National Aeronautics and
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LUNAR DUST TOLERANCE TESTING OF REPRESENTATIVE SEALS FOR LUNAR SURFACE ASSET SEALS

N. Jimenez[1], S. Gerdts[1], P. H. Dunlap[1], and J. Mather[2]
[1]NASA Glenn Research Center, 21000 Brookpark Rd., Cleveland, OH 44135, nathan.jimenez@nasa.gov, stephen.gerdts@nasa.gov, patrick.h.dunlap@nasa.gov
[2]The University of Akron, 302 E. Buchtel Ave., Akron, OH 44325, janice.mather@nasa.gov

INTRODUCTION:

The Moon's surface creates a uniquely challenging environment for mechanisms and materials. Electrostatic adhesion combined with a jagged particulate morphology makes lunar dust particularly destructive to the components and subsystems of lunar surface assets. One component that will be acutely impacted by lunar dust is seals, particularly those on the hatches that will be opened and closed to allow extravehicular activities (EVAs) and on docking systems that will connect surface assets and spacecraft together. Lunar dust on these seals can create leak paths for the pressurized atmosphere of a surface asset to escape. Quantifying the level of lunar dust contamination that is allowable for seals is of paramount importance for mission planners and asset designers. The paper described here covers dust tolerance testing that was conducted on representative hatch seals with the Uniform Dust Deposition System (UDDS) at the NASA Glenn Research Center. Subscale (≈30-cm diameter) versions of seals for the Orion docking hatch and NASA Docking System (NDS) were coated evenly with varying amounts of lunar dust simulant to evaluate its effect on seals' leak rates. The resulting leak-rate results from these flight-proven seal designs can help planners and designers construct robust missions and products.

OBJECTIVES:

Identify dust contamination levels at which seals fail their leak rate requirement at room temperature.

Evaluate the effects of temperature on the ability of the seals to hold pressure when contaminated with dust.

