Nuclear Power in your car

(Radioisotopic Thermoelectric Generators)

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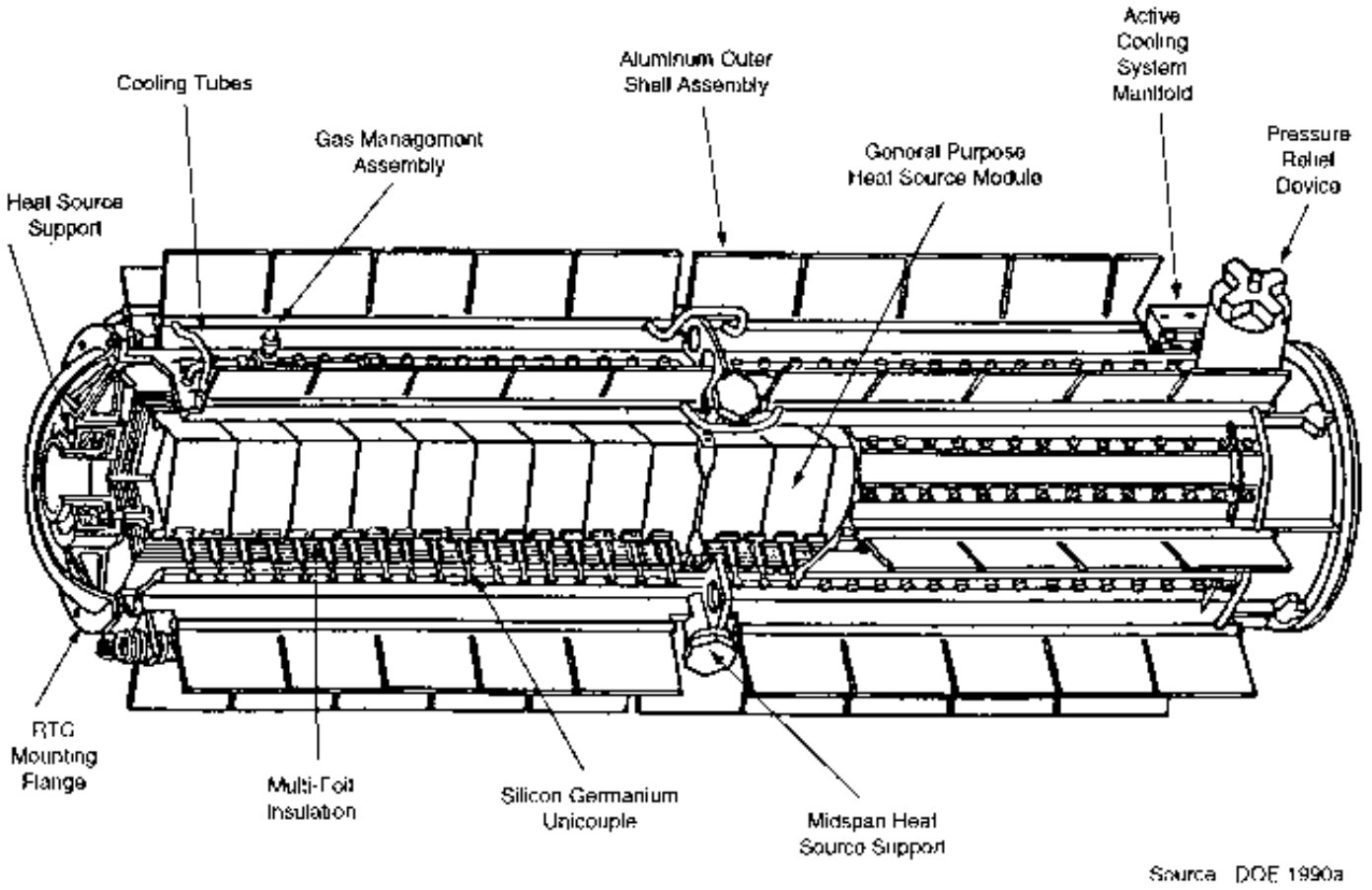
NPRE 498 – Energy Storage

Scope

- Background
- How it works
- Current Applications
- Advantages/ Disadvantages
- Possible Improvements
- RTG vehicle?

