A PORTABLE SCALABLE HIGH ENERGY DENSITY SOURCE TO POWER SPACE RESOURCES UTILIZATION MISSIONS AND A LUNAR GRID

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Space Resources Roundtable 2023

REFERENCES

- **AIAA SciTech 2022 Forum**

  "A Portable High-Density Power Technology for Space, Lunar, and Planetary Applications," Sang H. Choi, Dennis M. Bushnell, Robert W. Moses, NASA Langley Research Center, AIAA 2022-1911, https://arc.aiaa.org/doi/10.2514/6.2022-1911, January 3-7, 2022, San Diego, CA

- **AIAA ASCEND 2022**

  "A Portable High Energy Density Source to Power Lunar and Planetary Human Exploration Missions", Sang H. Choi (NASA), Dennis M. Bushnell (NASA), Robert W. Moses (NASA retiree), October 24, 2022, Las Vegas, NV

- **NASA Technical Memorandum 2021**

  "Frontiers of Space Power and Energy", Dennis M. Bushnell, Robert W. Moses, Sang H. Choi, NASA Langley Research Center, NASA/TM–20210016143, July 2021, https://ntrs.nasa.gov/citations/20210016143

NTAC – Nuclear Thermionic Avalanche Cell (NASA Patents licensed by TS)

MJ-TE – Metallic Junction – Thermo Electric (NASA Patents licensed by TS)

IMPORTANCE

- **We are currently handicapped by lack of portable high specific power systems EVERYWHERE**
- **Without high-grade energy input source (Co, Cs, …), no high specific power system is possible**
- **Successful commercialization of NTAC will lead to national competitiveness in terms of environment, military, industrial, and economy overall**

HIGH-GRADE ENERGY INPUT SOURCES

Customary Band (Wave) Energy and Grade

Band	Frequency	Wavelength	Energy	Color Temperature	Grade	
HF	3 ~ 30 MHz	10 ~ 100 m			Extremely Low	
VHF	30 ~ 300 MHz	1 ~ 10 m				
UHF	0.3 ~ 3 GHz	0.1 ~ 1 m				
L	1 ~ 2 GHZ	0.15 ~ 0.3 m				
S	2 ~ 4 GHz	0.075 ~ 0.15 m				
C	4 ~ 8 GHz	0.037 ~ 0.075 m				
X	8 ~ 12 GHz	0.025 ~ 0.037 m				
Ku	12 ~ 18 GHz	0.017 ~ 0.025 m				
K	18 ~ 27 GHz	0.011 ~ 0.017 m				
Ka	26.5 ~ 40 GHz	0.0075 ~ 0.0113 m				
Q	33 ~ 50 GHz	0.006 ~ 0.0091 m				
U	40 ~ 60 GHz	0.0075 ~ 0.005 m				
V	50 ~ 75 GHz	0.004 ~ 0.006 m				
W	75 ~ 110 GHz	0.0027 ~ 0.004 m				
F	90 ~ 140 GHz	0.00214 ~ 0.00333 m				
D	110 ~ 170 GHz	0.00176 ~ 0.00273 m				
Tera (TH)	700 ~ 1700 GHz	42.8 ~ 17.6 µm	0.003 eV ~ 0.007 eV	35 ~ 80 K	Lowest Grade	
Far IR (FIR)	6 ~ 15 THz	50 ~ 20 µm	0.025 eV ~ 0.06 eV	300 ~ 700 K	Low Grade	Current Power systems Anchored
Mid IR (MIR)	15 ~ 30 THz	20 ~ 10 µm	0.06 eV ~ 0.12 eV	700 ~ 1400 K	Low Grade	
IR	30 ~ 100 THz	10 ~ 3 µm	0.12 eV ~ 0.3 eV	1400 ~ 3500 K	Low Grade	
Near IR (NIR)	100 ~ 430 THz	3 ~ 0.7 µm	0.3 eV ~ 1 eV	3500 ~ 11600 K	Low Medium Grade	PV
Visible (Vis)	430 ~ 1000 THz	0.7 ~ 0.3 µm	1 eV ~ 4 eV	11600 ~ 46420 K	Low Medium Grade	
UV (UV)	750 ~ 1000 THz	0.4 ~ 0.3 µm	3 eV ~ 4 eV	34800 ~ 46420 K	Low Medium Grade	
Deep UV (DUV)	850 ~ 1200 THz	0.35 ~ 0.25 µm	4 eV ~ 6 eV	46420 ~ 69600 K	Medium Grade	
Vacuum UV (VUV)	1.2 ~ 3 PHz	0.25 ~ 0.1 µm	6 eV ~ 12 eV	69600 ~ 139200 K	Medium Grade	
Extreme UV (EUV)	3 ~ 300 PHz	100 ~ 1 nm	12 eV ~ 300 eV	139200 ~ 3480000 K	Medium Grade	
Soft X-ray (SXR)	300 ~ 600 PHz	1 ~ 0.5 nm	300 eV ~ 2 keV	3.48 ~ 23.2 MK	High Grade	NTAC
Hard X-ray (HXR)	0.6 ~ 24 EHz	0.5 ~ 0.0125 nm	2 keV ~ 100 keV	23.2 ~ 1160 MK	High Grade	
Gamma ray (γ-ray)	> 25 EHz	< 0.0125 nm	> 100 keV	> 1.16 BK	Extreme High Grade	