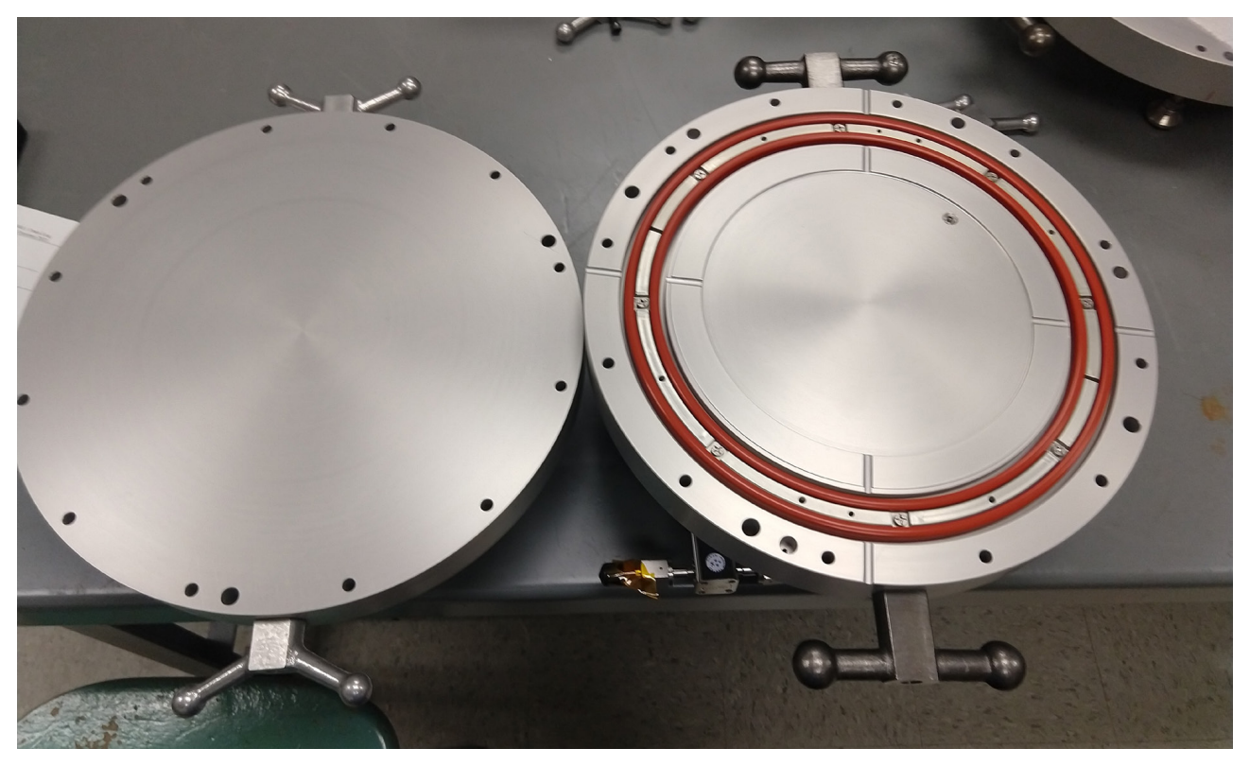

Figure (1): Leak test flow fixture with subscale NDS seal

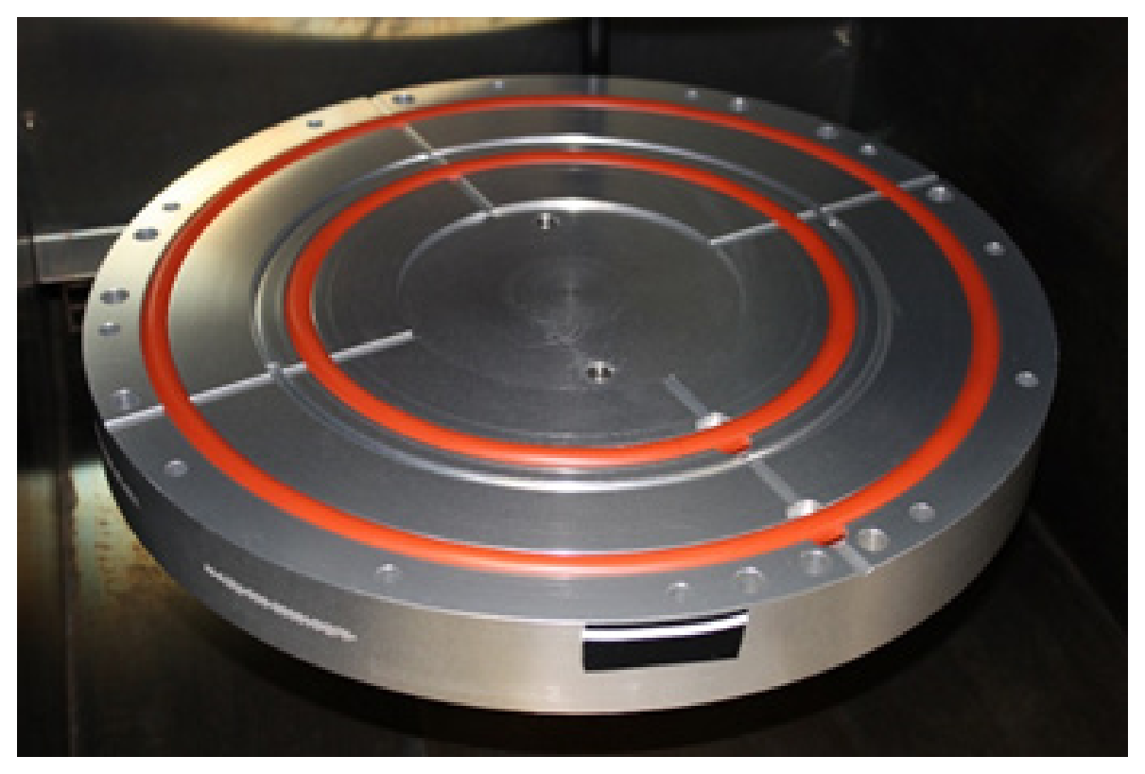

Figure (2): Leak test flow fixture with subscale DHS

METHODOLOGY:

Setup

For this testing, both seal geometries (NDS and docking hatch seal (DHS)) were installed in test fixtures with flight-representative grooves (Figures 1 and 2). These seals were 30 cm and 28.5 cm in diameter for NDS and DHS, respectively, and the cross sections were identical to the seals used on NASA's Low Impact Docking System and Lockheed Martin's Orion capsule. The seals were coated with Braycote™ (Castrol Limited) 601 EF grease and a leak rate test was performed on the seals prior to dust loading to provide a baseline leak rate that could be compared against the leak rate of the contaminated seal.

Dust Contamination

The JSC–1A simulant for this testing was presieved to only contain particles smaller than 250 µm and was baked out per ASTM D2216 to remove any moisture [1]. This particle size distribution was selected because it was assumed that larger particles would either not remain adhered or the crew would be compelled to clean them before closing a hatch [2]. The simulant was then loaded into the Uniform Dust Deposition System (UDDS) at NASA Glenn Research Center [3]. The chamber was purged down to a relative humidity under 0.5% before introducing the seal into the chamber. The UDDS then deposited controlled amounts of simulant onto the upper surface of the seal by rotating it under its deposition column (Figures 3 and 4).

Evaluation

Once contaminated, the seal was automatically transferred to an imaging station where a microscope took z-stacked images at eight locations around the perimeter of the seal (Figure 5). The images were then fed through a machine learning algorithm that counted the particles on the surface and produced a percent coverage measurement [4]. The fixture with the seal still installed in it was then removed from the UDDS, and the top plate of the fixture was installed and torqued to flight requirements. The test assembly was then placed into an environmentally controlled chamber and leak tested to evaluate the contaminated leak rate for the seal. For the thermal cycling tests, the fixture was evaluated at room temperature and then cooled to –50 °C to conduct additional leak tests at cold temperatures. Afterward, the fixture was heated to 74 °C and tested at that temperature before the final leak test was run at room temperature.

