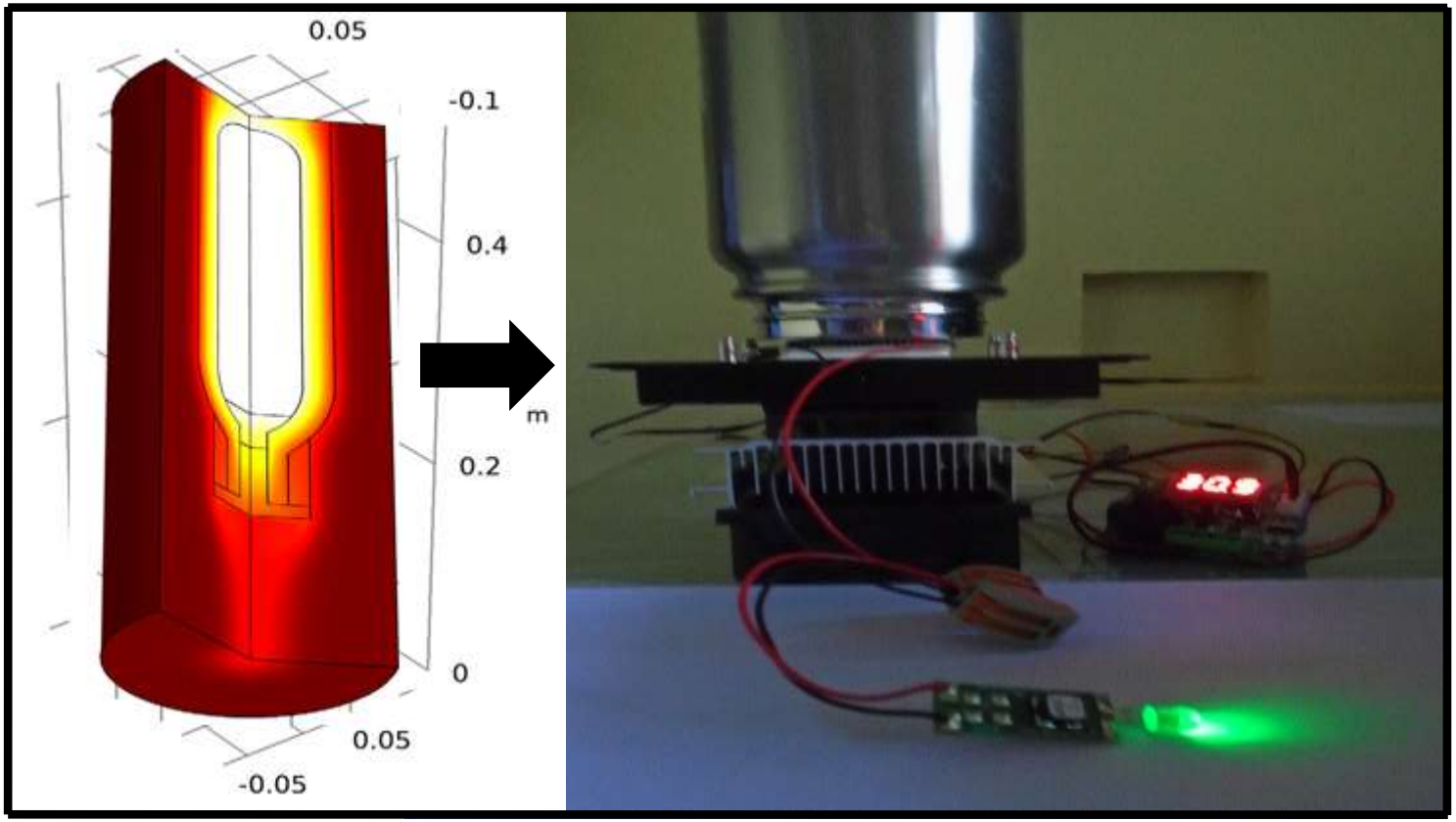
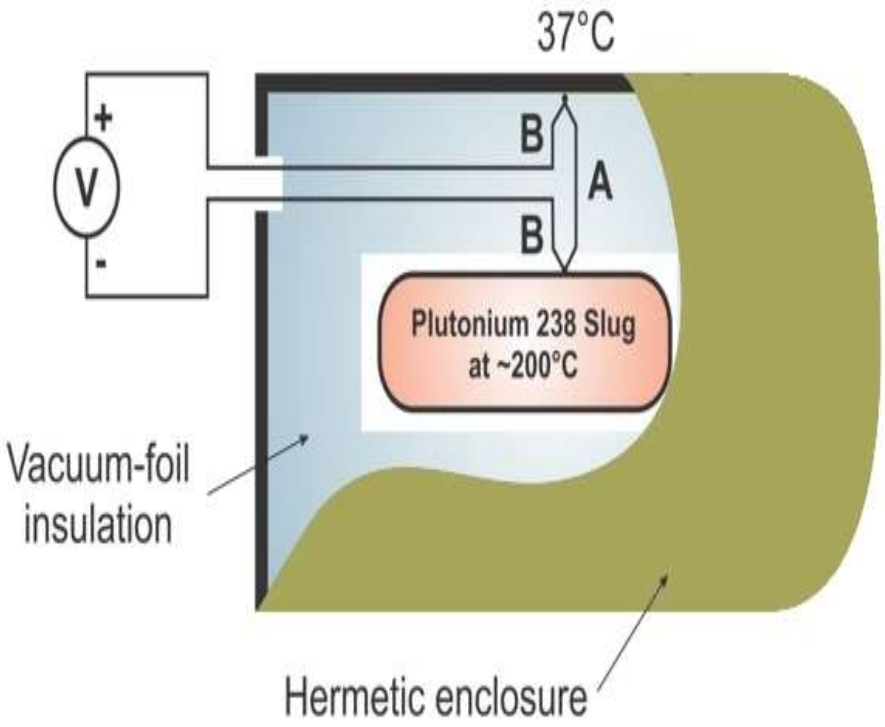
Design and validation of Sr^{90} radionuclide based Radioisotope Thermoelectric Generator (RTG) using COMSOL simulation

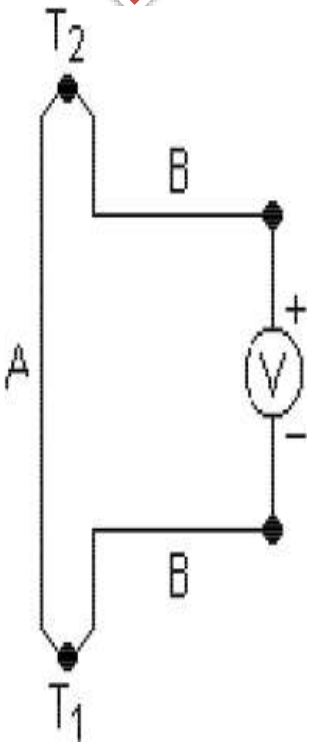


S.K. Mishra, SO/E, BARC, Trombay, Mumbai

Radioisotope Thermoelectric Generator

Radioactive source (Sr-90, Pu-238, Am-241) ⇨ Decay Heat ⇨ Thermoelectric Generator (TEG) ⇨ RTG O/P Electrical Power





