A PORTABLE SCALABLE HIGH ENERGY DENSITY SOURCE TO POWER SPACE RESOURCES UTILIZATION MISSIONS AND A LUNAR GRID. R. W. Moses[1], S. H. Choi[2], and D. M. Bushnell[3], [1]Tamer Space, LLC (robert.moses@tamerspace.com), [2]NASA Langley Research Center (sang.h.choi@nasa.gov), [3]NASA Langley Research Center (dennis.m.bushnell@nasa.gov).

Introduction: A new direct energy conversion concept called Nuclear Thermionic Avalanche Cell (NTAC) combined with a Metallic Junction Thermoelectric (MJ-TE) generator, both invented and patented by NASA, offers high specific power that uniquely scales from milliwatts to megawatts enabling portable, at point of use utilization for everything space from propulsion to spacecraft, satellites, rovers, ISRU, habs, and other mission systems[1-2]. Estimates based on experimental results and theoretical analyses suggest superior performance compared to radioisotope thermoelectric generators (RTG) by up to two orders of magnitude for the NTAC and three to four times better for the MJ-TE generator for the same mass. The NTAC technology uses energetic photons and beta particles from a variety of radioisotopes including nuclear waste to liberate a large number of intra-band (IB), inner shell electrons of atoms (10^5 C/cm^3) through the bound-to-free transition by high order interactions of gamma-ray photons and beta particles (100 keV to MeV). In contrast, conventional power generation uses low-grade energy yielding poor specific power because their intensity of energy can only allow the bound-to-free transition of the valence band electrons (3 C/cm^3) of the semiconductor or outer-most band electrons (8×10^3 C/cm^3) of the conductor atoms. This paper compares NTAC's performance with other power generation technologies and offers a key infrastructure element for powering space resources utilization missions and a lunar grid.

Key Features of NTAC: The key aspects of an NTAC are explained by the sequential photoionic interactions of high energy photons, including energetic beta particles, with atoms in material through primary, secondary, tertiary, and possibly higher-order couplings. The interaction mechanisms of energetic photons and beta particles are fundamentally dictated by photo-electric (pe), photonuclear (pn), Compton scattering (Cs), or electron/positron pair production (pp) processes or by combined, eventually resulting in the liberation (bound-to-free transition) of not only the electrons in outermost band but also intraband electrons from atoms. These aspects were proven by laboratory experiments performed for photoionic emission of intraband electrons with a 320 keV γ-ray source. The emitter current measurements in the experiments clearly demonstrated that the emitters made from high Z atoms emit more electrons than lower Z atoms. In the case of copper, the experimental data showed that the emission current by the photoionic process was measured to be more than 40% greater than the primary interaction alone when a 60 keV photon energy was used for a copper plate with 1 mm thickness. The result of 40% more current than the current in the primary interaction is a good indication for the sequential occurrence of secondary and tertiary interactions.

The key features of the NTAC system include: the use of a high-grade energy source, such as γ-ray (> 100 keV) and x-ray (2 keV – 100 keV) photons and energetic β-particles (> 10 keV), that enables multiple successive interactions, resulting in the avalanche release of a large number of free electrons from valence and intrabands of atoms through bound-to-free and free-to-free transitions which is all together translated into greater power generation capability, the power scaling from mW to MW which is determined by the amount of radiation source, the no-escape of radiation since the NTAC layers use up all of the high energy photons to liberate a large number of electrons, the thermal energy through scattering processes that keeps holding electrons thermalized to be more active and mobile for emission and the rest will be converted by the MJ-TE generator, the lowest system α among other energy conversion systems, lack of a specific doping requirement for p-n junction on emitter and collector materials, the simple system with no moving parts within the NTAC system, and the long duration of operation determined by the activity rate of radioisotopes.

Power Output and Mobile Feature of NTAC: Power output of an NTAC was estimated for a selected radioisotope. Theoretical estimates were based on experimental data. The efficiency of an NTAC is regarded to be very high (> 40%) because of the experimentally proven chain of multiple interactions and liberation of avalanche electrons by high-grade energy.

The NTAC performance was analyzed for three levels of efficiencies (10%, 20%, and 40%). The results from the design study of an NTAC suggest that an NTAC outperforms most other energy conversion systems, as shown in Figure 1. The size and weight of NTAC power systems rated with 100 kWe and 200 kWe, respectively, were estimated based on extrapolation of the NASA experimental results. Their mass and volume estimates seem appropriate for rovers, largely due to the high specific power by the use of high-grade energy (MeV level) and the avalanche electrons liberated from the intraband of atoms.

