Nuclear Power for Space Exploration

Stephen Buono, Jake Hecla, Vladimir Kobezskii, Julien de Troullioud de Lanversin, and Katie Mummah

Why nuclear space cooperation? Why now?

Because competition is ratcheting up!

- Anti-satellite tests
- Vacuums in international space law
- U.S. Space Force
- Competition for Lunar Resources

Because it's worked before!

- Apollo-Soyuz Test Project
- International Space Station
- Topaz II Program

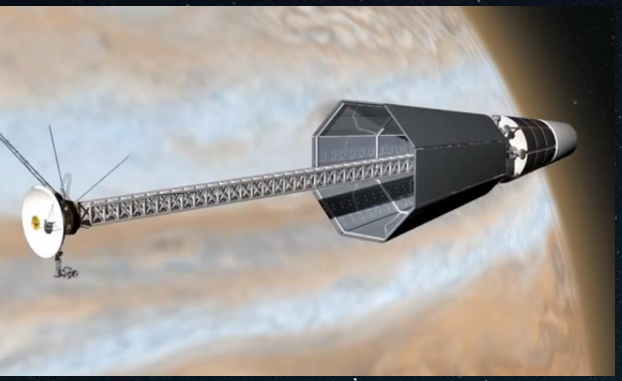
Applications of nuclear power in space

Process	Uses energy from fission reactions
Advantages	Longer travel distance (beyond solar system) Long life expectancy (decades) Continuous energy output (even in darkness) Highest power load possible in space (1 - 10,000 kWe)
Cons	Safety Non-proliferation (HEU) Developing material for high temperature operation
Applications	Space propulsion (not at launch) Surface power station In-situ resource utilisation

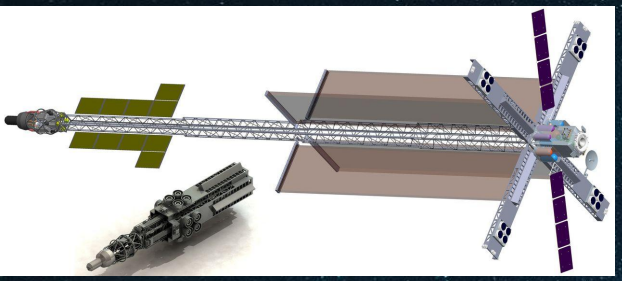
SNAP-10A: the first nuclear reactor sent into space by the U.S. (1965)

Proposals for technical collaboration between Russia and the U.S.

Cooperation goal and complementarity



Kilopower



“Space TUG”

Proposal 1:
it is possible to consider technically complementary combinations of basic modules or solutions to create a joint project for reaching the Luna/Mars.

