Evaluations of Candidate Materials for Advanced Space-Rated Vacuum Seals to Explore Space Environment Exposure Limits

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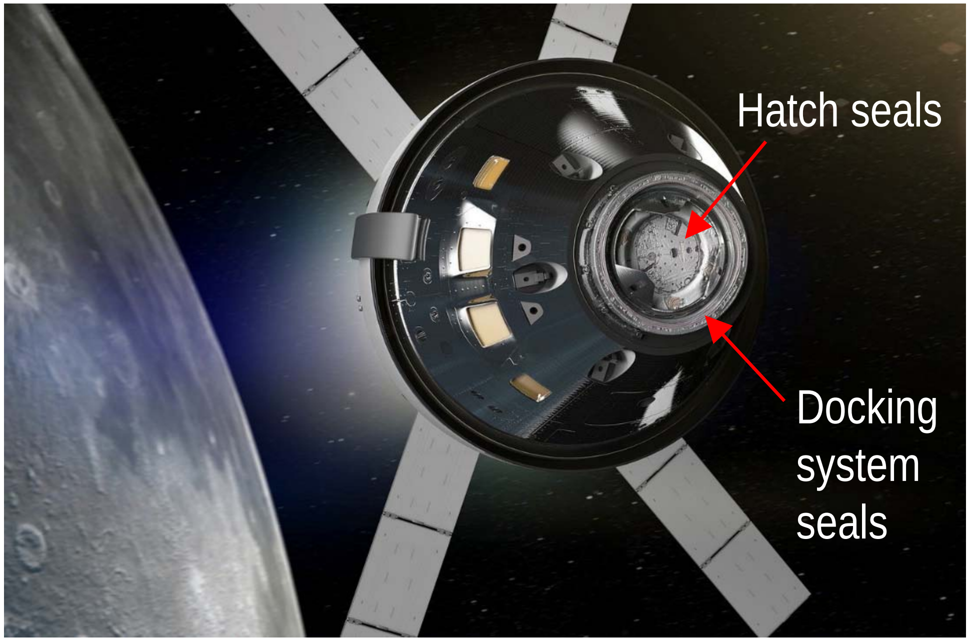
Introduction

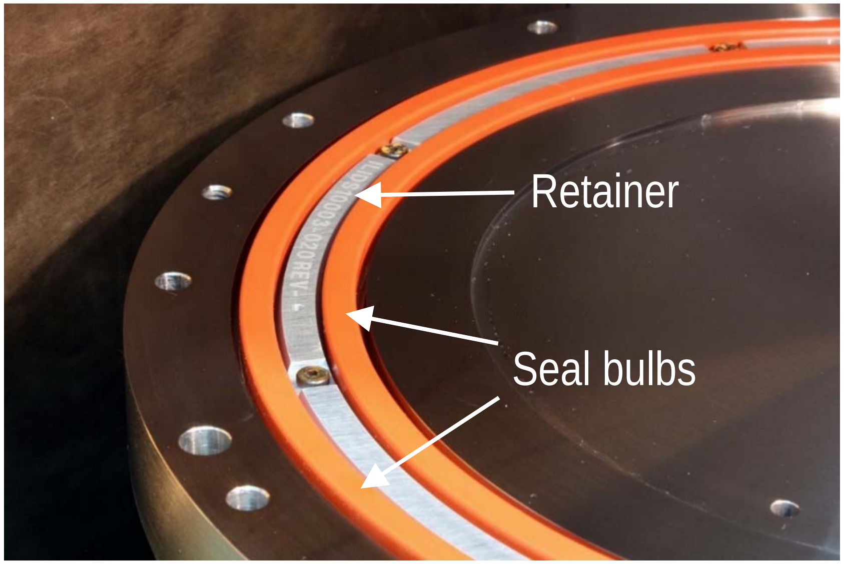


- NASA is developing advanced space-rated vacuum seals for future missions to LEO and deep space
- Seals must exhibit extremely low leak rates to ensure that astronauts have sufficient breathable air for extended missions
- In some applications seals are not mated during portions of the mission and are left uncovered and exposed to conditions in space (vacuum, atomic oxygen, ultraviolet radiation) before mating
- Exposure can cause degradation of seal material resulting in higher leak rates

