MEGAHIT* Roadmap: Applications for Nuclear Electric Propulsion

*Megawatt Highly Efficient Technologies for Space Power and Propulsion Systems for Long-duration Exploration Missions

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Overview

1) Introduction
   a) 'History': DiPoP=> MEGAHIT => DEMOCRITOS

2) European-Russian MEGAHIT
   a) study outputs: worldwide interests for MW NEP and
      high level spacecraft requirements,
   b) proposal: key technology plan including stakeholders and subsystems,
   c) plan for a political as well as public supportable reference space mission and
   d) MEGAHIT global roadmap for international realization of NEP respectively
      INPPS (International Nuclear Power and Propulsion System)

3) DEMOCRITOS

4) Summary and Recommendations

1) Introduction: DiPoP

- 2011-2012: EC FP 7 DiPoP (**Di**sruptive technologies for space **Po**wer and **P**ropulsion)

- DiPoP Final Review related to nuclear electric power generation
  a) European Nuclear Power Study 2005 recommendations
  '…A European roadmap for the development and use of nuclear power sources for space should be elaborated… It should include a comprehensive inventory and assessment of all potentially relevant existing facilities and capabilities in Europe…',
  => survey of European capabilities, technical options,
  potential space missions, public acceptance => **DiPoP roadmap**
  b) 2 Advisory Board meetings: DC (DLR office) and Moscow (KeRC)

Invitation to Europe by KeRC / A. Koroteev
to join Russian NPPS
(about 500 Million €, 2018 ground based test)

1) Introduction: DiPoP

RANGE OF POTENTIAL APPLICATIONS:

Mars Manned (split) missions: humans chemical propulsion, infrastructure nuclear.
Outer Planet Exploration: Jupiter sample return, Neptune orbital survey and lander.
Heliosphere and beyond Exploration.
NEO management: Earth threatening deflection/destruction, survey and mining.
Planetary surface or 'space port' power generation.
High power ground penetrating radar, ice-melting laser, long distance high data rate communications.
Space-based NEO tracking radar for trajectories obscured by the Sun.
Removal of 'dead' spacecraft from Earth orbit to reduce space debris.

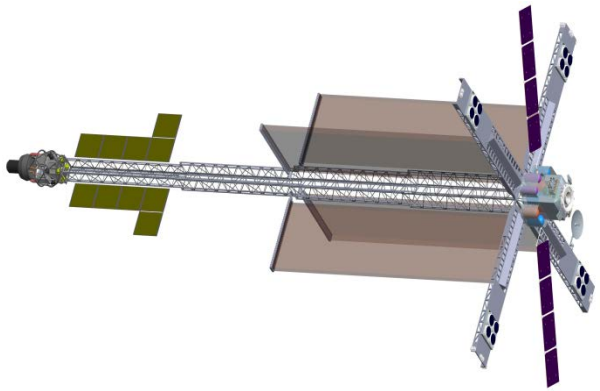
30 kWe prioritisation:
Planetary surface power generation, Small robotic exploration and NEO survey, high power radar.

200 kWe prioritisation:
NEO deflection, survey, mining, outer planet robotic exploration, large infrastructure transportation.

