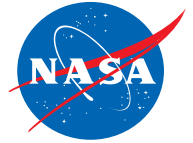


# Titanium-Water Thermosyphon Gamma Radiation Exposure and Results

Titanium-water thermosyphons are being considered for use in heat rejection systems for fission power systems. Their proximity to the nuclear reactor will result in some exposure to gamma irradiation. Non-condensable gas formation from radiation may breakdown water over time and render a portion of the thermosyphon condenser inoperable. A series of developmental thermosyphons were operated at nominal operating temperature with accelerated gamma irradiation exposures on the same order of magnitude that is expected in eight years of heat rejection system operation. Temperature data were obtained during exposure at three locations on each thermosyphon; evaporator, condenser, and condenser end cap. Some non-condensable gas was evident, however thermosyphon performance was not affected because the non-condensable gas was compressed into the fill tube region at the top of the thermosyphon, away from the heat rejecting fin. The trend appeared to be an increasing amount of non-condensable gas formation with increasing gamma irradiation dose. Hydrogen is thought to be the most likely candidate for the non-condensable gas and hydrogen is known to diffuse through grain boundaries. Post-exposure evaluation of selected thermosyphons at temperature and in a vacuum chamber revealed that the non-condensable gas likely diffused out of the thermosyphons over a relatively short period of time. Further research shows a number of experimental and theoretical examples of radiolysis occurring through gamma radiation alone in pure water.



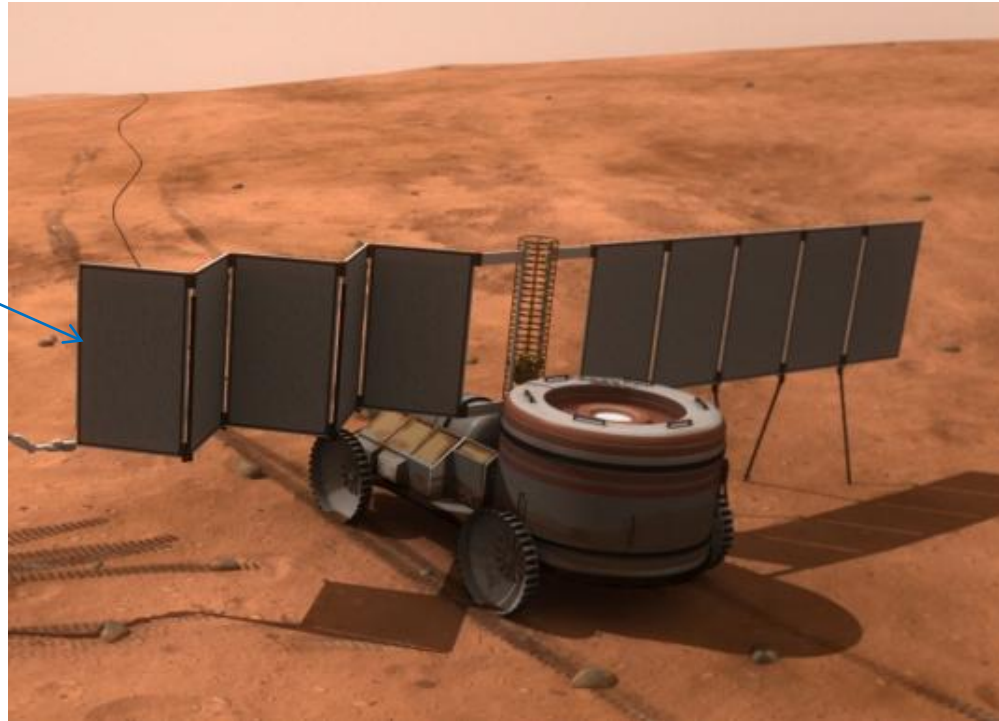
# **Titanium-Water Thermosyphon Gamma Radiation Effects And Results**

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Donald A. Jaworske  
Debra Goodenow

IECEC – International Energy Conversion Engineering Conference  
July 30 – August 1, 2012

