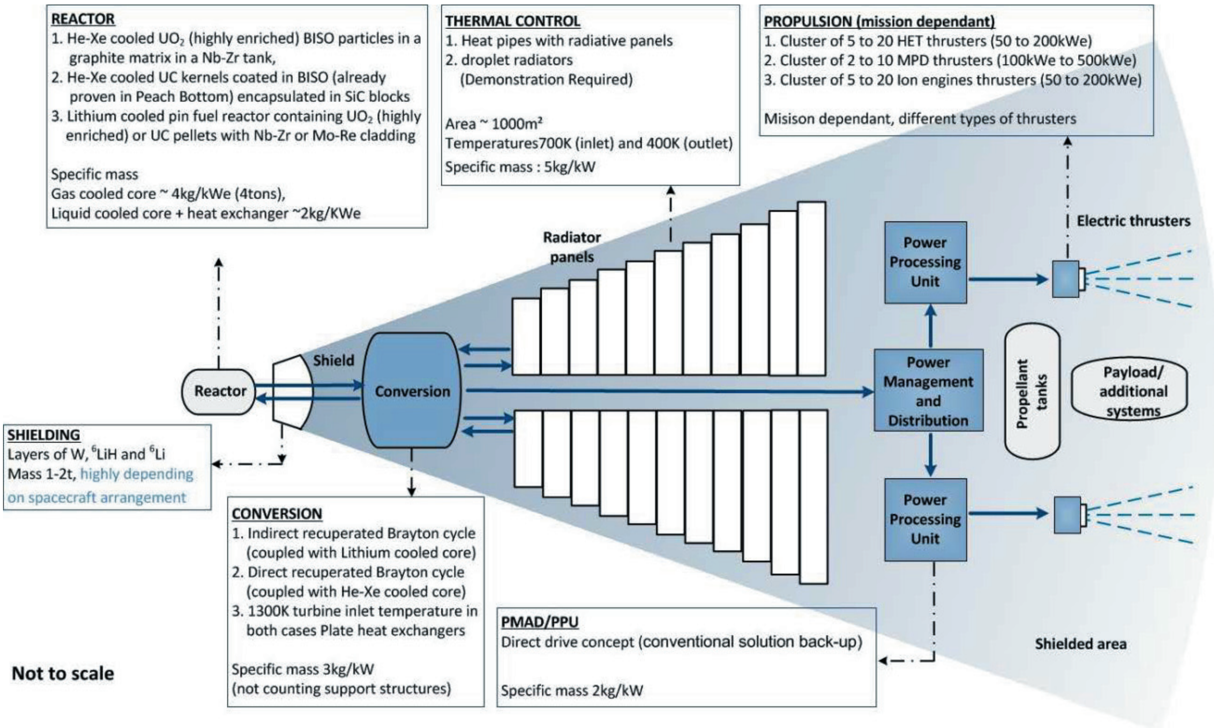

Figure 3. Proposed INPPS subsystems together with material, space technology and processes options.

Two key aspects of the thermal management in the MEGAHIT spacecraft radiators are identified: 1) their huge size and its deployment method and 2) the radiators materials composition to be used for long time, high temperature operations. Radiator co-development technology on the continents may be manufacturing processes of used material and required surface finishing as well as radiator deployment tests on ground and finally in space. These additive manufacturing advances are already being very actively pursued world-wide.

The excess heat of MEGAHIT flagship is a solvable issue for the heat dissipation of spacecraft sub-system electronics: in case of new material studies with the aim to decrease the heat dissipation. China Aerospace Science and Technology Corporation (CASC) is investigating (see in Ref. 5) the use of diamond powders alloyed with copper to improve heat dissipation, which would be an opportunity for international cooperation with Asiatic area countries. In addition industries in Japan and Asia Oceania region may find co-development opportunities in electric propulsion / high temperature / heat dissipation electronics in server farms / cloud computing. Another obvious synergy applications are within aeronautics industries for voltage, high temperature and rad-hard electronics. Scientific co-development contributions are also conceivable on research for room-temperature superconductor usages on INPPS flagship, because it can handle far more electric current than normal electric wire.

