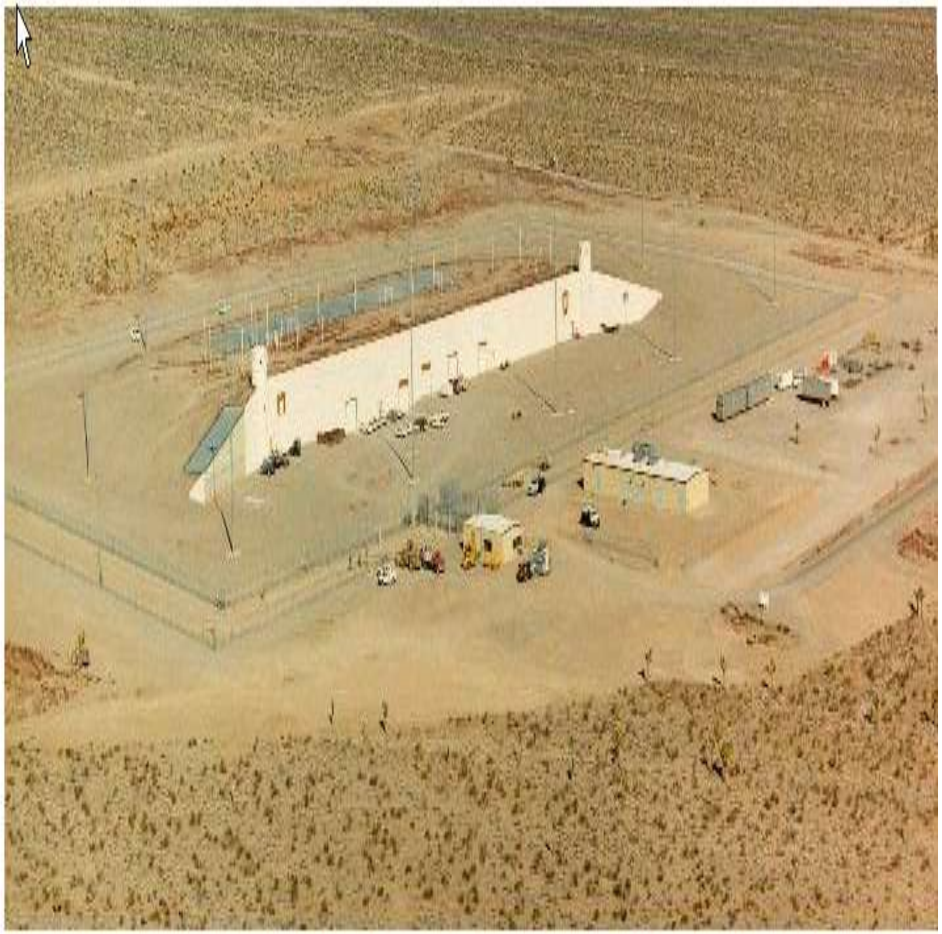

MCNP Simulations in Support of the Heat Pipe in Flat-Top Experiment

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Los Alamos NATIONAL LABORATORY

Outline

- Background
- Purpose
- Description of the Experiment
- Description of the Simulations
- Conclusions

Background

- For many years, NASA has dependably relied on radioisotope thermoelectric generators (RTGs) to power science missions

- David Poston, et al, "A Simple, Low-Power Fission Reactor for Space Exploration Power Systems," Proceedings of Nuclear and Emerging Technology for Space, February 2013.

- First experiment is performed in September 2012.

