UNIVERSITY OF BIRMINGHAM | COLLEGE OF ENGINEERING AND PHYSICAL SCIENCES

A long lifetime power source - the radioisotopic battery

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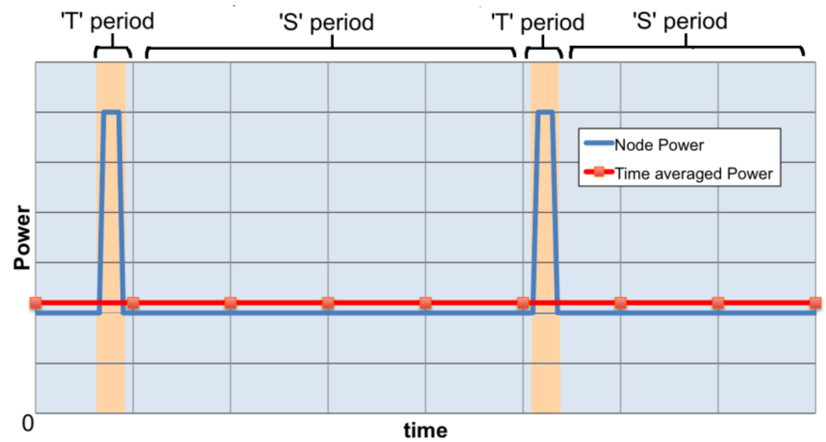
Motivation

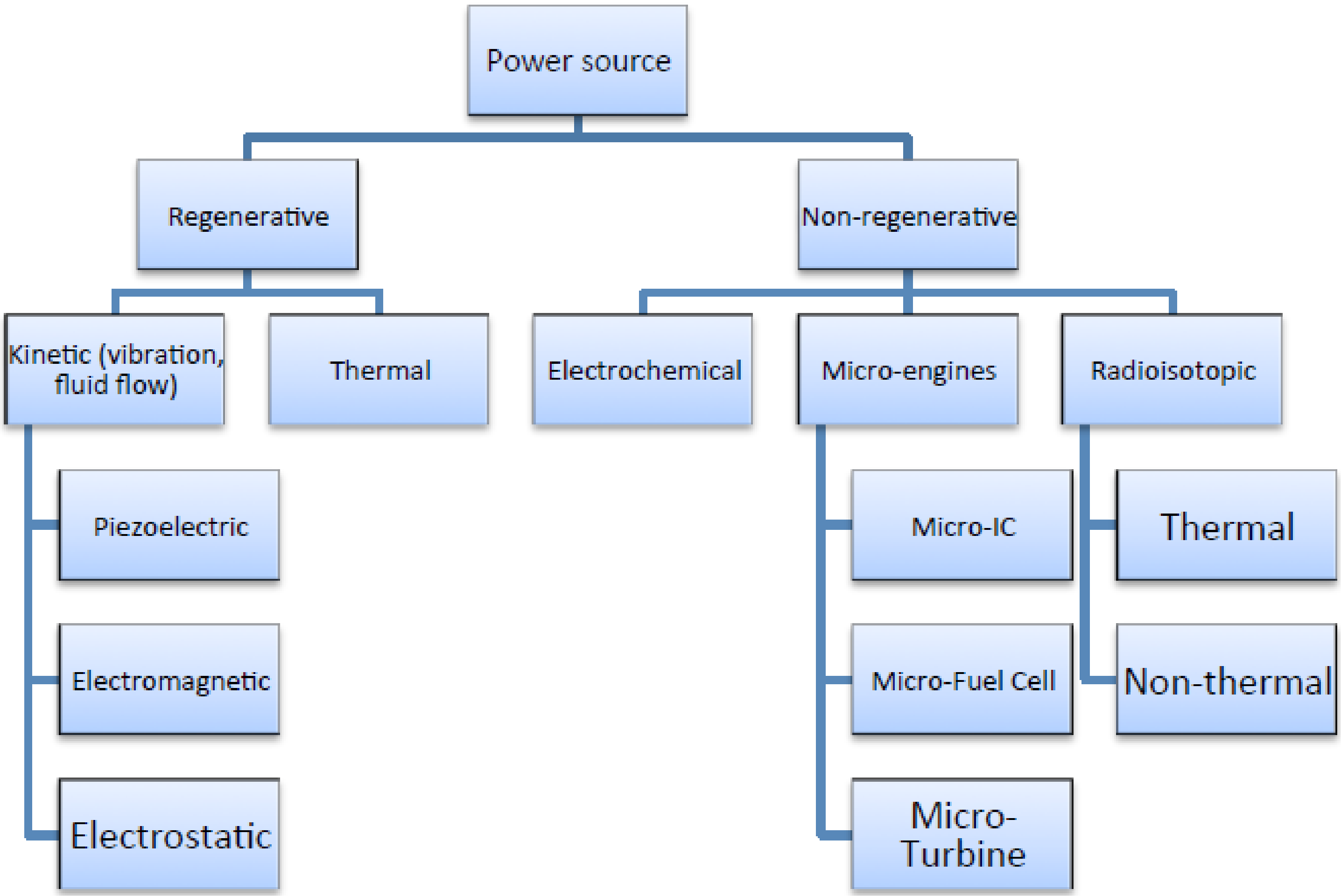
- >3 billion litres/day water leaks
- Buried pipe monitoring
- Sensor needs long term power
  - High replacement cost
  - Water pipes in ground for more than 100 years
  - Realistically power source needs to last 20+ years
- Harsh environment
- Maintain integrity of pipe

Power requirement



- Low measurement duty cycle
  - Spot measurements
  - once per day, once per hour
- Sensor nodes require
  - mW whilst transmitting
  - Very low average power 10's μW
- Ideally: High energy density, low power density

