VeriClean SEALS™

Your higher standard for clean seals

TECHNICAL WHITEPAPER

V4 · 2026

DATA CENTER COOLING · ESG & PROCUREMENT LEADS

Elastomeric seal supplier qualification for data center procurement: the cleanliness gap no standard closes.

THE SPECIFICATION GAP · CCD · VARIABILITY

Your supplier qualification record for elastomeric seals is complete by every standard that exists — and silent on surface particulate. VeriClean Seals™ and Cyclic Contamination Displacement™ close the gap with auditable, SKU-level cleanliness data.

PACIFICRUBBER.COM / VERICLEAN

PRP

Precision. Seals. Delivered.

Your elastomeric seal supplier qualification record has no line item for seal surface cleanliness. Not because anyone decided it wasn't important — because no standard requires it and no supplier has had the infrastructure to provide it. The Specification Gap is structural: no broadly adopted industry standard specifies acceptable surface-deposited particulate on an elastomeric seal at the component level, not ISO 3601-3, not OCP cold plate requirements, not ASHRAE TC 9.9.

What this means for ESG / Procurement Leads

Your supplier qualification record for elastomeric seals is complete by every standard that exists and silent on the one variable that CCD delivers into your coolant loop. There is no audit finding that surfaces this gap — because no standard requires the line item that would generate one. For ESG reporting programs that carry obligations tied to energy efficiency, chemical consumption, and component lifecycle, that silence has a cost: the energy penalty from cold plate fouling, the chemical consumption from accelerated glycol treatment, and the MTBF impact on CDU internals are all real, attributable to the seal surface, and currently unattributed in any facility operating record. VeriClean Seals™, through the VeriClean Cleanliness Qualification (VCQ), generates the first data that closes the gap — and gives you the qualification language and audit trail entry that currently don't exist.

As-received commercial seals have been measured across a SKU-average range of 1,000 to 98,500 particles per square centimeter at ≥1.3 µm sensitivity (PRP measurement data). Those particles enter your coolant loop through Cyclic Contamination Displacement™ — the normal operating mechanics of a pressurized fluid system — not as a commissioning event, but progressively, across every pressure transient and thermal cycle for the life of the seal. The qualification documentation you have is accurate. It simply does not address this variable.

The Specification Gap

The standards governing elastomeric seal procurement in data center cooling were designed for problems they solve well. Understanding that distinction is the first step to understanding why the Specification Gap exists — and why it cannot be closed by reading the applicable standards more carefully.

The standard was designed for a different problem

ISO 3601-3 specifies surface inspection at ×2 magnification. This standard was designed to detect molding defects — flash, tears, surface damage. It does that job. It is not designed to address fluid-path contamination. At ×2 magnification, particles at ≥1.3 µm — the size range relevant to a D2C coolant loop — are structurally invisible. OCP cold plate requirements address wetted material compatibility and coolant chemistry. ASHRAE TC 9.9 addresses data center thermal management at the systems level. Each standard addresses something real and important. None specifies acceptable surface-deposited subvisible particulate on the seal component.

Your supplier is compliant. That is the problem.

Your seal supplier ships seals that meet every published requirement. The certificate of conformance is accurate. The visual inspection passed. There is no negligence and no supply chain failure in the

conventional sense. The seals are in spec. The spec does not address what enters your fluid system. This is not fixable by finding a better supplier — every supplier operates to the same inadequate standard.

> *"Your seal supplier will ship seals in spec. The spec is the problem."*

For an ESG or procurement qualification record, this means the gap is not an oversight in your program. It is a structural absence in the standards your program was built on.

The contamination requires a methodology that doesn't exist

Particles at ≥1.3 µm require extraction, counting, and documentation to detect. That methodology does not exist at the component level anywhere in the industry. This is the Specification Gap. Until it is closed, the supplier qualification record that answers every other question about your approved seal sources is silent on the one variable that Cyclic Contamination Displacement delivers directly into your coolant loop.