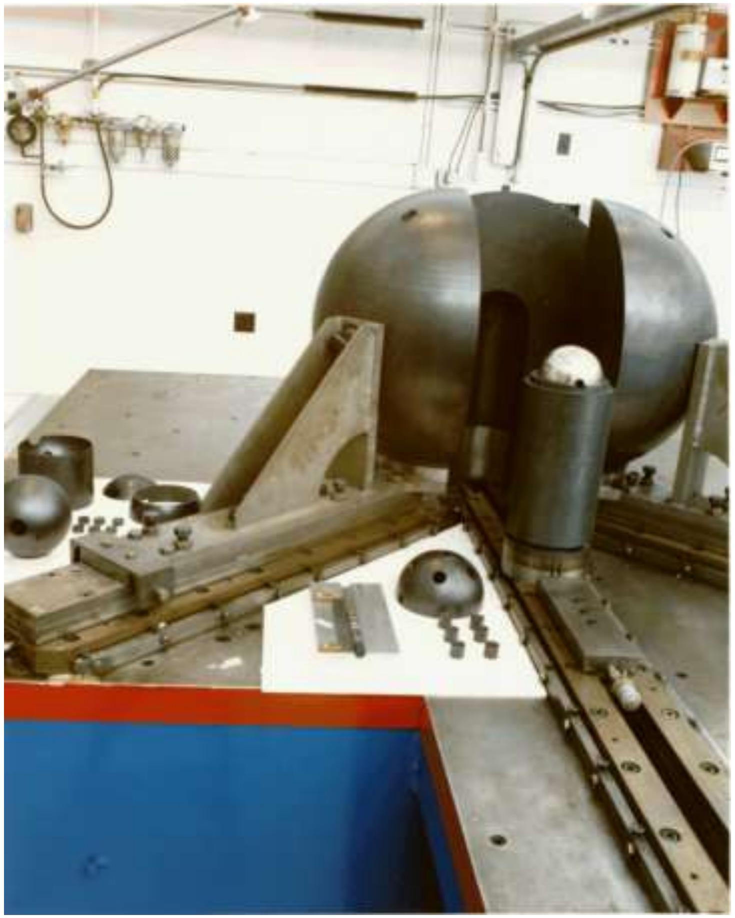
Purpose

- **MCNP Simulations in Support of the Heat Pipe in Flat-Top Experiment**

  - To demonstrate *that a heat pipe coupled to a Stirling engine could generate electricity from a nuclear generated heat source*

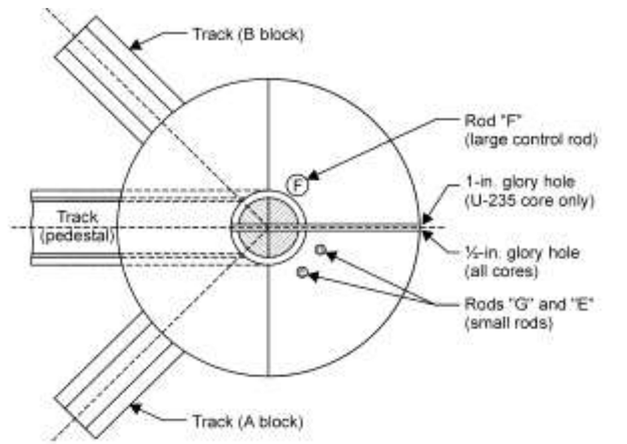
  - The simulations presented in this summary provided the basis to load the Flat-Top assembly with enough excess reactivity that would produce the energy needed for this experiment.

Flat-Top Assembly

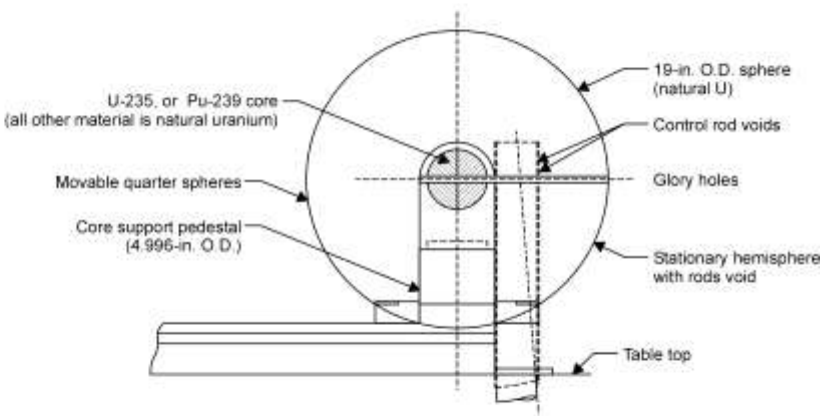


- Simple one-dimensional spherical geometry benchmark assembly that replaced the Topsy assembly at Los Alamos.
- Used originally for critical mass studies for thick uranium reflected systems in spherical geometry.
- 1000 kg natural (0.7 wt.% ^{235}U) uranium reflector
  - 500 kg hemisphere.
  - Two 250 kg quarter-sphere safety blocks.
  - Re-configurable pedestal to accommodate different cores.
- Can operate in “free run” mode up to several kilowatts
  - Temperature increases of up to 300˚C