Background – Nuclear Batteries

– Thermocouple type (Radioisotopic Thermoelectric Generators)



Source: DOE 1990a

FIGURE 2-5. DIAGRAM OF GPHS-RTG ASSEMBLY

Background – RTGs

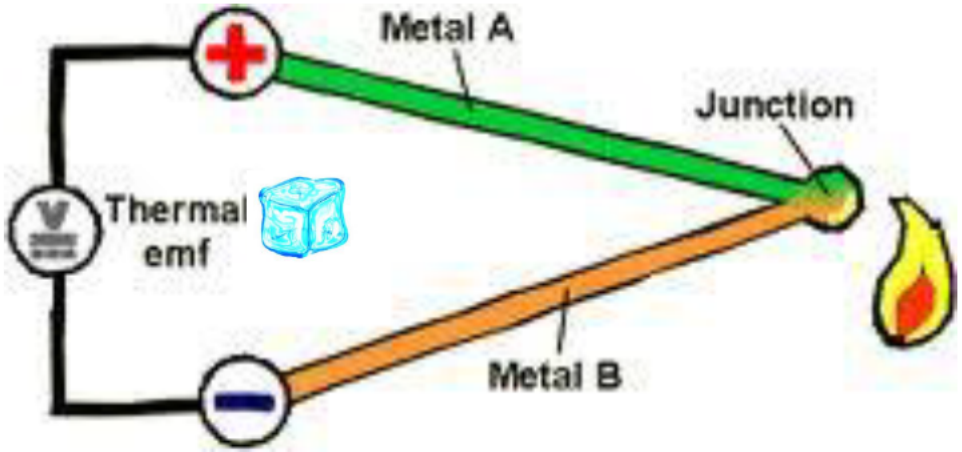
- First developed in the US in the 1950s by Mound Laboratories in Ohio
- Initially developed under the general designation: Systems for Nuclear Auxiliary Power (SNAP)
- First used in 1961 as SNAP 3 to power a navy spacecraft.
  - Weight: 4lbs, Power: 2.5W, Life: 280 days
- First Terrestrial use in “Fairway Rock” Alaska in 1966 (-1995)

How it works

- Energy Storage Medium: Radioisotopic Material capable of producing heat
- Direct conversion of heat to electricity
  - Seebeck Effect