Objectives & Approach

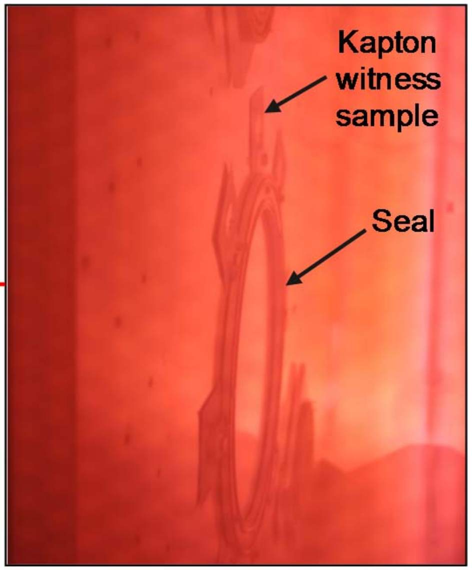
- Objectives of this study:
  - Determine if addition of titanium dioxide (TiO_2) to baseline silicone material provides protection to seals from damage caused by ultraviolet (UV) radiation exposure
  - Evaluate how much UV radiation exposure seals could tolerate and still satisfy leak rate requirements
- Approach:
  - Fabricate seals out of baseline silicone material with and without TiO_2 additive
  - Expose seals to atomic oxygen (AO) and increasing levels of UV radiation
  - Perform leak tests on seals before and after exposures

Seal Test Specimens



- Test specimens were subscale versions of multi-piece seal design:
  - Elastomer element: Two seal bulbs connected by web
  - Metallic retainer:
    - Installed between seal bulbs with periodic bosses that pass through openings in web
    - Anchors elastomer element to structure
  - Installed in groove
- Materials:
  - Baseline S0383-70 silicone
  - Baseline S0383-70 silicone + TiO_2

AO Exposures

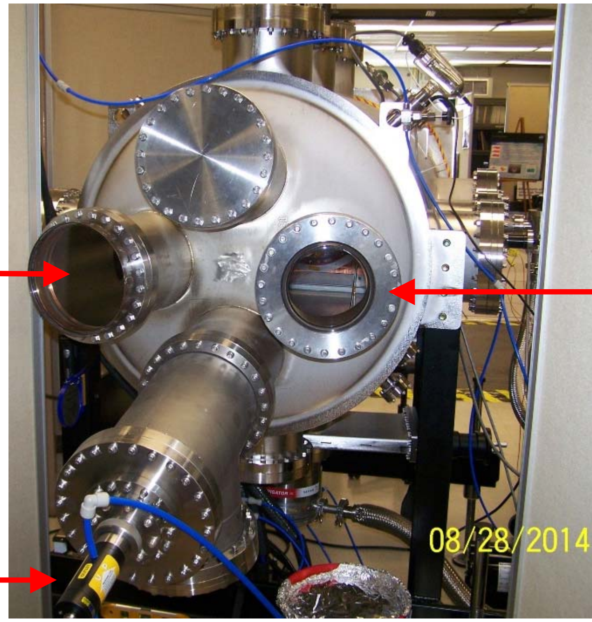


- All seals were exposed to nominal AO fluence of 8.8×10^{19} atoms/cm^2 (Kapton H) in Large Area Atomic Oxygen Exposure Facility at NASA Glenn Research Center
  - Corresponded to about two days of exposure in LEO for ram-facing (i.e., forward-facing) surfaces
  - Duration was chosen based on assumption that a vehicle would spend a short amount of time in LEO before travelling to a destination beyond LEO where AO is no longer present

