MEGAHIT: Update on the advanced propulsion roadmap for HORIZON2020

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Introduction:

Nuclear propulsion is an essential and enabling key asset for a significant number of exploration missions. Associated technological developments however require important financial efforts that can probably only take place in the frame of an international collaboration, sharing the efforts as this has been the case for the International Space Station.

MEGAHIT is a supporting action aiming at building a European roadmap for Megawatt level nuclear electric propulsion. It is funded by the European Commission under the 7th Framework Programme for Research and Technological Development, in preparation of the Horizon 2020 programme, starting in 2014.

MEGAHIT is driven by a consortium that is coordinated by the European Science Foundation and that includes CNES, DLR, Keldysh Research Center, the National Nuclear Laboratory from U.K. and Thales Alenia Space Italia. The consortium favors an open and participative approach in order that all interested stakeholders - research centers, agencies and industry-within consortium or not, can establish common research objectives and iniate research alliances. This approach will allow building a scientific and technical community on the topic in Europe and Russia. Potential collaboration opportunities at international level with other space fairing nations will be included.

Approach:

Megahit adopted an approach in 4 phases.

- **Phase 1: High level requirements**

Phase 1 collected inputs from space agencies and research centers on mission-related high level requirements.

- **Phase 2: Reference vision**

Phase 2 built a reference vision of what system we aim at, and what would be the best technological options.

- **Phase 3: Technological plans**

The rationale was that the best people for establishing technological plans are the stakeholders identified as being able to carry out the development. These stakeholders were associated through discussions and workshops on technologies they have expertise in.
Main workshop was hold in Brussels on December 2013 and was attended by about a hundred specialists. The workshop had two goals: a) formalize the technological plans. and b) create a community, giving the opportunity to each stakeholder of having a complete view of the project, technologies and system.

Phase 4: Road-maps

This is the current phase of the project. It aims at a synthesis of the three previous phases, translating into consistent road-maps what has been established in terms of key technologies and technological plans.

Missions and requirements

Mission analysis was conducted by KerC based on the following hypothesis/requirements:
Departure will be from a a sufficiently high orbit (800km or more). Spacecraft will be composed of at least 2 modules assembled in orbit: the transport power module with NPPS (20tons) and the module with payload (20 tons). Radiators can be foldable. System can function 5 years in full power on a total lifetime of 10 years.
A strong requirement would be safety: the reactor shall remain subcritical at all times during launch, even in case of a launch failure.

Three family of missions emerged as the most promising:

- NEO deflection: deflection would be done acting as a gravity tractor. System could deflect a NEO of Apophis size.
- Outer solar system missions: several tons of payload could be sent in Europe or Titan within 3 years. A chemical stage, without gravity assist manoeuver, would put only 300kg of payload in this orbit.
- Cargo missions: Lunar orbit tug or manned Mars mission cargo support mission.

Reference Vision

Large trade-off was conducted between possible technologies (Cf. figure 1) leading to down select 1 to 3 options for each main subsystem. A very preliminary « high level » concept was established, to give rough order of magnitude of mass and thermodynamic maps

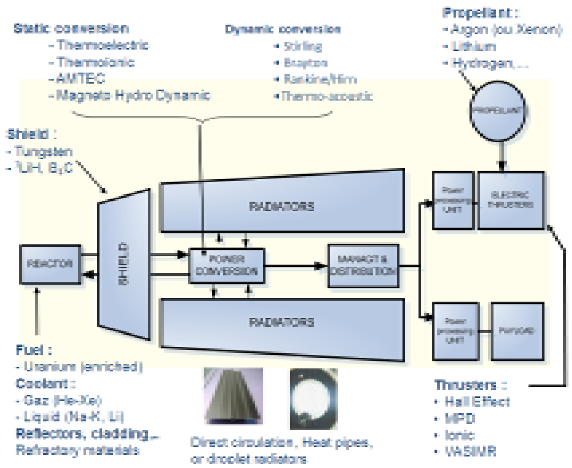

Figure 1 : general achitecture and list of candidates for subsystems.

