Titanium-Water Thermosyphon Gamma Radiation Effects

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Introduction: Titanium-water thermosyphons (TS) are being considered for use in heat rejection systems for fission power systems.[1] Their proximity to the nuclear reactor will result in some exposure to gamma irradiation. Non-condensable gas formation from radiation could breakdown water over time and render a portion of the thermosyphon condenser inoperable. Exposure to gamma irradiation was achieved at the Sandia National Laboratories (SNL) Gamma Irradiation Facility (GIF).

The 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. A decrease in temperature near the condenser end cap compared to the evaporator serves to indicate that the non-condensable gas is beginning to infringe on the working fluid at the condenser. Though non-condensable gas was evident, 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.

Materials and Methods: The experiment consisted of a cartridge heater-equipped heater block that held six thermosyphons at a time. Each thermosyphon was equipped with a Poco graphite foam saddle and graphite fiber/ isocyanate resin polymer matrix composite fin bonded to the thermosyphon utilizing Master Bond, Inc., EP30HT-LO epoxy doped with silver powder. A ceramic base was bolted to the bottom of the heater block to provide insulation.

The thermosyphons were arranged in a hexagonal pattern with cartridge heaters on either side of each evaporator, as shown in Figure 1. The heater block was machined to allow simple removal and replacement of the test articles. For each titanium-water thermosyphon exposed, thermoluminecsent detectors were attached (top, middle, bottom) to the thermosyphon; the counts for all three heights were averaged and a single dose was calculated with respect to silicon.

One thermoluminescent detector (TLD) run of 10 minutes followed by three sequential exposures of 48, 143, and 286 minutes and a final TLD run of 10 minutes constituted the complete duration of exposures obtained.

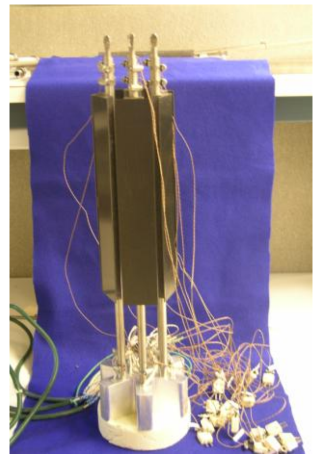

Figure 1. Thermosyphon Test Article.

The first TLD run of 10 minutes was utilized for facility documentation and was considered negligible in all subse-quent calculations. The last TLD run of 10 minutes was utilized for calculating accumulated dose. Doses were selected to bracket the expected doses anticipated in actual lunar operation, though the dose rate was greatly accelerated. Prior to testing, the matrix shown in Table 1 was developed by SNL to accommodate reference 2.[2] The decision to utilize the low dose rate configuration and timetable was made at the time of installation into the GIF.

Table 1. Time Intervals for High Dose Rate and Low Dose Rate Exposures.

Exposed TS	Dose [Mrad-Si]	High Dose Rate [R/s]	Low Dose Rate [R/s]	High Time [s]	High Time [min]	Low Time [s]	Low Time [min]
1, 2, 3, 4, 5, 6	0.5	1100	175	454.5	7.6	2857	47.6
1, 2, 3, 4, 7, 8	1.5	1100	175	1363	22.7	8571	142.9
1, 2, 7, 8, 9, 10	3	1100	175	2727	45.5	17142	285.7

Table 2. Expected Dose per Thermosyphon.

TS #	Dose [MRad-Si]
5,6	0.5
7,8	1.5
3,4	2
9,10	3
1,2	5

Total dose was calculated based on location, time, and the counts obtained from the processing of TLDs. Actual values were slightly less than predicted values, with the actual dose (Si) falling in the range of 0.3 to 4.1 Mrad compared to the earlier predicted dose (Si) summarized in Table 2 and falling in the range of 0.5 to 5 Mrad.

Results: Temperature difference (delta T) was utilized as a measure of non-condensible gas formation in the condenser end of the thermosyphons. A temperature difference that is greater than one or two degrees Kelvin would suggest the presence of non-condensable gas at that thermocouple location. . Small amounts of non-condensable gas that collect only at the top of the thermosyphon do not interfere with condenser operation, being compressed there by the working fluid. Larger amounts of non-condensable gas that begin to infringe on the finned region of the condenser begin to interfere with thermosyphon heat rejection capacity.

The data indicate that most of the thermosyphons exhibited some non-condensable gas formation. The trend appears to be an increasing amount of non-condensable gas formation with increasing gamma irradiation dose. The thermosyphons exhibiting the most non-condensable gas formation was the thermosyphon closest to the Co-60 source. The data indicate nearly all of the thermosyphons have fully functional condensers with the fins being unaffected by the non-condensable gas. Only the thermosyphon exposed to the maximum dose has a temperature difference greater than 2 K, suggesting the formation of enough non-condensable gas to begin infringing on condenser operation. Figure 2 summarizes the data by heat pipe. Also included in Figure 2 are the initial delta T values obtained on the individual thermosyphons prior to shipment to SNL. The data show that non-condensable gas formation is generally linear, as indicated by the tight bundle of data and similar slopes obtained from heat pipes 2, 3, 5,6, 8, 9, and 12. The onset of non-condensable gas formation in thermosyphon 4 appears delayed yet a similar slope is observed at greater dose values.

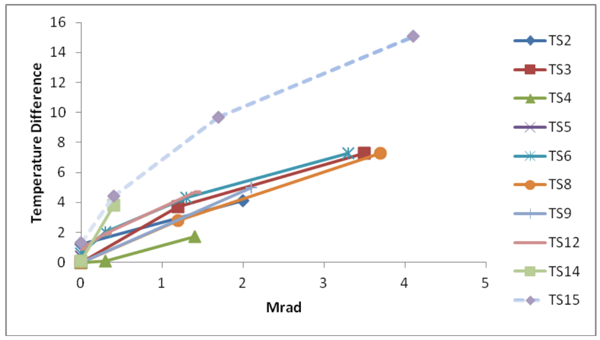

Figure 2. Evaporator to fill tube temperature difference, per thermosyphon.

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 non-condensable gas in all of the titanium-water thermosyphons tested. However, the amount was so small that even at the greatest exposure the performance of the thermosyphons was not affected. All aspects of the thermosyphon radiator, including the Epotek epoxy with silver filler used for bonding, the Poco graphite used as a saddle, and the polymer matrix composite face sheet, appeared durable to the exposure environment.

References: [1] Titanium-Water Heat Pipe Radiation Effects, Milestone Report Donald Jaworske Sept. 2011
[2] L.Mason Fission Surface Power System Initial Concept Definition January 2010