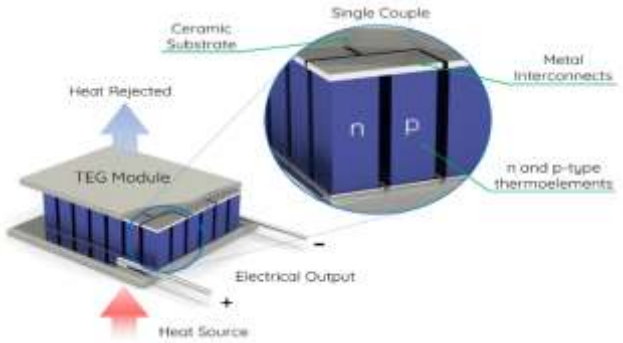
Schematic of RTG

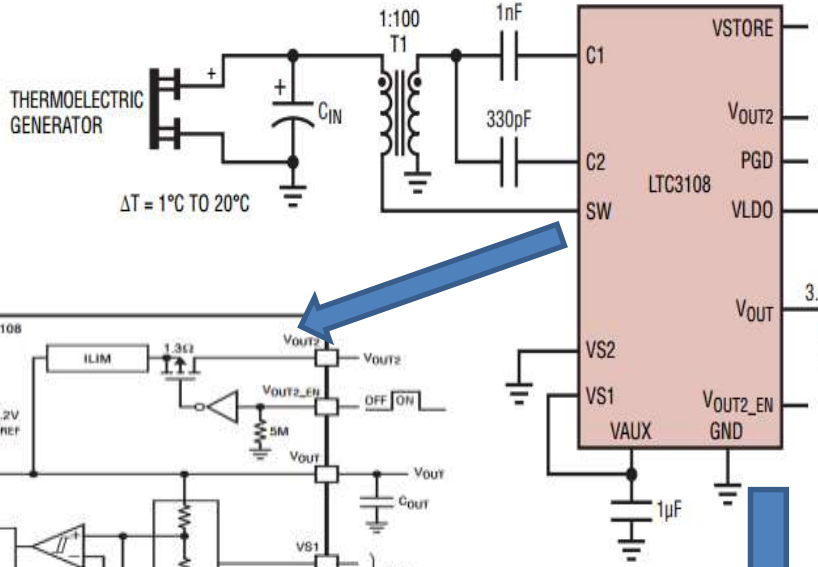
Application for power sources in satellites, space probes and interplanetary space mission where solar cells are not suitable and where power requirement is for long duration.

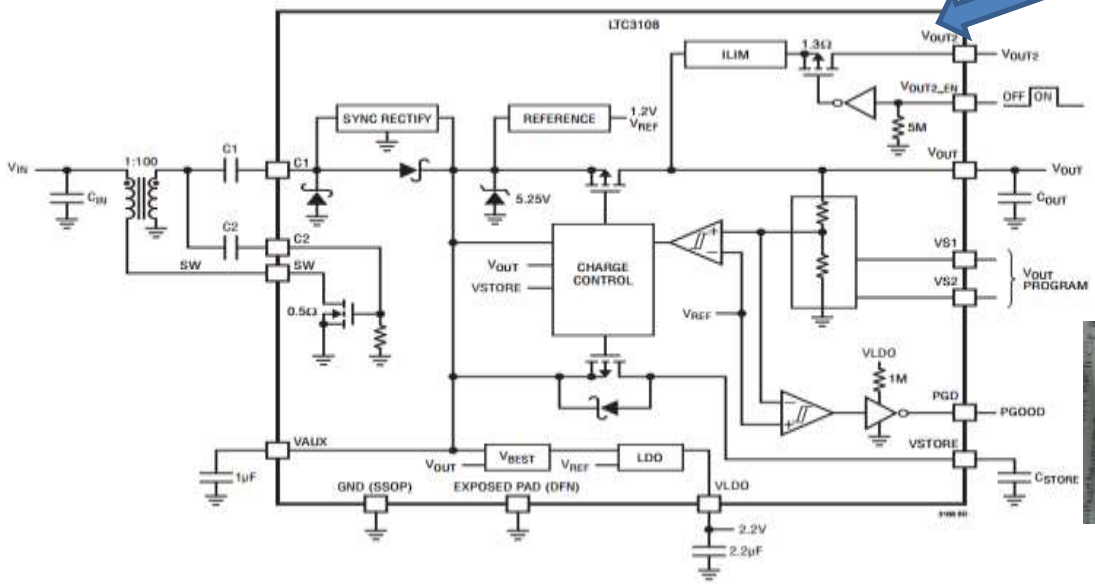
Development of TEG & DC converter

भाभा परमाणु अनुसंधान केंद्र
BHABHA ATOMIC RESEARCH CENTRE

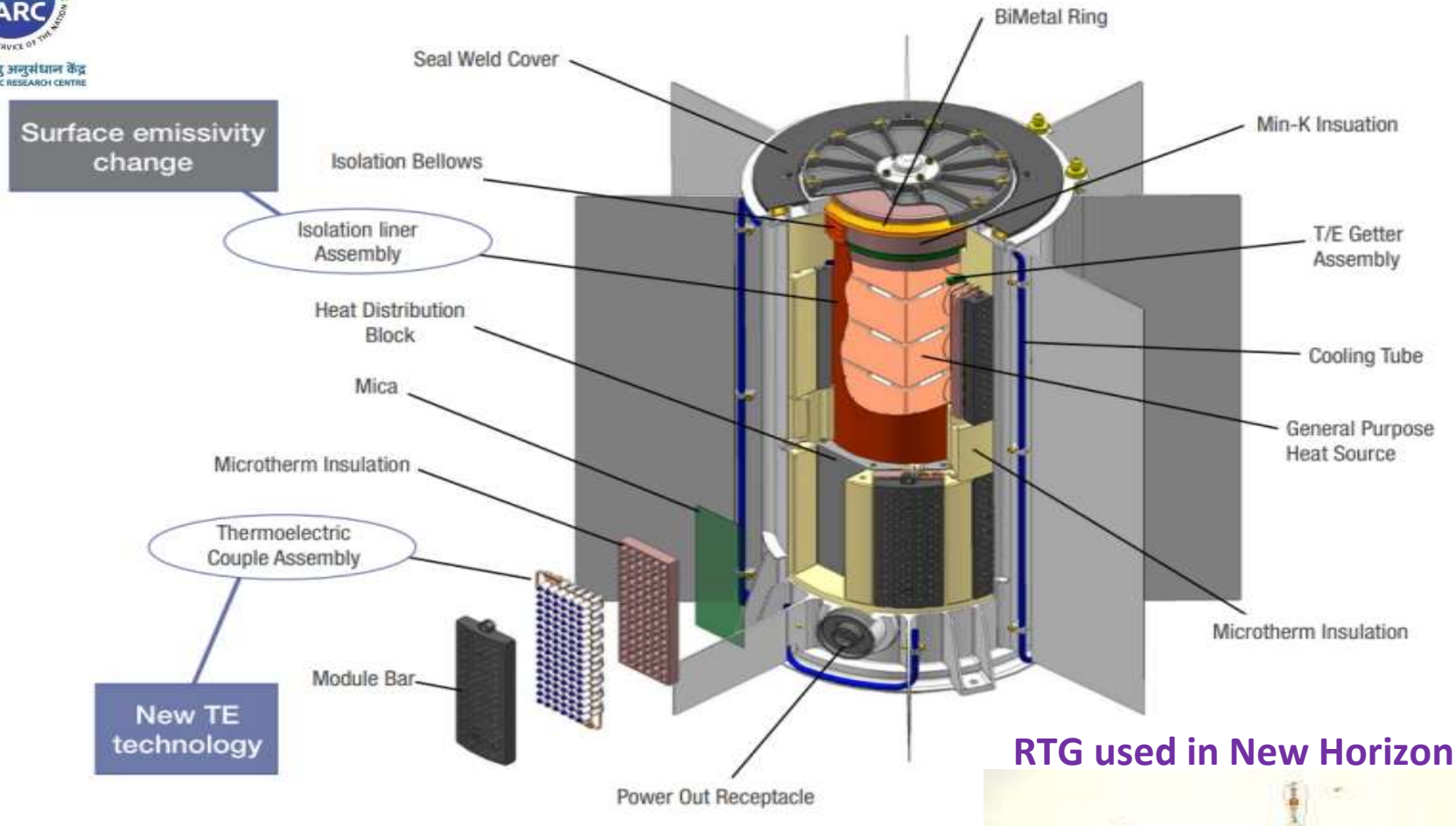
Decay Heat → Thermoelectric Generator (TEG) → Ultralow Voltage Step-Up Converter → Electrical Load