The INPPS subsystem structures as well as the material components, the assembly and deployment is a very meaningful, visible and strategic co-development contribution from the countries in the interested continents. Large parts of the MW-class INPPS e.g. thermal subsystem can be designed as autonomous systems, can be launched separately and be assembled in orbit. Robust, lightweight, integrated and deployable structures are required. Technologies e.g. for components/systems integration to the structure, deployment technologies (e.g. for radiators), structural interfaces for high temperature parts (e.g. reactor and radiator area), technologies for active vibration control of structural response for mass reduction needs to be developed and improved. Extensive co-development is the robotic assembly. Due to the high assembly orbit (above 800km), autonomous robotic operations will be the preferable option for the INPPS assembly (Fig. 4). The space robotics will profit from recent ground based industrial robotic developments, including autonomous and semiautonomous drones too.

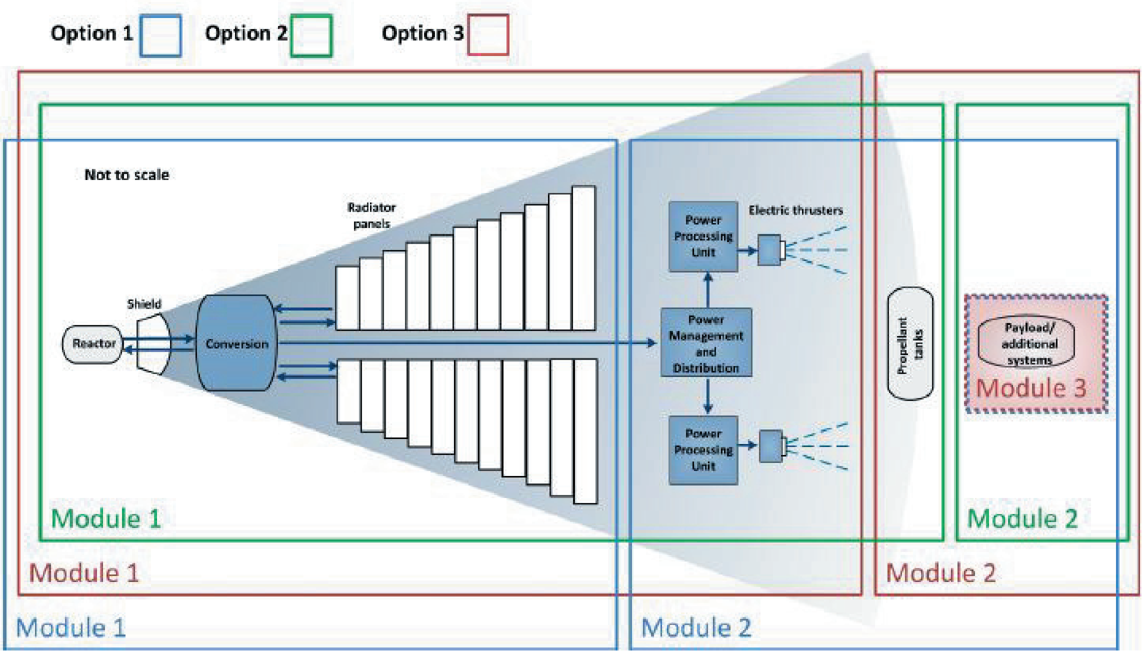

Figure 4. The three options of high Earth in-orbit assembly of each from two INPPS modules.

In the MEGAHIT roadmap, nearby/future/heavy launchers disposability was studied to transport in minimum two or more modules with different rocket launch systems. In Fig. 5 is displayed the very important INPPS modules launch order: first all non-critical and non-nuclear subsystems will be launched and assembled in high Earth orbit. The final launch is the subcritical reactor module launch with the automatic assembly to INPPS. Insofar the safe launches, deployment and assembly is proven for the public and politics as well. The economic aim is also to push the nations on the different continents interest in INPPS realization, especially to verify the usage of their smaller (Fig. 6) and medium size launchers as potential transport contribution or co-developments for INPPS payload (e.g. for Asteroid mining and other payload systems).

The successful INPPS flagship becomes a truly global project and is comparable with Apollo and ISS projects. Therefore it may demand a prompt public-private investment programme for realization - globally, on the continents and in nations.