# Introduction

**Heat Pipe -  
Thermosyphon  
Radiator Panels**

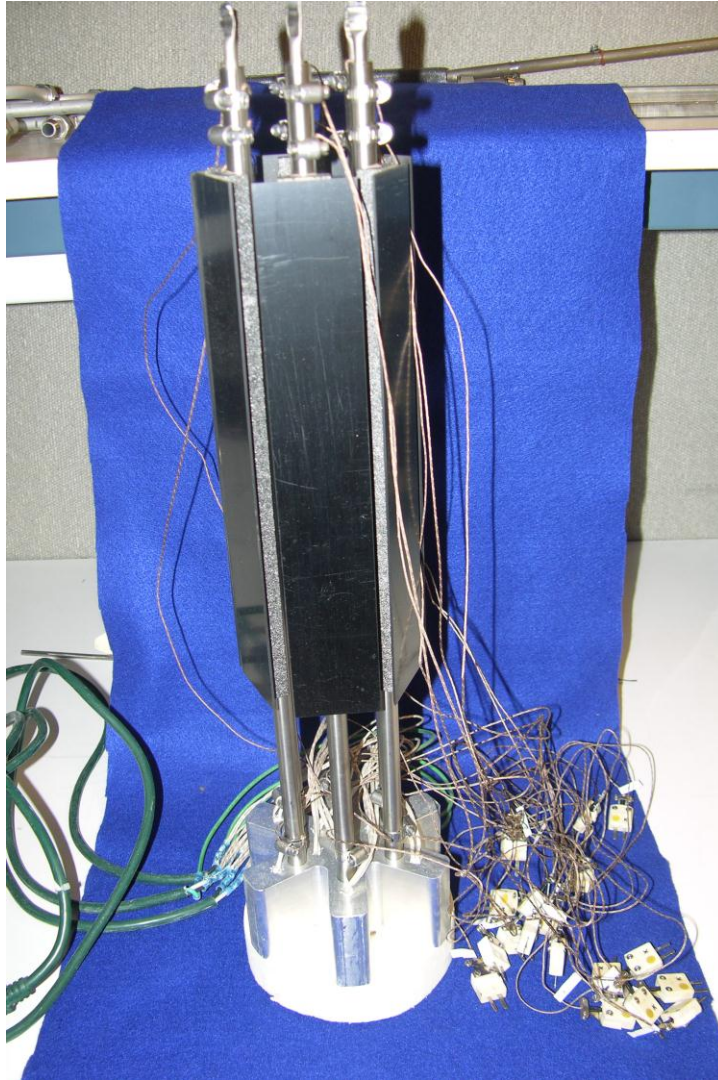


**Artist's concept of a fission power system on Mars**

# Introduction

- Titanium-water thermosyphons are being considered for use in heat rejection systems for fission power systems.
- Hardware was built and tested for the potential concern that noncondensable (NCG) gas may evolve due to the proximity to the reactor and radiolysis of the water.
  - Hydrogen and hydroxyl radicals are created
  - Radicals either follow a pathway where numerous hydrogen and oxygen species are formed, or
  - Recombine to form water
- The test hardware built were titanium-water thermosyphons with foam saddles, carbon fiber polymer matrix fins, and bonded with epoxy.
  - Instrumented with thermocouples
  - Temperature differences were used to identify presence or absence of non-condensable gas
- The hardware was exposed to gamma irradiation at the Sandia National Laboratories (SNL) Gamma Irradiation Facility (GIF).

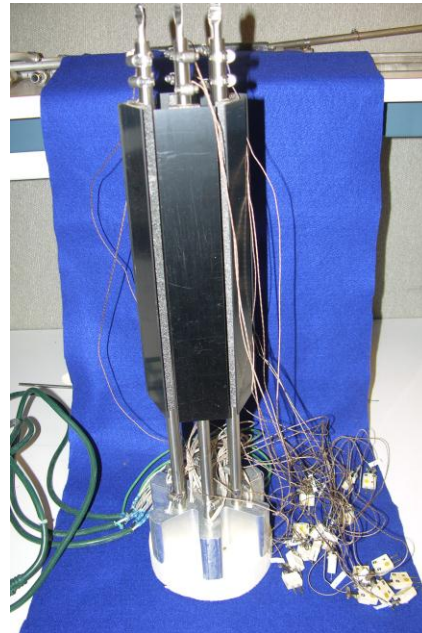
# Thermosyphon Test Article



- Ten Titanium –water thermosyphons
- POCO foam saddle
- Carbon fiber polymer matrix fin
- Silver filled epoxy: bonding fin to saddle, bonding saddle to thermosyphon
- Aluminum heater block with cartridge heaters
- Type K thermocouples with ceramic plugs
- Setup used for initial and radiation testing
- Thermoluminescent Dosimeters (TLD) mounted top mid and bottom

