LUNATICS

TSGC LUNAR SURFACE NUCLEAR REACTOR CONCEPTUAL DESIGNS & CONOPS

The University of Texas at Austin
Aerospace Engineering and Engineering Mechanics
Cockrell School of Engineering

AUTHORS: ZAKARIA AMOR, ZOE HENRY, JACOB HOYT

MENTORS: ROBERT NUCKOLS, ADAM NOKES

MISSION OBJECTIVE

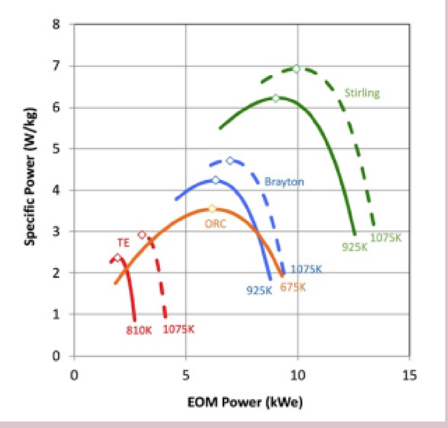
Our mission objective is to design a nuclear reactor that can operate on the lunar surface in order to power future manned lunar bases. The reactor needs to be designed in order to survive the harsh lunar climate while meeting power output needs of 40 kWe. The design needs to last for 10 years with a 1 year demonstration period and a 9 year operational period. We also need to establish the power allocation and distribution systems for the various in-situ resources on the lunar surface utilizing power mapping and energy storage. Creating evacuation CONOPS in the case of emergency is another part of our objective to keep future crews safe from potential disasters.

LOCATION

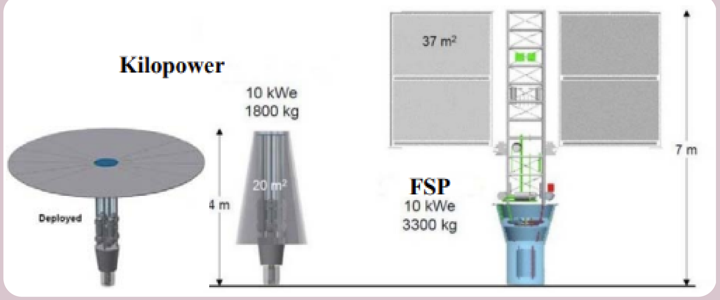
As part of NASA's Artemis plan to return humans and establish a permanent presence on the moon, the "First Lunar Outpost, FLO" serves as the gateway for not only future advancements in Lunar science, but also for the verification of systems to one day be used on Mars. Previous studies done by the Artemis mission indicates the best landing spots for this lunar base are to be on the lunar South Pole. For this study, the assumed location will be just outside Shackleton Crater. The area around Shackleton Crater has a high density of surrounding shallow craters, which can be used as radiation shielding and in-situ resource utilization as craters protect ice deposits within the lunar surface.

REACTOR DESIGN

The focus of choosing a reactor design for this project was centered around efficiency, as maximizing efficiency will minimize overall system weight, which is always the main goal of any space system. As seen in the figure before, leveraging current thermal to electricity technologies, namely Stirling engines, the highest specific power occurs at around 10 kWe while using a Stirling engine at 1075 K. With a power output requirement of 40 kWe, this system will be employing 4 10 kWe U-235 nuclear fission reactors for thermal energy generation, and a respective Stirling engine operating at 1075 K for electrical energy conversion. By breaking up the 40 kWe over multiple reactors, there is increased flexibility in responding to various energy demands.



The next aspect of the chosen reactor design is the radiator design. The two options for that are the Kilopower and FSP designs, both shown below. The Kilopower configuration was chosen for its smaller reactor and radiator size. By leveraging the two studies, this system uses an reactor that minimizes weight and size while maintaining the proper energy generation needs.