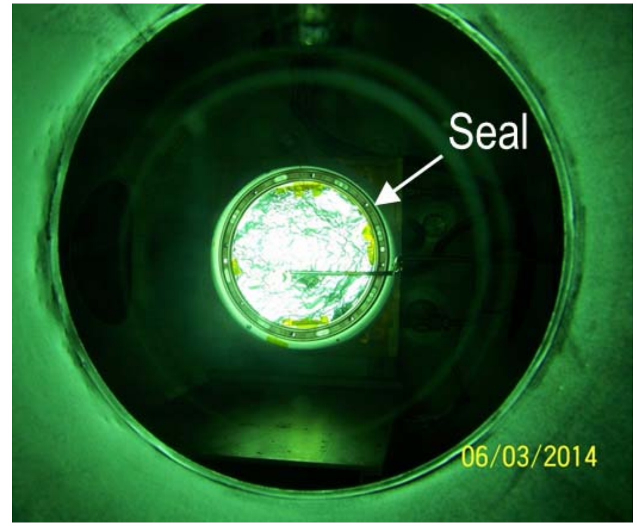
UV Radiation Exposures

NUV lamp port

VUV lamp



View port for photos and specimen alignment

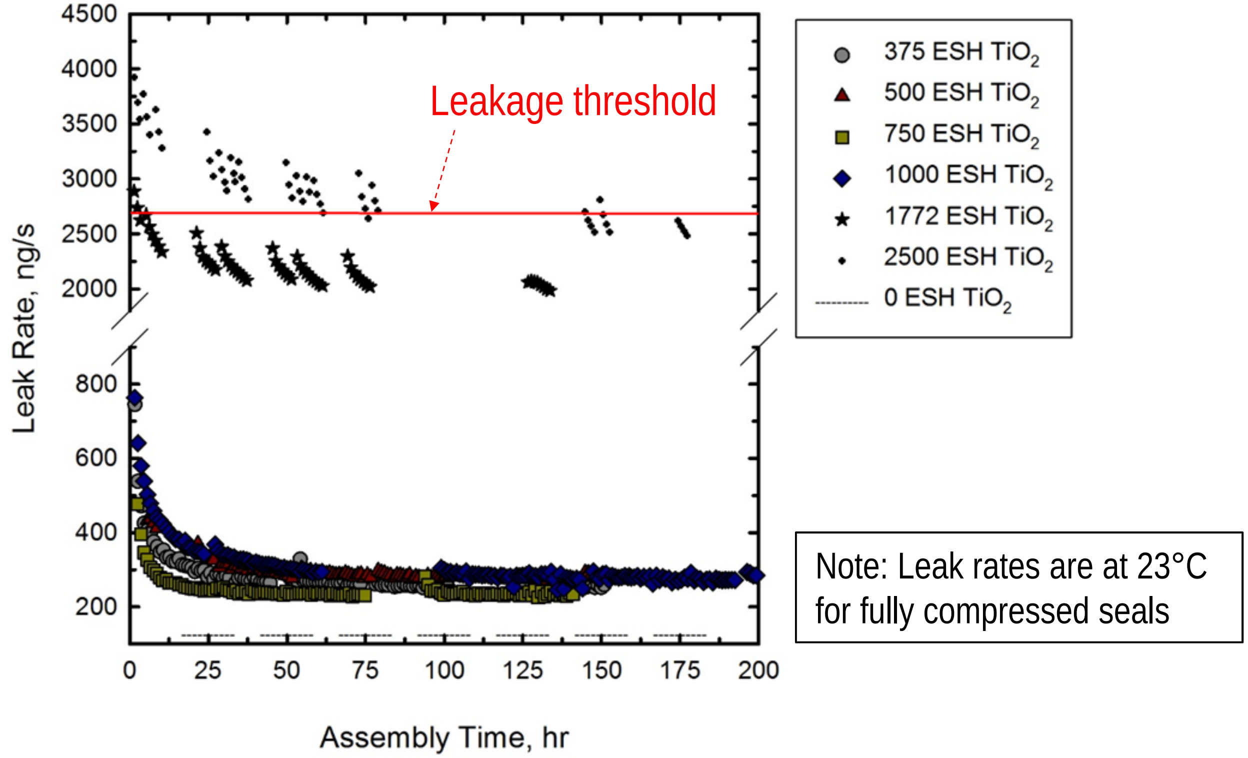


- UV radiation exposures were performed in X-25 Solar Simulator Facility at NASA Marshall Space Flight Center
- Seals were simultaneously exposed to both near UV (NUV) and vacuum UV (VUV) radiation
  - NUV: Wavelength range of 250 to 400 nm
  - VUV: Wavelengths up to ~200 nm
- Exposures were performed under vacuum