# Gamma Radiation Facility

- Test article exposed to Co-60 source at Sandia National Labs
- The thermosyphons are arranged in a circular pattern and could be removed and replaced easily
- The thermosyphon locations and duration determined the cumulative radiation exposure



Co 60 source

56 cm

12 o'clock  
(TS 15)

(TS 5)  
(TS 8)

(TS 14)  
(TS 3)

(TS 12)  
(TS 9)

(TS 4)  
(TS 2)

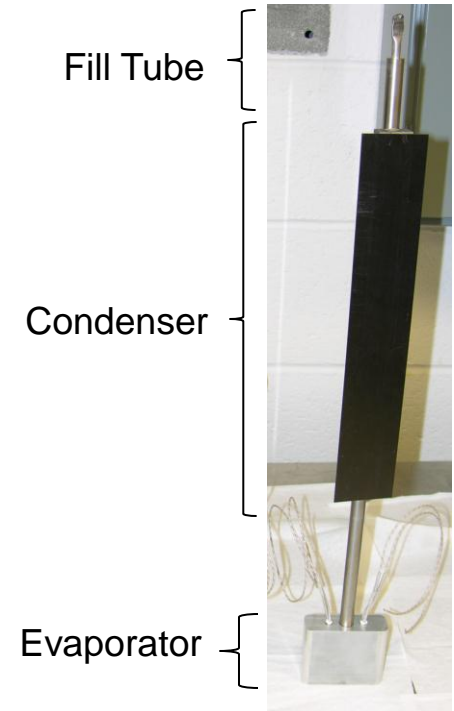
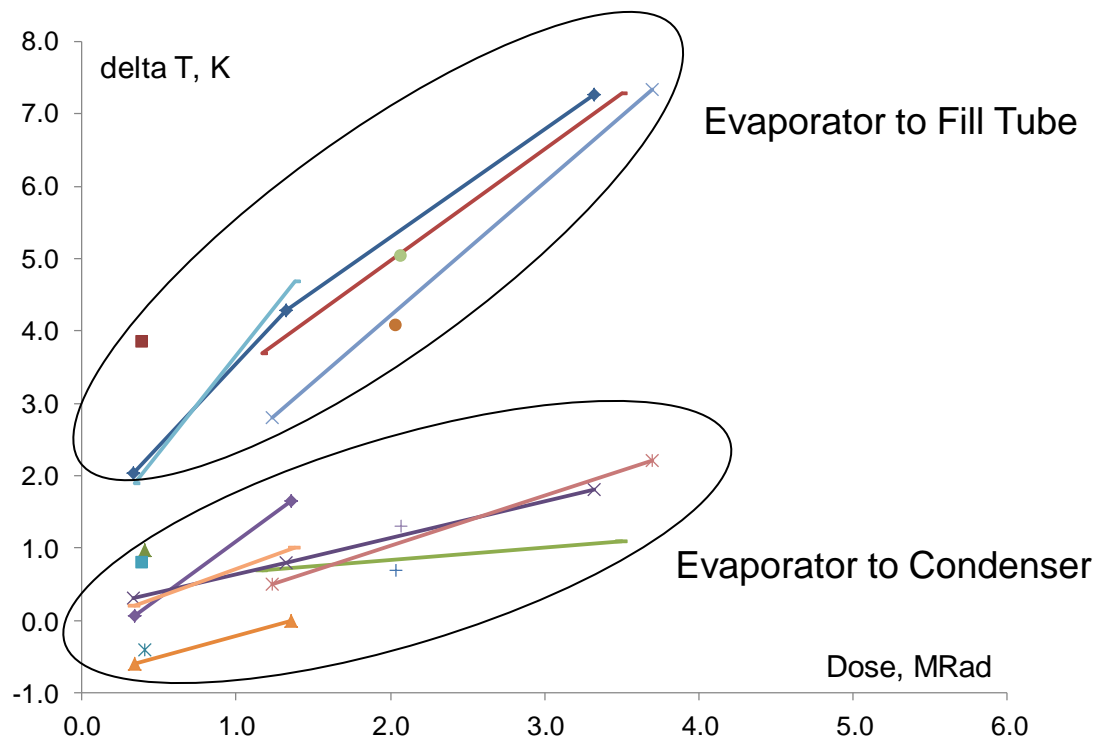
(TS 6)