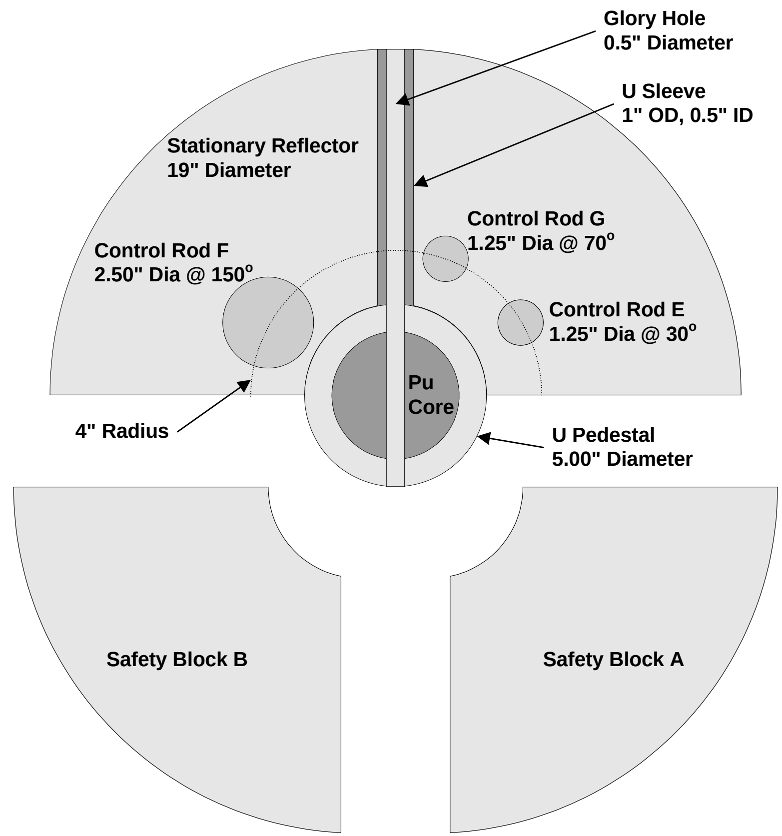
Flattop Core Design



Plan View



Elevation View



Pu Core: 3.57" Diameter
U Core: 4.77" Diameter
Rod Diameters are 13 mils less than the shown hole sizes

