VeriClean SEALS™

Your higher standard for clean seals

TECHNICAL WHITEPAPER

V4 · 2026

DATA CENTER COOLING · THERMAL & SYSTEMS ENGINEERS

Elastomeric seal particulate contamination in liquid-cooled infrastructure: what your CDU spec doesn't measure.

THE SPECIFICATION GAP · CCD · VARIABILITY

Commercial elastomeric seals carry 1,000–98,500 particles/cm² at ≥1.3 µm — and Cyclic Contamination Displacement™ delivers them into your TCS loop through the same pressure cycling your system was designed to run under. No current specification measures it.

PACIFICRUBBER.COM / VERICLEAN

PRP

Precision. Seals. Delivered.

Yes — elastomeric seals contaminate liquid cooling loops, and the mechanism is active in every system you've commissioned. As-received commercial seals have been measured at 1,000 to 98,500 particles per square centimeter at ≥1.3 µm (PRP measurement data), and the mechanism that delivers those particles into your coolant — Cyclic Contamination Displacement — operates through the same pressure cycling your TCS loop was designed to run under. If you're investigating throttling and thermal margin erosion with no identifiable root cause, tracing an unexplained particulate spike post-commissioning, the seal surfaces in your loop are a documented source. No standard in your current specification requires measuring or documenting them.

The Specification Gap

Your TCS loop specification is thorough. Pump head, CDU internals, cold plate microchannel geometry, QDC valve seats, manifold connections — each component has been specified for dimensional tolerance, material compatibility, and fluid system performance. What the specification doesn't contain is a cleanliness criterion for the elastomeric seal surfaces at any of those connection points. Not because it was evaluated and found acceptable. Because no seal supplier has ever offered the measurement, and no standard has ever required it.

The standard was designed for a different problem

ISO 3601-3 defines surface inspection for O-rings at ×2 magnification. It's an effective standard for the macroscopic defects it was designed to detect — flash, tears, surface damage, embedded visible material. It does that job. It is not designed to address fluid-path contamination. At ×2 magnification, particles at ≥1.3 µm — the size range at which CCD delivers contamination into your coolant loop — are structurally invisible. The gap between what ×2 magnification resolves and what a calibrated particle counter measures at ≥1.3 µm sensitivity is exactly where the contamination problem described in this paper exists.

Your supplier is compliant. That is the problem.

The Certificate of Conformance that arrives with your seal shipment is accurate. Dimensional conformance: confirmed. Material lot: documented. Mechanical and chemical tests: completed. The seals passed visual inspection. 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."*