Three MEGAHIT mission analyses were conducted by the Keldysh Research Centre. 1) NEO deflection by INPPS. In case of initial INPPS spacecraft mass equal to 20 t and specific impulse value of about 7000 s initial analysis shows that the payload delivered to the asteroid orbit will be of the order of 16 t. Required duration of asteroid orbit gravitational correction will be about 40 days in a 2021 Apophis approach asteroid (see Fig. 7) or 200 days in case of the approach in 2027. 2) INPPS outer solar system exploration missions. Several tons of payload could be sent by INPPS to Jupiter's Europe or Saturn's Titan moons within three years. In comparison: chemical thrusters would put only half ton payload in this orbit (for example Cassini and Galileo orbiters payload mass was only 670 kg and 118 kg). A 40 t INPPS deliver - into a Europa orbit – three to ten tons (depending on the specific impulse (in the 6000 – 8000 s range)). The duration of the INPPS transfer to a Jupiter satellite orbit, lies within the range 2.5 to 3.5 years. Insofar the use of nuclear power propulsion system of megawatt power level will allow nations to transport fast, high payload mass to distant celestial bodies in the solar system or even to local interstellar medium. 3) INPPS Moon & Mars cargo missions. In case of 1 MW lunar tug would make two trips per year, 650 t of payload can be brought in lunar orbit in ten years. For a Mars mission, the duration of the transfer defines the optimum value of the specific impulse and the payload mass. The variation in the specific impulse in the range from 4500 s to 9000 s involves the increase of the transfer duration from 350 to 600 days and the growth of the payload mass from 11 to 18 t respectively. The MEGAHIT mission analysis results show that there are two optimal ranges of electric propulsion system specific impulse values: 2500 - 4000 s (near Earth and Moon orbits) and 4000 – 8000 s (Mars and deep space missions).

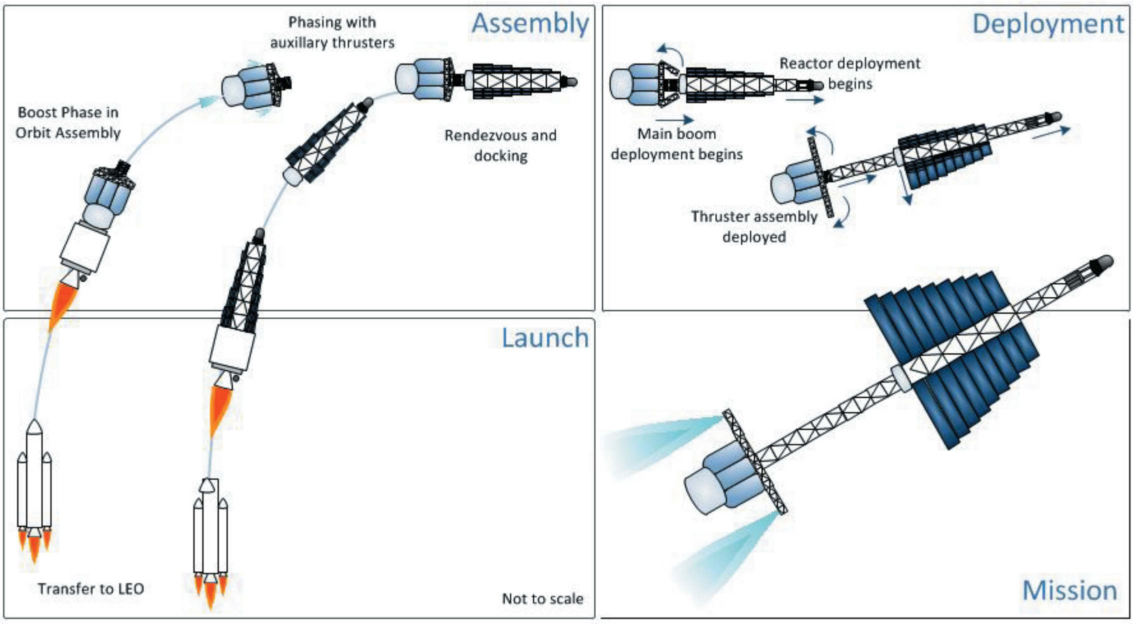

Figure 5. Phases of the launch (finally with the non-critical nuclear reactor (right side in the lower left image)), assembly, deployment and mission of the INPPS flagship – many different opportunities for contributions of nations on the different continents.