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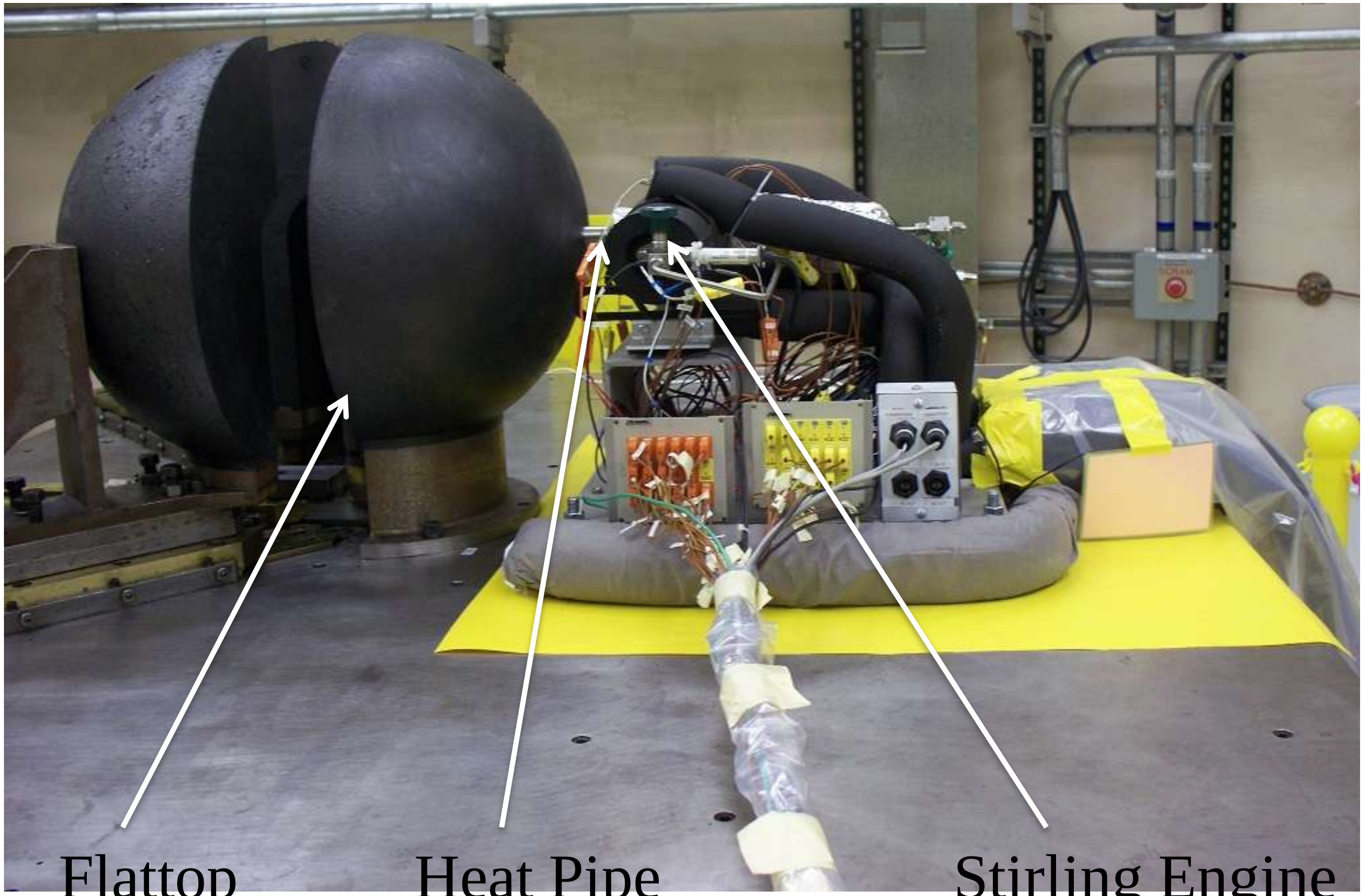
Heat Pipe in Flat-Top Assembly