Leak Tests

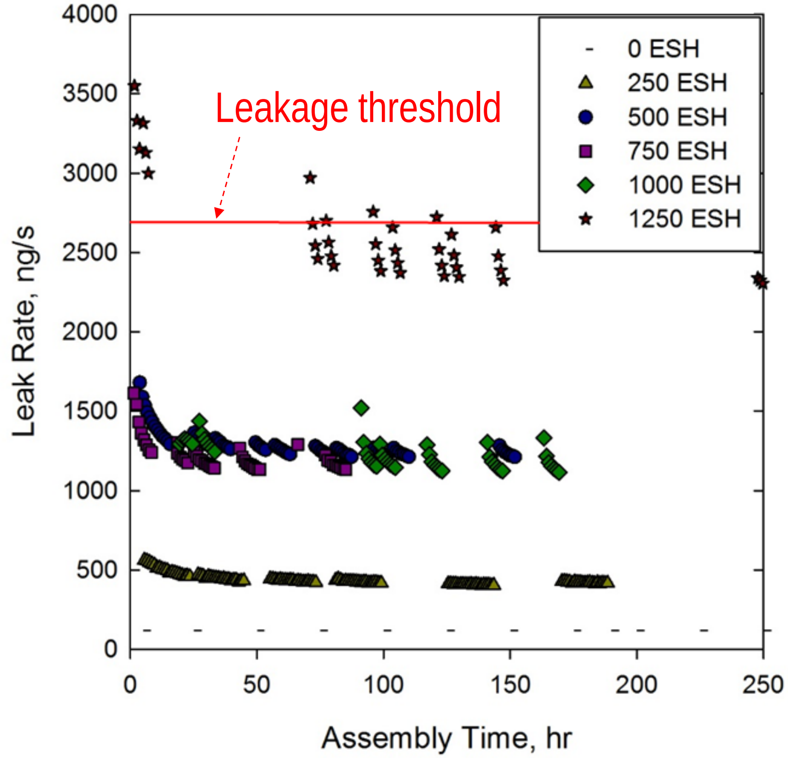
- Seals were installed in groove in bottom plate of leak test fixture and compressed against flat surface on top plate of test fixture
- Test conditions:
  - Fully and partially compressed seals
  - Most tests at 23°C (73°F); some at -7°C (19°F) and 56°C (133°F)
- Tests were performed using pressure decay methodology; leak rates were quantified using mass point leak rate technique with comprehensive error analysis
- Reported leak rates were for inner seal bulb of each test specimen

Test Results: Effects of Test Duration, Seals with TiO_2



- Leak rates for exposed seals decreased as test progressed with most of decrease in first 24 hr of test. Steady state leak rates were:
  - 35-60% of initial values for UV radiation exposures up to 1000 ESH
  - 60-70% of initial values for seals exposed to 1772 or 2500 ESH of UV radiation
- Behavior may be beneficial for long-term sealing applications as seals seem to “recover” over time from AO and UV radiation exposure
- Leak rates for unexposed seals remained constant throughout a test