Different parts of RTG used for Space probe



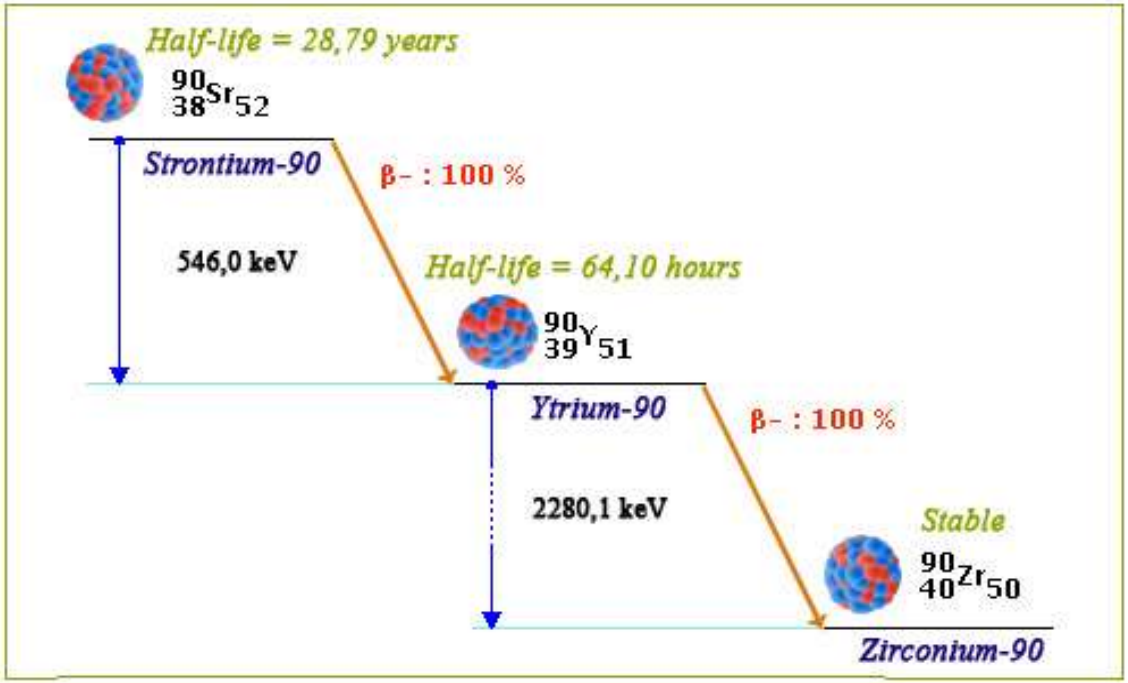
RTG used in New Horizon

New Horizons' electrical power comes from a single radioisotope thermoelectric generator (RTG). The RTG provides power through the natural radioactive decay of plutonium dioxide fuel, which creates a huge amount of heat. Unlike a normal reactor, the Plutonium-238 used in the RTG cannot undergo a chain reaction.

Development of a RTG from Indian scenario

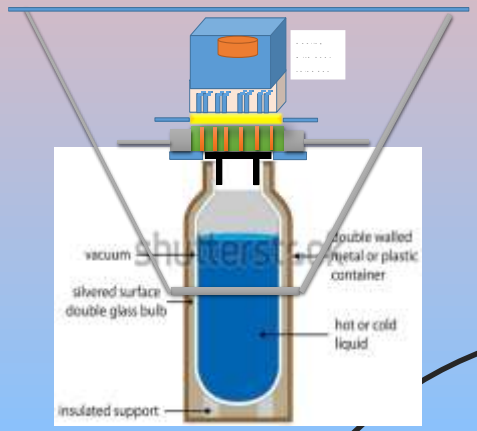
- In India, High level radioactive liquid waste generated from spent fuel reprocessing contains large quantities of ^{90}Sr and ^{241}Am , which can be used as a substitute of ^{238}Pu based RTG electrical power source.
- In present scenario we have designed, developed & demonstrated a RTG of 150 mW electrical output power using ^{90}Sr radionuclides.
- COMSOL simulation helps to successfully design a prototype RTG for initial testing.

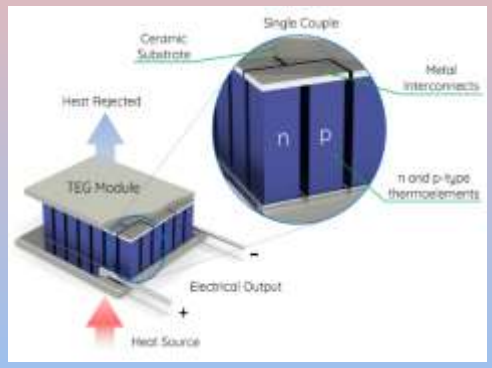
- **^{90}Sr** generates0.94 W/gm [140 Ci/gm].
- **^{90}Sr** is contained as liquid form in 1 molar nitric acid (HNO3).
- The decay heat of ^{90}Sr decreases with a function of $e^{-\lambda t}$, t = time in hour and λ = 2.74 * 10^{-6} .



^{90}Sr Decay diagram

Block diagram for ^{90}Sr RTGS for a electrical load of 150 micro Watt





^{90}Sr (2.93 m gm / 0.411Ci) = 2.67 m W Decay Heat

Reduces as a function of $e^{-\lambda t}$, t = time in hour and λ = 2.74 * 10^{-6} is Decay constant for **^{90}Sr**

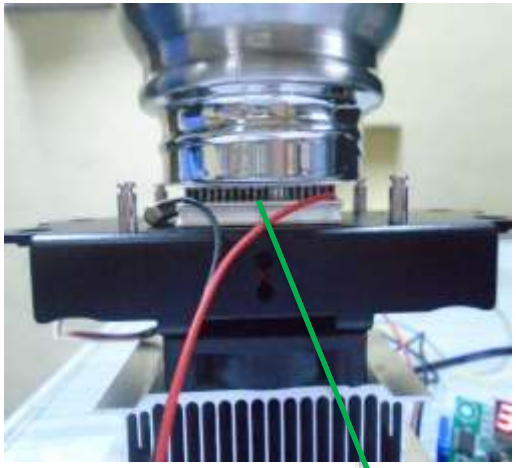
Heat Loss 20 %

2.14 m W (J/s)

Efficiency 07% (TEG efficiency + converter loss)

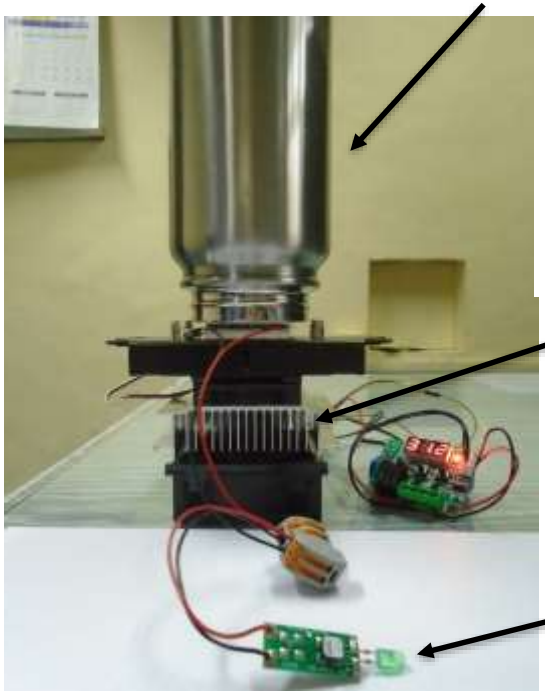
150 micro W (Single LED light)