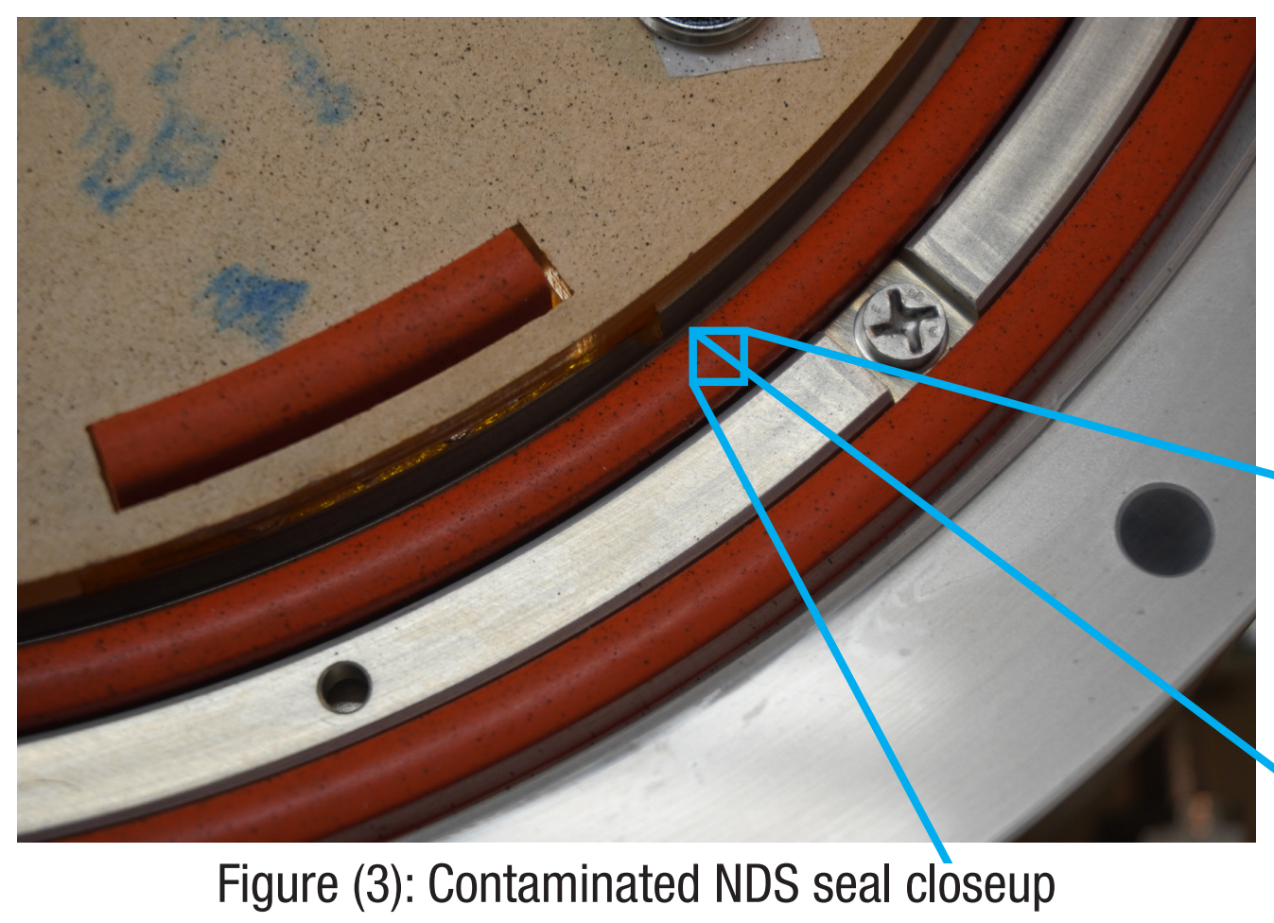

Figure (3): Contaminated NDS seal closeup

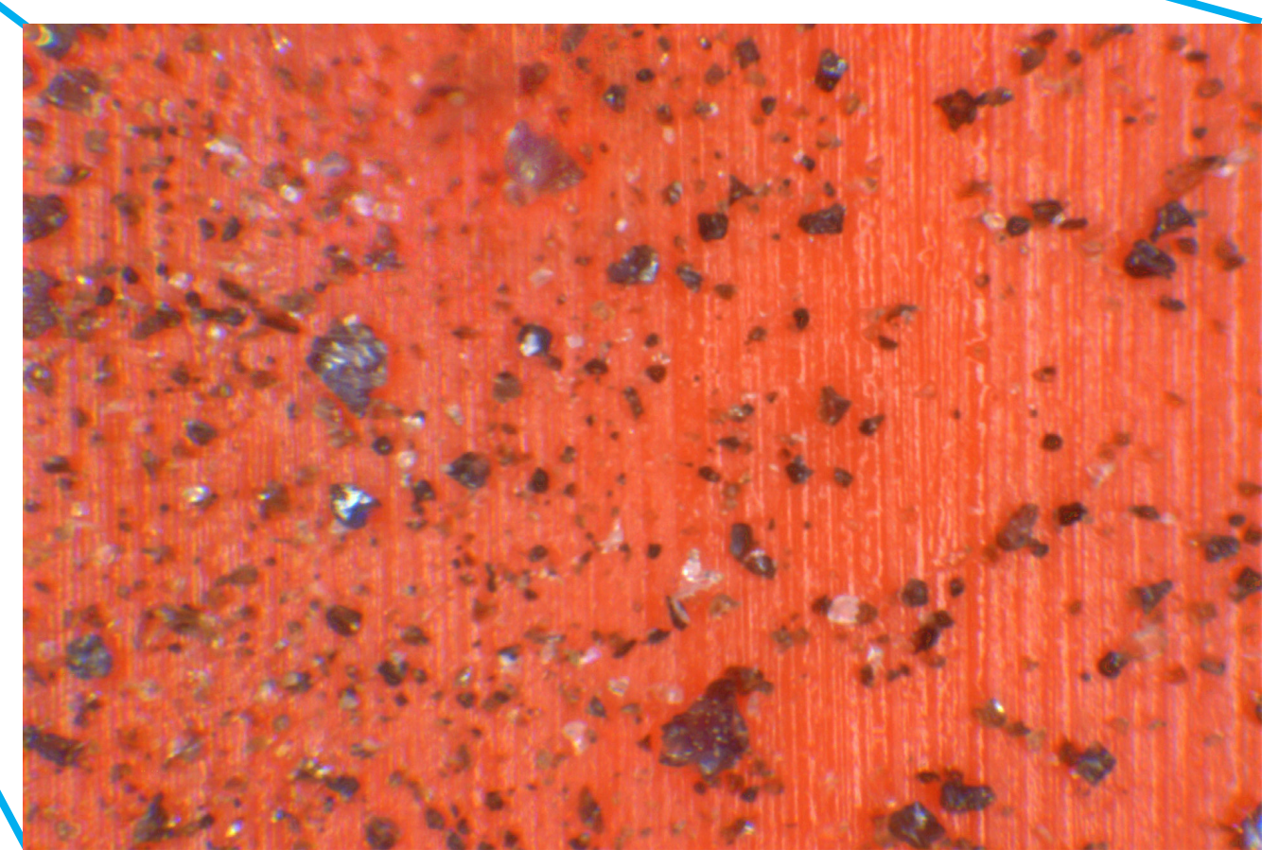

Figure (4): Micrograph of NDS seal contaminated to its breakthrough level of 22% coverage