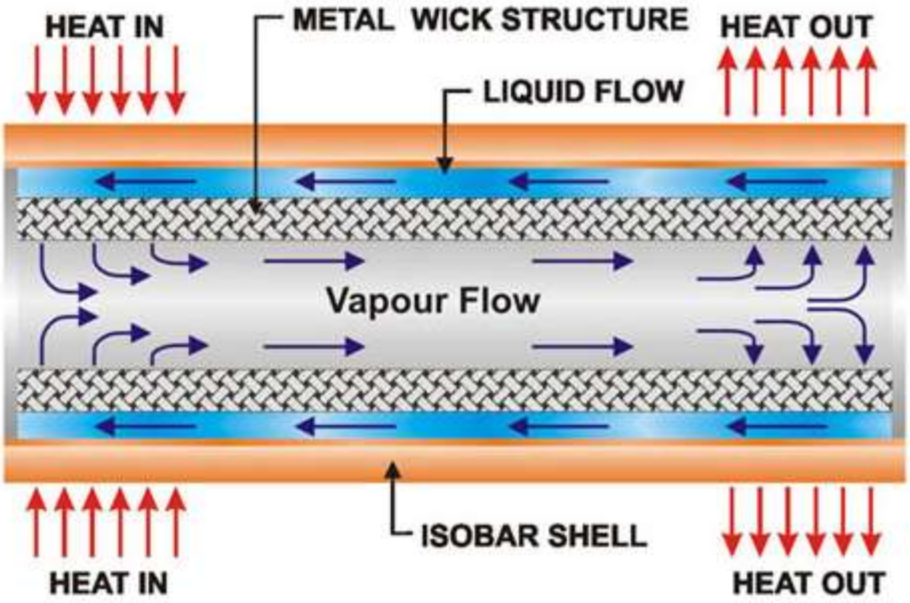
Heat Pipe in Flattop



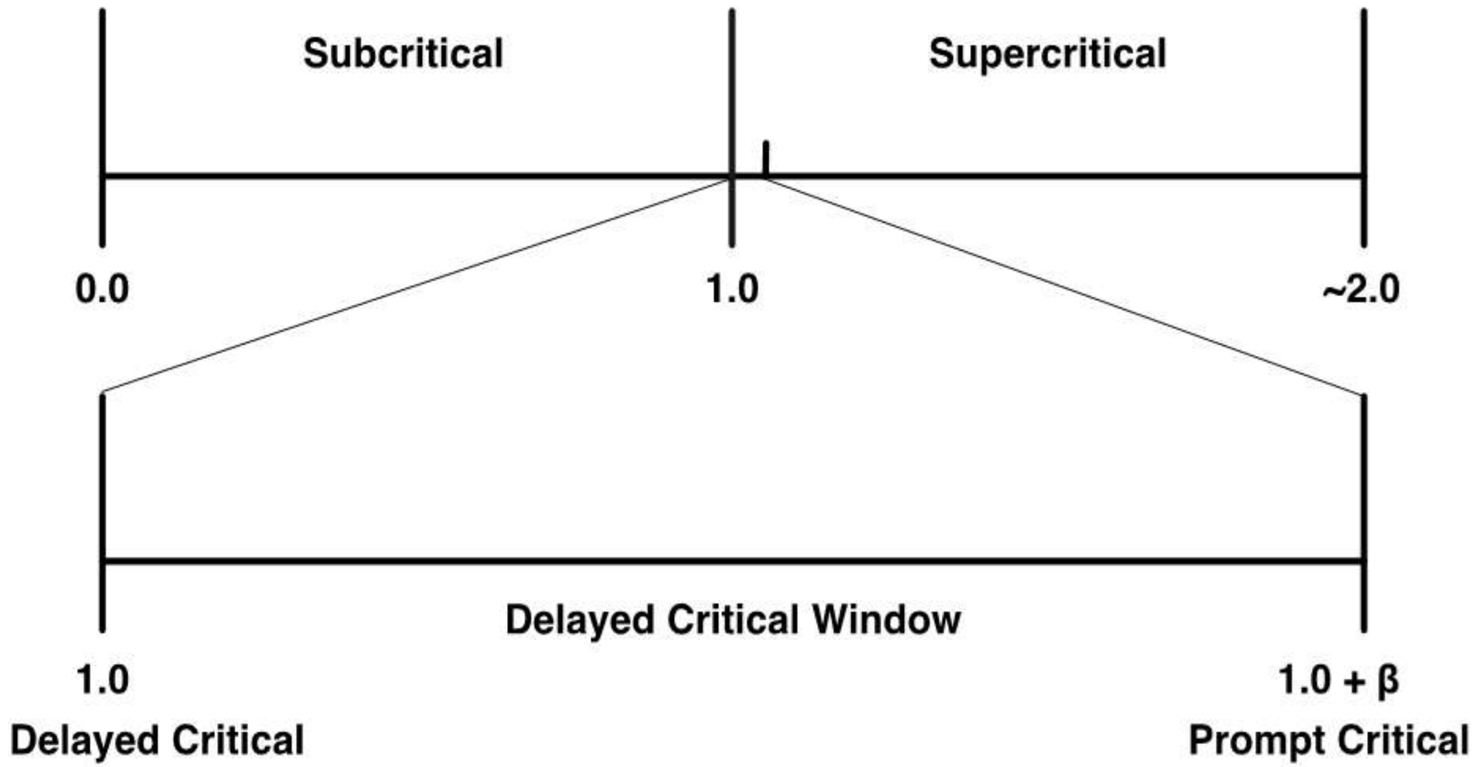
Heat Pipes

- Fabricated by Advanced Cooling Technology, Inc.
- Contained between 0.015 and 0.065 liters of water
- Approximate dimensions: 0.5-in OD and 45 inches in length
- Heat pipe is a device that is used to transfer energy from one solid surface to another