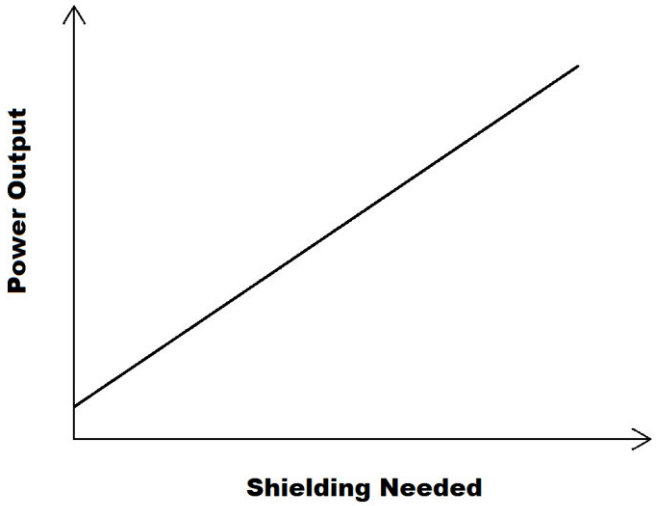
How it works

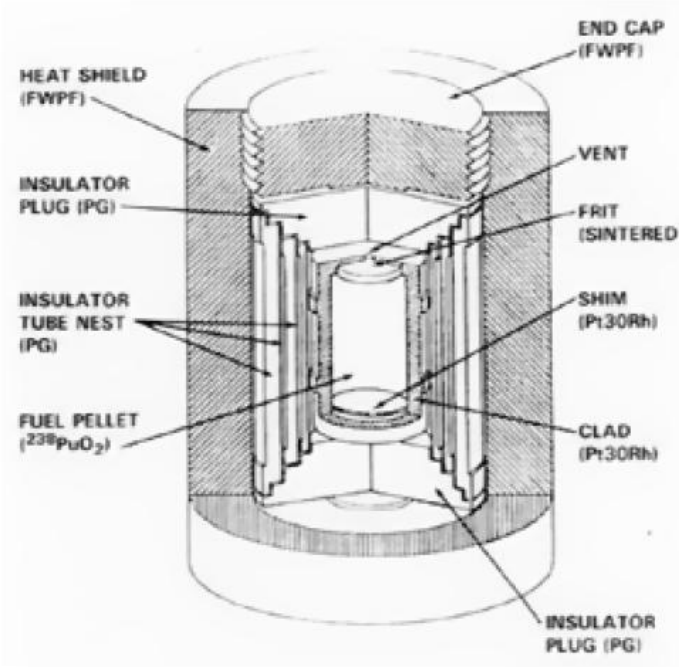
- Seebeck Effect
  - production of an electromotive force and consequently an electric current in a loop of material consisting of at least two dissimilar conductors when two junctions are maintained at different temperatures. (Source: Encyclopaedia Britannica)



How it works

- Criterion for selection of Isotopes
  - 100 days < Half-Life < 100 years
  - No gamma emission
  - Power > 0.1 W(th)/g





Radioisotope Heater Unit

Current Applications

- Power Source in space
- Power for remote facilities/ equipment

Curiosity Rover

Unmanned Buoy

Advantages

- Long Lifetime of continuous power
- Minimal maintenance needed (No moving parts)
- Small size and weight
- Independent of any external input
- Safety (No parts prone to failure)

Disadvantages

Name & Model	Used On (# of RTGs per User)	Maximum output		Radio-isotope	Max fuel used (kg)	Mass (kg)
		Electrical (W)	Heat (W)			
ASRG*	prototype design (not launched), Discovery Program	~140 (2x70)	~500	^{238}Pu	~1	~34
MMRTG	MSL/Curiosity rover	~110	~2000	^{238}Pu	~4	<45
GPHS-RTG	Cassini (3), New Horizons (1), Galileo (2), Ulysses (1)	300	4400	^{238}Pu	7.8	55.9–57.8
MHW-RTG	LES-8/9, Voyager 1 (3), Voyager 2 (3)	160	2400	^{238}Pu	~4.5	37.7
SNAP-3B	Transit-4A (1)	2.7	52.5	^{238}Pu	~2	2.1
SNAP-9A	Transit 5BN1/2 (1)	25	525	^{238}Pu	~1	12.3
SNAP-19	Nimbus-3 (2), Pioneer 10 (4), Pioneer 11 (4)	40.3	525	^{238}Pu	~1	13.6
modified SNAP-19	Viking 1 (2), Viking 2 (2)	42.7	525	^{238}Pu	~1	15.2
SNAP-27	Apollo 12–17 ALSEP (1)	73	1,480	^{238}Pu	3.8	20
Buk (BES-5)**	RORSATs (1)	3000	100,000	^{235}U	30	~1000