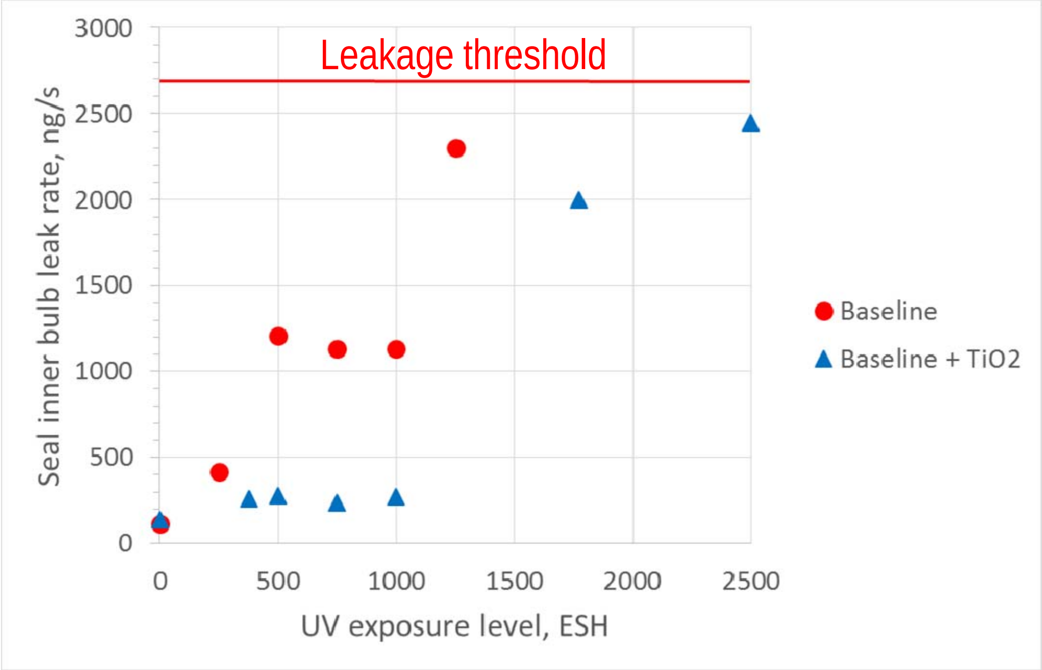
Test Results:
Effects of Test Duration, Baseline Seals



Note: Leak rates are at 23°C for fully compressed seals

- Leak rates for baseline seals also decreased as tests progressed, although magnitude of decrease was less than what was seen for seals with TiO_2 additive