Angara-A5

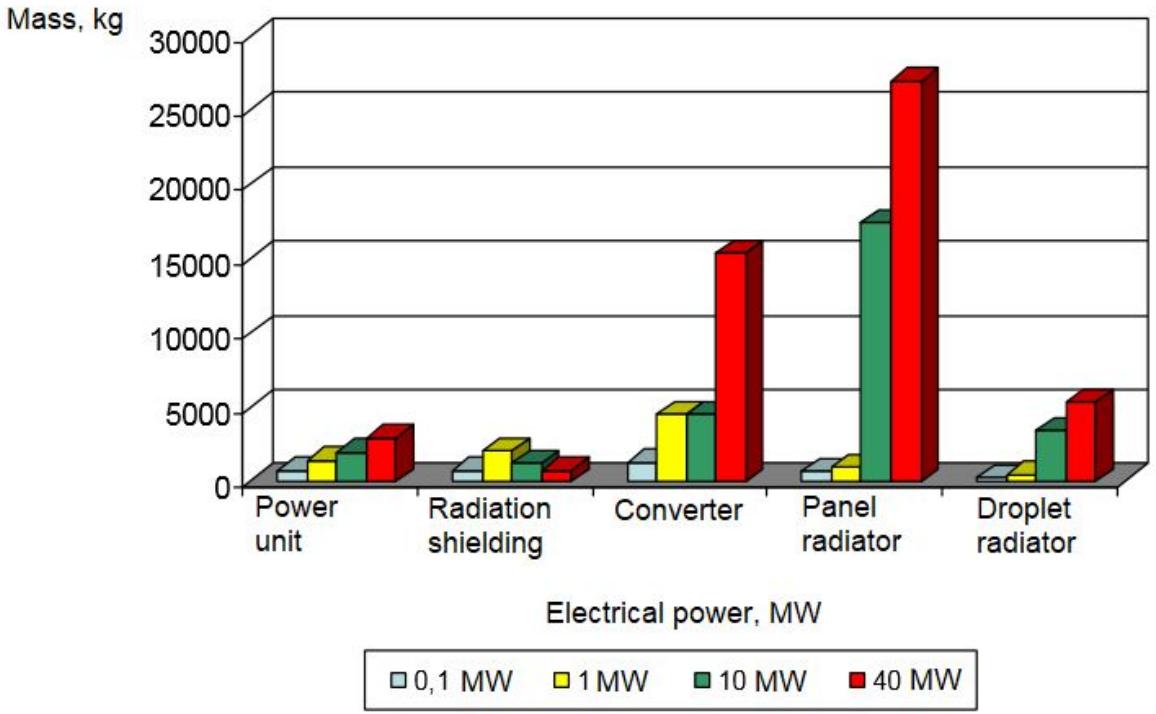
Falcon-9 FT

Proposal 2: usage of US Falcon-9 FT / Heavy, capable of putting a suitable payload into orbit.

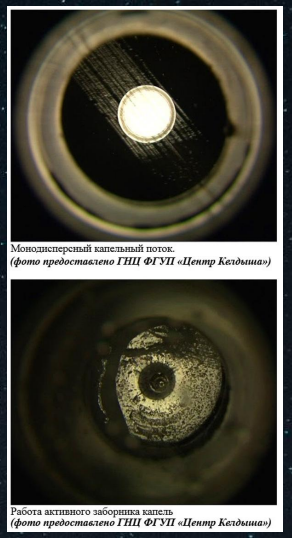
Proposal 3: US-RF joint development of the high power ion engine.

ID-500

Cooperation on the solving heat removal problem



Pic. 2. Masses of the main components of a nuclear power plant based on the generated power.



Монодисперсный капельный поток.
(фото предоставлено ГНЦ ФГУП «Центр Келдыша»)

Работа активного заборника капель
(фото предоставлено ГНЦ ФГУП «Центр Келдыша»)