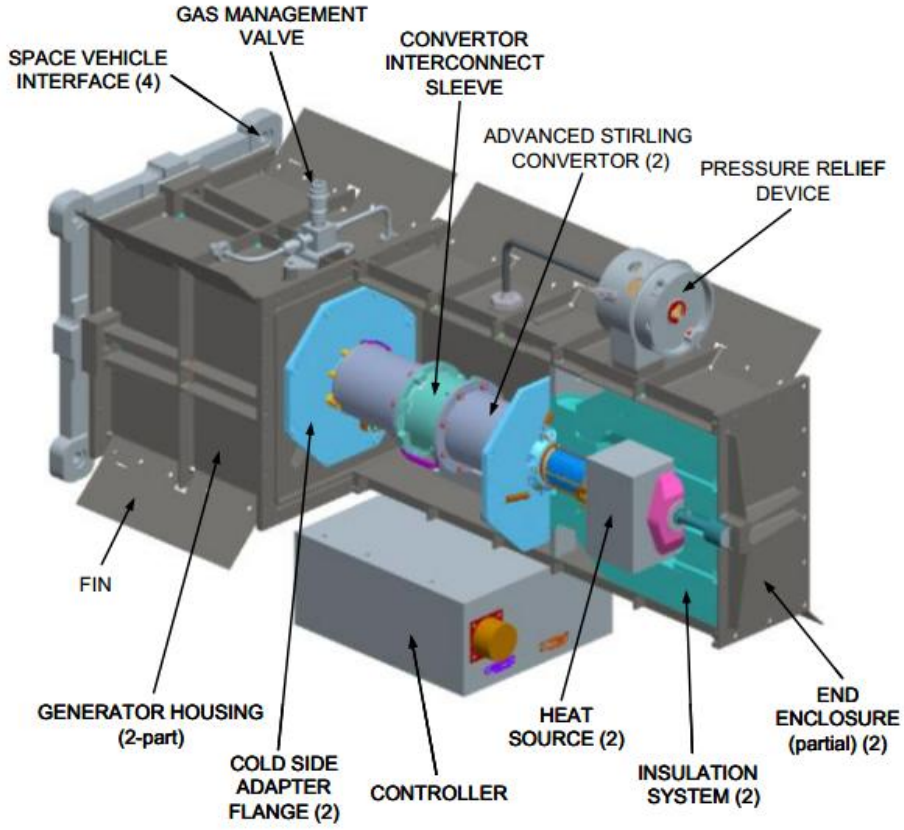
Space Usage of RTGs

Disadvantages

- Low Efficiency (<10%)
- Radioisotope decay (~0.7-0.8% power loss per year)
- Safety
  - Radioactive Contamination
  - Proliferation