Power source options



Power source options - limitiations

- Li-ion – can’t be sealed, max 20year lifetime
- Solar power – obviously not an option
- Thermoelectric – very small temperature differences
- Water turbine/flow harvester – integrity of pipe
- Fuel cells – limited lifetime/thermal losses
- Induction from surface – location dependent
- Vibration – location dependent, sporadic
- **Radioisotopes ?**

Radioisotopes

- same number of protons in their atomic nuclei but **differing numbers of neutrons**.
- Release energy when decay into a more stable form - β, γ radiation
- Decay at different rates
  - half life : Minutes – 1000's years
  - Opportunity for long term power
- e.g. Uranium-235, radium-226, Carbon-14, Tritium, Americerium-241, Nickel-63, Plutonium-238

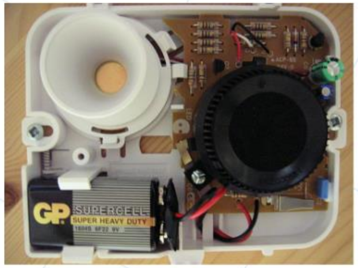
Radioisotopic power sources

Advantages relative to conventional batteries

- Very high energy density
- Very long life (potentially) – isotope dependent
- Continuous operation devices
- No (or very few) moving parts
- Very little sensitivity to environmental changes
- High reliability
- Scalable to microns (generally)

Seem ideal !

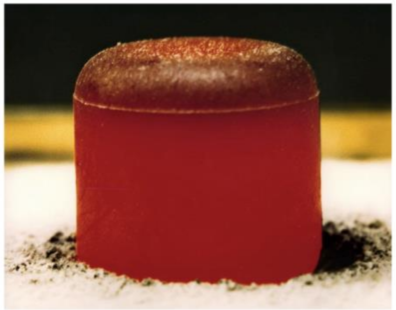
Uses of Radioisotopes



Smoke Detectors using Am-241 as ionizing source

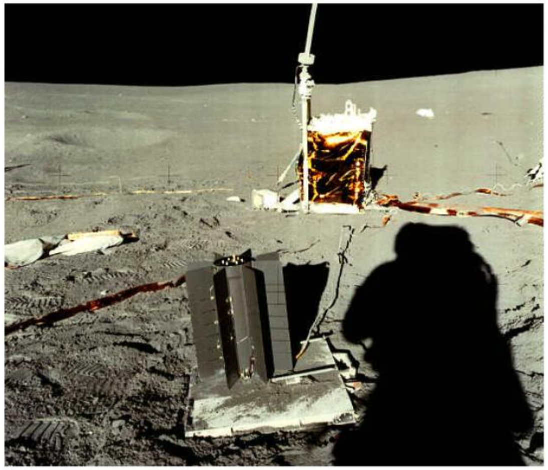
Smoke detectors – Am241

Self powered emergency signs



Pellet of Pu-238 (US Department of Energy)

Pellet of Pu-238

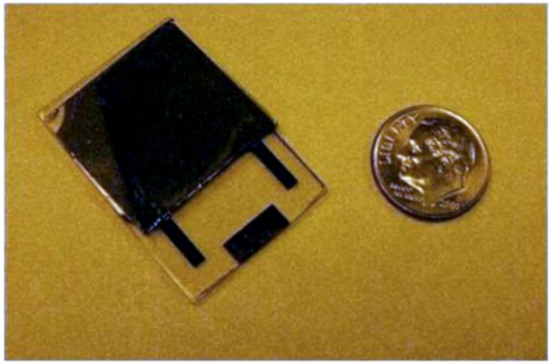


RTG from Apollo 14 mission to the moon (NASA, 1971)

NASA – since 1961

Pacemaker powered by Pu-238 decay (1974)

Pacemakers 70's

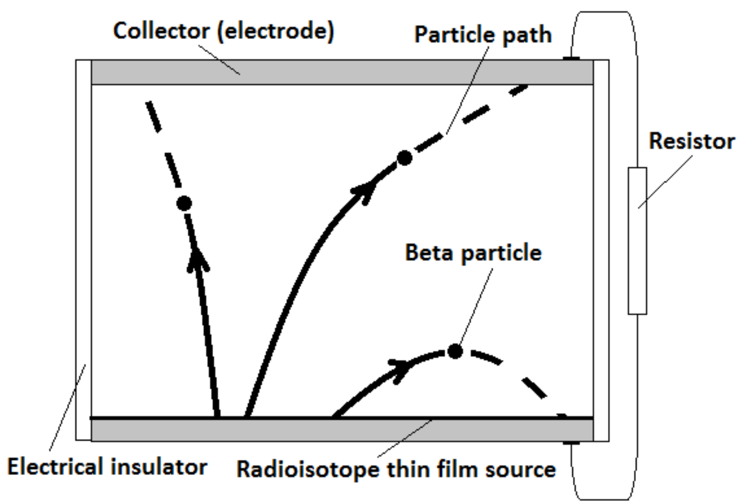


(Jae Wan Kwon, University of Missouri, 2009)

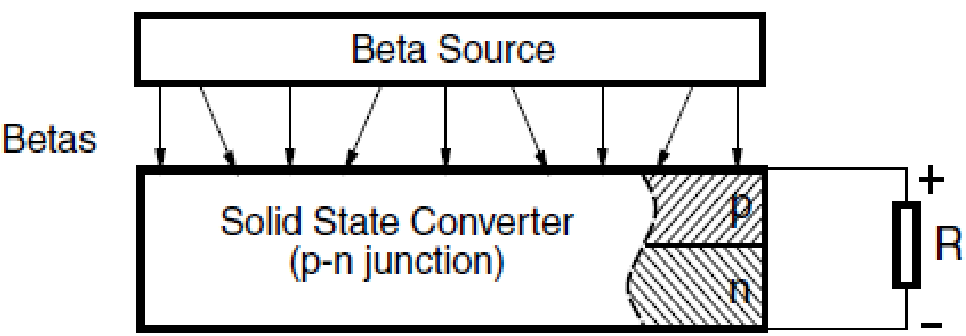
Batteries - University of Missouri 2009

Non-thermal radiosotpic energy conversion

- Direct Charge
  - High Voltage (100kV+)
  - Low Current (< 100nA)