Test Results: Effects of Exposure to AO & UV Radiation

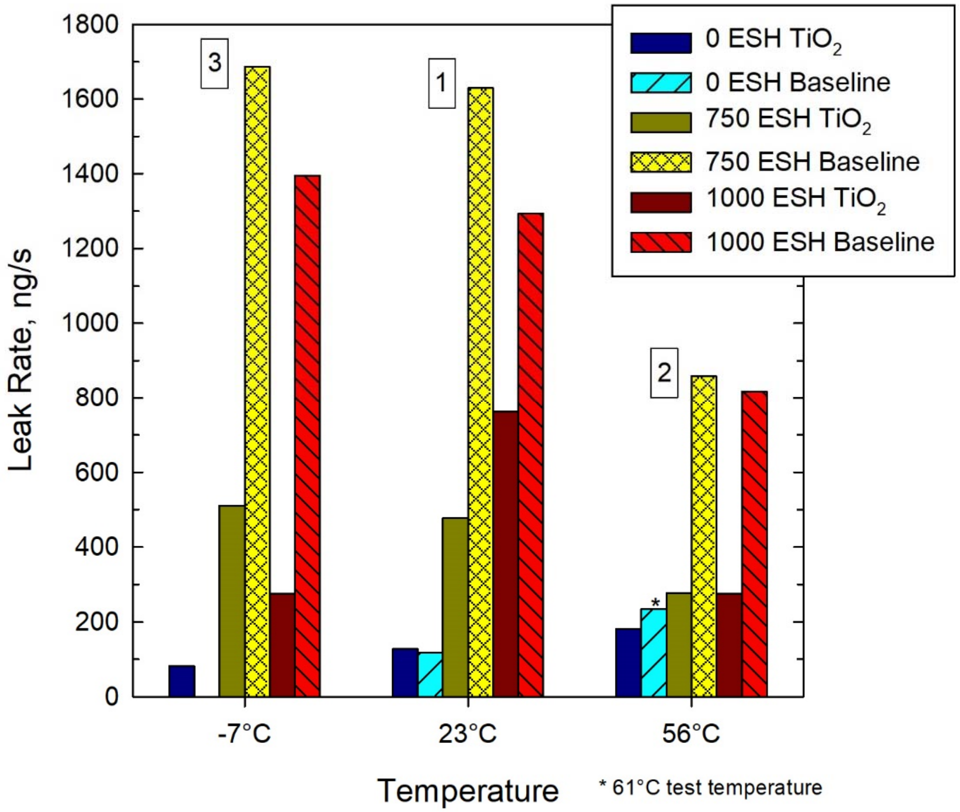


Note: Leak rates are steady state values at 23°C for fully compressed seals

- Leak rates generally increased as amount of UV radiation exposure increased
- Addition of TiO_2 to baseline seal material provided protection from damage caused by UV radiation exposure
  - For UV radiation exposure levels up to 1000 ESH, leak rates were ~4-5X higher for seals made of baseline compound than for seals with TiO_2
  - Seal with TiO_2 additive had similar leak rate after 2500 ESH UV radiation exposure as baseline seal exposed to only 1250 ESH of UV radiation

Test Results: Effects of Test Temperature

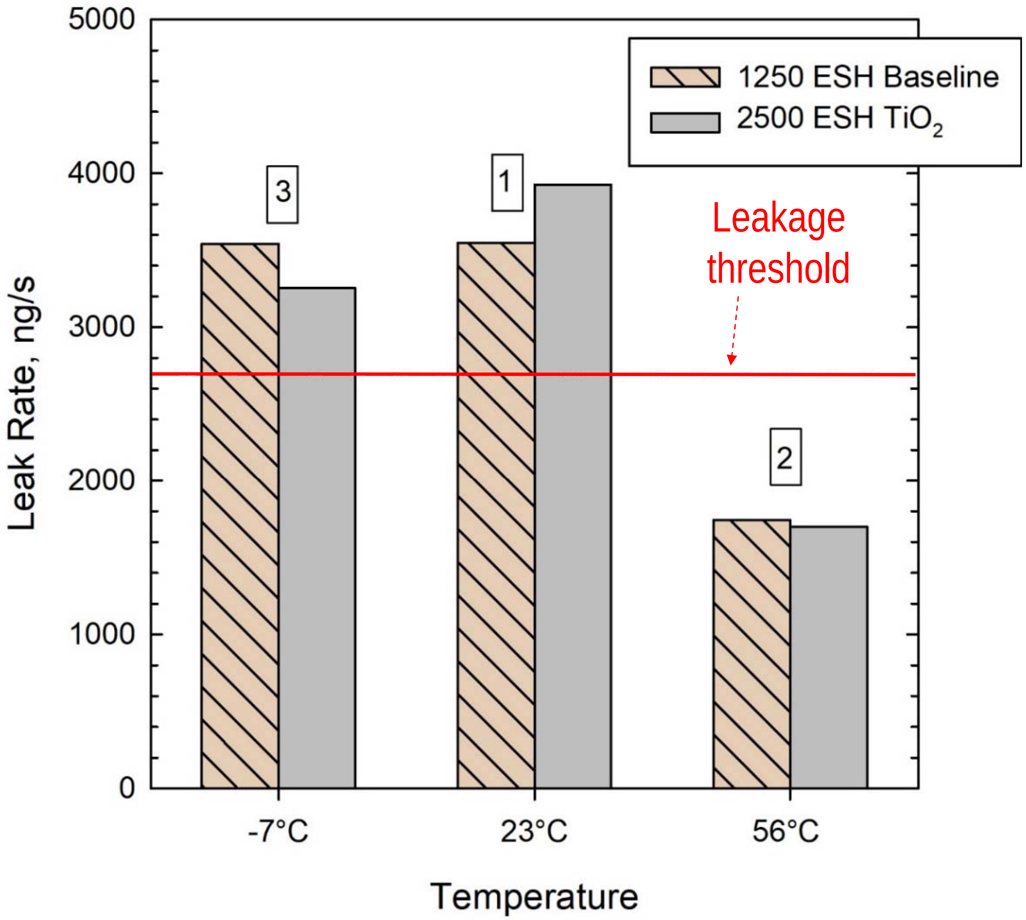
- Leak rates increased as temperature increased for unexposed seals
- However, leak rates generally decreased as temperature increased for exposed seals. Unclear why exposed seals behaved differently than unexposed seals.
- After exposure to 1000 ESH of UV radiation, leak rates at warm and cold temperatures for seals made of baseline material were 3-5X higher than those for seals made of TiO_2 material