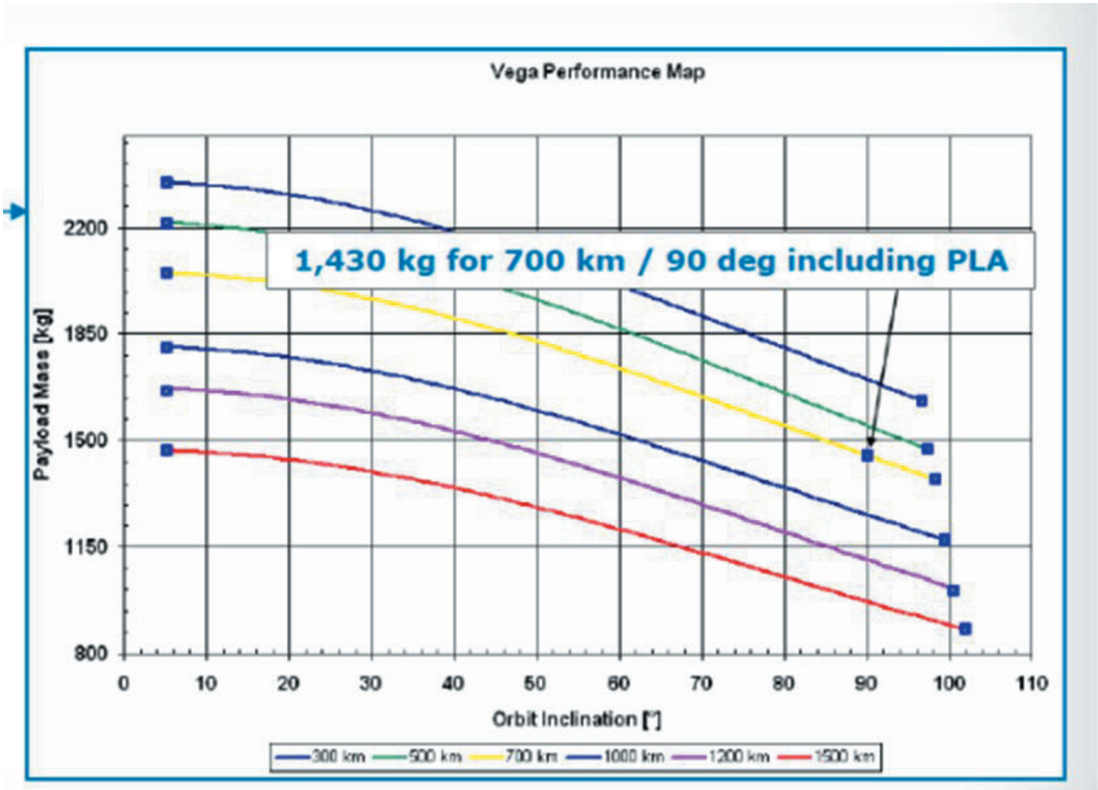

Figure 6 Several heavy international launchers were studied for INPPS usage. Here the example for the small VEGA launcher: the performance map includes the launcher as a rocket for very low mass INPPS parts to high Earth orbit.