TWO KEY OPPORTUNITIES

- **NTAC for direct conversion of gamma rays to electric power**

  Opportunity for Spent Nuclear Fuel and other radioisotopes that produce gamma rays

- **Metallic Junction Thermo Electric (MJ-TE) conversion of heat to electric power**

  Converts heat from radioisotopes and other sources to electrical power

BASIS OF THIS TECHNOLOGY

- **NASA Data & Patents**
- **Tamer Space holds exclusive license for ALL fields of use of NASA's NTAC and MJ-TE technologies**
- **Moses holds additional patents (some pending) related to NTAC technologies**
  - Cooling system
  - On/Off Switch and Throttling
  - Material & electrical enhancements
  - For including Beta Particles in power generation
  - Power generation with Spent Nuclear Fuel
  - Fission & Advanced Reactors "Alternator" for Electric Power Generation
  - TRISO variant for a new generation of advanced reactors
- **Tamer Space has in hand a kWe-level prototype design for testing with high-grade energy sources**

MJ-TE PERFORMANCE BASED ON NASA DATA

MJ-TE

GPHS-RTG MMRTG

Images credit to NASA

NASA Goal > 100 W_e/kg

(NTAC > 1 kW/kg)

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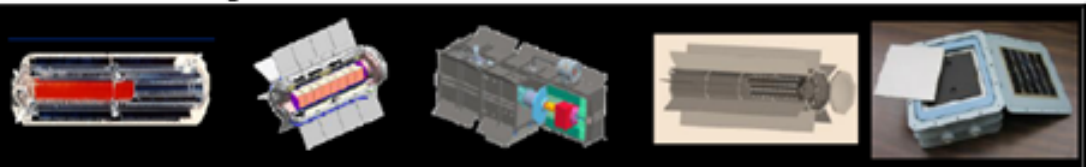
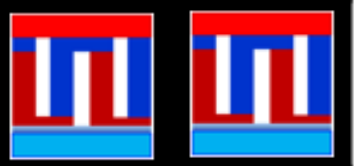