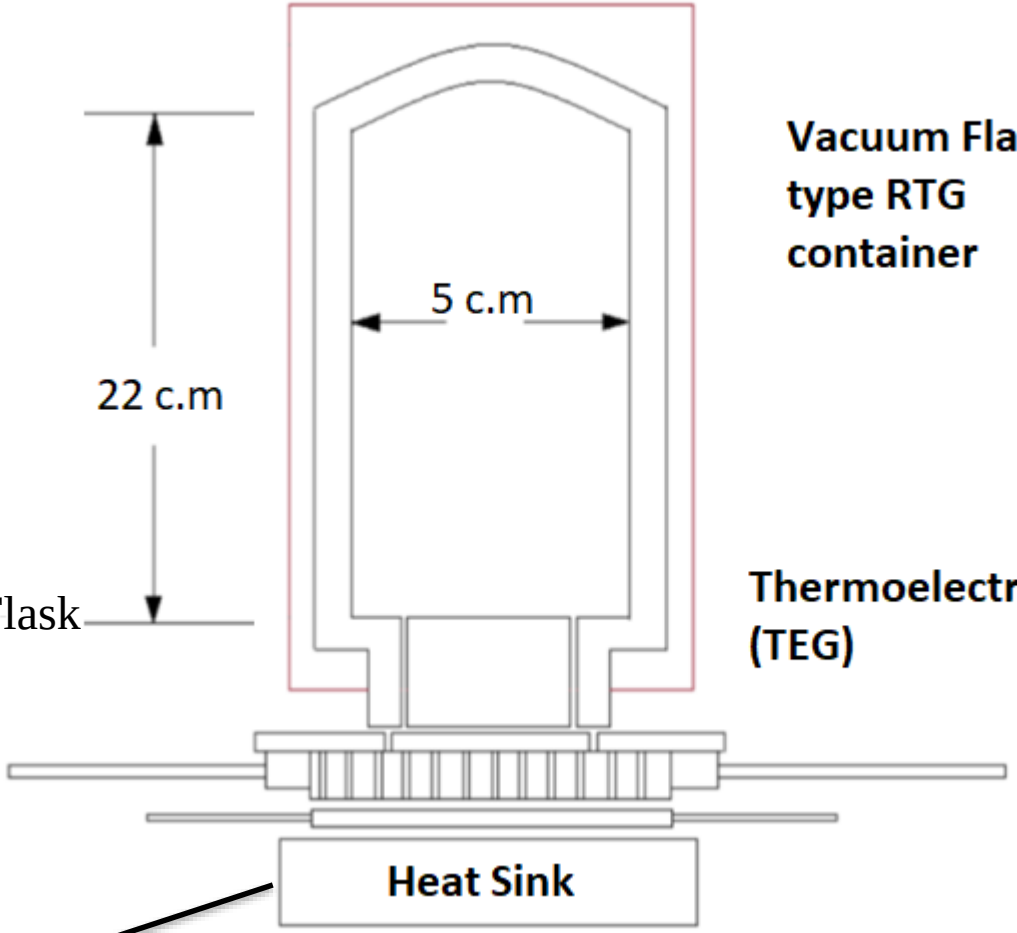
Vacuum Flask container to reduce Thermal losses



Thermoelectric Generator

Vacuum Flask





Vacuum Flask type RTG container

Thermoelectric Generator (TEG)

Prototype RTG designed based on Vacuum flask container using radioactive heat source as liquid medium

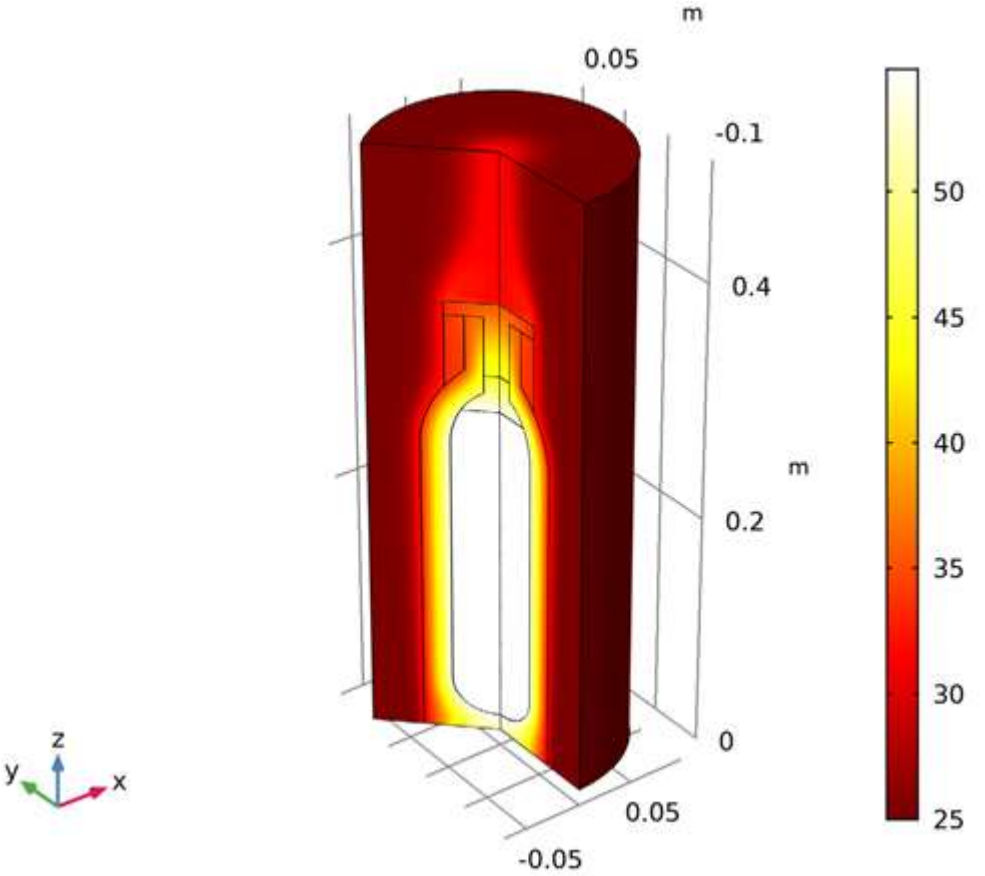
Electrical Load of 150 micro W

COMSOL solves the following difficulties

- The main objective is to calculate the containers cooling power; heat loses per unit time and equilibrium temperature inside the radioactive liquid vacuum flask container for generating stable electrical output power.
- ^{90}Sr radionuclides in 1 molar nitric acid generates decay heat, which reduces with time as per the half life of the radionuclide. So the heat source is a time dependent problem.
- The container dissipates thermal energy and some portion of the thermal energy converted to electricity using TEG.
- Calculation of amount of ^{90}Sr required in Ci for a predefined electrical load.
- Concentration of ^{90}Sr in HNO3 liquid as concentration is a limiting factor.
- Optimisation of design parameters for vacuum container to reduce thermal losses.
- Screening of interface material to maximize the heat transfer from hot liquid to TEG.