1) Introduction: DiPoP technical options

DiPoP Launch to 800km minimum in-orbit commissioning altitude

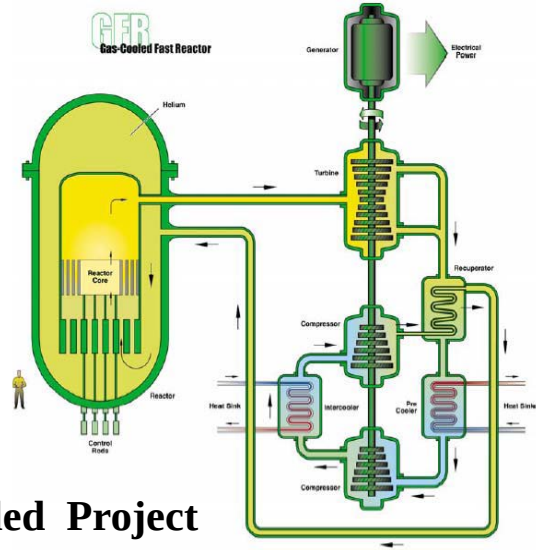
Ariane 5 ECA



MEGAWATT Class NPPS

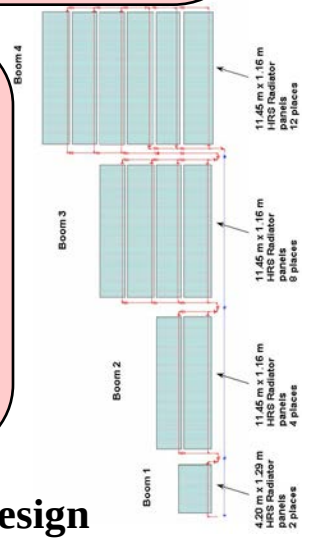
DiPoP Reactor
Core: pin-fuel fast, particle/ pellet bed epi-thermal, refractory metal fast, liquid metal or gas cooled.
Load following negative thermal control with rods or drums.
Highly enriched ceramic oxide, carbide or nitride of uranium. Shield: layered Be, LiH and W; 28° shadow, 22.5 m boom (200 kWe).

DiPoP Power Conversion:
Stirling: strong contender for 30 kWe but concern about robustness,
Brayton: preferred for both 30 kWe and 200 kWe (scalable to 2 MWe).



Allegro Gen IV Gas Cooled Project

DiPoP Radiators:
Fixed: high temperature low mass materials
Deployable: low temperature, less micro-meteoroid protection, heat exchanger;
Russia developing droplet radiator (ISS trial 2013)



NASA Deployable Design

1) Introduction: DiPoP survey European capabilities (topics & response)

High Temperature Reactor Technology

EC JRC (Germany, Netherlands), CEA (France), SCK-CEN (Belgium), VTT (Finland), Demokritos* (Greece), MTA-EK (Hungary), NCBJ (Poland), VUJE (Slovakia), PSI (Switzerland), NNL(UK), CV-Rez (Czech Republic), AREVA (France, Germany), Studsvick (Sweden), AMEC (UK), Rolls Royce and Leicester University* (UK).

Energy Conversion

CEA, CNES (France), SCK-CEN*, Demokritos*, MTA-EK, NCBJ, VUJE, NNL(UK)*, AREVA, ThalesAlenia (Italy, France), AMEC*, Rolls Royce*, SEA (Stirling UK), Snecma Moteurs (France) and Leicester University*. (* Study)

Power Management and Distribution

EC JRC, CNES, AREVA, Galileo Avionica* (Italy), AMEC*, EADS Astrium (France, Germany, UK) and Stuttgart University (Germany).

Project Management (including Public Acceptance, Safety and Sustainability)

ESA, CNES, DLR, VTT**, MTA-EK, ESF, ThalesAleniaSpace, Studsvick**, AMEC** EADS Astrium, SEA, Snecma Moteurs (France) and Stuttgart University (public acceptance). (** Consultancy)

Launch and Operations:

ESA, CNES and UK Space Agency (licensing).

1) Introduction: DiPoP resources

European Commission: Horizon 2020 programme (materials research), Generation IV high temperature reactor research and development: longer term prototype space fission nuclear reactor development.
ESA: General Studies programme (mission analysis), high power electrical system and high temperature radiator R&D.
National Governments: Redundant nuclear research, development, build and test facilities and expertise, support Public Acceptance, Safety and Sustainability.
Industry: R&D where there is a spin-off to other space or non-space applications within an acceptable return on investment timescale.

1) Introduction: DiPoP Advisory Board views

Applications:

- Focus on higher power (30 kWe limited capability & little cost, risk, schedule savings),
- NEO deflection, robotic outer-planetary exploration (ESA JUNO mission very limited).

Technical Options:

- Gas cooled fast preferred in principle but Europe more experience with liquid metal,
- Low temperature better for electrical equipment and possible with droplet radiator,
- Not to dismiss thermionic and thermo-electric power conversion completely.

Capabilities:

- European fuel expertise mainly in Uox and little in UN and UC.

Public Acceptance, Safety and Sustainability:

- Needs infrastructure investment: investigate safety capsule for launch failure.