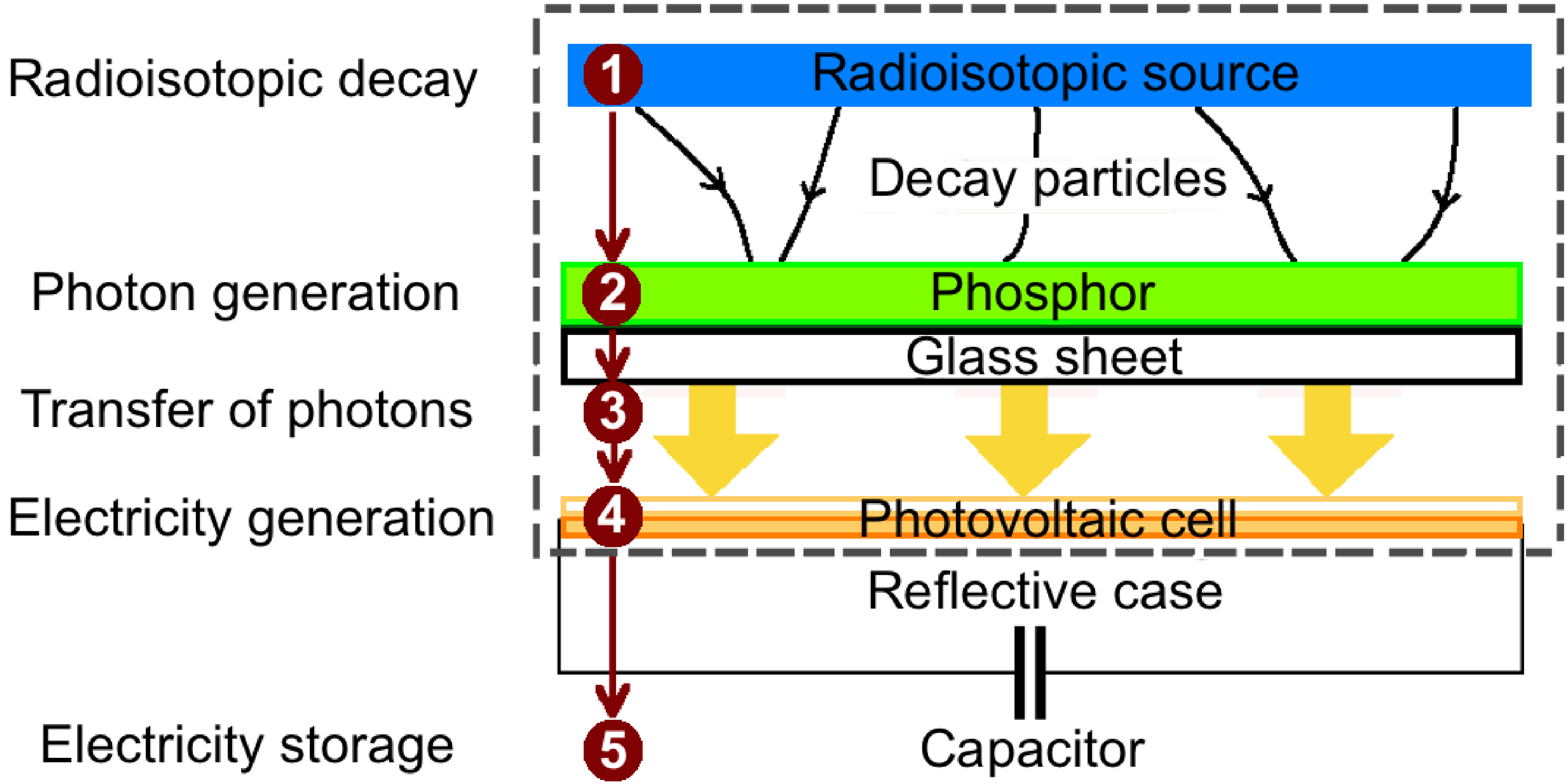


- Direct conversion
  - Low voltage (5V), higher current(0.1mA)
  - Semiconductor suffers radiation damage



Indirect conversion (ICRB)

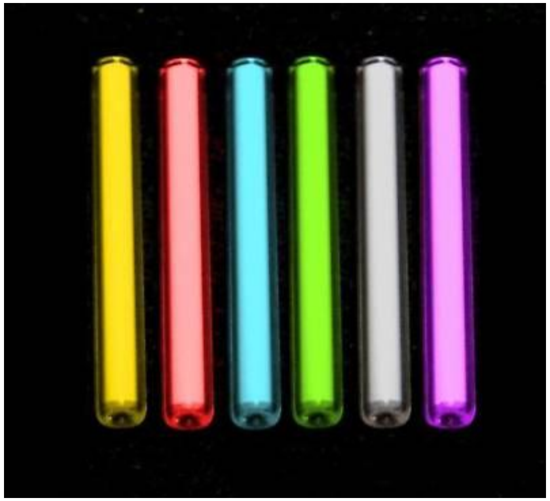
Decay particle → Light → Electricity



How do we produce a phosphor coated radioisotope?