Heat Pipes


HEAT IN
METAL WICK STRUCTURE
HEAT OUT
LIQUID FLOW
Vapour Flow
ISOBAR SHELL
HEAT IN
HEAT OUT

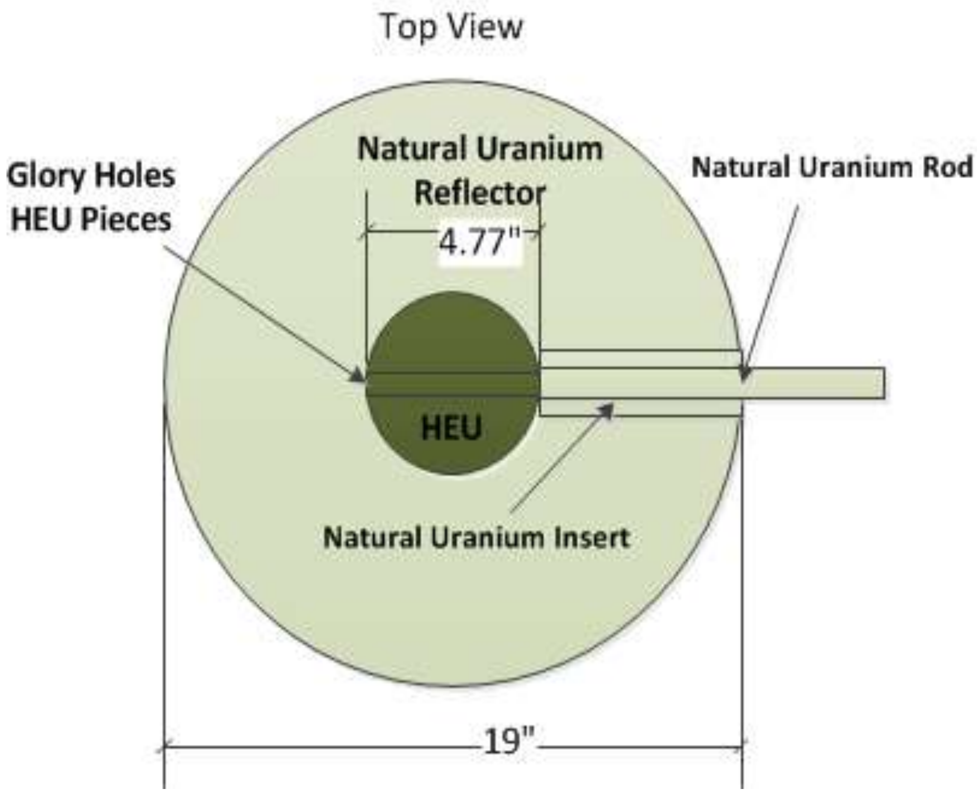
Behavior of Critical Systems



MCNP Simulations

- **The MCNP simulations were performed using ENDF/B-VII neutron cross section data**
- **Each simulation had a total of three million histories. The first 50 generations were skipped**
- **The MCNP code was operated in the k-code mode**

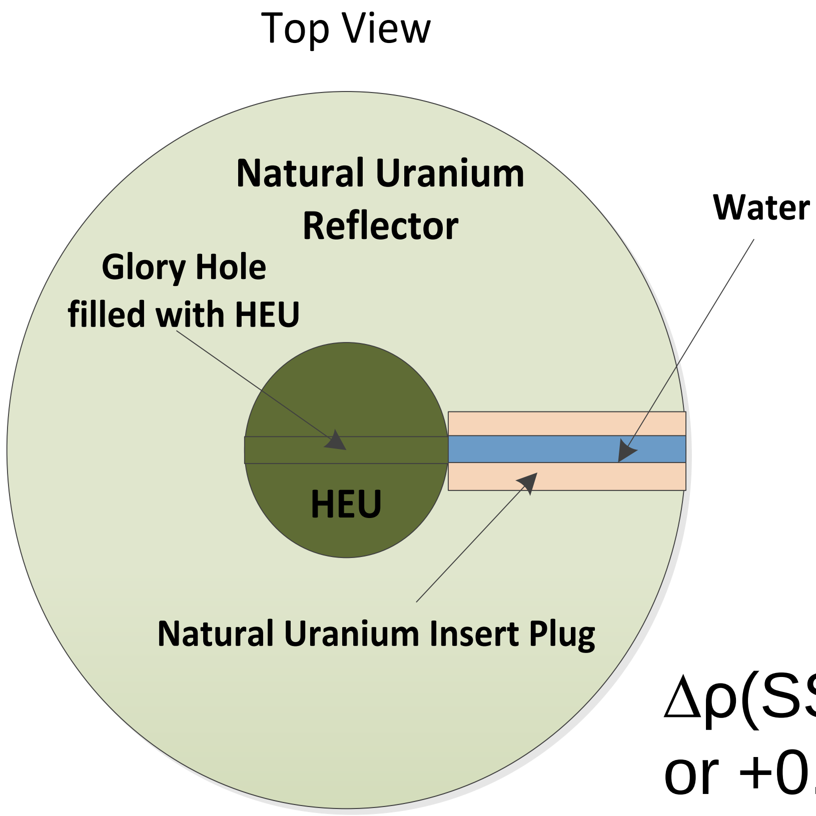
Base Case (First MCNP Simulation)