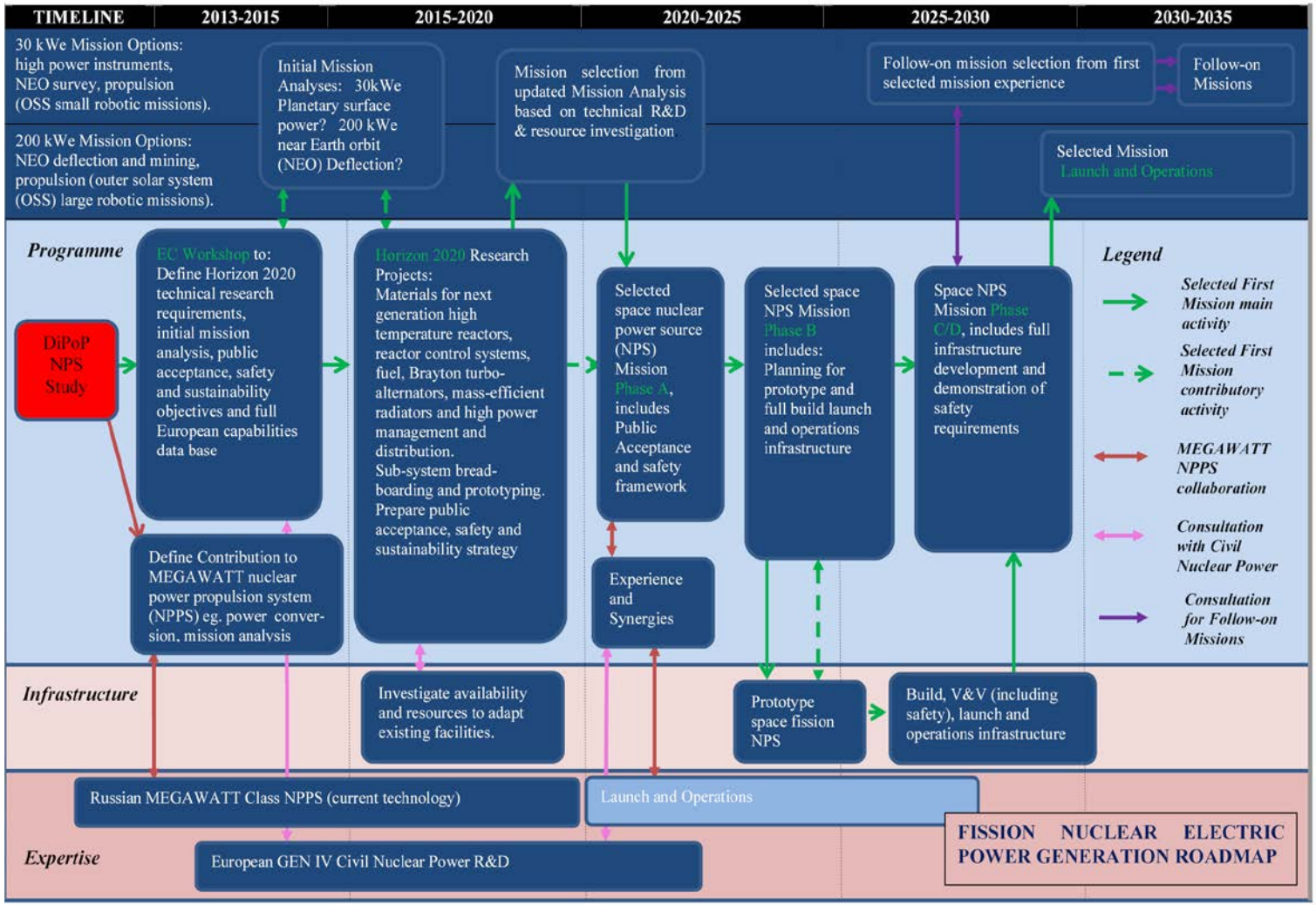
Resources:

- Cost whole programme (Prometheus) not just to ground testing (Megawatt Class NPPS),
- Beware application driven requirements (eg long life fuel) with high cost deltas

Collaboration:

- Russian invitation to collaboration on MWe development (Heavy Spaceship),
- US situation review …

1) Introduction: DiPoP (low power) roadmap



1) Introduction: DiPoP main conclusions

The **ENPS 2005** recommendations progressed significantly.
Advisory Board guidance leads to a coherent European NPS Roadmap.
Space and Civil/Submarine fission NPS requirements differences remain.
NPS Advisory Board advise focus on higher power in applications prioritisation of:
30 kWe: power sources for planetary infrastructure/high power instruments,
200 kWe: Earth threatening NEO deflection/outer solar system exploration.
Technical: 30 kWe and 200 kWe gas cooled or LM closed cycle Brayton
Europe has the potential capability and interest but needs:
technical and infrastructure development and
practical experience.
Collaboration: Europe Generation IV NPS, Russia MEGAWATT Class NPPS.
Public Acceptance Management integral early part of any project.
European Safety Framework for NPS and infrastructure to deliver required.
Sustainability requires long term programme of R&D for multiple missions.
NPS R&D priorities for EC Horizon 2020 (short, medium longer term) identified.
Mission analysis needs space science & exploration, R&D and nuclear organisations.

