A NEW REACTOR POWER SYSTEM CONCEPT FOR MANNED LUNAR BASE APPLICATION. Hu Gu[1] and Xie Jiachun[2], [1]Department of Reactor Engineering Design, China Institute of Atomic Energy, P.O.Box 275(33) Beijing, 102413, China, Email: huguciae@gmail.com, [2] Department of Reactor Engineering Design, China Institute of Atomic Energy.

Introduction: With the development of space exploration technologies and urgent demand for resources exploitation, many countries have made their plans to explore the moon in the next few years. China is carrying out the moon exploration project - ChangE and has already made great achievements. In the foreseeable future, China will actualize manned lunar exploration and build a lunar outpost.

For human missions, power requirements may vary from 10s of kWe to support initial human visits to 100s of kWe for a permanent lunar base, especially if in-situ resource utilization processes are required. In such output power range, preponderant planetary surface nuclear power is being considered because it can provide constant energy for human life-support systems, recharging rovers, mining for resources, and so on. Alternatives such as solar power systems are limited because the moon is dark for up to 14 days at a time and has deep craters that can obscure the sun.

A lunar nuclear power system is different from traditional nuclear reactors because of the special application environment. The system should be small, compact, robust and low mass to satisfy the launch requirement. The system should be simple and highly reliable because it is difficult, even impossible to maintain the reactor in the lunar surface. The system should be safe and easy to operate considering lack of professional operators. The system must be suitable for the lunar environment such as low gravity and near vacuum. Also, we hope the reactor system are a long life time and have no single point of failure.

Considering the lunar reactor characteristics mentioned above, a lithium heat pipe cooled modular fast reactor (HPCMR) conceptual design has been developed to support future China manned lunar base application. The system has a solid reactor core and is designed to use static thermoelectric conversion to produce over 100 kW electricity for up to ten years. Whole system efficiency is ~7% and has a mass of ~3.2 tons. Waste heat is rejected by potassium heat pipe radiator. HPCMR has advantages of low mass, long lifetime, no pumped liquid coolant, and no single point of failure. (Table 1)

HPCMR (Figure 1) is comprised by three modules to easily satisfy China current launch vehicle load requirement. Each module is comprised by one reactor core block (Figure 2-3), one shield block, two thermoelectric conversion modules, two potassium heat pipe radiator panels, and other support structures. The Potassium heat pipe radiator panels are folded during delivering period (Figure 4-5). The maximum width and length of folded HPCMR module are 2.3 meters and 3.7 meters respectively. The HPCMR modules are launched to the moon separately and assembled to a whole system on the moon surface. Then the reactor core is set into a lunar regolith hole of 1.8 meters deep. Lunar regolith is used to shield the radial radiation from the reactor to decrease the whole system mass. The potassium heat pipe radiator is deployed to a 45 degrees angle with the lunar surface (Figure 1).

The lithium heat pipes penetrate the axial reflector and bend around (Figure 5) the shield above the reactor core. The condenser section is connected to the thermoelectric conversion module by the heat exchangers, thus transferring the reactor core heat to the hot end of thermoelectric conversion module. Part of the heat is converted to electricity when it passes through the thermoelectric couple conversion module. The remaining heat (waste heat) is conducted to the potassium heat pipe's evaporator section connected to the cold end of thermoelectric conversion module, and is rejected to the environment by radiator.

This system has following merits:

1) Modularization design satisfies China launch vehicle load requirement. Launch criticality accident is avoided because a single module never achieve criticality.

2) Such design with solid core reactor, heat pipe cooling and thermoelectric conversion has no moving or rotating parts for fatigue failure and no flowing cooling fluids that can leak, fail the whole system. Such design is also robust, simple and has high reliability.

3) Reactor core is cooled by lithium heat pipes. Single lithium heat pipe failure almost has no influence to operation of whole system. Waste heat is rejected by potassium heat pipe radiator. Single or several potassium heat pipe failure also won't fail the whole system. Thermoelectric couple conversion also has the merit of no single point of failure.

Preliminary HPCMR concept calculations have already been done. Detailed work and further optimization will be done if the program is funded by the government in the future.

References: [1] Hu Gu, Zhao Shouzhi, Sun Zhiyong, Yao Chengzhi, (2013) "A Heat Pipe Cooled Modular Reactor Concept for Manned Lunar Base Application", *Proceedings of the 21th International Conference on Nuclear Engineering, ICONE21-16006.*

Table 1. HPCMR Power System Main Parameters

Parameter	Value	Annotation
Rated Thermal Power, MW	1.6	
Lifespan, year	10	
System Efficiency, %	7	
Electricity Output, kW	112	BOL
	100	EOL
System Mass, t	3.2	
UN Mass, kg	371	
^{235}U Enrichment, %	42	
^{235}U Mass, kg	147.2	
Burnup, MWd/t	15741	EOL
Control Drums Total Reactivity Worth, △k/k%	-8.6	
Maximum Temperature of Fuel, K	1694	Average Channel, BOL
	1754	Hot Channel, BOL
Working Temperature of Thermoelectric Couple, K	748-1215	BOL
	808-1274	EOL