REQUIREMENTS

NOMINAL CONOPS

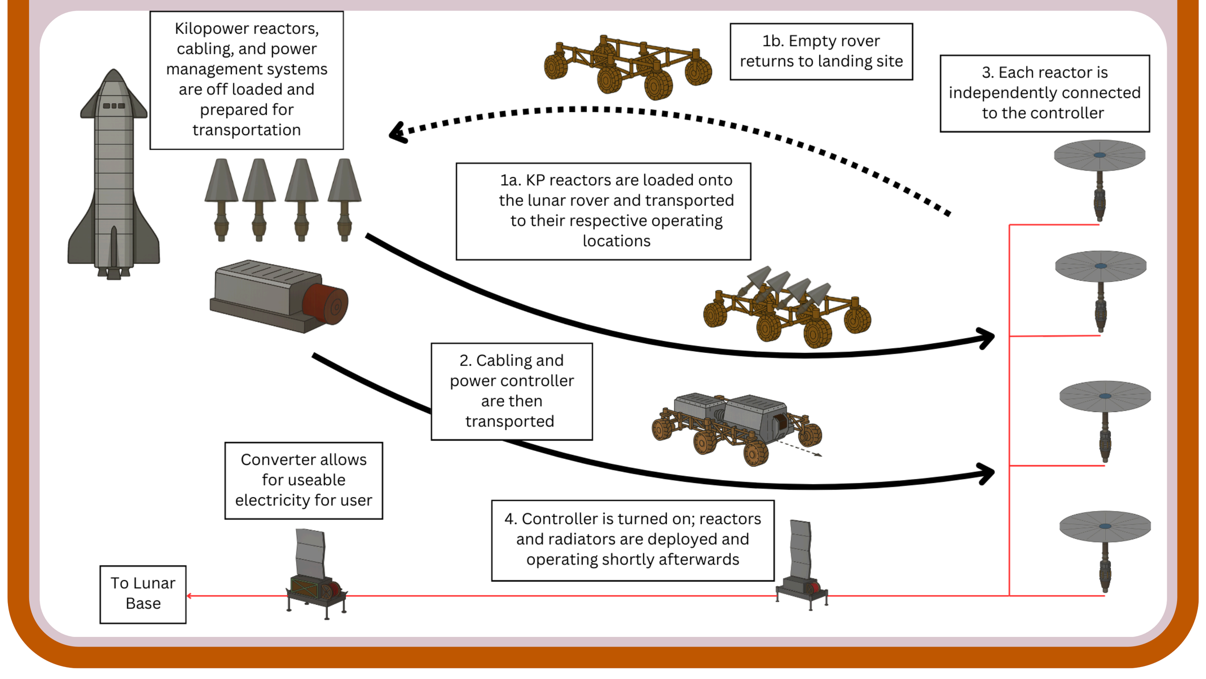
Reactor deployment shall follow the proceeding outlined conceptual concept of operations:

Set-Up Phase:

- System components are pre-integrated and modular, allowing for efficient, autonomous on-site assembly.
- Two rover trips deliver all structural, power conversion, and shielding modules 1 km to the deployment sites.
- Autonomous rover deploys reactor chassis, unfolds radiators, and positions shielding panels.

Nominal Operation Phase:

- Reactors operate independently, each providing 10 kWe with internal control logic for autonomous shutdowns.
- Generated power is rectified and transmitted as HVDC to the habitat, where RFCs store excess power during low-demand periods via continuous PMAD telemetry.
- Radiator panels maintain optimal temperature differentials for power conversion.



ENVIRONMENT

The lunar environment is harsh with several dangers present such as: cold temperatures, ionizing radiation, and regolith particles. These factor can disrupt electronics and may even cause total breakdown if not correctly mitigated during design. Temperatures can reach as low as -200˚C in the permanently shadowed regions of the moon, so the heat generated from the reactor will protect electronics from the temps. Regolith particles and micrometeoroid showers can physically impact our systems. Our chosen material should mitigate damages to our systems from both physical and radiological danger.

EVACUATION CONOPS

In an event of a total reactor meltdown:

1. The affected reactor autonomously goes into a safe shutdown mode through the deployment of control rods while simultaneously disconnecting from the controller, ensuring it is completely isolated.
2. Small charges, located around the rim of the reactor's crater, detonate, causing regolith to be dislodged and fall down into the crater, burying the reactor and acting as an in-situ radiation shield.
3. Once the temporary barrier is in place, astronauts, on board a rover, follow a clearly marked path to the return vehicle while out of the line-of-sight path to the reactor
4. Once inside the launch vehicle, the astronauts can analyze the situation and make one of two decisions:
   a. If determined to a stable situation, remote diggers dig up the buried reactor,
      i. If unrecoverable: place it on a small rocket, and launch it into deep space.
      ii. If repairable: necessary parts are replaced and reactor is put through extensive testing before operation
   b. If determined to be unstable, the astronauts launch into lunar orbit, and wait until the site can be quarantined and/or the site becomes stable

POWER MAPPING

GENERATION

The primary energy generating elements in the power infrastructure for a fully operational lunar habitat will leverage four autonomous "KRUSTY" nuclear fission reactors, each generating 10 kWe, with a total of 40 kWe of power generation capacity. The modular approach to reactor design and power allocation is also intentionally scalable, ensuring the infrastructure can accommodate future expansion as the lunar base grows in size and complexity. The total power demand during peak crew activity for this basis of the FLO is estimated to be around 12 kWe for the habitat, with 2KWe during times the outpost will be uncrewed and in ready mode for the next period of occupancy. The total power required for all of the rovers can range up to around 6 kWe, with additional allocations for the ISRU, and scientific research. With these demands, a total generation of 40 kWe provides ample margin.