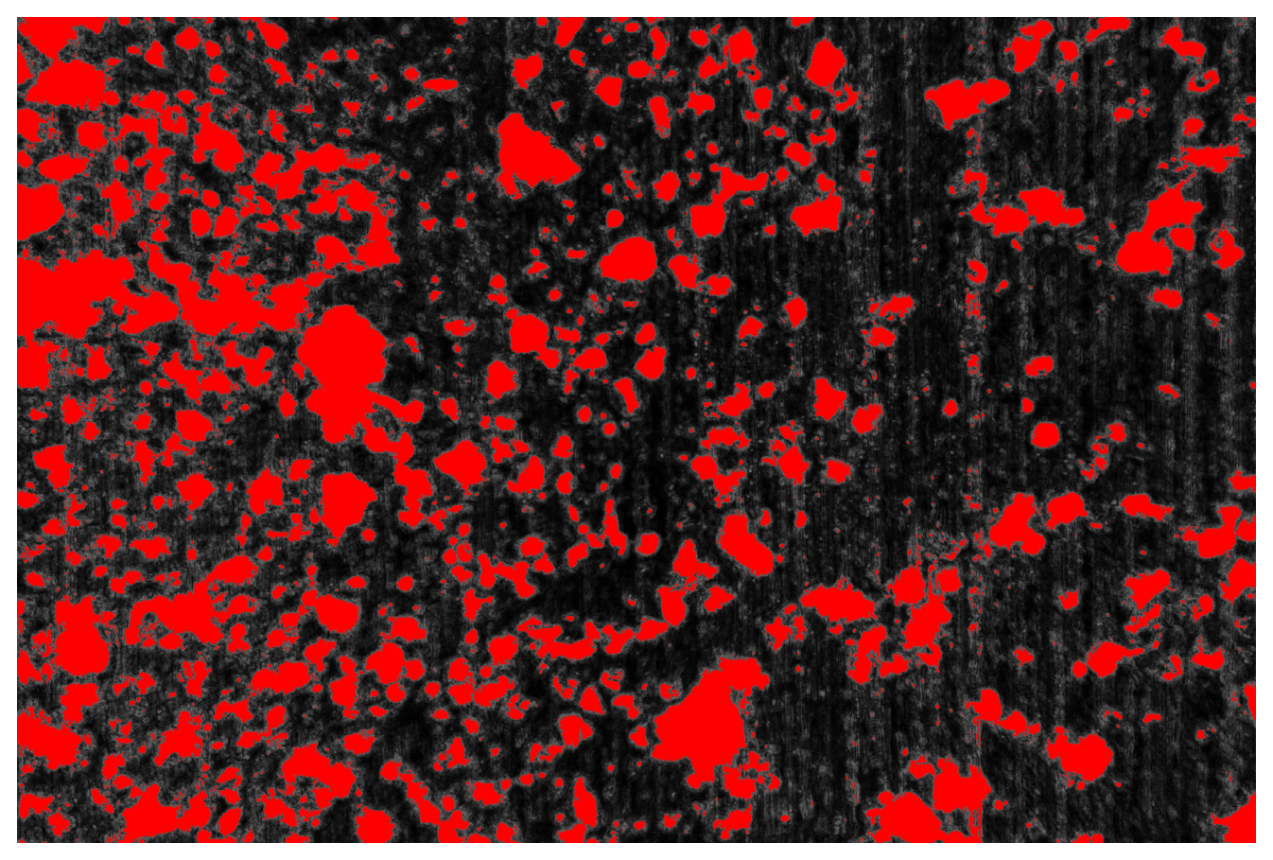

Figure (5): Segmented micrograph (50x) of dusted seal at 22% coverage

RESULTS:

Breakthrough Point Test Results

During this testing campaign, 15 NDS and 10 DHS seals were evaluated at room temperature over a range of contamination levels. The range of contamination levels was to be large enough to include marginal increases in leak rates, the breakthrough point, and catastrophic failures. The breakthrough point was defined to be the maximum contamination level that was present on a seal that would cause it to fail its leak rate requirement. It is to be noted that the scaled leak rate requirements for both seal designs were different, 2.7e+3 ng/s for the NDS and 7.3e+4 ng/s for the DHS, which themselves represent a 18.7x and 190x increase from baseline leak rates, respectively.

The lighter maximum contamination levels of less than 14% for NDS and 10% for DHS represented between 1 and 2 times the increase in leak rates from the baseline. These lighter levels help quantify the levels of contamination that the two seal designs would be allowed to sustain without any dust mitigation efforts being needed. This quantification could be done via optical image analysis in situ on the lunar surface.

The median deposition ranges of 14 to 22% for the NDS and 10 to 14% for the DHS designs helped determine the breakthrough point. The upper bound of this range yielded the breakthrough point, which was approximately 22% for the NDS and 14% for the DHS designs. The transition from the passing contaminations past the breakthrough point was catastrophic in nature. The leak rates increased exponentially after their breakthrough points, resulting in leak rate orders of magnitude higher than their allowable requirements, as shown in Figures 6 and 7. A couple of test seals were evaluated above the breakthrough point in the heavy deposition range to confirm the behavioral trend.