Gaseous Tritium Light Sources (GTLS)

- **Commercially available fishing lures !**
- A transparent glass tube having a thin layer of a scintillating agent coated to its inside walls (normally a phosphor)
- Pressurized **Tritium (3H)** is injected into the tube which is then sealed at both ends



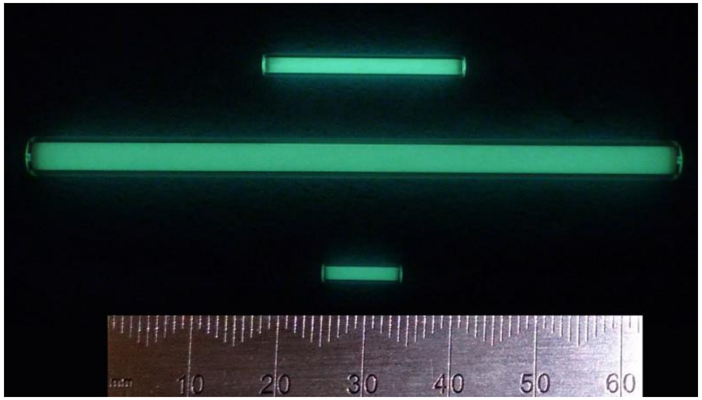
GTLSs of various colours

Tritium $^{3}H \dashrightarrow {}^{3}He + \beta^{-}$ + anti-neutrino

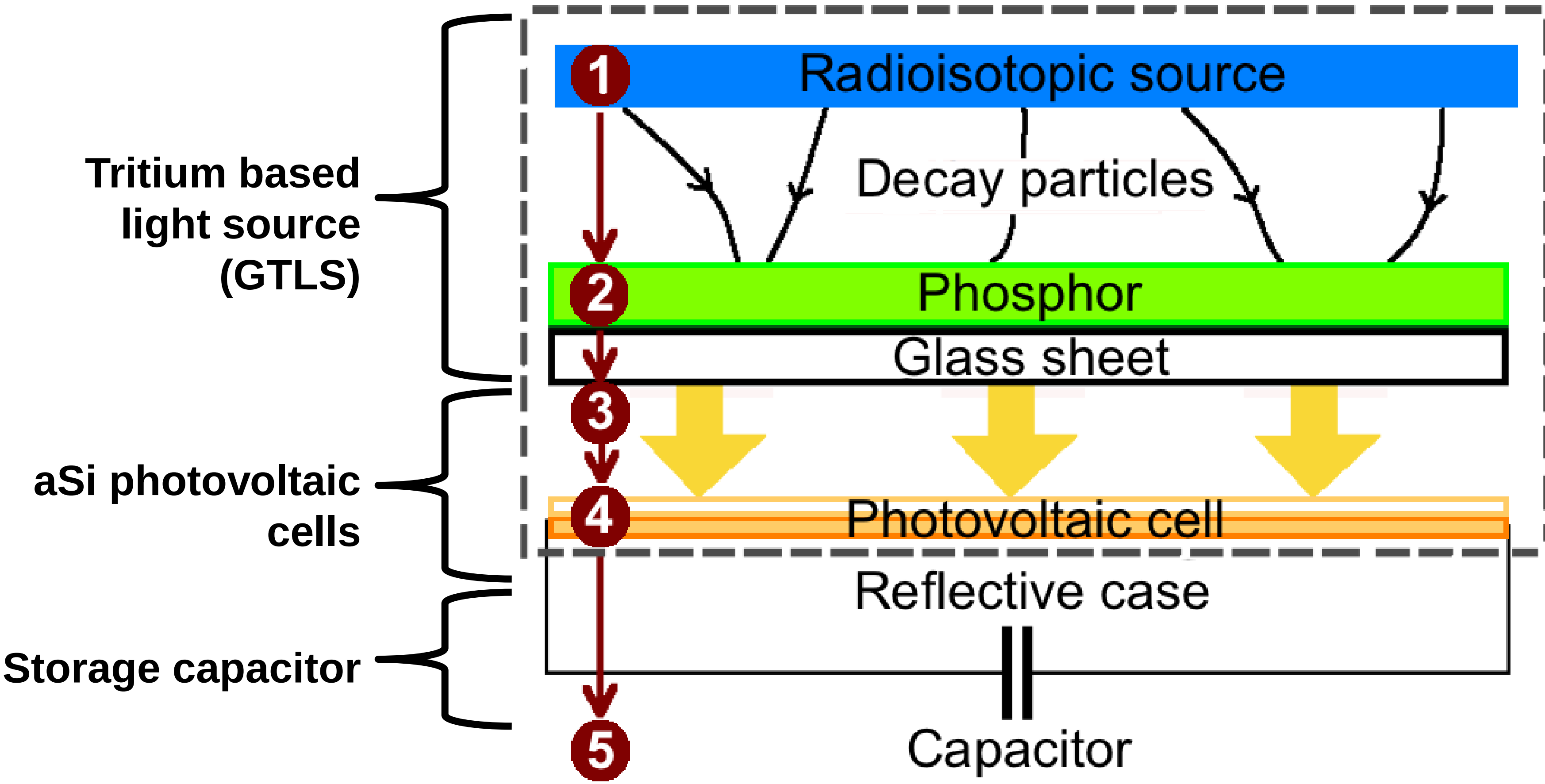
- Beta radiation from Tritium can travel 6mm in air, 6µm in water, and will not penetrate the dead layer of skin on humans