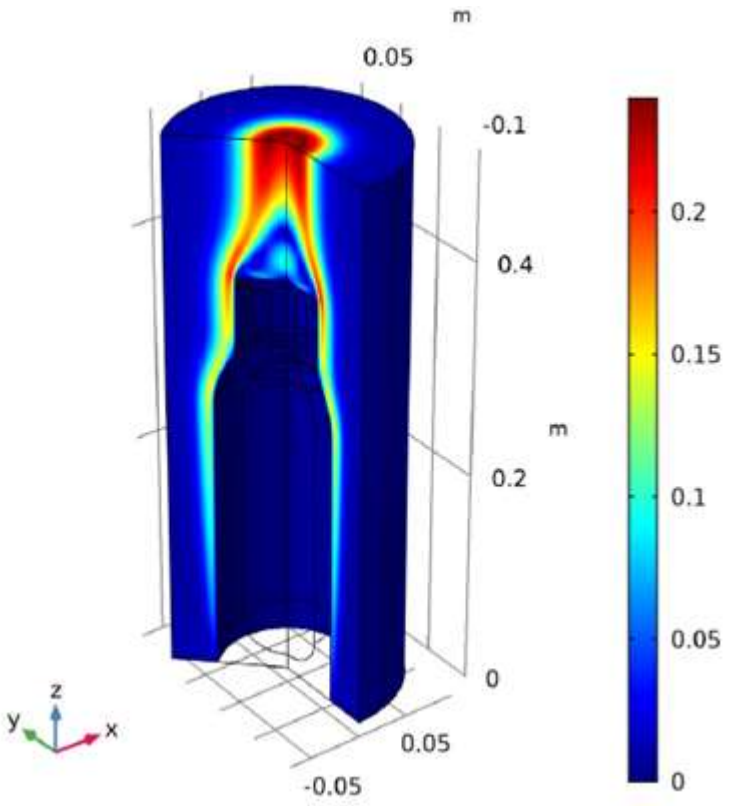
COMSOL SIMULATIONN RESULTS FOR RTG

Temperature distribution in RTG and surrounding air



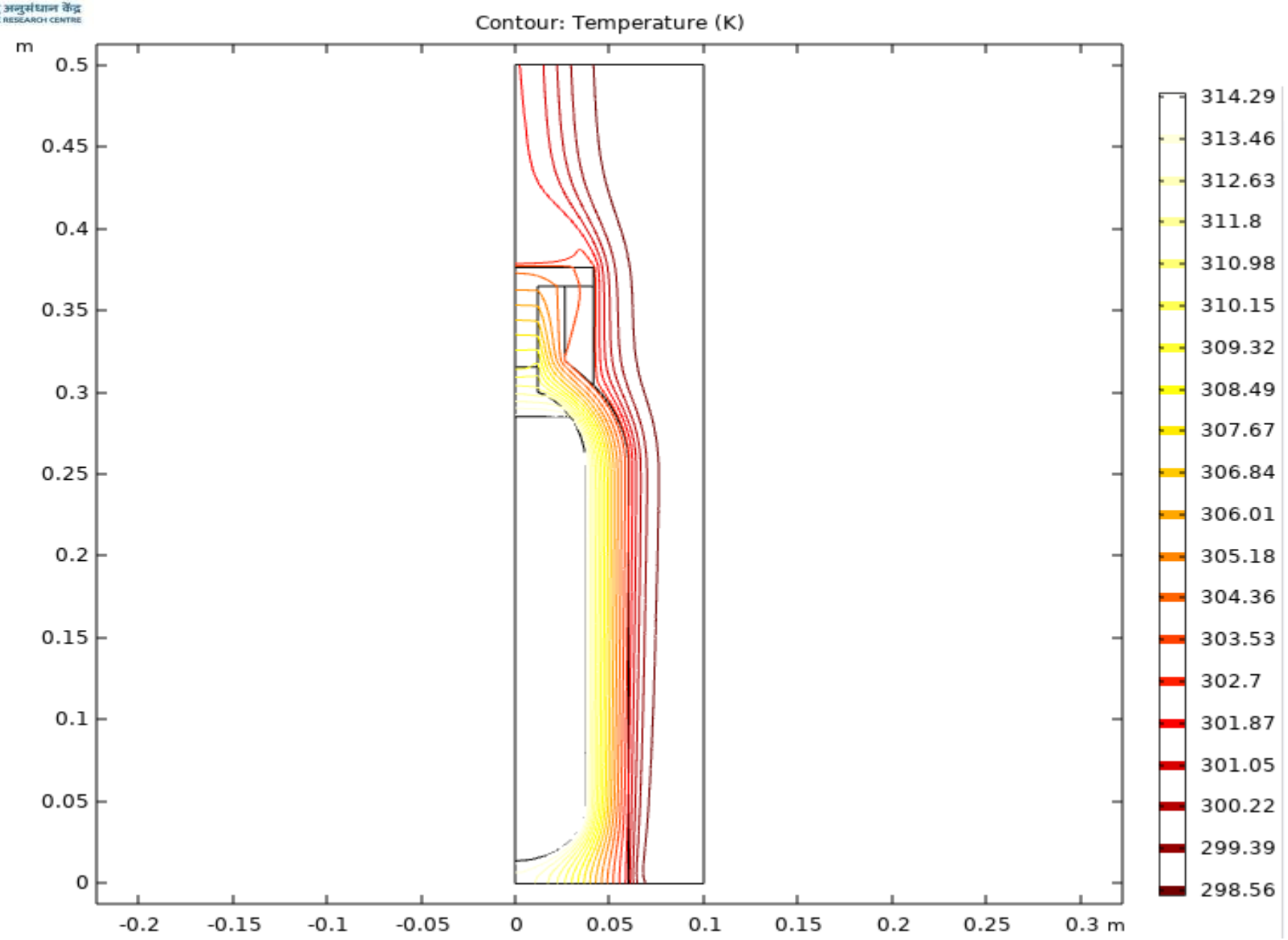
Temperature (degC)

Fluid velocity for air around the RTG

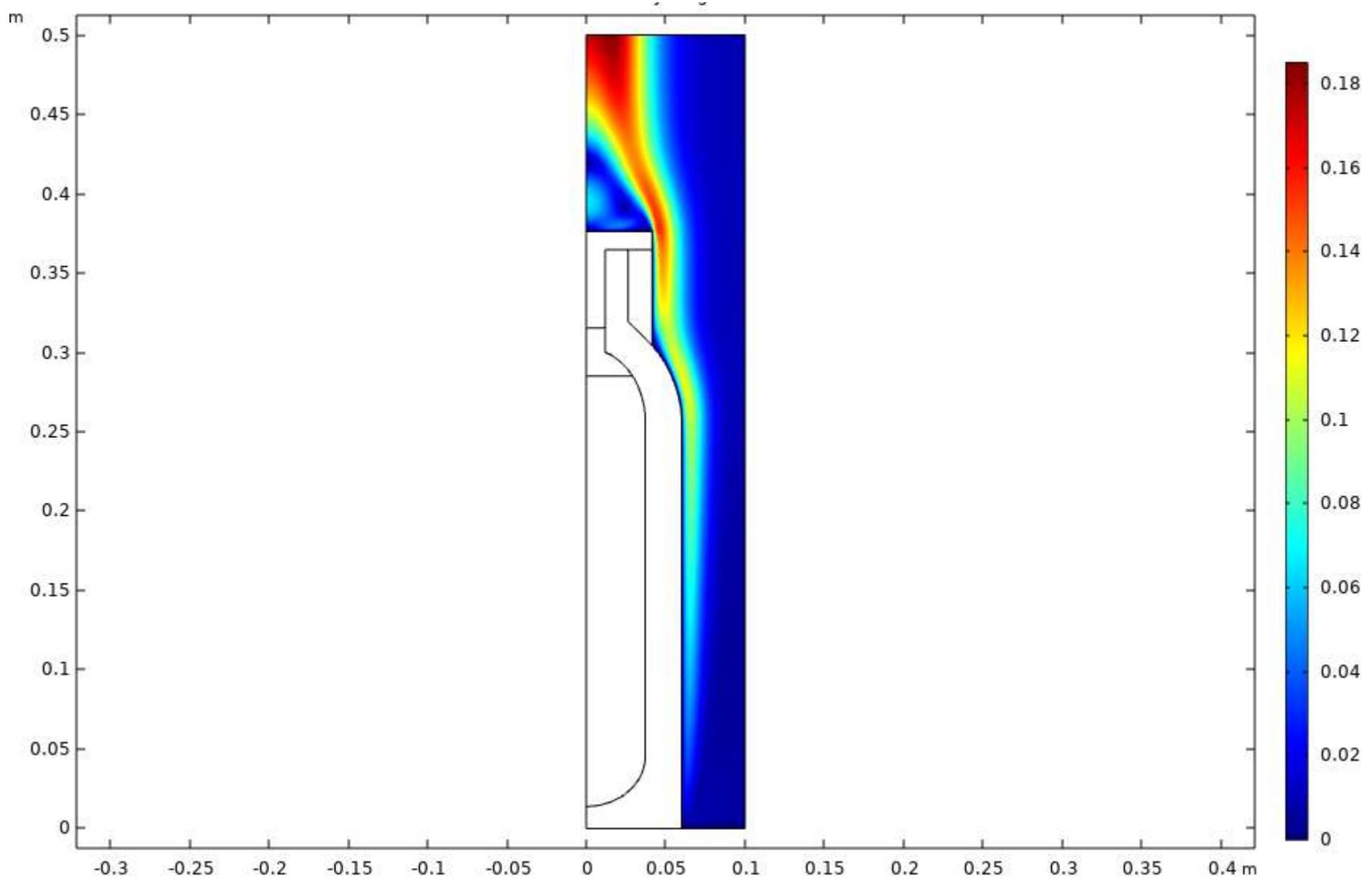


Velocity magnitude (m/s)