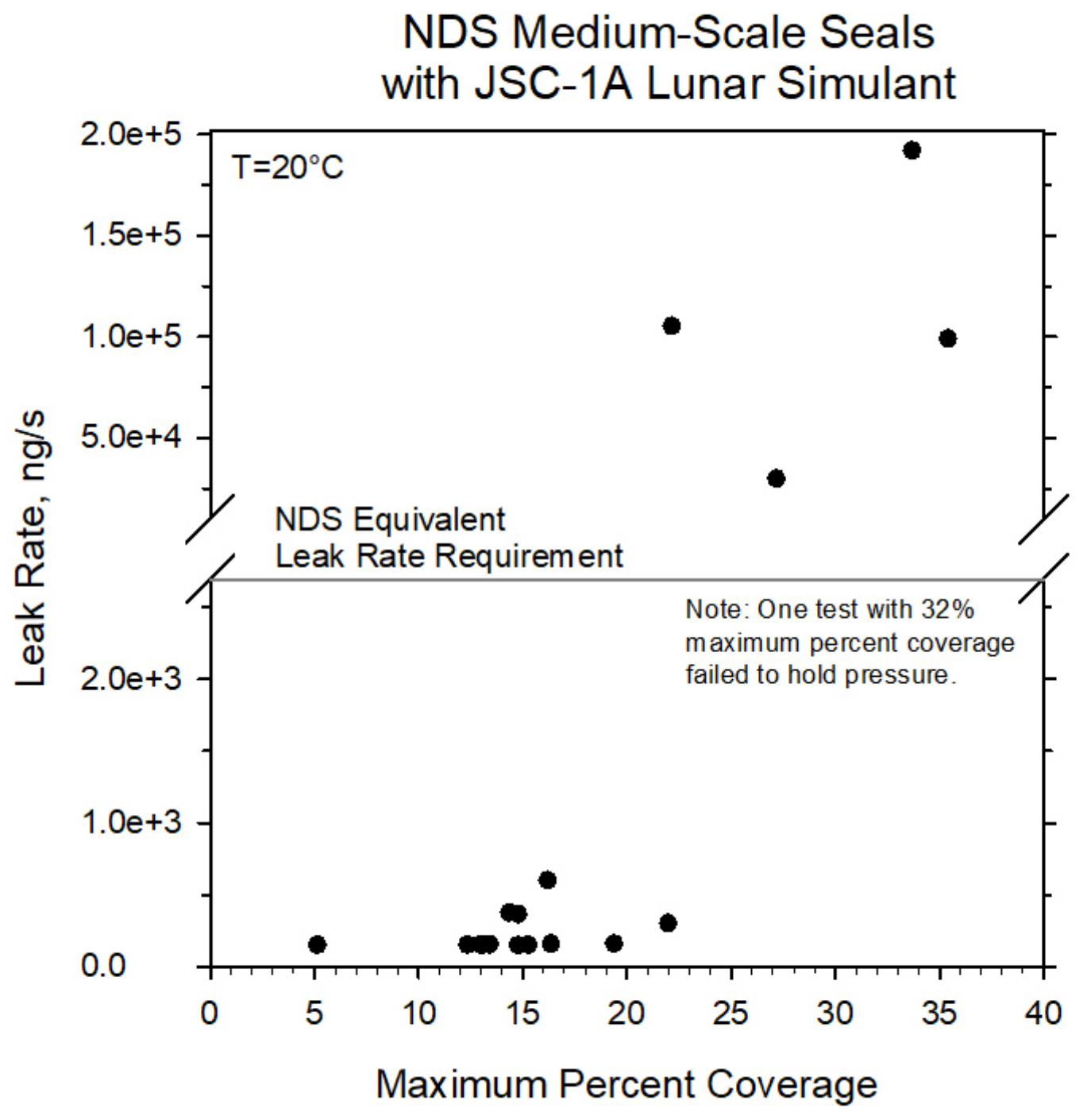

Figure (6): Maximum percent coverage vs. leak rate for NDS seals

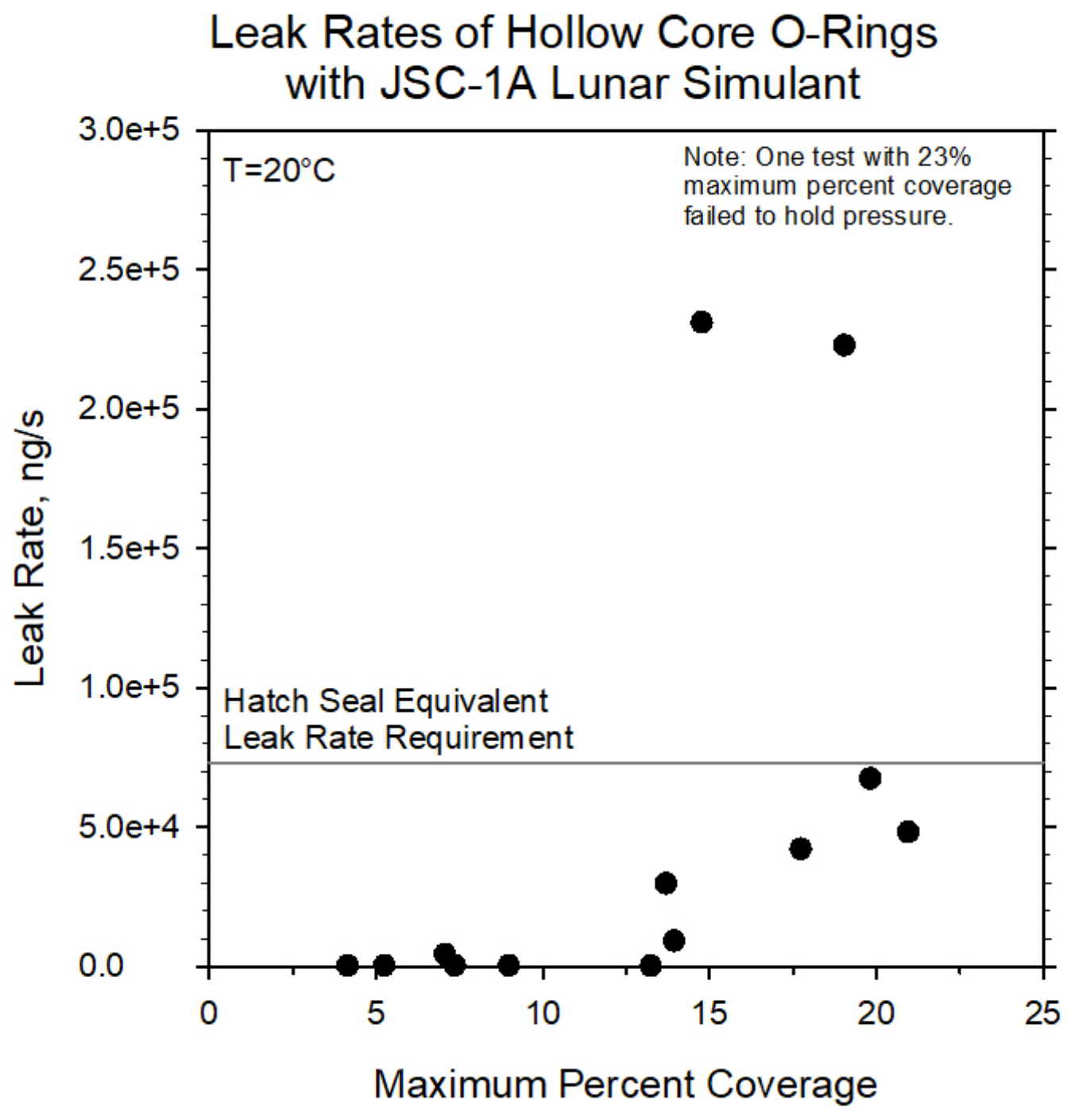

Figure (7): Maximum percent coverage vs. leak rate for DHS

Thermal Test Results

For the thermal testing portion of this campaign, four seals of each design were evaluated over three temperatures. One seal of each design was coated just under its breakthrough point, and the rest were coated well below their breakthrough point. The lighter contamination was done to evaluate the effects of temperature on a leak rate that was well under the requirement. The contamination level just under breakthrough was selected to see if temperature could have a positive effect on seals that were near their leak rate requirement. The seals were contaminated and were first leak tested at room temperature in the environmental chamber to ensure a passing leak rate was achievable. The test fixtures were then cooled to –50 °C and allowed to reach a steady-state temperature before another leak test was conducted at the cold temperature. Following the cold test, the seals were heated to 74 °C without removal from the environmental chamber. Once a steady-state temperature was reached, the final leak test was run and the testing was complete for that seal. This process was the same for both the NDS and DHS designs.

Over the course of this testing, it was noted that at lower temperature the seals would fail their leak tests, whereas at higher temperatures they seem to meet their requirements more easily [Figures 8 and 9]. The behavior believed to be causing these results is the stiffening and contraction of the seals at lower temperatures. It is possible that the cold seals resist the envelopment of the dust particles at lower temperatures, creating larger leak paths. This could become exacerbated by the thermal contraction of the seals. However, these are only hypotheses and remain to be proven as the causes for the increased leak rates.