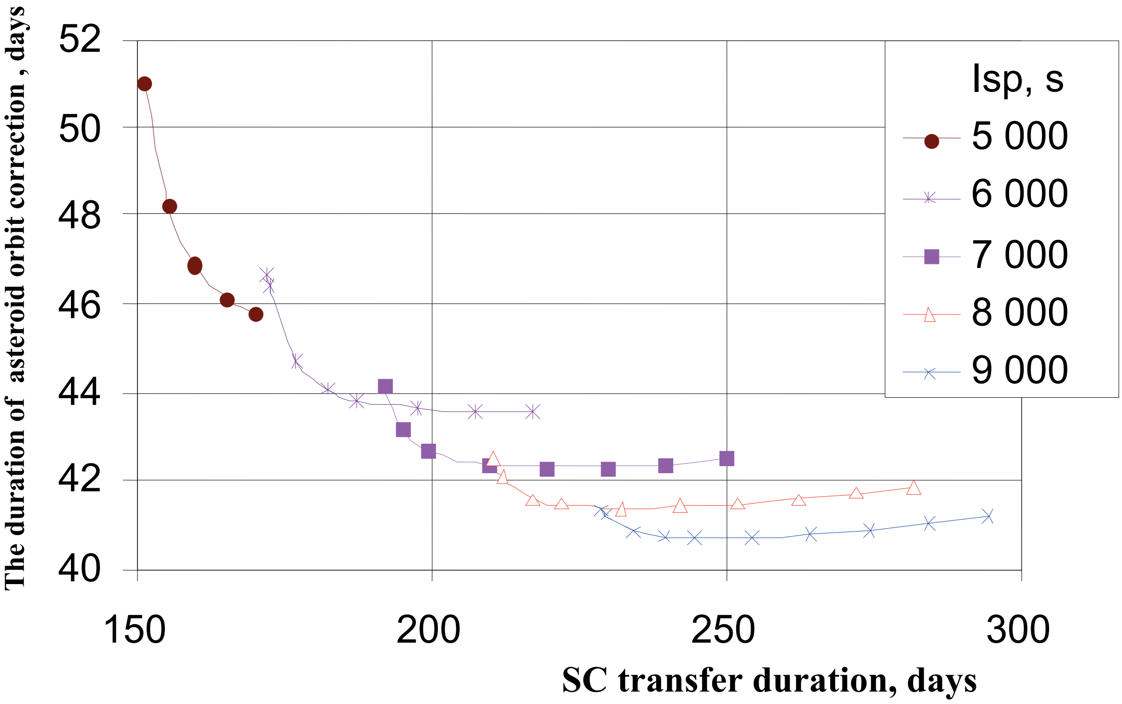

Figure 7. Asteroid Apophis orbit correction duration versus the INPPS transfer to the asteroid duration and for different specific impulse (Isp) values. The start date of INPPS transfer is 01 January 2021.

IV. DEMOCRITOS

The design trade off study for the INPPS flagship is carried out in European Commission funded project DEMOCRITOS. DEMOCRITOS started in 2015 investigating the INPPS critical technologies and key issues in three demonstrator projects: the DEMOCRITOS Ground Component (DEMOCRITOS-GC), the DEMOCRITOS Space Component (DEMOCRITOS-SC) and the DEMOCRITOS Core Component (DEMOCRITOS-CC). DEMOCRITOS-GC will investigate the interaction of the INPPS subsystems (thermal, power management, propulsion, structures and conversion) between each other and with a (simulated) nuclear core providing high power (in the order of several hundred of kilowatts). DEMOCRITOS develops the preliminary designs of all the subsystems and the required test bench of the necessary ground experiments with the purpose of maturation of the related necessary technologies.

DEMOCRITOS-GC conceptualizes the simulated nuclear space reactor and outline the specifications for a Core Demonstrator, including an analysis of the regulatory and safety framework that will be necessary for such a demonstration to take place on the ground. In addition system architecture and robotic assembly studies will be done, to investigate in detail the overall design of the INPPS flagship. The aims are to achieve a pragmatic strategy for assembly and deployment in orbit of such a large structure coupled with a nuclear reactor. This thematic aspect of the project is also referred to as DEMOCRITOS Space Component (DEMOCRITOS-SC). The consortium partners will provide a preliminary design of the nuclear powered spacecraft and its subsystems, detailed assembly and servicing strategy in orbit as well as proposal for in space demonstration missions with the aim of maturing various necessary technologies that either do not fit within the DEMOCRITOS-GC or have the opportunity to fly in synergy with other European or international initiatives.

V. Conclusion

It is expected that during the DEMOCRITOS project several detailed co-development strategies are identified and potential interested parties from other industrial areas will be approached by the project consortium.