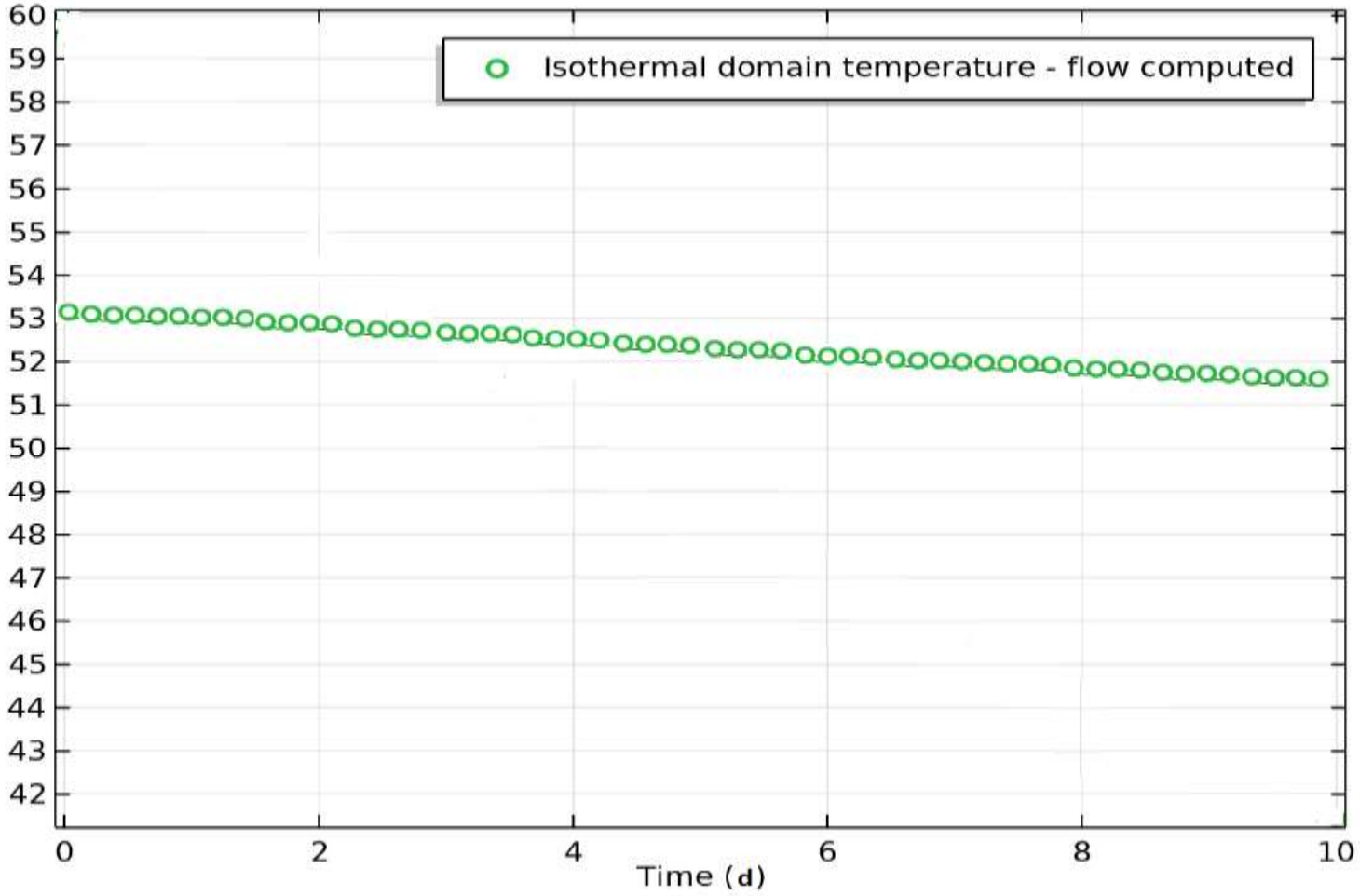
Isothermal Contours



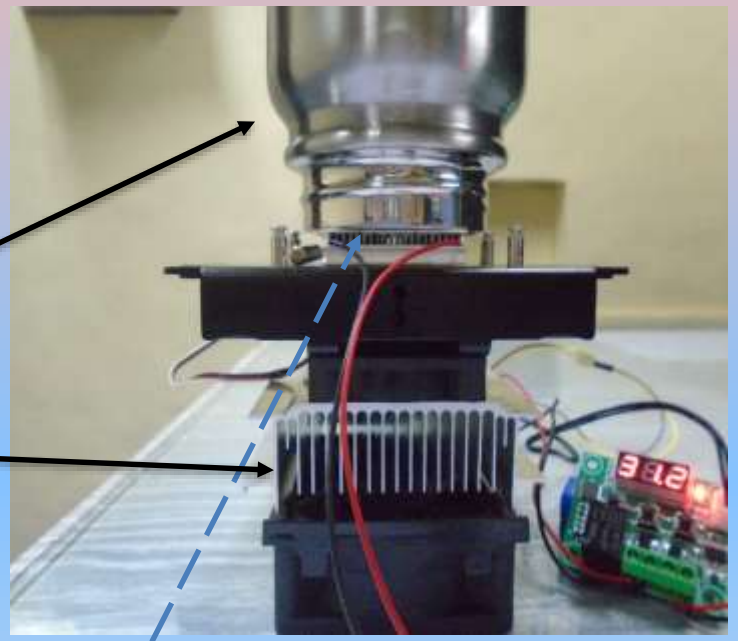
Velocity magnitude (m/s) on RTG outer surface



^{90}Sr liquid temperature vs Time



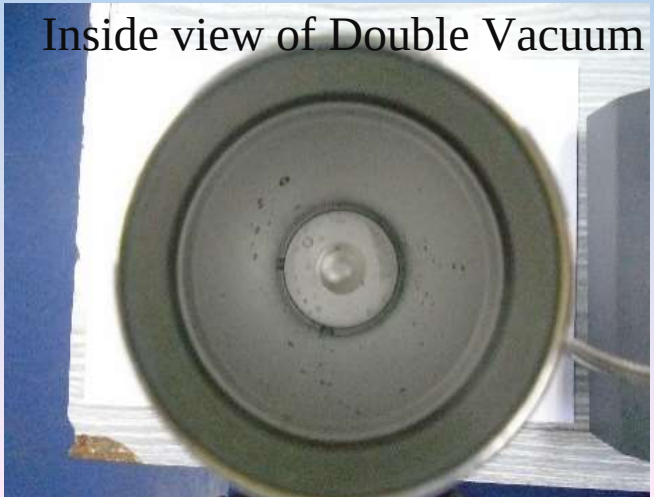
Experiments done and output is as per designed value