# Predicted and Accumulated Dose per Thermosyphon

Predicted Dose Mrad-Si (SNL)	Predicted Dose Rate R/Sec	Time	Thermosyphon numbers	Cumulative dose Mrad-Si (Thermosyphon No.)
TLD		10	4,5,6,12,14,15	
0.5	175	47.6	4,5,6,12,14,15	0.3 (5,14)
1.5	175	142.9	3,4,6,8,12,15	1.3 (4,12)
3	175	285.7	2,3,6,8,9,15	2.0 (2,9)
TLD		10	2,3,6,8,9,15	3.5 (3,8)
				4.1 (6,15)

•Thermosyphon 15 exhibited thermocouple error and was omitted from the results and discussion

# Delta T versus Dose (Si)



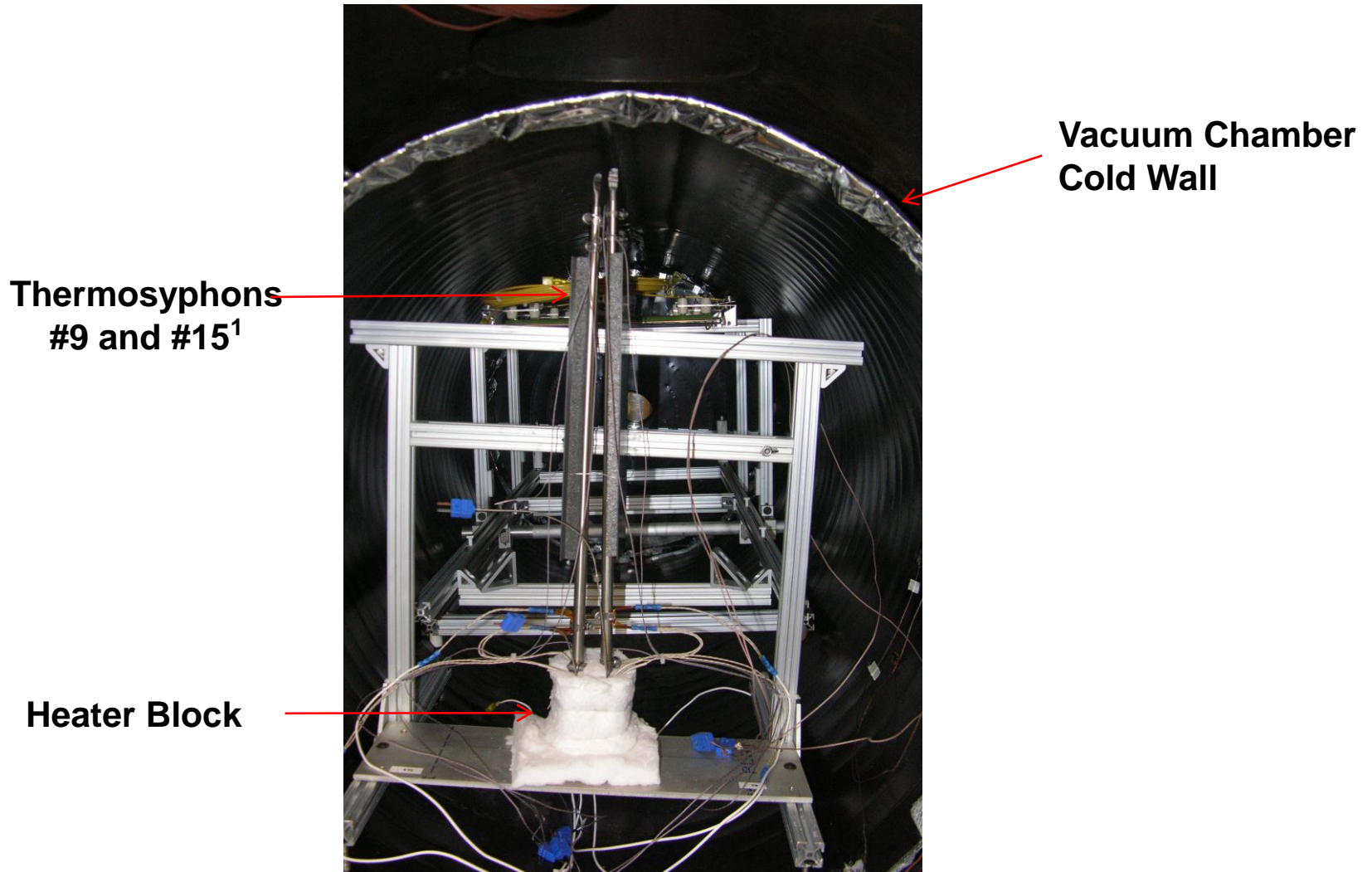
- Non-condensable gas is forming but has a negligible effect on heat rejection