GTLS device regulation

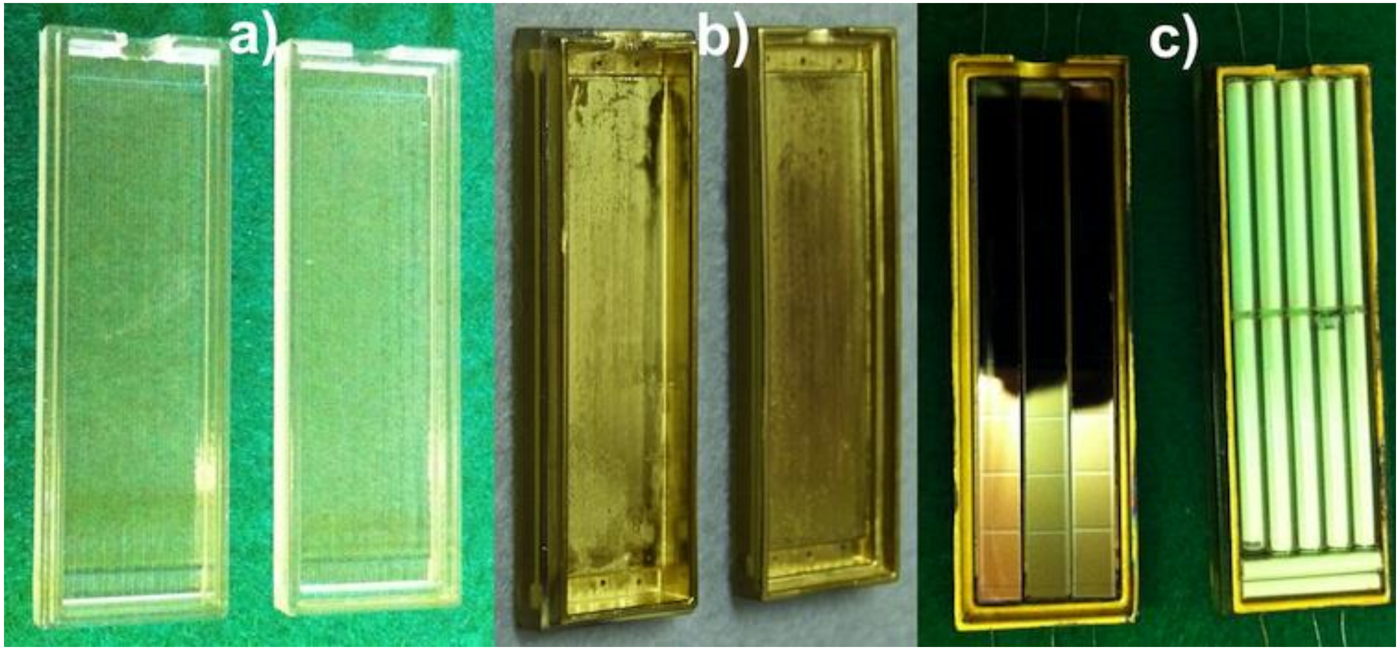
- Environmental Protection, England and Wales: The Environmental Permitting (England and Wales) Regulations 2010
- 1000GBq limit for a device made of these sources
- Single ones 20GBq
- If contaminate ground water health consequences of ingesting tritium in the form of tritiated water
- Disposal route depends on amount



GTLS based battery

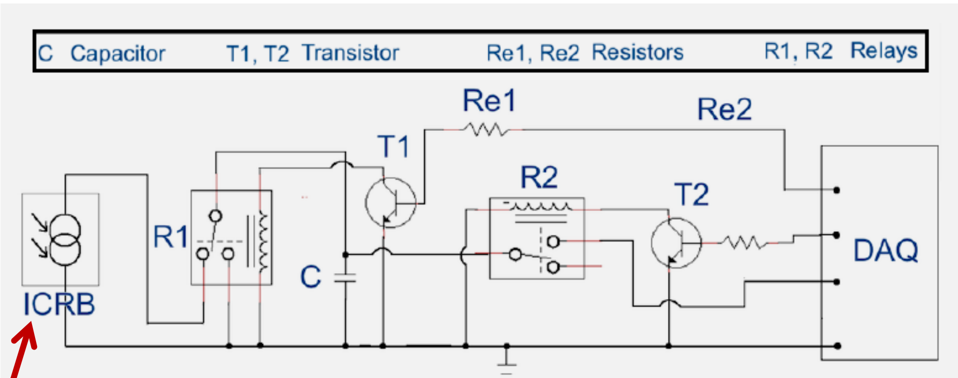


Prototype GTLS battery



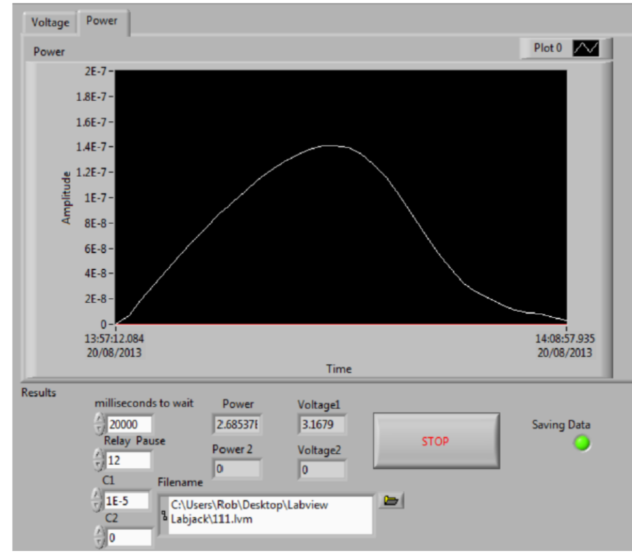
a) 3D printed casing
b) reflective coating(Au or $BaSO_4$)
c) PV cells and GTLS Capacitor