Note: Leak rates are steady state values for fully compressed seals. Test order noted by numbered boxes.

Test Results: Effects of Test Temperature (cont.)

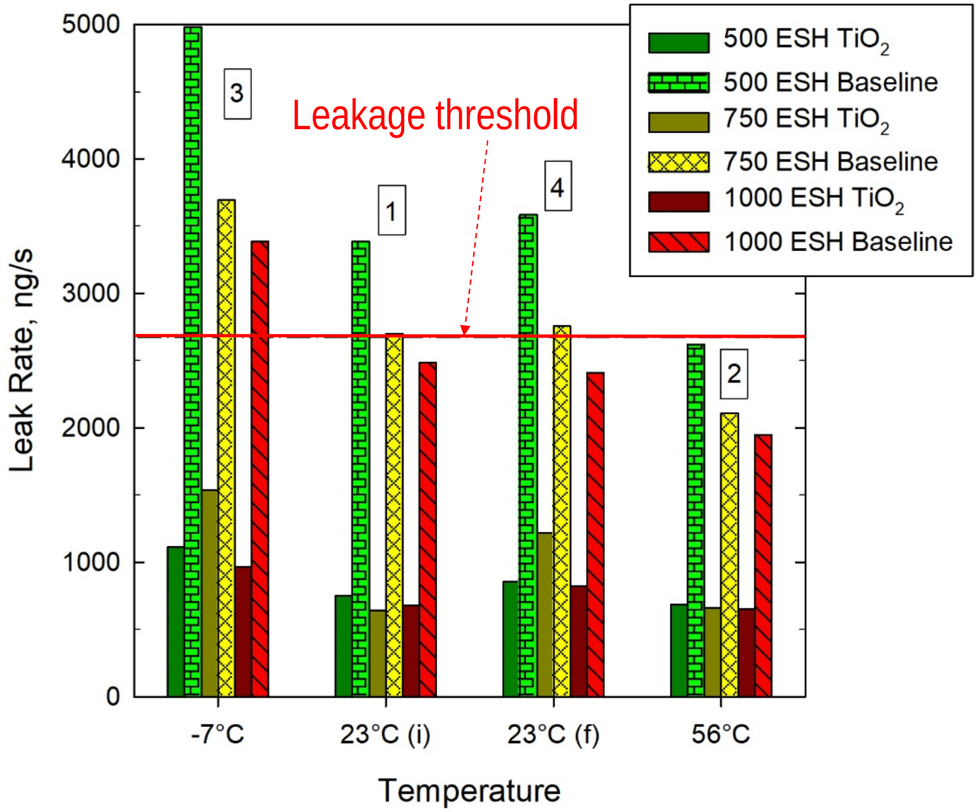
- At each test temperature, leak rates for baseline seal exposed to 1250 ESH of UV radiation and TiO_2 seal exposed to 2500 ESH were comparable (within 3-10%) → Further evidence that addition of TiO_2 provided protection from damage caused by UV radiation exposure



Note: Leak rates are steady state values for fully compressed seals. Test order noted by numbered boxes.