The contamination requires a methodology that doesn't exist

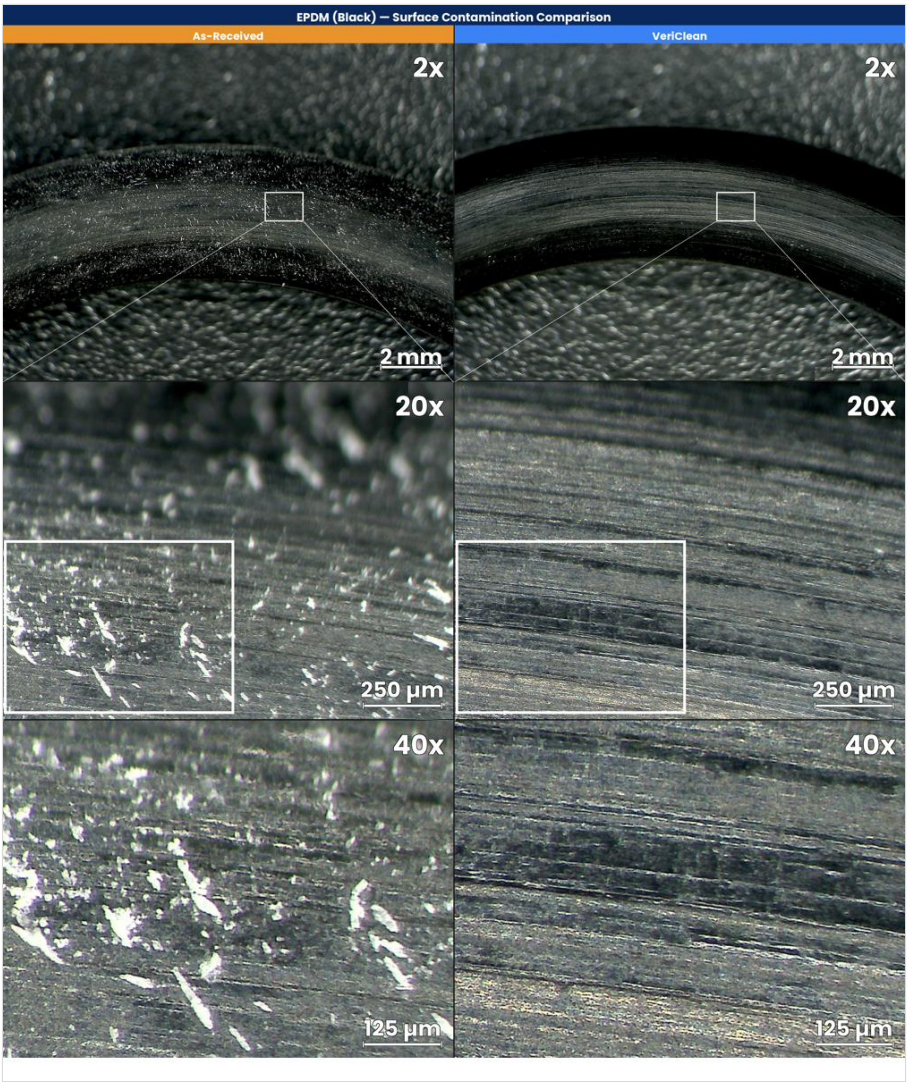
Particles at ≥1.3 µm require extraction, counting, and documentation to detect. That methodology does not exist at the component level anywhere in the industry. No CoC line item. No supplier qualification criterion. No audit trail. This is the Specification Gap: the engineering documentation for your TCS loop seals is

complete on every measured dimension and entirely silent on the one variable that enters your cold plates through normal mechanical operation.

As-received seals from standard commercial supply channels have been measured at 1,000 to 98,500 particles per square centimeter, SKU-average, at ≥1.3 µm. Individual seals within those populations range from 630 to more than 127,000 particles/cm² (PRP measurement data). Seal-to-seal variability within the same purchased bag reaches 20-fold — measured under identical conditions, same lot number, same CoC.

The contamination sources that produce this burden include talc at 1–20 µm, carbon black at 0.01–100 µm, polycarbonate cryogenic grit at 5–50 µm, and textile fibers at 50–2,000 µm+. Those are four of eleven contamination classes documented in full — see the full technical paper for the complete taxonomy.

Particulate agglomeration and adhesion fouls microchannels, blind sensors, erodes and occludes valve seats and pump impellers.



EPDM seal surface — as-received (left) vs. VeriClean processed (right). At ×2 magnification (ISO 3601-3 inspection standard), both surfaces appear acceptable. At ×20 and ×40, crystalline contamination on the as-received surface is clearly visible. Scale bar: 125 µm.

CCD — the delivery mechanism

The static gland model is the correct framework for evaluating leak rate, extrusion resistance, compression set, and chemical compatibility. It is not the correct model for evaluating contamination exposure. Real TCS loops don't operate at a static snapshot. They cycle — pressure transients, thermal shifts, QDC actuation events, pump ramp cycles. Every one of those events is a contamination displacement event.

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 to maximize fluid contact. Under pressurization, thermal cycling, and mechanical cycling — normal operating conditions for any CDU or cold plate assembly — the effective wetted area expands 3:1 to 8:1 beyond the static footprint (PRP measurement data). The seal is functioning exactly as designed.

That expansion brings previously dry gland surface — and the contamination load it carries — into contact with the coolant. The particle layer adhered to that surface by mold release oils and electrostatic films is mobilized by the same interfacial shear the system was designed to generate. Liberated particles are immediately entrained in the thin coolant film the gland retains under operating conditions and carried into the bulk fluid. No direct bulk fluid contact with the contaminated seal surface is required.