Testing battery performance



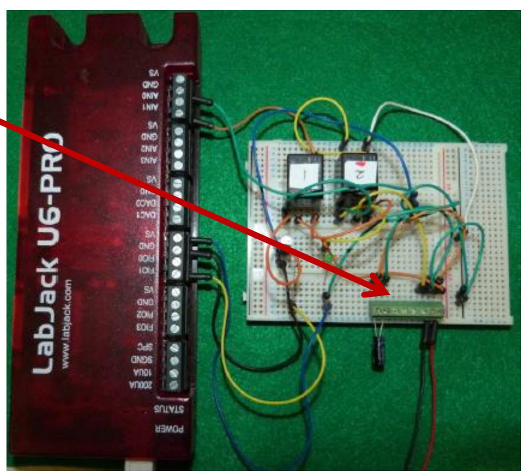
Test circuit for ICRB battery testing

Charge 1µF Al Electrolytic capacitor



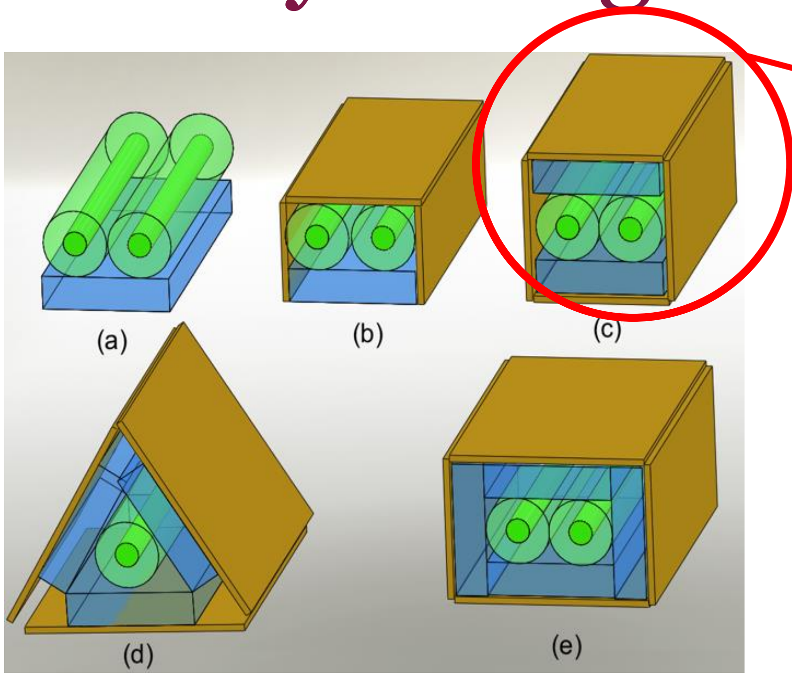
LabVIEW measurement program

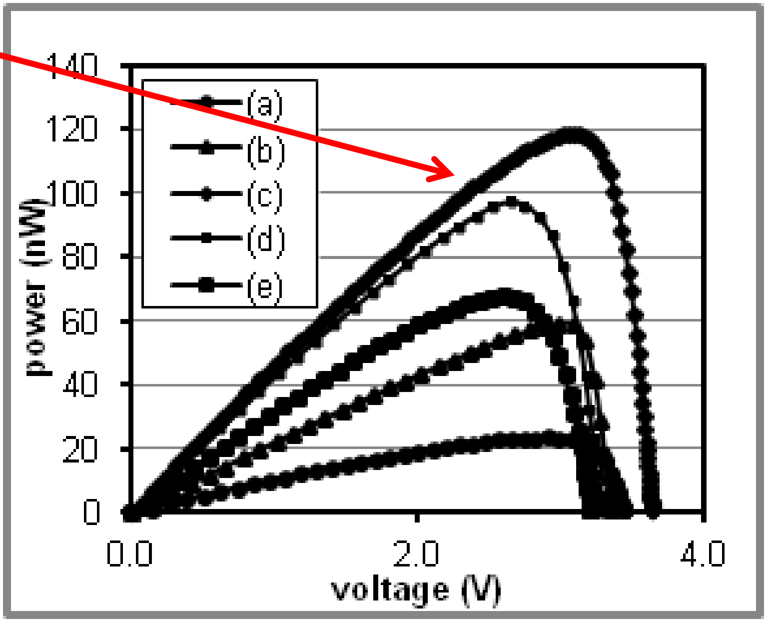
Battery



$$p = \frac{\frac{1}{2}C(\Delta v)^2}{\Delta t}$$

Battery configuration test





Charging curve

- Different GTLS/PV cell configurations investigated
- Harvested power compared

Battery power testing results

PV cell type	PV cell dimensions (mm)	Reflective coating	GTLSs (mm)	Peak power (nW)	Power (nW/GBq)	Power (nW/cm3)	Power (nW/cm2)
m-Si	2 59.9 X 30.0 X 2.6	none	12 25X3Ø	10.2	0.05	0.68	0.58
p-Si	2 49.8 X 19.9 X 2.6	none	14 15X3Ø	7.7	0.10	0.92	0.63
a-Si	6 54.5 X 4.5 X 1.2	gold	10 25X3Ø + 2 15X3Ø	575.1	3.18	123.28	39.08
a-Si	2 91.9 X 24.8	none	30 25X3Ø + 1 22.5X3Ø	* 1606.2	3.06	126.90	35.24
a-Si	2 34.9 X 13.8 X 1.2	none	12 15X3Ø	241	3.79	78.31	25.02
a-Si	2 34.9 X 13.8 X 1.2	gold	12 15X3Ø	250.1	3.93	75.15	25.96
a-Si	2 34.9 X 13.8 X 1.2	barium sulfate	12 15X3Ø	283.6	4.46	72.22	29.44
a-Si	2 72.3 X 15.0 X 1.2	gold	24 15X3Ø	696.9	* 5.48	114.12	32.13
a-Si	2 103.1 X 15.5 X 1.2	none	34 15X3Ø	786.2	4.36	88.54	24.60