Possible Improvements

- Stirling Engine
  - 4x efficiency over pure RTGs



Current Battery Powered Vehicle

Tesla Model S

- Power output: 270kW / 362 hp
- Battery Capacity: 85 kWh
- Range: ≈ 300 miles

Space Usage of RTGs

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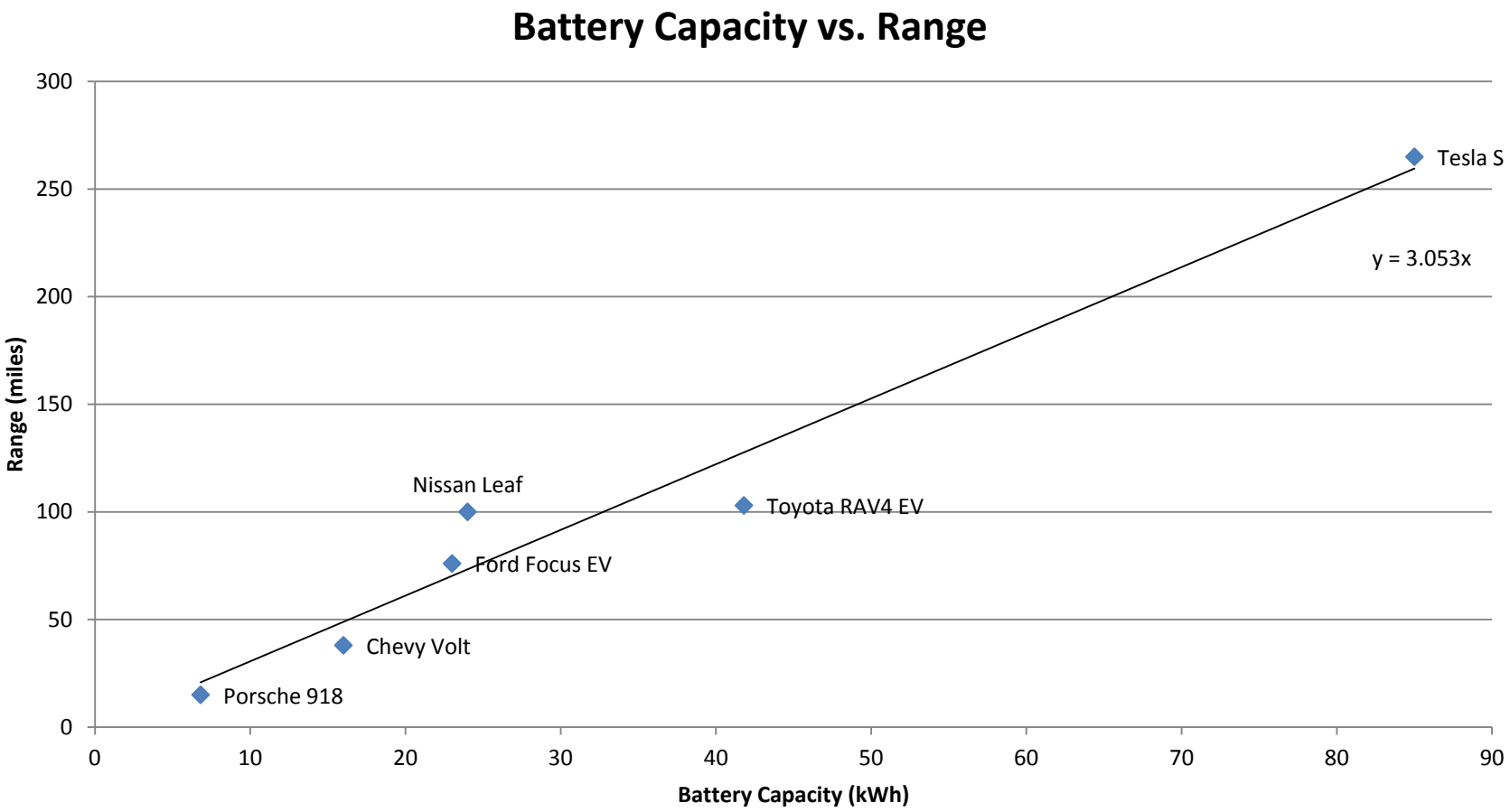
RTG powered vehicle

- 4 hp (3kW) Car! -> Max Speed: 22 mph
- Range: However far you can drive in 3 years at 22 mph! (578160 miles)

Other Possible Terrestrial Uses



1 kWh → 3.053miles range!!

- American average daily mileage: 27 miles (Source: Pike Research Survey)
- Battery power needed daily:

$$\frac{30miles}{\frac{3.053miles}{kWh}} = 9.8264kWh$$

- Equates to:

$\frac{9.8264kWh}{24h} = 409.4\ W_{electric}$

device running for 24 hours a day

- Assuming use with a Stirling Engine, η≈28%
- Thermal Power Needed: $\frac{1}{0.28} \times 409.4 = 1462.2\ W_{th}$

Power , P= $1.6 \times 10^{-13} \frac{E\lambda A_v}{M} \left(\frac{W_{th}}{g}\right)$