2) European-Russian MEGAHIT project

- 2013-2014: EC FP 7 MEGAHIT
  (Megawatt Highly Efficient Technologies for Space Power and Propulsion Systems for Long-duration Exploration Missions)

- MEGAHIT study phases

Phase 1

High level requirements: Collect inputs from space agencies world-wide on mission-related high level requirements their interest for international cooperation on the subject.

Phase 2

Reference vision: The key technologies will be identified and a reference vision of what the MEGAHIT system aims at will be sketched out.

Phase 3

Technological plans: MEGAHIT approached stakeholders that can carry out the development and engaged with them through discussions on the technologies they master

Phase 4

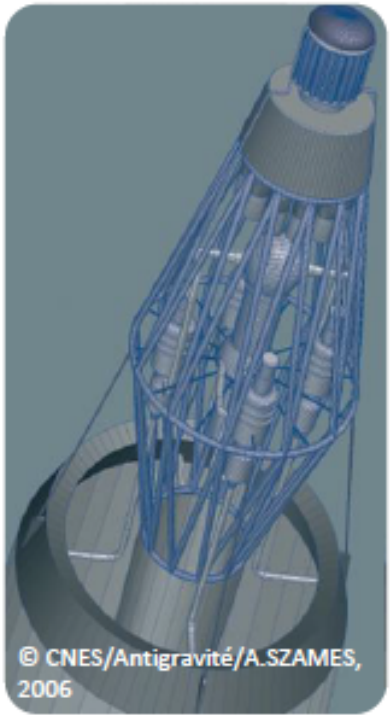
Road-maps: This is the synthesis of the three previous phases, translating into consistent road-maps what has been established in terms of goals, key technologies and technological plans

2) European-Russian MEGAHIT project

- MEGAHIT topics:

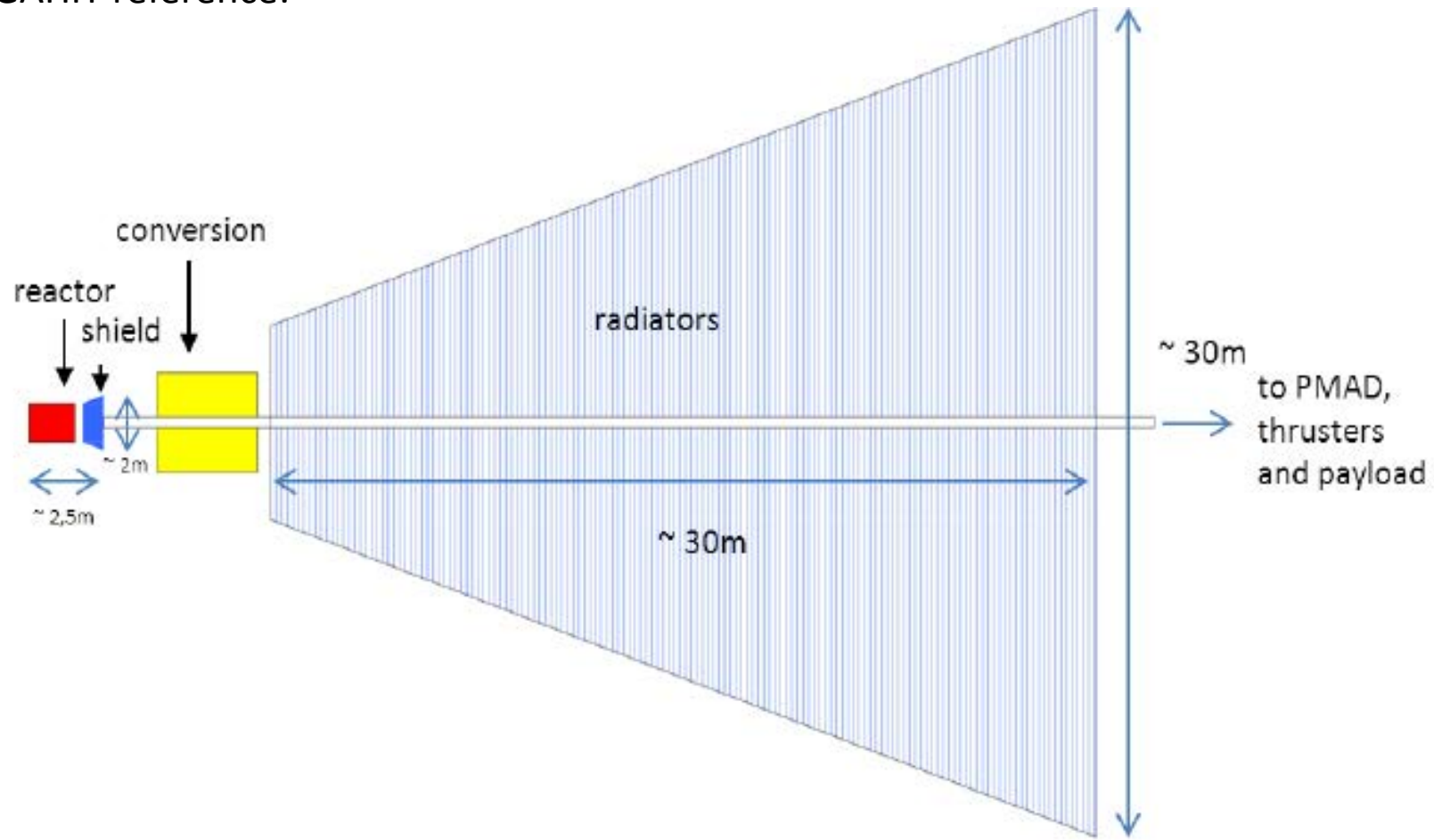
The topics addressed by MEGAHIT cover all the areas of space nuclear electric propulsion. The technological plans cover eight topics