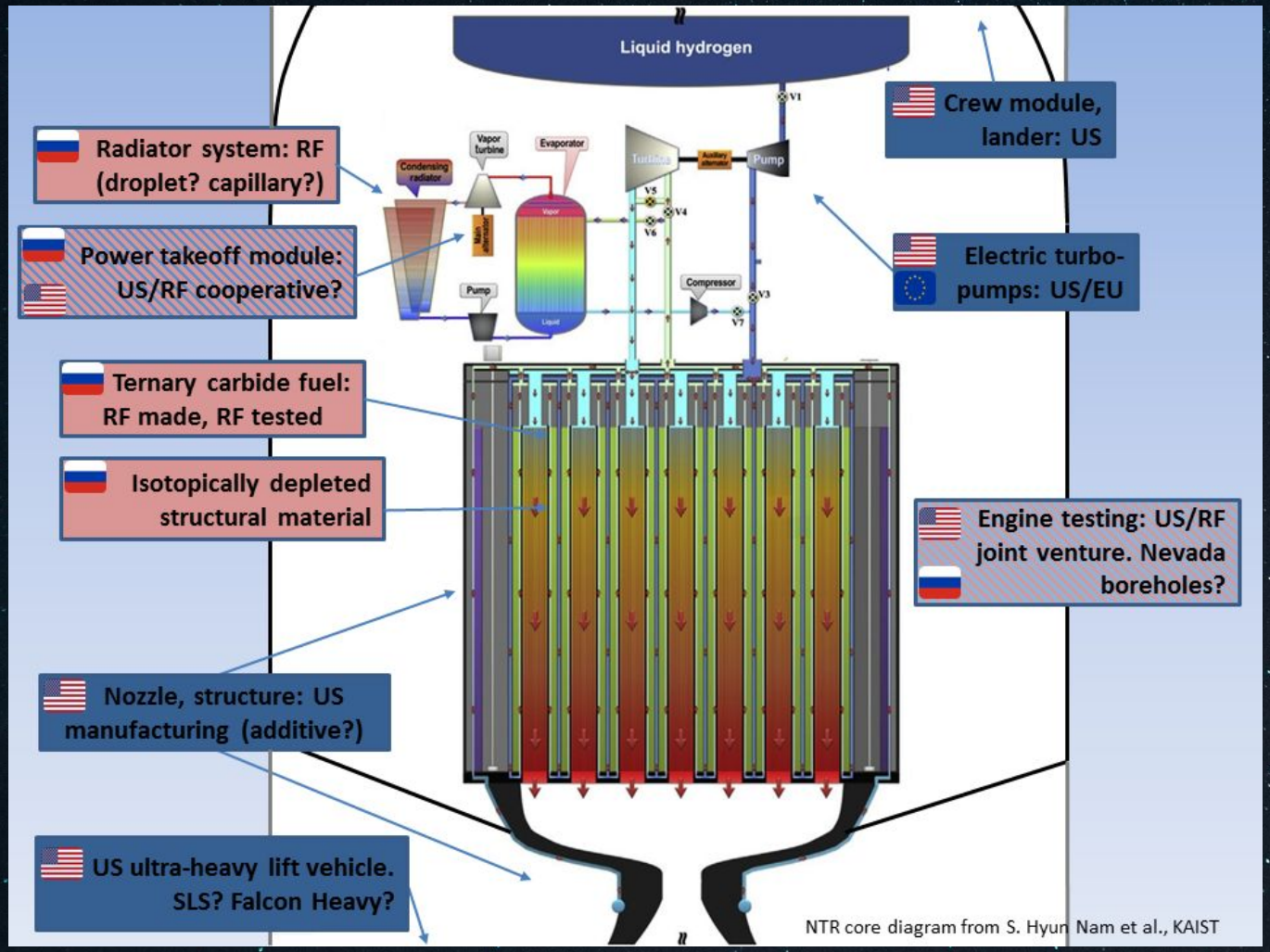
Droplet's flow

Kapla-2 experiment on ISS

Proposal: sharing RF test data about Droplet radiators with US and cooperating over implementing it on the joint project seems very reasonable.

Escaping LEO with US-RF technical complementarity

Proposal: Cooperate using RF expertise in high temperature materials, stable isotope enrichment etc. to develop a LEU NTR for Lunar/Martian transport. Mission would use US lift vehicle, spacecraft, testing facilities and control assets.



NTR core diagram from S. Hyun Nam et al., KAIST

Gov't agencies involved:
NASA/Roscosmos
Rosatom/DOE

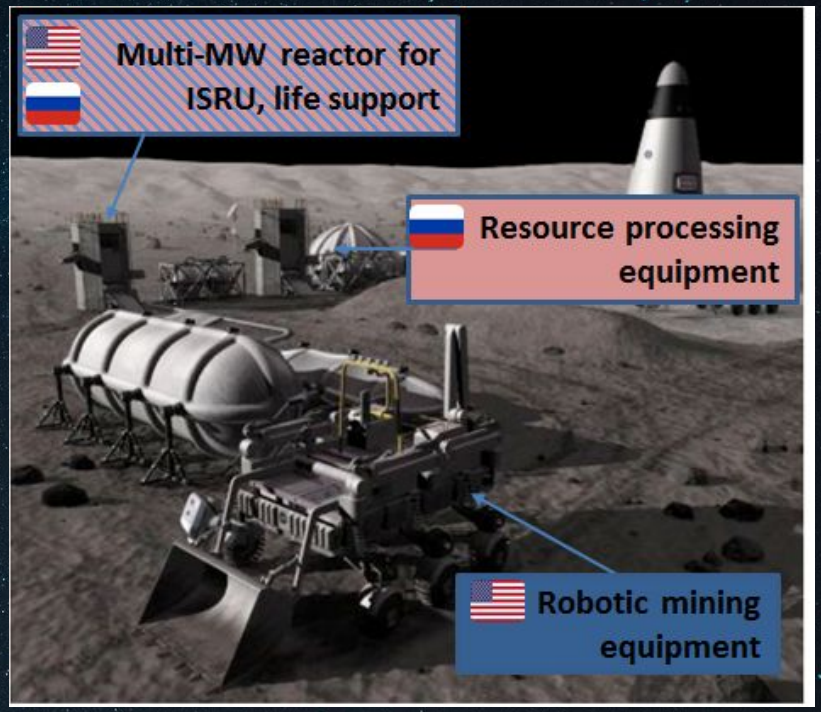
Possible industry partners:
JSC ECP- stable isotopes
NPO Luch- ternary carbide
PNPI PIK- fuel irradiation
SpaceX- lift vehicle
RocketLabs- turbomachinery