90 Nos of PN jun. TEG

RTG output is sufficient to glow an LED continuously

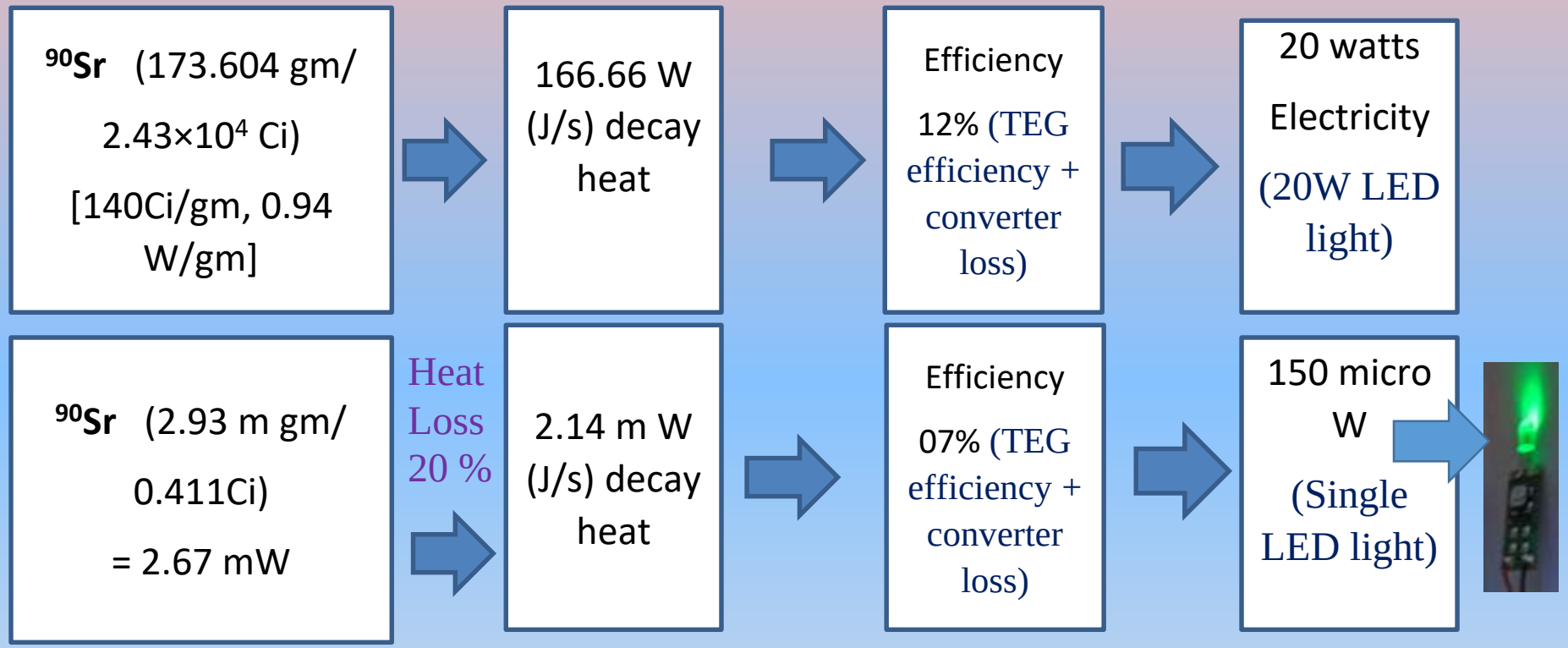
Inside view of Double Vacuum container



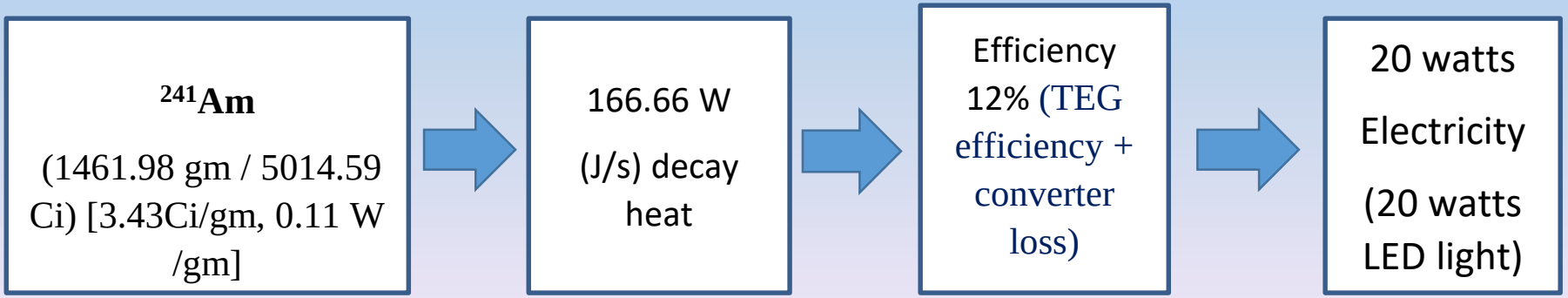
Experimental validation with inactive liquid

Thank You

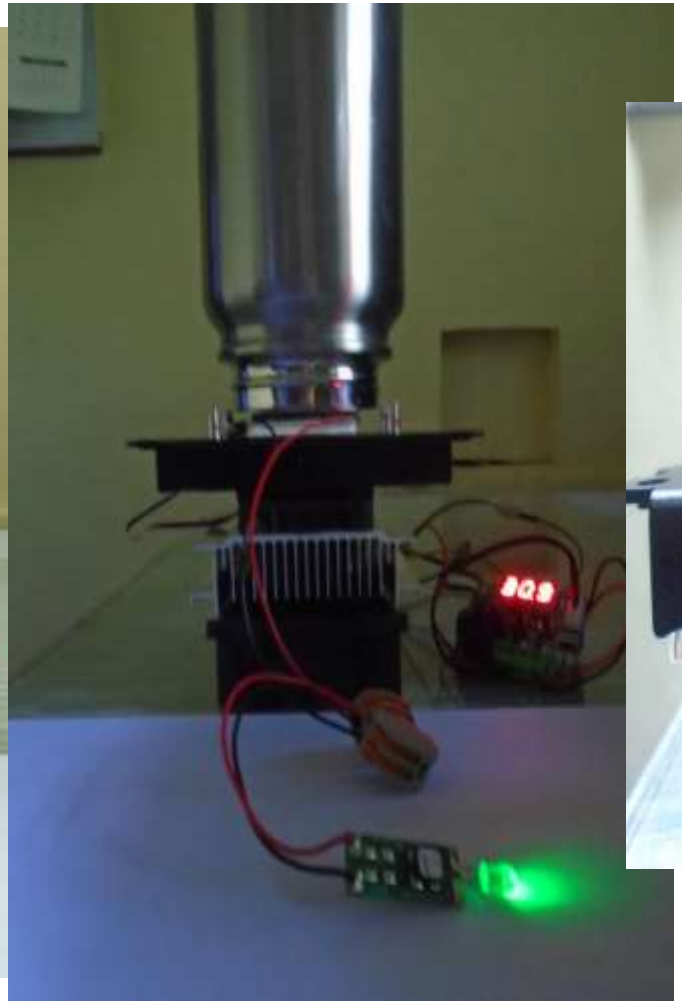
Block diagram for ^{90}Sr RTGS for 20W based electro-thermal power:



Block diagram for ^{241}Am RTGS for 20W based electro-thermal power:



20 m^3 of high level waste (HLW) treatment using ASDF (Actinide Separation Demonstration Facility), Tarapur will be adequate to recover desire amount of ^{241}Am for suitable to 20W RTG.