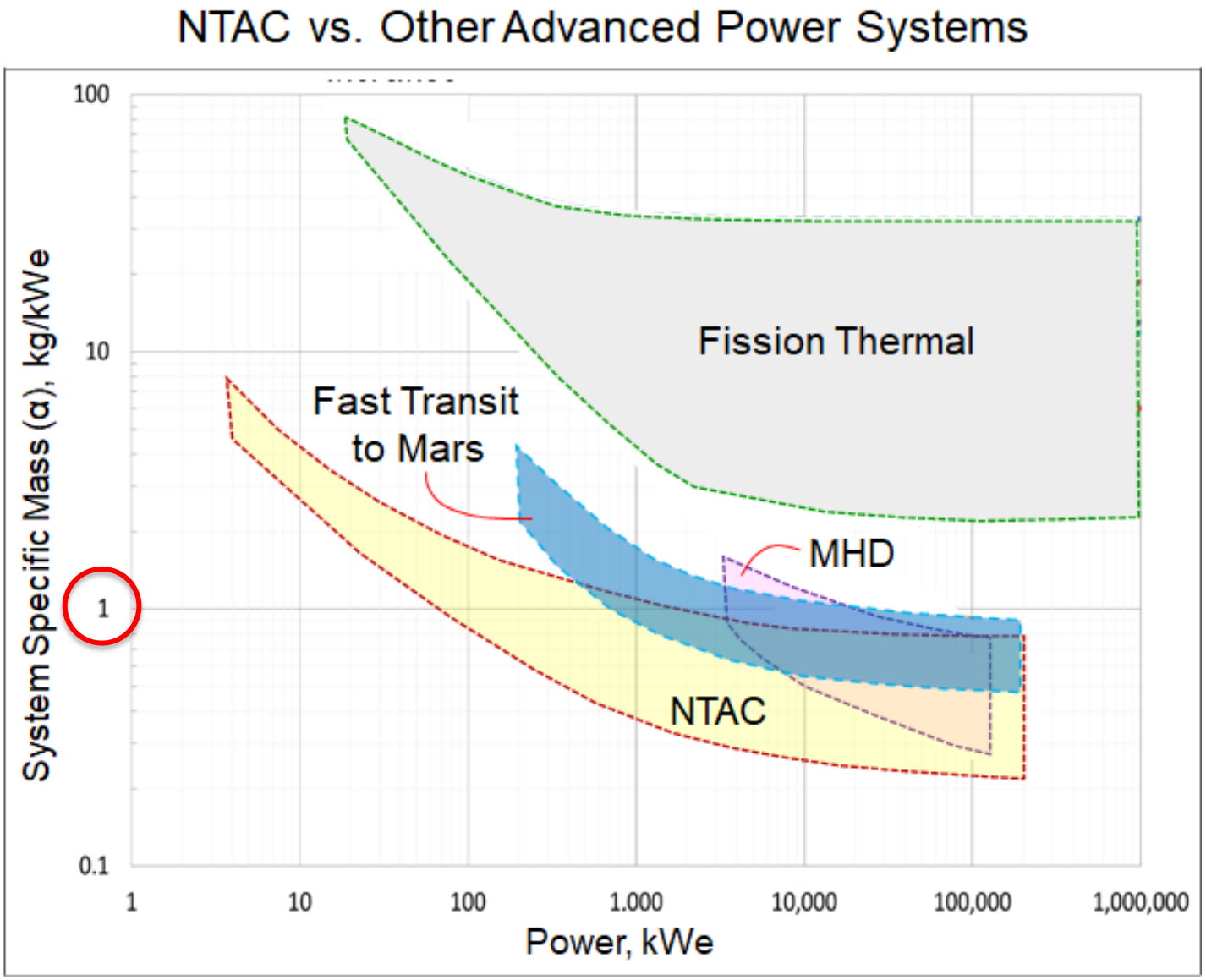


	GPHS-RTG Past	MMRTG Present	ASRG In Development	ARTG Future	TPV Future	MJ-TE	MJ-TE
Electric Output, BOM, W_e	285	125	~140-150	~280 to 420	~38-50	1125~1350	600~740
Heat Input, BOM, W_e	4500	2000	500	3000	250	4500	2000
RPS System Efficiency, BOM, %	6.3	6.3	~28-30	~9-14	~15-20	25~30	30~37
Total System Weight, kg	56	44.2	~19-21	~40	~7	~ 30	~ 18
Specific Power, W_e/kg	5.1	2.8	~7-8	~7-10	~6-7	37 ~ 45	33 ~ 41
Number of GPHS Modules	18	8	2	12	1	18	8
GPHS Module Weight, kg	25.7	12.9	3.2	19.3	1.6	< 15	< 7
^{238}Pu Weight, kg	7.6	3.5	0.88	5.3	0.44	7.6	3.5

GPHS-RTG: General-Purpose Heat Source — Radioisotope Thermoelectric Generator
MMRTG: Multi-Mission Radioisotope Thermoelectric Generator
ASRG: Advanced Stirling Radioisotope Generator
ARTG: Advanced RTG

TPV: Thermo-Photovoltaic
MJ-TE: Metallic Junction Thermoelectrics
NTAC: Nuclear Thermionic Avalanche Cell