Cooperatively establishing extraterrestrial habitation

Crewed Mars exploration requires in-situ resource utilization for propellant and habitation, which requires nuclear power to be provided in extremely low temperatures and with minimal maintenance.

- US has vehicles etc to land many-ton payloads on Mars, and a small reactor program
- RF has extensive space/low temperature reactor experience
- RF has low-temperature chemistry experience from mining operations

Proposal: US/RF collaborate on the creation of a robust, high-power reactor for surface operation on Mars for long term habitation, use RF's extensive mining industry to assist in development of tools for extraction and processing



We are in a crucial moment for knowledge retention

"TOPAZ International Program had **no formal mechanisms** to **record** and **archive** the technical knowledge gained from the space power nuclear reactor technology efforts so that it would be **accessible** for future efforts"

-The National Academies, 2001

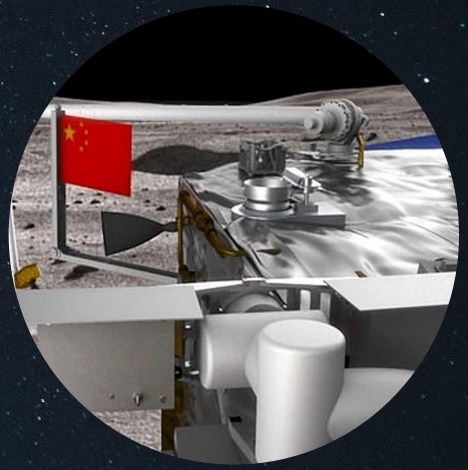
Proposal: US/RF technical collaboration on future uses of space nuclear technology should include collecting oral and written histories as well as organizing and making freely available historical technical documentation

Technicians during the Thermionic Systems Evaluation Test at UNM, 1992 (Dabrowski, 2013)

Benefits beyond technology

US-Russia collaboration can stimulate and support efforts to clarify and improve the Outer Space Treaty.
Ex: Should we allow HEU for space?
Ex: What should we do with nuclear waste on extraterrestrial bodies?

US-Russia collaboration could encourage and convince other space powers, such as China, to enter some form of collaboration on nuclear technologies for space exploration.