ALLOCATION

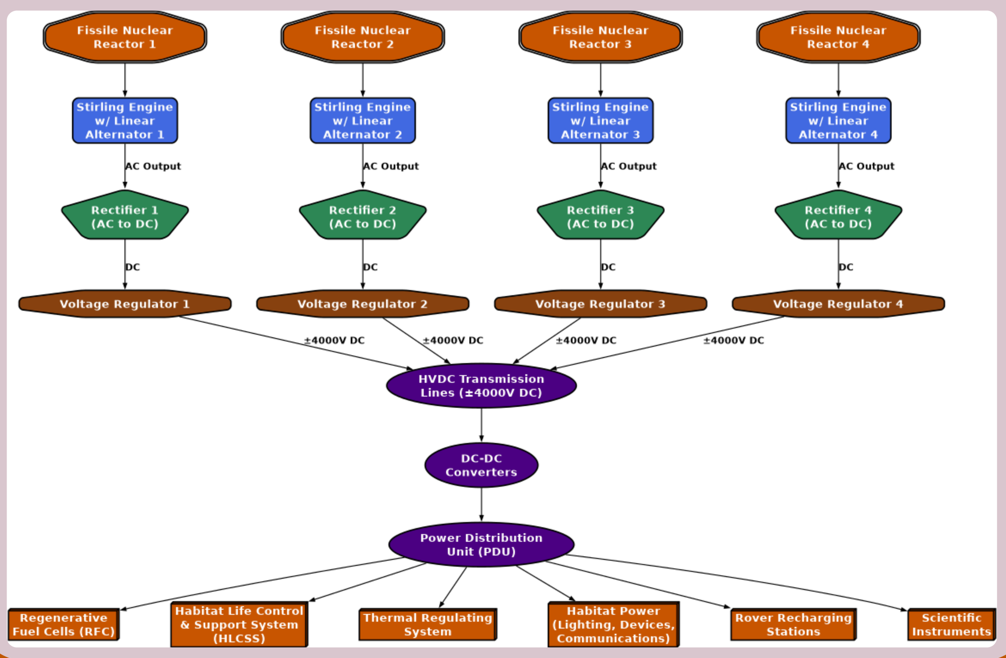
A lunar outpost's greatest power demand stems from life-sustaining systems such as the ECLSS, which regulates air composition, temperature, and humidity. This, along with the thermal regulation, habitat pressurization, lighting, and communications systems require a stable supply of 10-12 kWe during crewed operations and around 2 kWe in standby mode. Mobility systems, including crewed rovers, logistics vehicles, and autonomous science platforms, add a load of 1.5 to 2.7 kWe per mission, with a combined power requirement of up to 6 kWe. Scientific payloads such as geophysical instruments and ISRU technologies, like oxygen extraction from regolith, contribute additional demands of up to 2 kWe per processing cycle and 0.93 kWe for continuous scientific operation.

STORAGE

Regenerative fuel cells are our chosen method of power storage. RFCs have significant power storage that meet the demands of the lunar base, the only limiting factor being the size of the reactants storage.

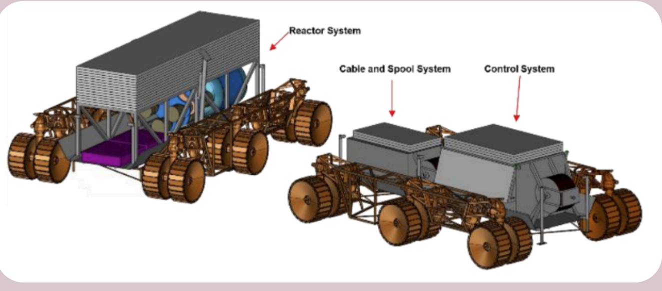
DISTRIBUTION

Efficient power transmission from the reactor to the remote habitat must encompass a robust system of interfaces and voltage conversions to overcome distance, mass constraints, and the extreme conditions. The Stirling engines generate low-voltage AC, which must first be rectified into DC for HVDC transmission, which is chosen for its efficiency and suitability over long distances with lightweight, insulated aluminum cables. Upon reaching the habitat, the HVDC must then be converted back into regulated, useable voltages through multi-stage, radiation-hardened semiconductor-based power electronics to enable safe distribution to the subsystems. RFCs are integrated to bridge the 14-day lunar night and buffer peak loads, while load scheduling and PDUs ensure continuity and redundancy across all mission phases.



REACTOR TRANSPORTER

Once successfully landed on the Moon, the reactor system needs a transportation system to travel from the landing spot to its operation site. The team has decided to leverage past NASA studies/designs of a lunar rover with a chassis with a maximum payload capacity of 11.75 cubic meters. By using a Kilopower reactor design, the four 10 kWe reactors total to 7 cubic meters, allowing this reactor system to use existing technology for its transportation.



REFERENCES