What is on a conforming, commercially supplied seal? The contamination has identifiable sources. Talc used as an anti-tack mold release agent arrives at 1–20 µm. Carbon black, liberated from the polymer matrix during compounding and deflashing, spans 0.01–100 µm. Biological material from operator handling — skin squames — measures 20–50 µm. Textile fibers shed from handling garments and packaging contact range from 50 to 2,000+ µm. These are four of eleven contamination classes documented in the full technical paper — the complete taxonomy, with morphology, size ranges, and supply chain origin for all eleven classes, is available there.

As-received seal surfaces have been measured across a SKU-average range of 1,000 to 98,500 particles per square centimeter at ≥1.3 µm (PRP measurement data). Individual seals within those same populations range from 630 to more than 127,000 particles per square centimeter. Within a single purchased bag, the spread between the lowest- and highest-burden seals reaches 20-fold or more.

VMQ (silicone) seal surface — as-received (left) vs. VeriClean processed (right). Fiber and particulate contamination visible at ×2.5 and ×20. Standard incoming inspection does not detect contamination at this scale. Scale bar: 250 µm.

Cyclic Contamination Displacement (CCD) — the mechanism

A seal's static wetted footprint is a small fraction of its total surface area. This is by design — gland geometry, compression, and material compliance are engineered for sealing performance, not contamination minimization. The static model describes the seal at installation. Real systems don't operate at a static snapshot.

Under pressurization, thermal cycling, and mechanical cycling — normal operating conditions for any CDU connection, manifold branch line, or QDC seat — the effective wetted area expands 3:1 to 8:1 beyond the static footprint (PRP measurement data). The seal is functioning as designed. That expansion brings previously dry gland surface — and the contamination load on it — into contact with the process fluid.

Three mechanisms drive this release. As system pressure increases, the seal translates toward the low-pressure side of the gland, exposing surfaces that were dry at installation. Differential thermal expansion between the elastomer and the surrounding metal hardware introduces shear stress at the seal-gland interface across every thermal cycle, progressively bringing new surface area into fluid contact. Particles liberated by these movements are entrained in the process fluid film on the gland surface and carried directly into the bulk fluid path — without requiring direct bulk fluid contact with the contaminated seal surface.

Contamination release is cumulative and ongoing, not a one-time commissioning event. A commissioning flush intercepts particles that are freely mobile at startup. CCD-released contamination was on the seal surface at commissioning, held there by mold release oil films and electrostatic adhesion. It enters the loop progressively over months of operation — after the flush, after sign-off, after the facility is live. There is also a filtration topology constraint that cannot be engineered around: at every pump outlet, QDC seat, and manifold branch connection in a D2C cooling system, at least one seal exists downstream of the last filtration stage. What those seals release passes directly into the downstream fluid path without interception.

CCD is not a flaw in seal design. It is contamination release from a seal doing exactly what it was designed to do. Only surface cleanliness control at the component level addresses it.

> For full CCD mechanism visualization — including wetted area expansion diagrams, operating cycle analysis, and the complete contamination class dataset — download the full technical paper: *'Surface Particulate Contamination on Elastomeric Seals'* at pacificrubber.com/resources.

Particle load variability and documented control

The contamination problem cannot be managed by visual inspection, lot-level assumptions, or supplier selection. The data makes the case directly.

Within-lot variability at the SKU-average level reaches 3× across lots from the same source (PRP measurement data). Within a single purchased bag, individual seals have been observed to differ in particle burden by more than 20-fold under identical measurement conditions. A lot-average result is statistically incapable of detecting the highest-burden seals in that population. The only resolution is a process applied to the full population — not more frequent sampling of the box.

Visual grade and price are poor proxies for cleanliness. Particle count and particle volume across the PRP supply chain dataset show only weak correlation with price tier (R=0.47). A premium-priced seal is not a cleaner seal. Premium pricing reflects compound performance and dimensional precision, not surface cleanliness — because surface cleanliness has never been a controlled variable in the supply chain.