# Gamma Radiolysis

- Radiolysis is the disassociation of water into hydrogen and hydroxyl radicals through energy imparted by incident radiation.
- First thought that recombination of radicals would dominate, however, research indicated a number of cases (both theoretical & experimental) where the chemical pathway to form hydrogen (and various oxygen species) dominated.
- The noncondensable gas accumulated at the top of the thermosyphons is thought to be hydrogen.
- NCG detected by temperature difference,  $\Delta T$ , increasing with dose.
- Though a small amount of hydrogen was generated from the radiolysis of water, thermosyphon performance was not affected.
- Thermosyphons were tested to the dose equivalent for an 8 year mission.
- A test was conducted to determine if the NCG would diffuse through the thermosphon envelope.

# Post Radiation Thermal Vacuum Test



<sup>1</sup>TS 15 exhibited spurious thermocouple error and was omitted from results and discussion.

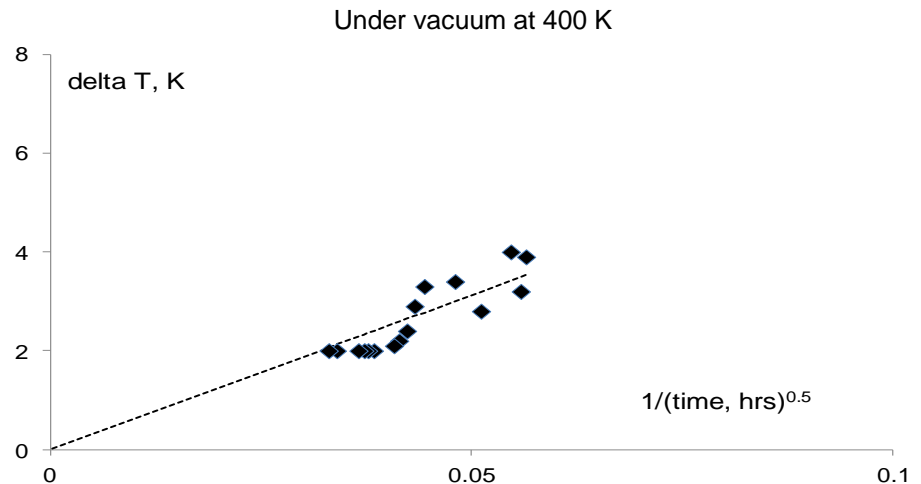
# Fick's Second Law of Diffusion

- Fick's Second Law summarizes diffusion from a finite source of atoms, that is, the interior of the thermosyphon:

$$C(t) = B/(\pi Dt)^{0.5}$$

where concentration in the source,  $C$ , at a given time ( $t$ ) is a function of the total number of atoms diffusing,  $B$ , the diffusivity of the atoms,  $D$ , and time,  $t$ .

- Assuming the quantity of noncondensable gas is proportional to the  $\Delta T$ , as measured, the data suggest that about half of the noncondensable gas diffuses out of the system in a few hundred hours.



# Conclusions

- Titanium-water thermosyphons were operated at 400 K in a gamma irradiation exposure environment simulating the order of magnitude that might be expected in eight years of fission power system heat rejection system operation.
- Data collected during gamma irradiation indicated the formation of some noncondensable gas (NCG) in all of the titanium-water thermosyphons tested.
- The amount of NCG was so small that the heat rejection of the thermosyphons was not affected.
- Fick's second law of diffusion showed that hydrogen diffusion at temperature was rapid compared to hydrogen generation over the anticipated 8 year lifetime of the system.
- All aspects of the thermosyphon radiator, including the epoxy with silver filler used for bonding, the Poco graphite saddle, and the polymer matrix composite face sheet, appeared durable to the exposure environment.

# Acknowledgments

- The authors thank Robin Sharpe for his thoughtful preparations at Sandia National Laboratories prior to our visit and for serving as host while at the Gamma Irradiation Facility.