k_{eff}= 1.00004 $\pm$ 0.00038

This base case simulation represents 0.50$ $\pm$ 0.01

Second MCNP Simulation (NU rod replaced with water)



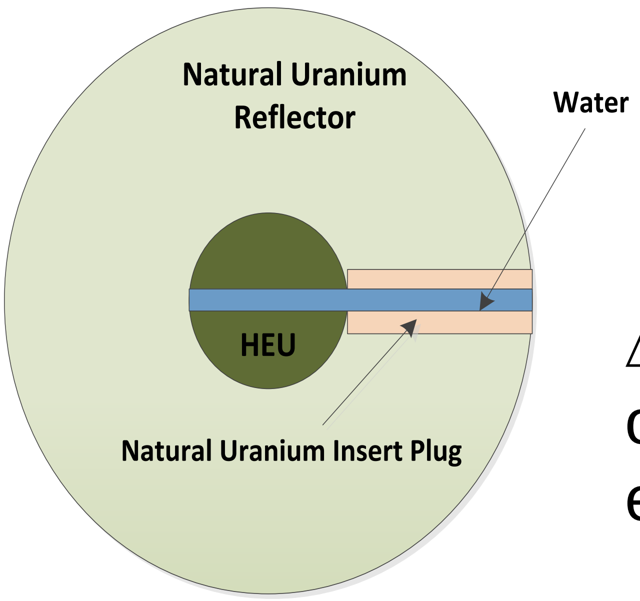
$k_{eff} = 0.99999 \pm 0.00037$

Assuming a β_{eff} of 0.00664

$\Delta\rho(\$) = (k_2 - k_1)/(\beta_{eff}\, k_1 * k_2)$

$\Delta\rho$(SS – Base Case) = -0.0075\$ $\pm$ 0.08 or +0.4925\$ $\pm$ 0.08 based on the measured excess reactivity of the assembly