For nuclear core, 3 fuel candidates UO2, UC and UN were retained for reference. High enrichment and fast spectrum were retained to optimize the mass, but also to follow UN recommendation to avoid Pu239 formation linked to thermal spectrum [1]. For shield, tungsten seems the best protection against gamma rays. Protection against neutron can be done with ^{6}Li, ^{6}LiH, and $^{10}B_4C$.

The reference for the thermo-electric conversion was taken to be the Brayton cycle. Heating is performed by the nuclear core at constant pressure, expansion is done in a rotating turbine coupled with an alternator. For power distribution, a hybrid architecture is preferred wrt centralized or channelized architectures. A Direct drive concept was chosen

The Radiator provides the cold source for the Brayton cycle. For radiator technology, a heat pipe system was selected due to its simplicity and good performance [2]. Droplet radiator is a promising technology under maturation, and was kept as a back-up. For other heat exchangers, plate heat exchanger was selected.

For electric thrusters, solutions with higher TRL levels were down-selected: hall-effect thrusters, ion engines and magnetoplasmadynamic (MPD) thrusters. MPD thrusters currently offer the highest thrust level [3].

On system level, it is proposed to consider a 1300K hot temperature as a reference because this level is mandatory to reach the specific mass objective for the system (<20kg/kWe). Two variants are then considered: a direct Brayton cycle with He-Xe an in-direct He-Xe Brayton cycle with a Lithium cooled core. In order to give an ambitious longer term perspective a third option was assessed: 1600K indirect Brayton cycle.

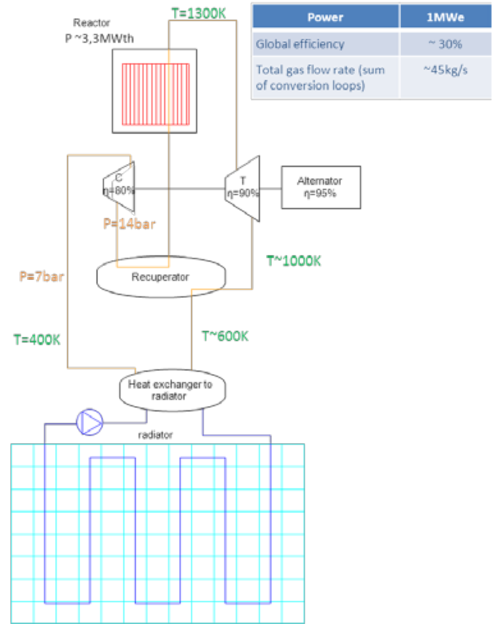

Figure 2 : thermodynamic map for reference cycle n°1

First feedback from the workshop

The workshop enabled the MEGAHIT consortium to consolidate the list of possible alternatives, to identify the contested issues, and to establish the first drafts for the final roadmap.

Among the contested issues, the high working temperature and/or long life duration requirement will be a big challenge for the nuclear reactor, the turbine blade and disk, the bearings, and the heat exchanger between primary and secondary circuit (if a heat exchanger is required). New developments will be needed for these parts. A strategy for transient phases should also be defined, allowing coherent functionning between core, turbine, radiator and thrusters. The need to assemble many parts in orbit may require advances in robotics.

References

[1] 47-68 UN-COPUOS Resolution « Principles relevant to the use of nuclear power sources in outer space »
[2] “Intermediate Temperature Heat Pipe Life Tests” by W.G. Anderson of Advanced Cooling Technologies, Inc. and D.L. Ellis, NASA Glenn Research Center
[3] Gorshkov, O., Development of High Power Magnetoplasmadynamic Thrusters in the USSR, IEPC-2007-136
[4] Cliquet, E., Roux, J-P, et al., Study of space reactors for exploration missions, EUCASS 2011, Saint Petersburg, July 2-8th 2011