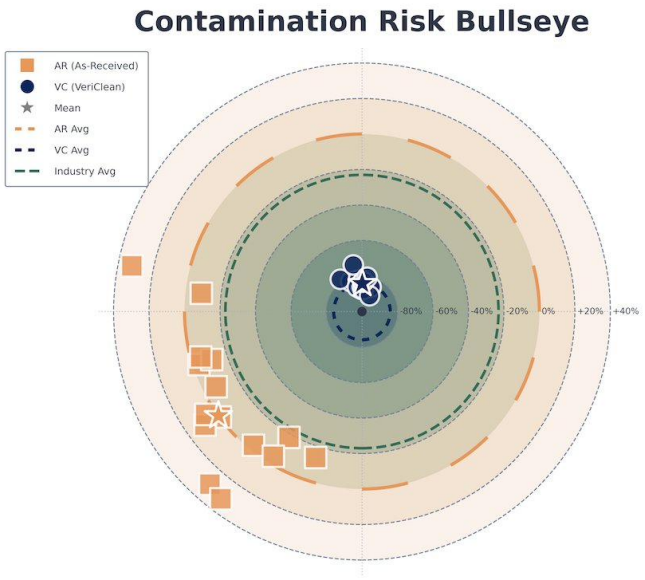
This variability requires a documented, repeatable measurement methodology applied at the SKU level. Not lot level. Not visual inspection. Not supplier assertion. No current industry standard provides that methodology at the component level.

ESG reporting programs that carry obligations tied to energy efficiency, chemical consumption, and component lifecycle need to understand the impact from hundreds — thousands — of seals continually adding particulate to your TCS coolant loops. This uncontrolled contamination carries an energy and sustainability cost. It can now be audited, and controlled.

What's inside the full technical paper

The full 20-page technical paper — *'Surface Particulate Contamination on Elastomeric Seals'* — contains the complete dataset, mechanism documentation, and standards landscape analysis that this paper necessarily omits. Every omission below is a reason to access it.

- 11 contamination source classes — full taxonomy with morphology, size ranges (0.01 µm to 2,000+ µm), supply chain origin, and fluid-path impact
- Complete particle count dataset: 1,000 to 98,500 particles/cm² SKU-average; individual seals 630 to more than 127,000 particles/cm² (≥1.3 µm)
- Particle volume density analysis across 16 size buckets: 45,000 µm³/cm² to more than 5.4 million µm³/cm² SKU-average
- Within-lot variability: 3× lot-to-lot; 20× seal-to-seal within same bag
- Full CCD mechanism with wetted area expansion ratios (3:1 to 8:1) and operating cycle analysis
- Standards landscape mapping for data center cooling: ISO 3601-3, OCP cold plate requirements, ASHRAE TC 9.9, ISO 3601 dimensional — surface particulate coverage assessed for each
- VeriClean processing methodology and performance data: 49–72% particle volume reduction; 37–70% particle count reduction across tested elastomer families (low-reduction results are characteristic of seals entering processing with a low baseline burden — an outcome that reflects favorably on supply chain control)
- 20 pages · 5,300 words · 24 cited references



VeriClean Qualification (VCQ) — Contamination Risk Bullseye, one of several visual analytical outputs in the VCQ report.

About the bullseye. The Contamination Risk Bullseye shown here is one of several visual analytical outputs in the VCQ report. Each marker represents independent particle extraction and quantification for an individual seal: n=15 as-received measurements and n=15 VeriClean-processed. The distribution of as-received markers across the chart reflects the seal-to-seal variability within a single submitted lot, and positions that population against the same compound family average from PRP's full supply chain dataset. The complete VCQ report delivers this and other visualizations alongside all raw particle count and volume data across 16 size bins.

The full data is available. The full paper is accessible now.

'Surface Particulate Contamination on Elastomeric Seals' — 20 pages · 5,300 words · 24 cited references. The complete mechanism, the complete dataset, and the measurement methodology that closes the Specification Gap.

Download at pacificrubber.com/resources

VeriClean Seals bioburden reduction of 92–100% is a process characterization finding validated per ISO 11737-1. It is not a batch-monitored VCQ deliverable and does not constitute a sterility guarantee. Results vary by elastomer compound and initial contamination state.

VeriClean Seals™ and Cyclic Contamination Displacement™ are trademarks of Pacific Rubber & Packing, Inc.