At a conceptual level, a mobile power station hosting 4 NTAC units rated for either 100 kWe or 200 kWe, based on the mission scales, could deliver electrical power to clients at mission locations. Total weight and total power of the 4 units of NTAC rated with 200 kWe power output are 1276 kg and 800 kWe, respectively, which are 5 times lighter than the weight of a fission reactor [3] and provides 20 times more power delivery.

This mobile power station can be designed to autonomously drive to mission operation sites for power delivery, wirelessly transmit power to remotely located client systems, or connect directly to a lunar grid. The wireless power transmission (WPT) can be made with laser for long-distance or high frequency microwave, such as W-band (100 GHz), for short-distance. Laser power beaming had been studied in early 1990s at NASA Langley Research Center [4-5]. It requires high efficiency laser oscillators and high-performance photovoltaic cells for conversion.

The use of microwave for discovering and melting water ice is an interesting approach to get pure water out of regolith-bound water ice for in-situ resources utilization (ISRU) activities on the Moon and Mars. The resonant frequency of water ice is 2.339 GHz which is very close to that of water, 2.45 GHz [6]. Microwave technology for S-band (2 ~ 4 GHz) is readily available and can be effectively used for acquiring water from dirt water ice on the Moon and Mars.

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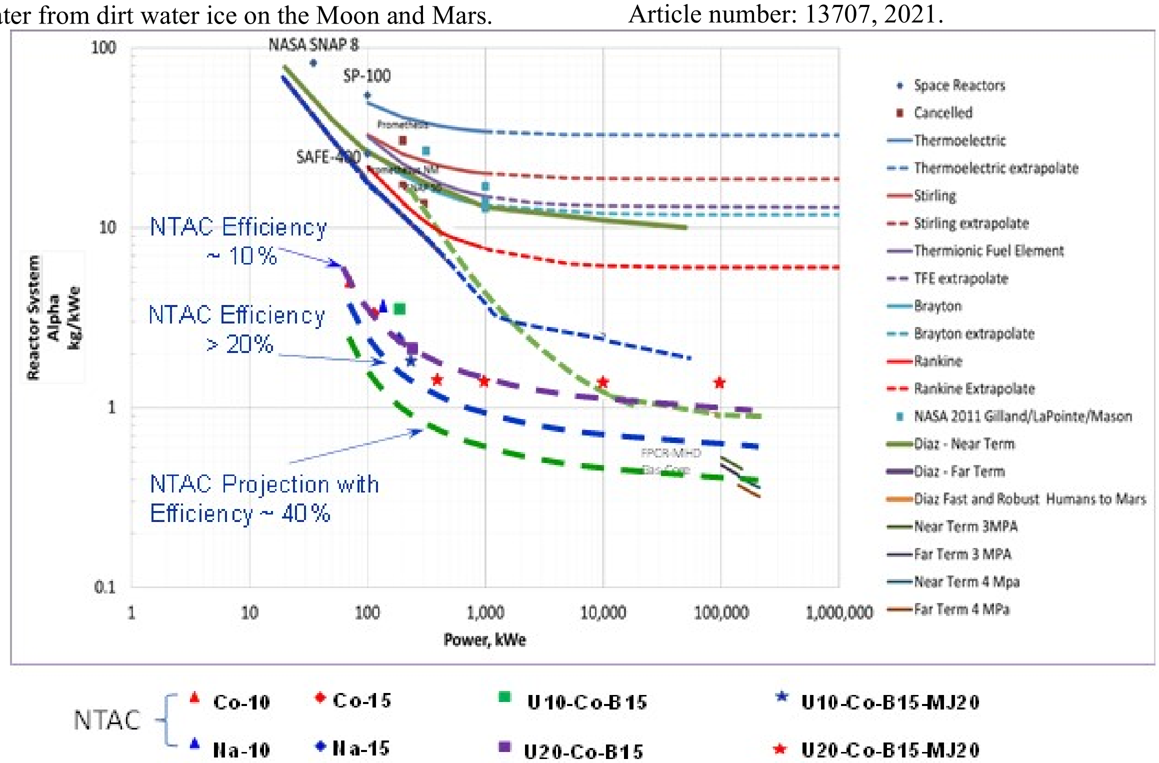

Figure 1. Plot of system α (kg/kWe) versus power for various energy conversion systems