Therefore DEMOCRITOS will implement DiPoP and MEGAHIT recommendations for a public communication strategy of INPPS project. It will need advocates in key parts of the structure of government in all participating countries to ensure that there is sufficient support for the endeavour. Several general and detailed suggestions were developed in MEGAHIT (Ref.5). For example, a constructive relationship with communication media must be developed and the project will need an appropriate 'spokes team' of credible knowledgeable spokesperson(s) with the need to cover a variety of ages, both genders and represent all participating countries / continents. That ensures that the cultural differences are factored in. Insofar the MEGAHIT roadmap is considered as a basis for a wider scale international cooperative development. INPPS flagship creates new perspectives for our civilization on Earth for peaceful international cooperation in space. The economic growth on the continents is comparable with projects like Apollo and International Space Station.

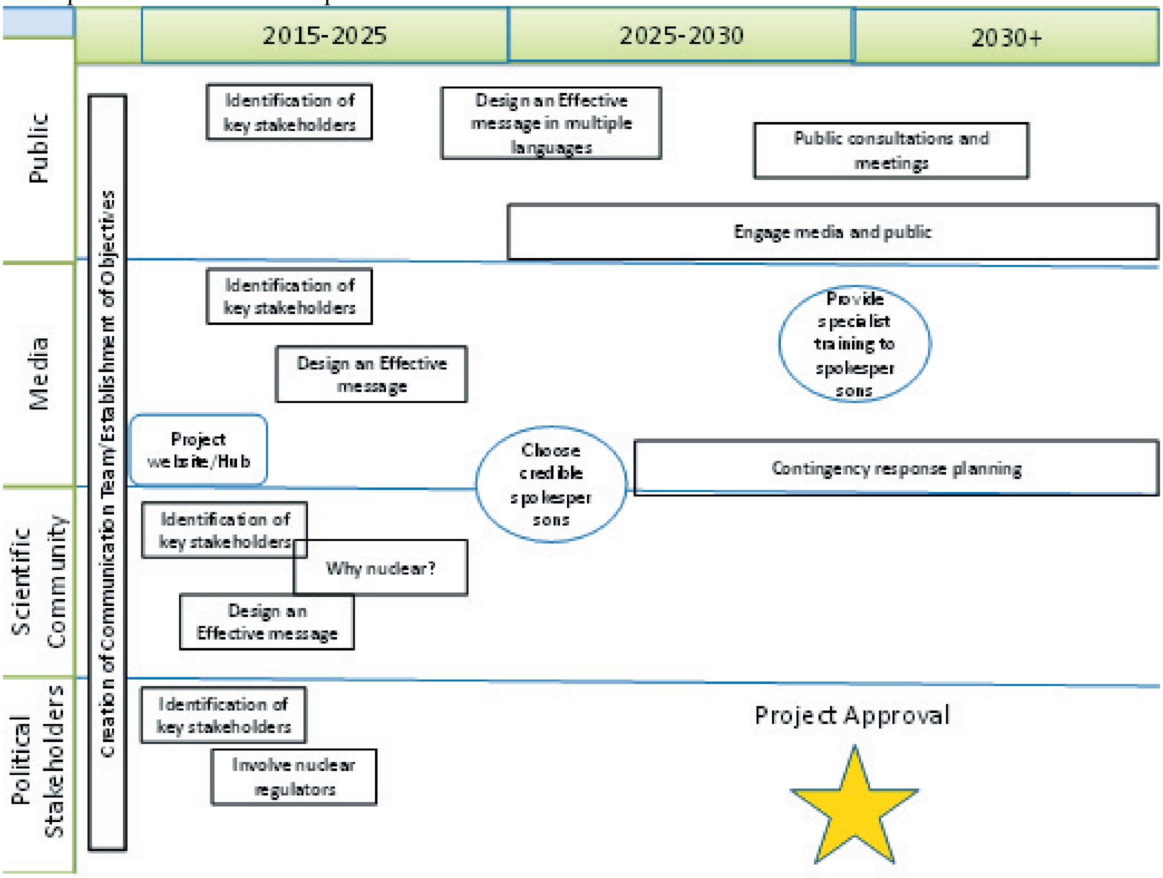

Figure 8. Programmatic aspects like policy, science & technology, media and public for INPPS project.

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