Design of Induction heating furnace for Cesium pencil fabrication facility

Outside Hot cell

1.5 Meter

Hot cell - 19

Hot cell - 18

3 P, 120 A MCCB

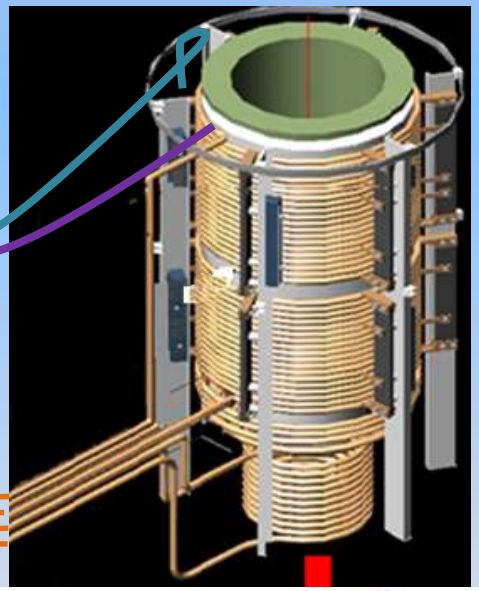
20 KW 5 KHz

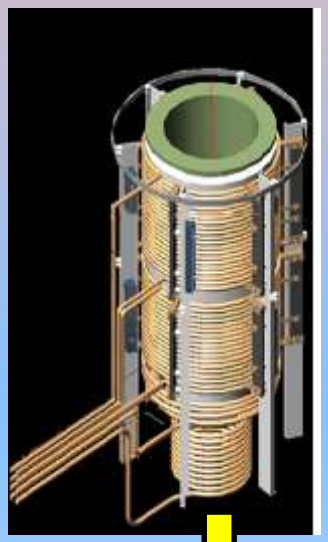
5 KW 10 KHz

Temp. Transmitter & Local Display

Cell Wall

Reheating of Cesium loaded glass





Thermo well

Cooling Water

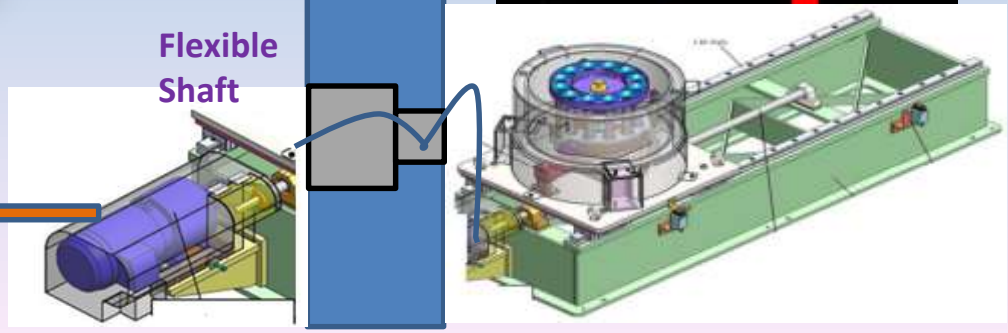
Capacitor Bank

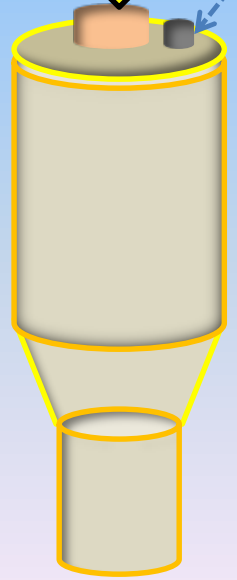
Cell Plug

Pouring Control remote pedant

Flexible Shaft

Control Panel & VFD panel

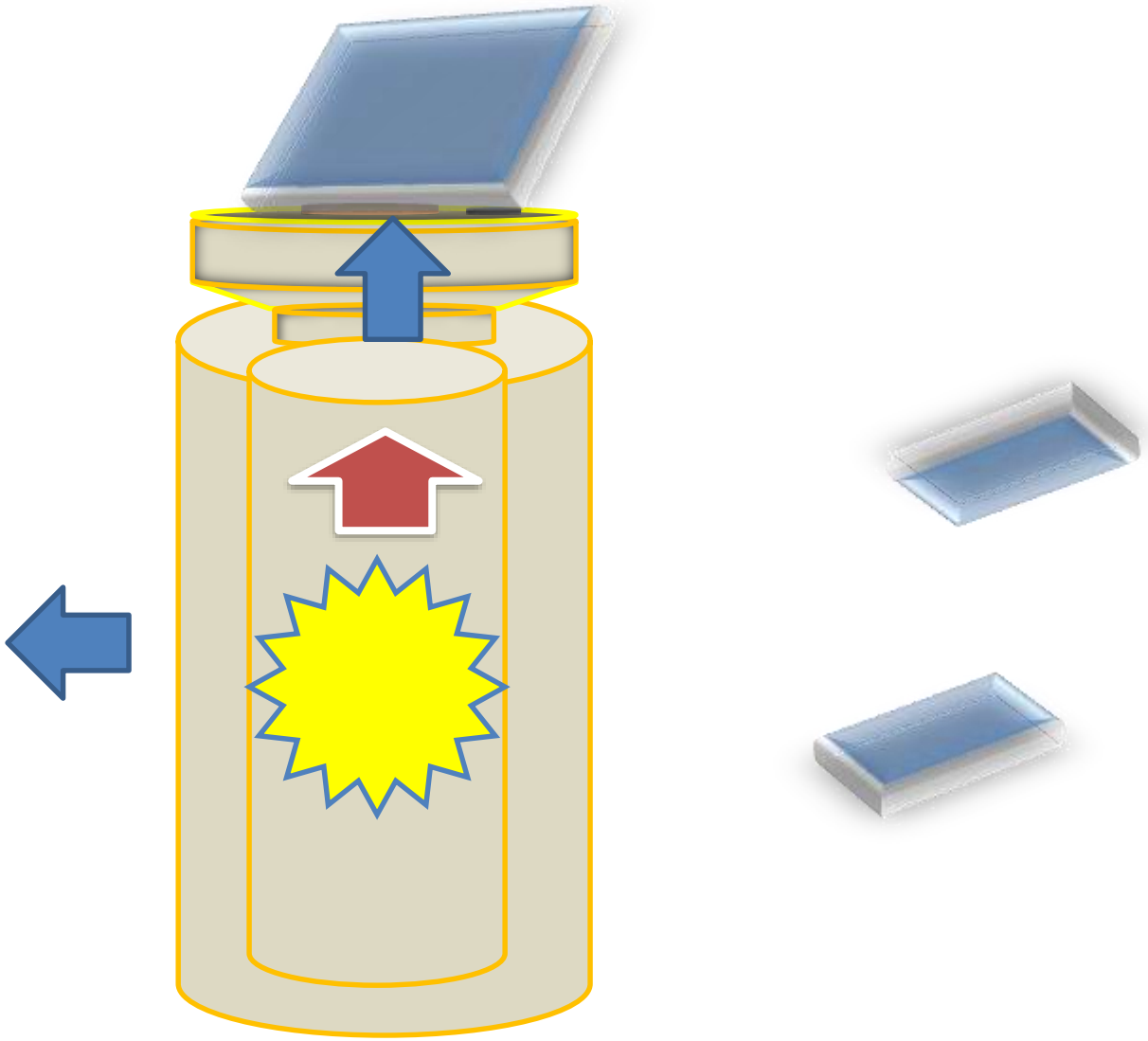




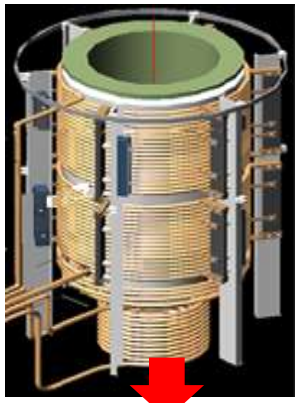
Cs process Pot

Heat loss as

1) Radiation
2) Convection
3) Conduction



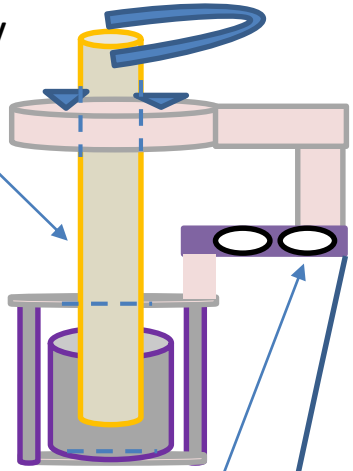
Strain
Gauge type
Load cell



Collection pot
Guide fixed
cylinder

Retrievable Load cell
Assembly

Hanging
Collection pot



Indexing
Assembly

Collection pot

Load cell

Load Cell
Assembly

Limit Switches

Base

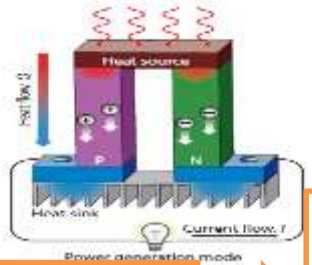
Ball Screw
Assembly

Load cell cable
Fishing out from Ho
cell Plug

Problem faced in Pencil weight measurement system during production

Development of Sr^{90} & Am ^{241} based thermoelectric generator

HLLW contains large quantity of ^{90}Sr and ^{241}Am , which can be used as a substitute of ^{238}Pu based electrical power source



Radioactive source (Sr-90, Pu-238, Am-241)

Decay Heat

TEG

DC converter

RTG O/P Electrical power

Low Efficiency (8 – 13 %)

Search for different technique to increase the thermocouple efficiency

Graphene based thermo element

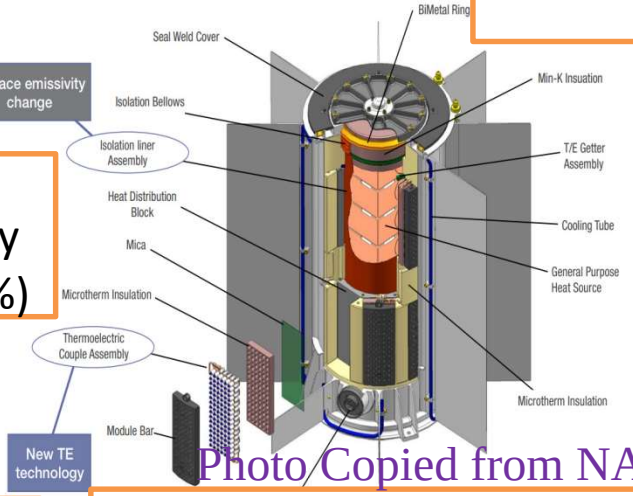


Photo Copied from NASA web.

Which Reduces overall efficiency of RTG

Due to low efficiency more amount of Radioactive source required

Application for power sources in satellites, space probes and interplanetary space mission where solar cells are not practical and where power requirement is for long duration.