This is Cyclic Contamination Displacement. Contamination release is cumulative and ongoing — not a one-time commissioning event. The contamination that caused your commissioning flush to read clean was the freely mobile fraction. The CCD-driven fraction was adhesively retained at commissioning. It enters your loop over months of subsequent pressure cycles, thermal transients, and QDC actuations, after the flush, after sign-off, after the facility is live.

Critically: CCD is not a flaw in the seal. It is contamination release from a seal doing exactly what it was designed to do. Only surface cleanliness control at the component level solves 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 or lot-level assumptions. Seal-to-seal particle burden within a single purchased lot is characteristically variable: individual seals from the same bag have been observed to differ in particle burden by more than 20-fold, measured under identical conditions (PRP measurement data). Lot-to-lot variability across the same SKU reaches 3× in the upper quartile of the supply chain database.

The correlation between price, visual grade, and contamination burden is weak — R=0.47 across the PRP database. A premium-priced seal is not a cleaner seal. A seal with an acceptable average particle count may carry disproportionately high volumetric burden if its size distribution is skewed toward larger particles. Count and volume are only weakly correlated, which means count-only assessment systematically misses the seals that carry the highest physical blockage risk for microchannel geometries.

Within a 20-fold spread, a lot-average result is statistically incapable of detecting the highest-burden seals. The only resolution is a process applied to the full population — not more frequent sampling of the box, and not a better supplier. This variability requires a documented, repeatable measurement methodology applied at the SKU level. No current industry standard provides that methodology at the component level, and no system-level fluid measurement captures the seal-sourced contamination entering the coolant through CCD after commissioning.

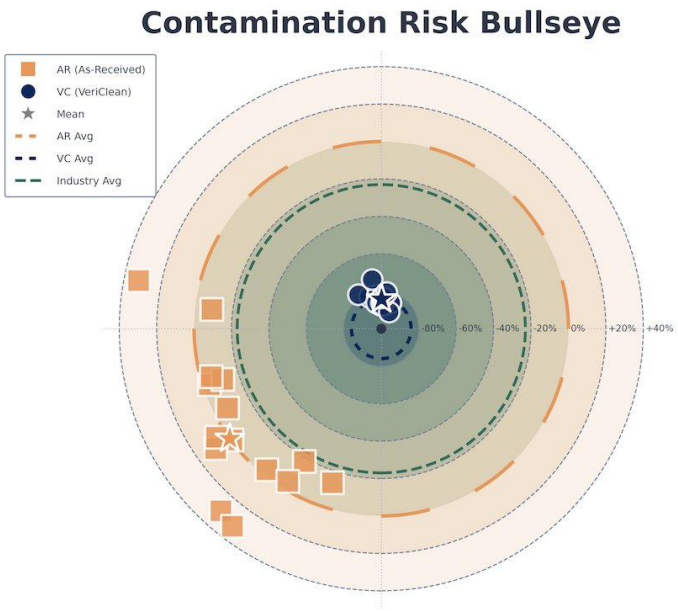
What this means for Thermal / Systems Engineers

If you are responsible for TCS loop design, component qualification, or field reliability at a CDU manufacturer, cold plate vendor, or D2C cooling OEM, the seal surfaces in your installed systems represent an uncharacterized contamination input that your current specification does not close. The CDU seal surface cleanliness variable is upstream of your filtration topology at every pump outlet, QDC seat, and manifold connection point — meaning contamination released from those positions bypasses filtration entirely, regardless of filter rating. If you are tracing an unexplained particulate spike, investigating thermal margin erosion, or qualifying a new system architecture, the liquid cooling loop particulate contribution from seal surfaces is a documented, measurable variable that has not been in your design history file. It can be now.

What's inside the full technical paper

'Surface Particulate Contamination on Elastomeric Seals' — 20 pages · 5,300 words · 24 cited references — contains the complete mechanism, dataset, and measurement methodology that closes the Specification Gap for liquid-cooled infrastructure applications.

- **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 4406:2021) — scope of each standard and the seal surface cleanliness gap each leaves open
- **VeriClean Seals™ processing methodology** and performance data
- 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 data (92–100%) is derived from process validation studies conducted under ISO 11737-1. Bioburden reduction is not a VCQ deliverable and is not guaranteed for any individual lot or SKU.

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