Comparison of battery configurations

Very low light levels for PV cell operation, low efficiency

- * **525 GBq**
- * **127 GBq – a scaled version would produce 2800nW @525GBq (1000GBq limit)**

Other research on ICRB's

Battery type	PV cell	Radioisotope	Activity (GBq)	Voltage (V)	Power	Efficiency	Type
AeroGel	a-Si	Tritium	214,600	-	2mW	1.00%	theory
AeroGel	AlGaAs	Tritium	118,400	-	2mW	1.80%	theory
Thin film	m-Si	Nickel 63	-	-	0.92nW	1.53%	theory
Polymer	Si	Promethium 147	166.5	-	20µW	-	practical
GTLS	a-Si	Tritium	24.2	0.24V	2.57nW	0.17%	practical
GTLS	AlGaAs	Tritium	8.2	>0.78V	74nW	0.98%	practical
Thin film	AlGaAs/GaAs	Plutonium 238	11.1	0.75V	10µW	0.11%	practical
GTLS	AlGaAs	Tritium	48.84	1.2V	234nW	0.53%	practical

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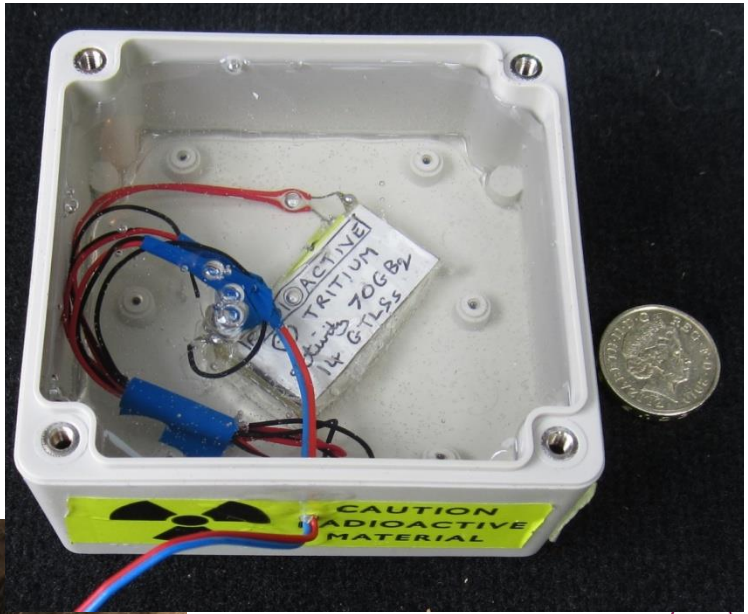
Buried trials

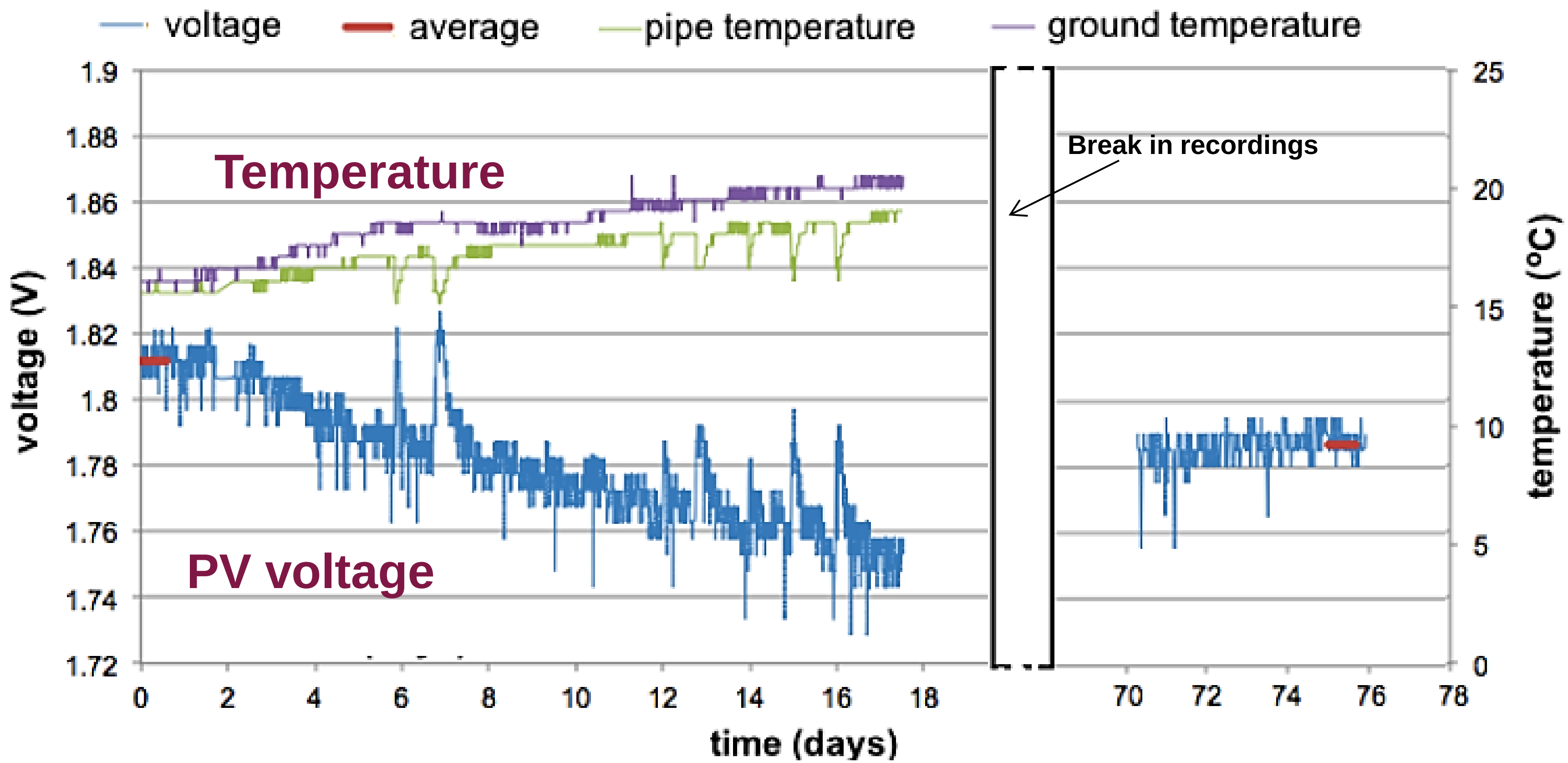
- Radioisotopic battery potted in polyurethane in IP55 waterproof casing