Test Results: Effects of Partial Compression

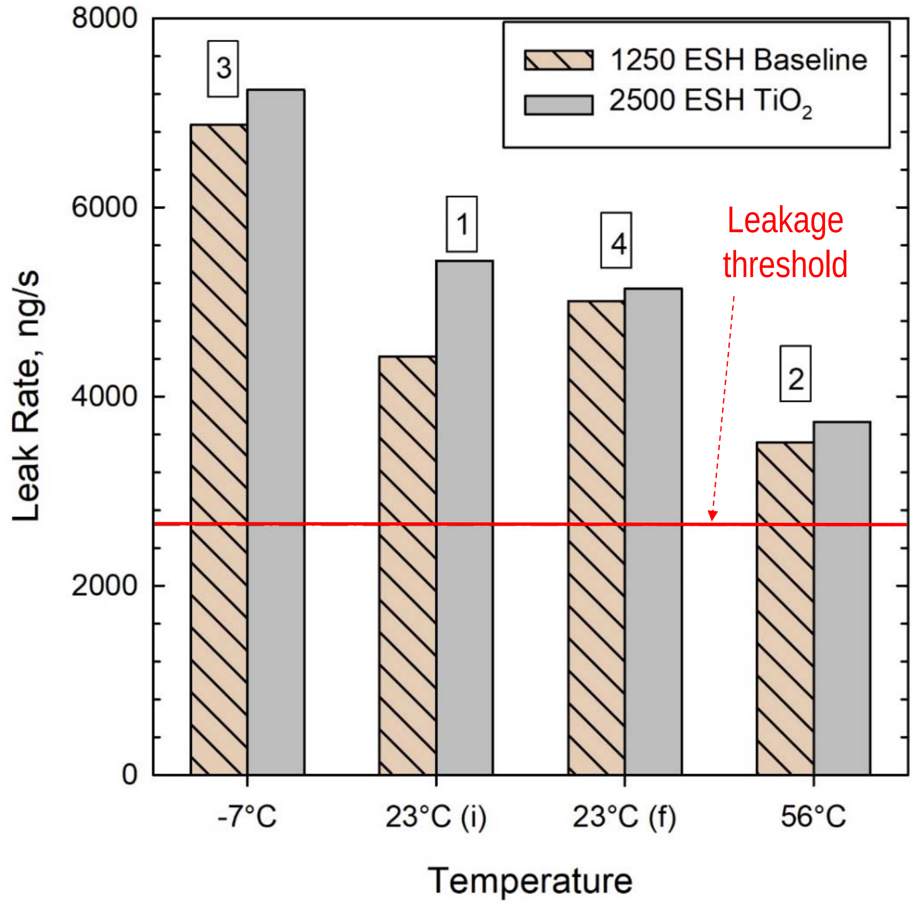
- Leak rates generally decreased as temperature increased
- In most cases, final leak rate at 23°C was greater than what was measured initially at that temperature
- Under "worst-case" conditions (partial compression, temperature extremes), leak rates for seals made of TiO_2 material were below leakage threshold in all cases



Note: Leak rates are steady state values for partially compressed seals (0.066 cm gap). Test order noted by numbered boxes.

Test Results: Effects of Partial Compression (cont.)

- At each test temperature, leak rates for baseline seal exposed to 1250 ESH of UV radiation and TiO_2 seal exposed to 2500 ESH were comparable and above the leakage threshold



Note: Leak rates are steady state values for partially compressed seals (0.066 cm gap). Test order noted by numbered boxes.

Summary & Conclusions

- Tests were performed to evaluate addition of TiO_2 to baseline silicone material as potential approach for improving seal resistance to damage from UV radiation
- The following findings were observed for seals exposed to AO and UV radiation:
  - Leak rates decreased as leak tests progressed. Behavior may be beneficial for long-term sealing applications as seals seem to “recover” over time from exposure.
  - Leak rates generally decreased as test temperature increased for both fully and partially compressed seals (opposite of what occurs for unexposed seals)
  - Seals made of baseline silicone material with TiO_2 consistently exhibited lower leak rates than seals made of baseline material → New material was more resistant to damage from UV radiation exposure
  - Seals made of TiO_2 material withstood 1000 ESH of UV radiation exposure and still satisfied leak rate requirements even under worst-case conditions of partial compression at temperature extremes
- Based on results of these tests, seals made of baseline silicone material with TiO_2 additive show promise of being able to withstand increased exposure to AO and UV radiation for future seal applications beyond LEO

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