Where E is the Energy Release per disintegration

λ is the decay constant of the isotope

A_v is the Avogadro's number

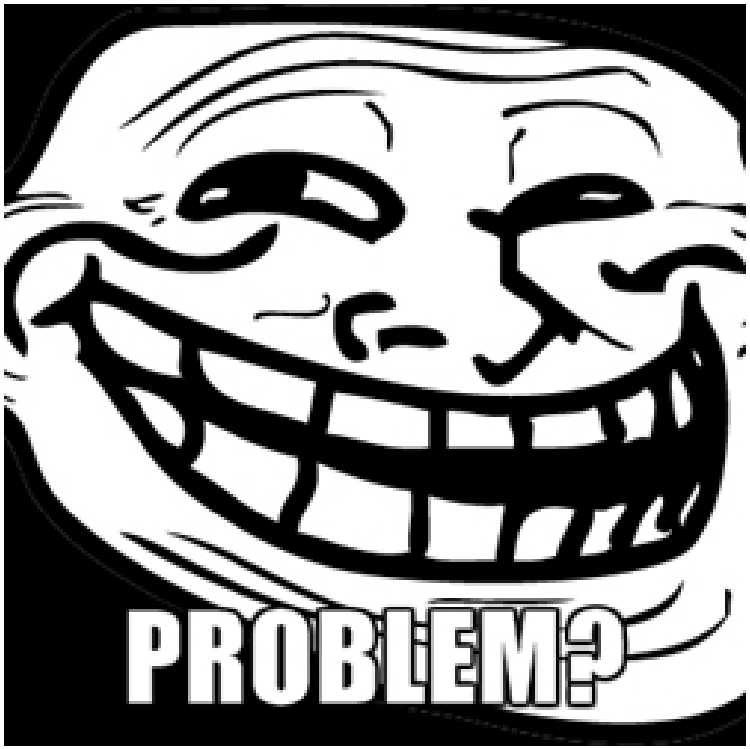
M is atomic weight

Using the above equation for Pu-238, we get

P = 0.56W/g

For 1462.2 W_{th}, we need:

<u>2.611kg</u> of Pu-238



- At $4000/g, 2.611kg of Pu will cost:

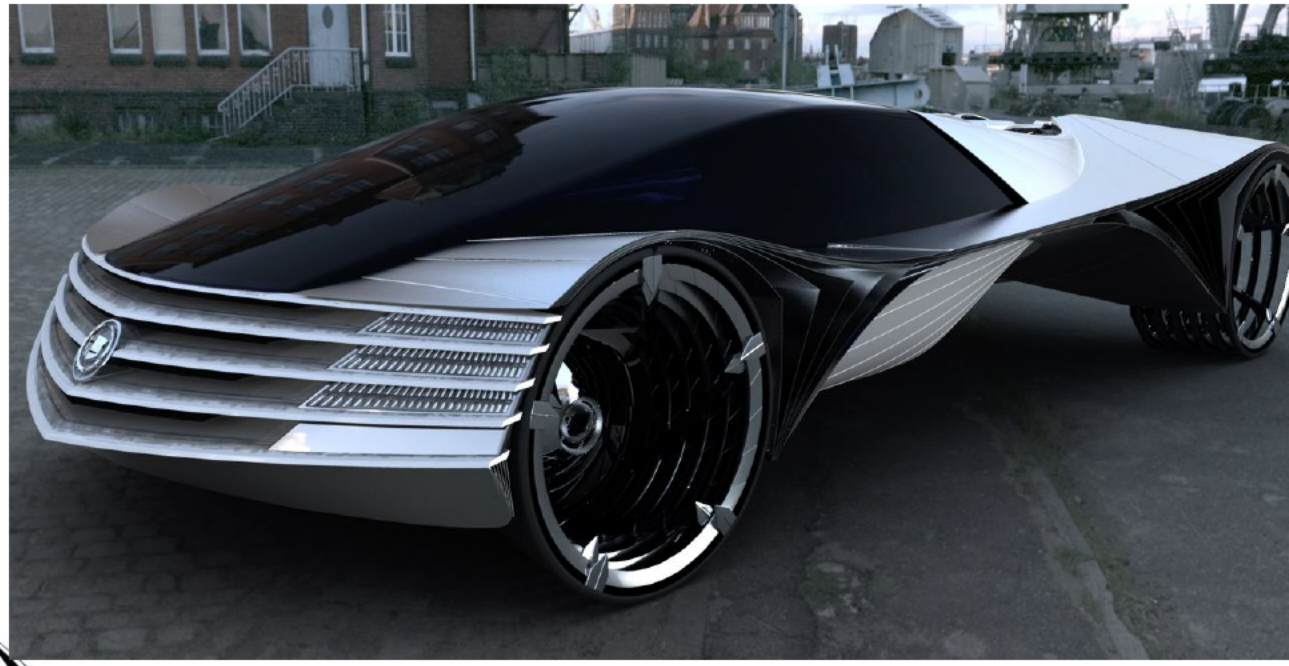
  $10.44 million!