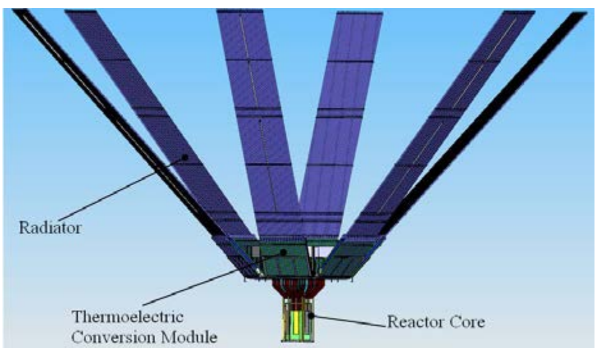


Figure 1. Deployed State of HPCMR

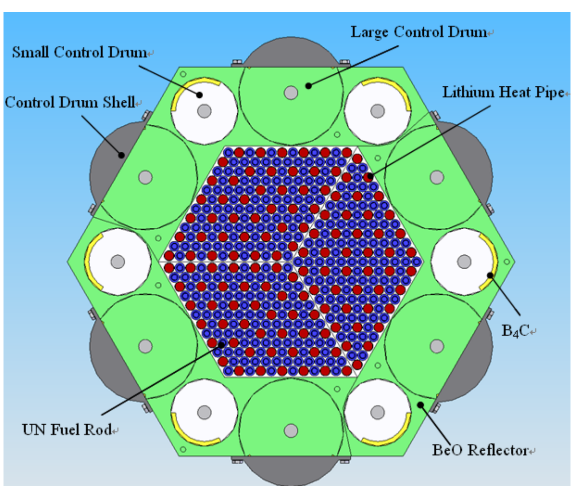


Figure 2. Radial Cross-sectional View of HPCMR Core

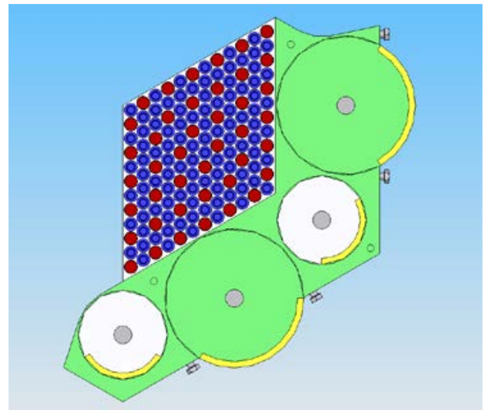


Figure 3. Cross-sectional View of One Core Block

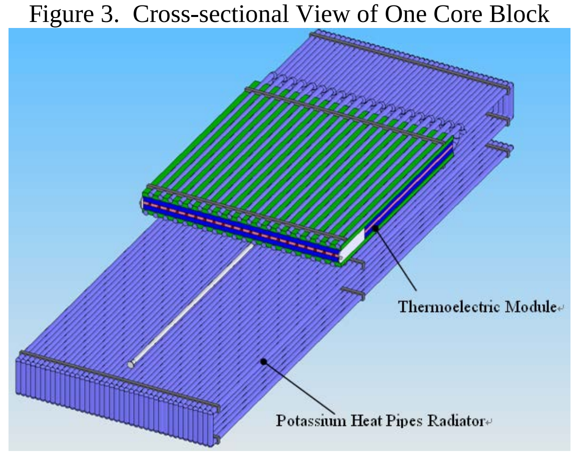
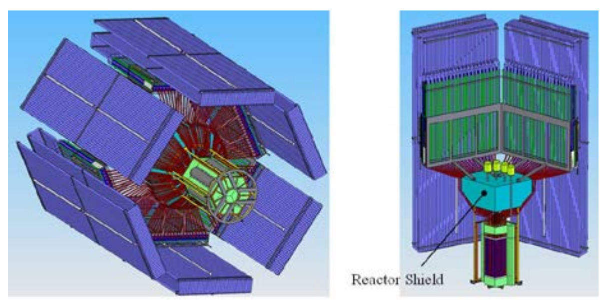


Figure 4. One Folded Potassium Heat Pipes Radiator Panel



A. Folded HPCMR B. One HPCMR Module

Figure 5. Folded State of HPCMR

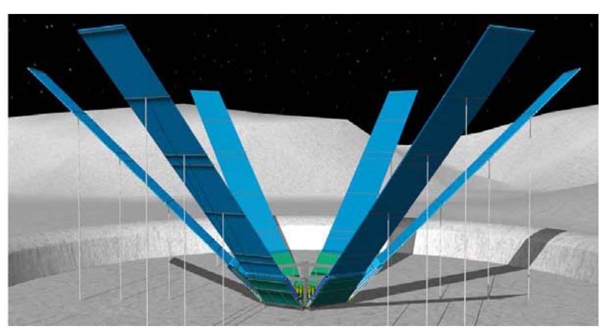


Figure 6. Vision of HPCMR