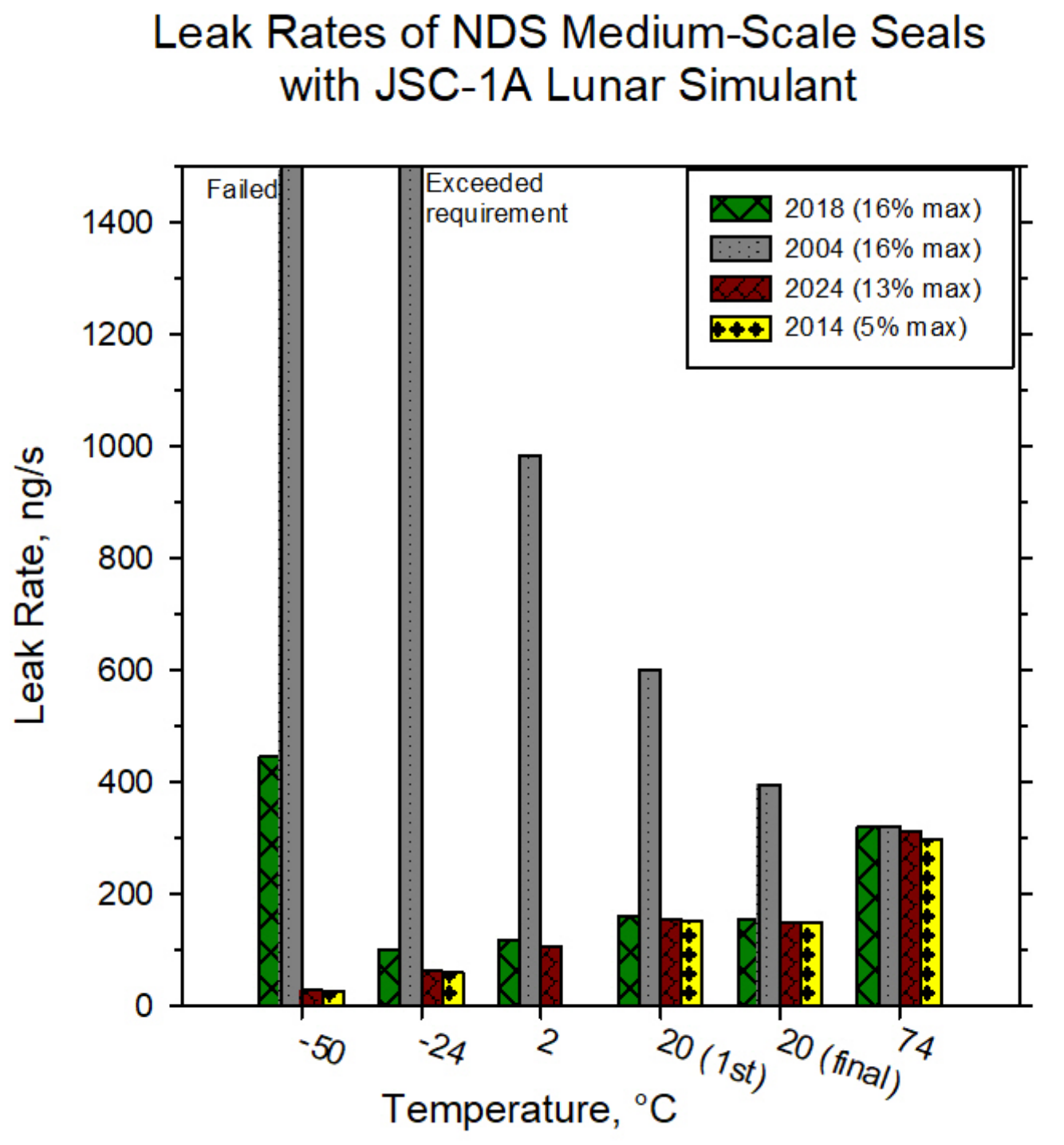

Figure (8): Temperature vs. leak rate for NDS seals

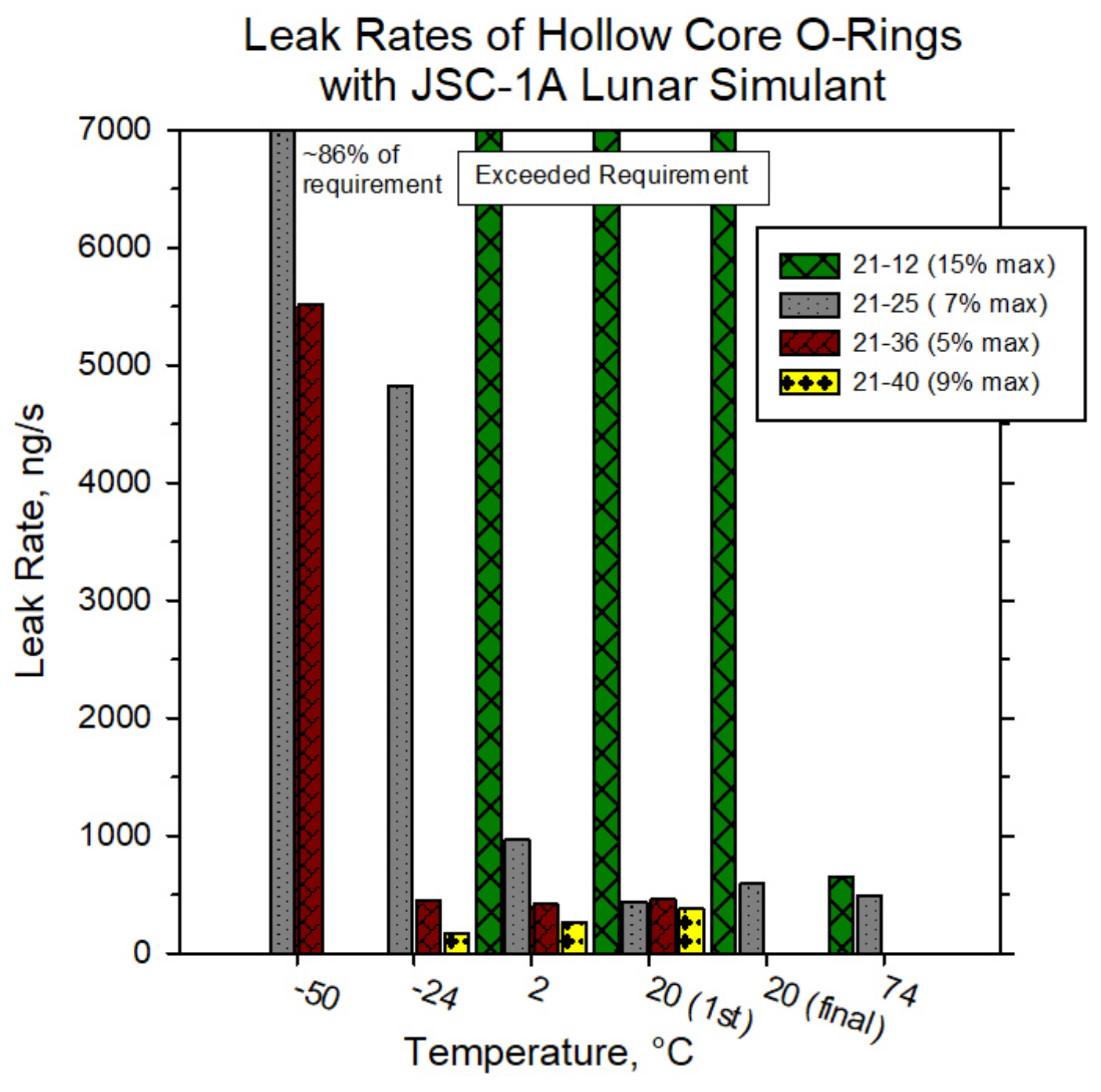

Figure (9): Temperature vs. leak rate for DHS

CONCLUSIONS:

This testing was able to determine the breakthrough contamination levels at which leak rates exceeded requirements after contamination of two seal designs (NDS and DHS) at room temperature. From that testing it was revealed that the design of a seal can greatly impact the allowable contamination level. In the case of the two designs evaluated, the NDS seal could tolerate 8% more contamination than the DHS when compared to each of their respective leak rate requirements. The failures near the breakthrough points were catastrophic in nature, and dust mitigation strategies should be employed at or near the breakthrough points.

The thermal testing demonstrated that colder temperatures will cause elevated leak rates for dust-contaminated seals of either design. Future testing will evaluate the effects of various cleaning techniques, surface treatments, and novel dust mitigation techniques for these seal designs near or above their breakthrough contamination levels.

ACKNOWLEDGMENTS:

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