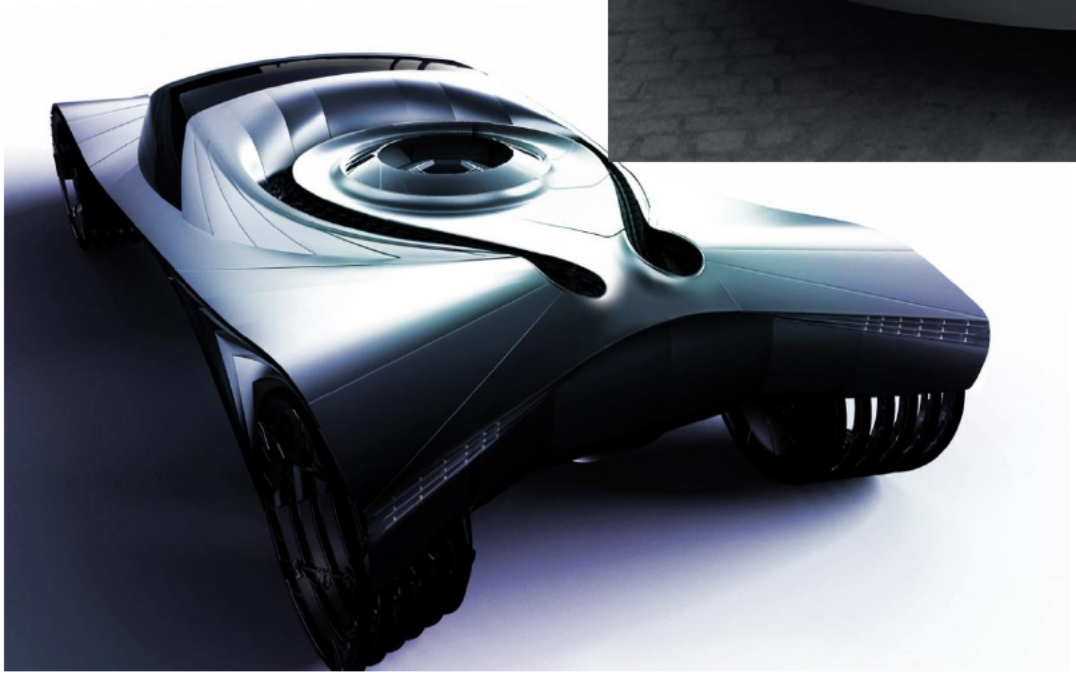
- Proliferation Issues, etc.

Directions for advancement

- Another Radioisotope which produces MORE POWER / GRAM than Pu-238, but which requires LESS SHIELDING
- More efficient way to convert heat to electricity inside of a small space constraint

The future?





Every great advance in science has issued from a new audacity of imagination.

~John Dewey, The Quest for Certainty, 1929

No one should approach the temple of science with the soul of a money changer.

~Thomas Browne

References

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Questions?