1. **Fuel and core**, relating to nuclear technologies and including shielding.
2. **Thermal control**, addressing heat transfer and radiating devices.
3. **Conversion**, addressing the technologies of conversion of thermal energy into electricity at high power level.
4. **Propulsion**, relating to electric thrusters technologies
5. **Power management and distribution**, relating to the high power converters and distribution cables between the generator and spacecraft.
6. **Spacecraft arrangement and system architecture** addressing the system architecture, lightweight structures and assembly in-orbit.
7. **Safety and regulations**, addressing the nuclear safety and other regulations.
8. **Communication and public awareness**, addressing the necessary steps to take to successfully communicate a nuclear space project to the public.



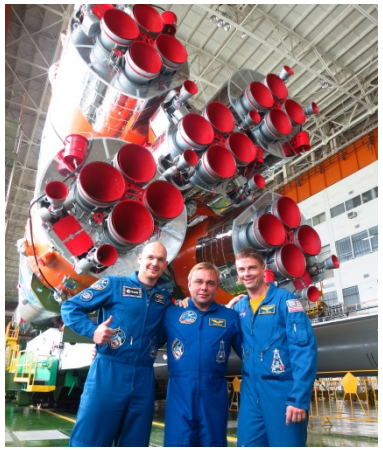
2) European-Russian MEGAHIT project

- MEGAHIT reference:



2) European-Russian MEGAHIT project

- MEGAHIT roadmap: **INTERNATIONAL NUCLEAR POWER AND PROPULSION SYSTEM (INPPS) ROADMAP**



Successful project realization is a truly global project and comparable with the Apollo and ISS projects.

3) DEMOCRITOS project

- 2015-2016: EC Horizon 2020 DEMOCRITOS
  (**Demo**nstrators for **C**onversion, **R**eactor, Rad**i**ator And **T**hrusters for Electric Pr**o**pulsion **S**ystems)

- DEMOCRITOS very good content + schedule: DiPoP + MEGAHIT roadmaps + Russian NPPS

- Demonstrator Concepts regarding NEP
  1) DEMOCRITOS-GC (Ground Component): a) interaction of the major subsystems (thermal, power management, propulsion, structures and conversion) between each other and with a (simulated) nuclear core providing high power (~100kW) and b) preliminary designs of all INPPS subsystems and ground based test benches
  2) DEMOCRITOS-CC (Core Component): concepts of nuclear space reactor, specification of a core demonstrator incluiding analysis of the regulatory and safety framework
  3) DEMOCRITOS-SC (Space Component): preliminary design of INPPS, detailed assembly and servicing strategy in orbit

DEMOCRITOS CEF study (DLR Bremen)

- forming a cluster around NEP (invitation to external stakeholders plus workshop)
- propose ideas for ground and flight demonstrator realizations
- expanding international cooperation Europe/Russia + other nations for demonstrators realizations

4) Summary and Recommendations

DiPoP: www.DiPoP.eu (documents and roadmap)

MEGAHIT: www.megahit-eu.org (documents, roadmap/recommendations (end of September 14))

In the focus for INPPS demonstrations and realization:
politics (strong guidance),
public,
space industry,
space organisations and related organisations,
space & space facing nations

INPPS

Successful project realization is a truly global project and comparable with the Apollo and ISS projects.