NTAC PERFORMANCE BASED ON NASA DATA



ENGINEERING MODEL – NTAC: 100kW – 4 MW

BASED ON NASA DATA

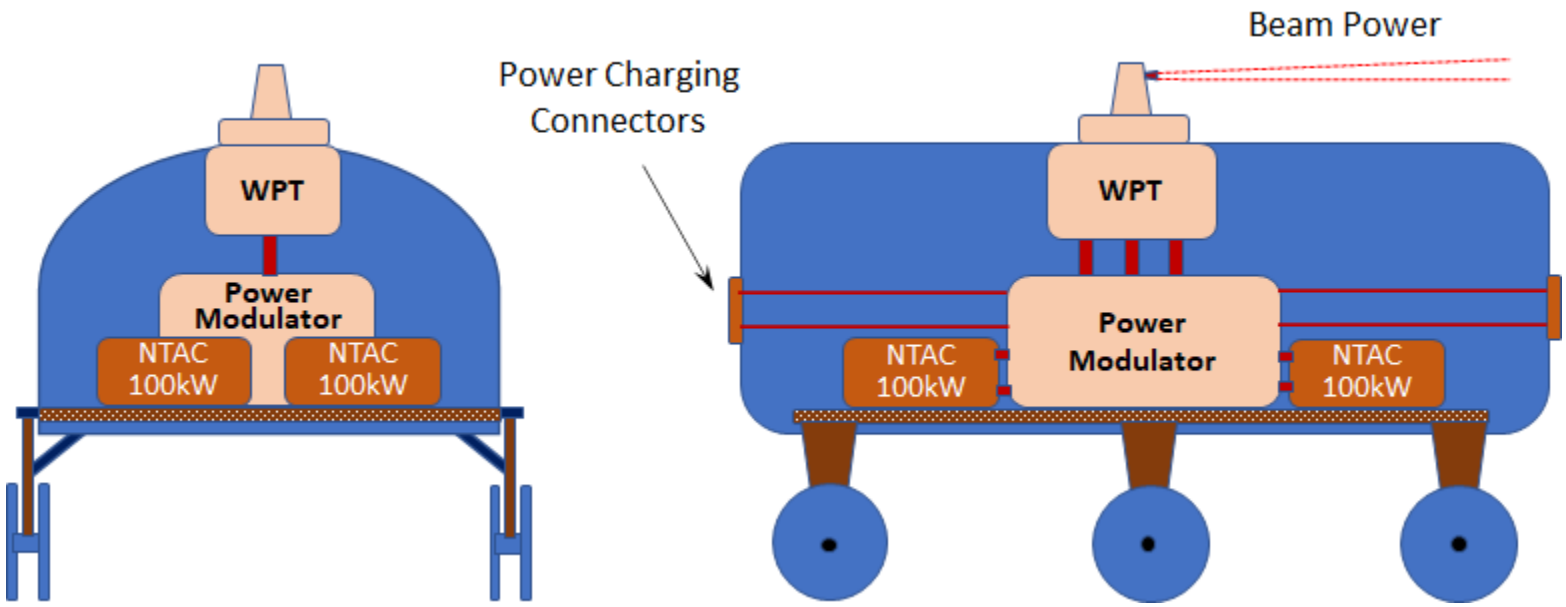
System Power Output Rating		Actual Power Output		NTAC Power Output	MJ-TE Power Output	Co-60 Weight	NTAC Shell Weight	Shielding Weight	MJ-TE Weight	Total Weight	Total Volume: Diameter (D) Height (H)	NTAC Specific Power	NTAC System α	Total Specific Power	Total System α
kW	hp	kW	hp	kW	kW	kg	kg	kg	kg	kg	meter	kW/kg	kg/kW	kW/kg	kg/kW
100	134	148.287	199	114.067	34.220	25.833	62	68	57	213	D: 0.484 H: 0.225	0.535	1.868	0.696	1.437
200	268	319.543	428	245.802	73.741	55.667	90	95	78	319	D: 0.584 H: 0.234	0.772	1.296	1.003	0.997
300	402	499.285	669	384.065	115.220	86.980	123	124	101	435	D: 0.684 H: 0.234	0.883	1.132	1.148	0.871
400	536	647.074	867	497.749	149.325	112.726	160	155	125	553	D: 0.784 H: 0.229	0.900	1.111	1.170	0.854
500	670	880.738	1181	677.491	203.247	153.433	204	190	153	701	D: 0.884 H: 0.229	0.967	1.034	1.257	0.796
600	804	978.598	1312	752.768	225.830	170.481	206	192	154	722	D: 0.884 H: 0.234	1.042	0.960	1.355	0.738
700	938	1086.444	1456	835.726	250.718	189.269	252	229	183	853	D: 0.984 H: 0.227	0.980	1.020	1.274	0.785
800	1072	1278.169	1713	983.207	294.962	222.670	255	231	185	894	D: 0.984 H: 0.234	1.100	0.909	1.430	0.699
900	1206	1455.914	1952	1119.934	335.980	253.635	307	273	217	1050	D: 1.084 H: 0.229	1.067	0.937	1.387	0.721
1000	1340	1617.683	2168	1244.372	373.311	281.816	309	274	218	1084	D: 1.084 H: 0.234	1.148	0.871	1.493	0.670
2000	2681	2995.710	4016	2304.392	691.318	521.882	381	331	262	1497	D: 1.184 H: 0.259	1.540	0.650	2.002	0.500
3000	4021	4313.821	5783	3318.324	995.497	751.510	518	437	343	2050	D: 1.384 H: 0.259	1.618	0.618	2.104	0.475
4000	5362	5871.590	7871	4516.608	1354.982	1022.888	676	557	435	2691	D: 1.584 H: 0.259	1.678	0.596	2.182	0.458