Next MCNP Simulation (Entire GH and NU rod replaced with water

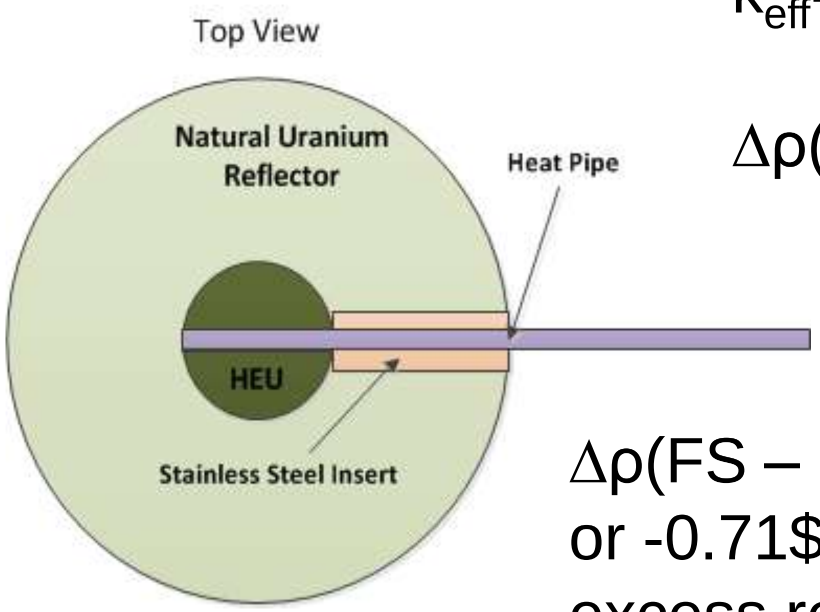


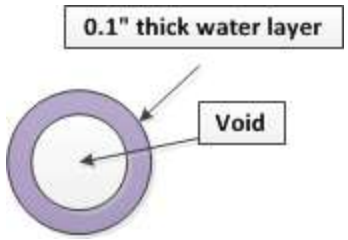
k_{eff}= 0.99438 $\pm$ 0.00037

$\Delta\rho(\$) = (k_2 - k_1)/(\beta_{eff}\, k_1 * k_2)$

$\Delta\rho$(TS – Base Case) = -0.86\$ $\pm$ 0.08 or -0.36\$ $\pm$ 0.08 based on the measured excess reactivity of the assembly

Next MCNP Simulation (Heat Pipe in the GH)



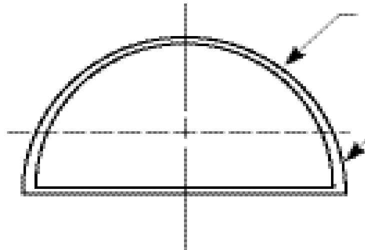


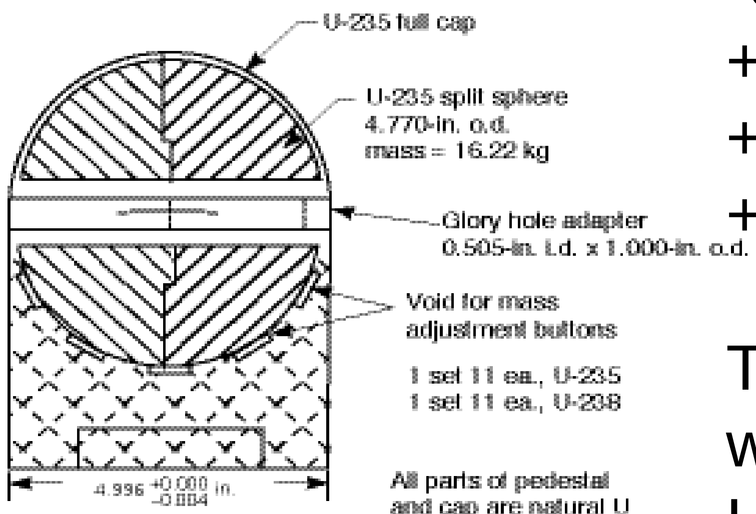
$k_{eff} = 0.99210 \pm 0.00029$

$\Delta\rho(\$) = (k_2 - k_1)/(\beta_{eff}\, k_1 * k_2)$

$\Delta\rho$(FS – Base Case) = -1.21\$ $\pm$ 0.07 or -0.71\$ $\pm$ 0.07 based on the measured excess reactivity of the assembly

Split cap vs Full HEU Cap





Based on the previous simulation

-0.71$ ± 0.07 (hp with Split Cap)
+1.52$ ± 0.01 (hp with Full Cap)
+0.81$ ± 0.07
+0.81$ ± 0.15 (hp water content)

The measure excess reactivity with heat pipe in place and Full HEU cap was 0.67$ ± 0.01

Temperature Coefficient of Reactivity

$$\frac{\Delta\rho}{\Delta T}(¢/°C)$$

Negative – temperature reactivity quench
Positive – autocatalytic or divergent reaction

Assembly	Approx. Temp. Coeff.
Godiva IV, Big Ten, Flattop U	-0.3 (¢/°C)
Flattop delta phase Pu	-0.2(¢/°C)
SHEBA U(5) solution	-4.0 to -10.0 (¢/°C)
CNPS(U(20)O_2-C matrix	-1.2 (¢/°C)

Contributions from expansion, Doppler shifts, geometry changes

$$\Delta T = \frac{\Delta\rho}{\Delta\rho/\Delta T} = \frac{0.67\$}{0.003\$/°C} = 223.3°C$$

Conclusions

- Simulations agreed quite well with the experimental value of reactivity

- The experiment was planned, designed and executed in a three months

- The experiment was successful in producing electricity by using the heat pipe to transfer the heat from the core to the Stirling engine