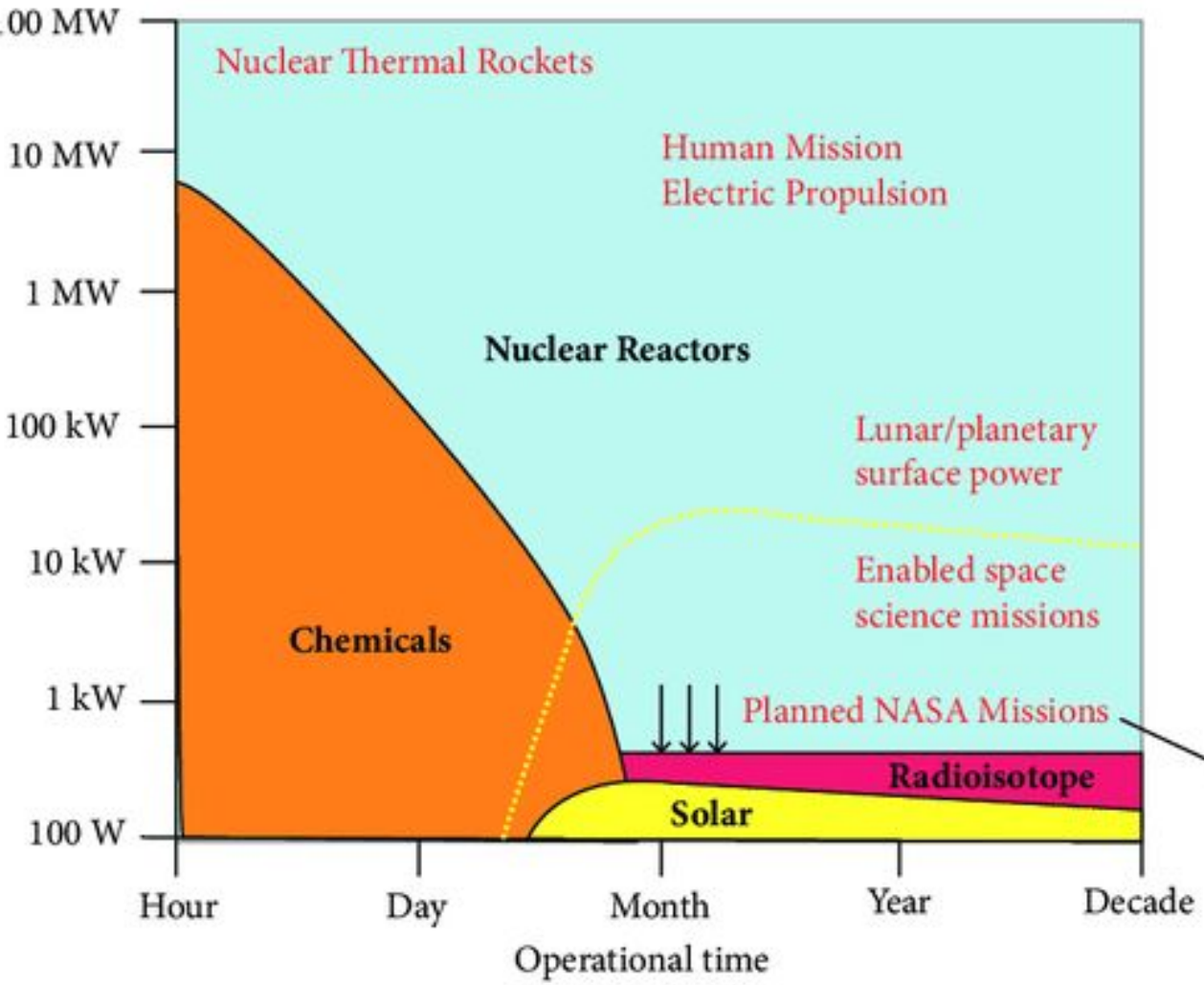
Спасибо!

Thank you!

Applications of nuclear power in space

	Fuel cell	Solar panel	RTG	Fission reactor
Energy/Power density	*<500 We/kg*	*<500 We/kg*	*< 10 We/kg*	*<20 We/kg*
Power load	*1 – 100 kWe*	*1 – 500 kWe*	*0.1 – 1 kWe*	*1 – 10,000 kWe*
Continuous/ Intermittent	*Continuous*	*Intermittent (darkness)*	*Continuous*	*Continuous*
Distance from sun	*Beyond solar system*	*Orbit of mars*	*Beyond solar system*	*Beyond solar system*
Life expectancy	*Calendar life < 15 years* *Discharge time < months*	*Long (decades)*	*Long (decades)*	*Long (decades)*
Size	*Small*	*Small - Large*	*Small*	*Moderate - Large*
Application	*Temporary storage* *Electricity for equipment* *Surface transportation* *Commodities generation (oxygen, propellant)*	*Electricity for equipment* *Space propulsion* *Surface power station*	*Electricity for equipment* *Space propulsion*	*Space propulsion* *Surface power station* *In-situ resource utilisation*

Uses of various technologies in space



This chart included estimates of mass, practicality and utility of each source.

The utility of solar power is obviously dependent on distance from sun and/o possibility of day-night cycle.

Yellow region is estimate of utility at 1(dotted yellow line is estimate 1 AU (no eclipse application).

Limited ^{238}Pu supply has lowered the threshold for entry-level fission syste