NTAC Efficiency: 25 % MJ-TE Efficiency: 10 %

VEHICLE CONCEPT

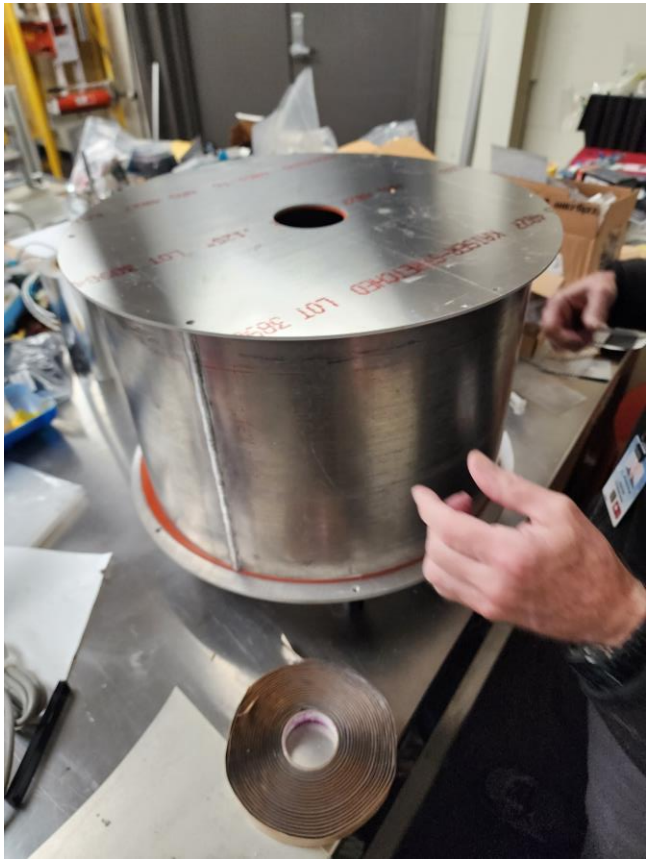
Mobile Power Station by NTAC

NTAC	Diameter	Height	Unit Weight	Units Onboard	Total Weight	Total Power	System α
100 kW_e	0.484 m	0.23 m	213 kg	4	852 kg	**400 kW_e**	1.87
200 kW_e	0.584 m	0.24 m	319 kg	4	1276 kg	**800 kW_e**	1.30



WPT: Wireless Power Transmission

RESEARCH PROTOTYPE



SUMMARY

- **Tamer Space is developing these technologies for both terrestrial and space applications**
- **Based on NASA's Studies and Tests, these technologies**
  - are scalable from Watt to MW levels
  - promise to unlock new capabilities through increased power densities that are also mobile and deployable
- **Tamer Space possesses a research prototype for testing with high-grade sources**