- Fourteen 14.5x2.5mm GTLS's
- Two 34.9x13.8mm a-Si PV cells
- 294nW @1.8V at start of testing

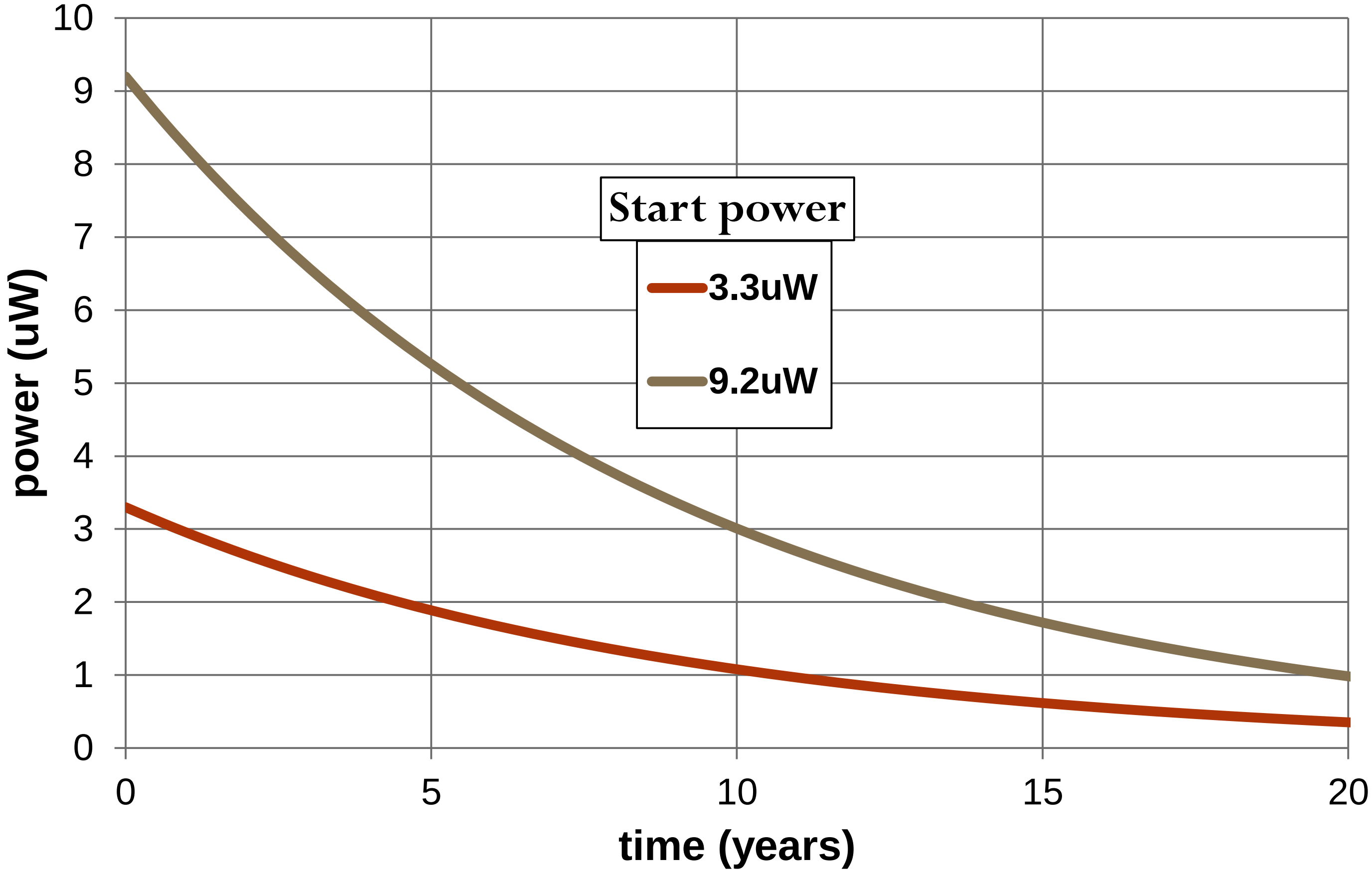
- Attached to a buried water pipe
- Cables brought out to monitor battery

Radioisotopic battery buried testing



- Battery performance over time whilst buried on a water pipe
- Temperature alters PV cell output

Calculated battery power over time



- Tritium half life 12.3 years
- Need higher starting power for longer life at spec power
- Alternative radioisotope would give more stable power

Conclusions

- Designed and manufactured Indirect conversion Radioisotopic battery (ICRB) using Gaseous Tritium light sources (GTLS) and a-Si PV cells
- Limit on activity 1000GBq
- Highest power produced 1600nW (@525GBq)
- Best efficiency 5.48nW/GBq
- Survived burial
- 1 μW of power after 10 years requires 3.3μW at beginning of life
- Longer lifetime requires longer half life

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Questions ?