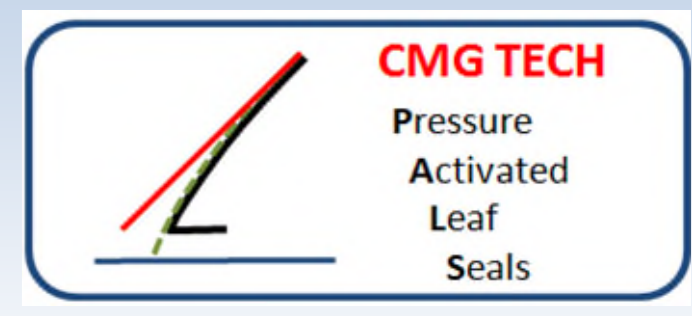


PRESSURE ACTUATED SHAFT SEAL DEVELOPMENT FOR sCO2 APPLICATION*

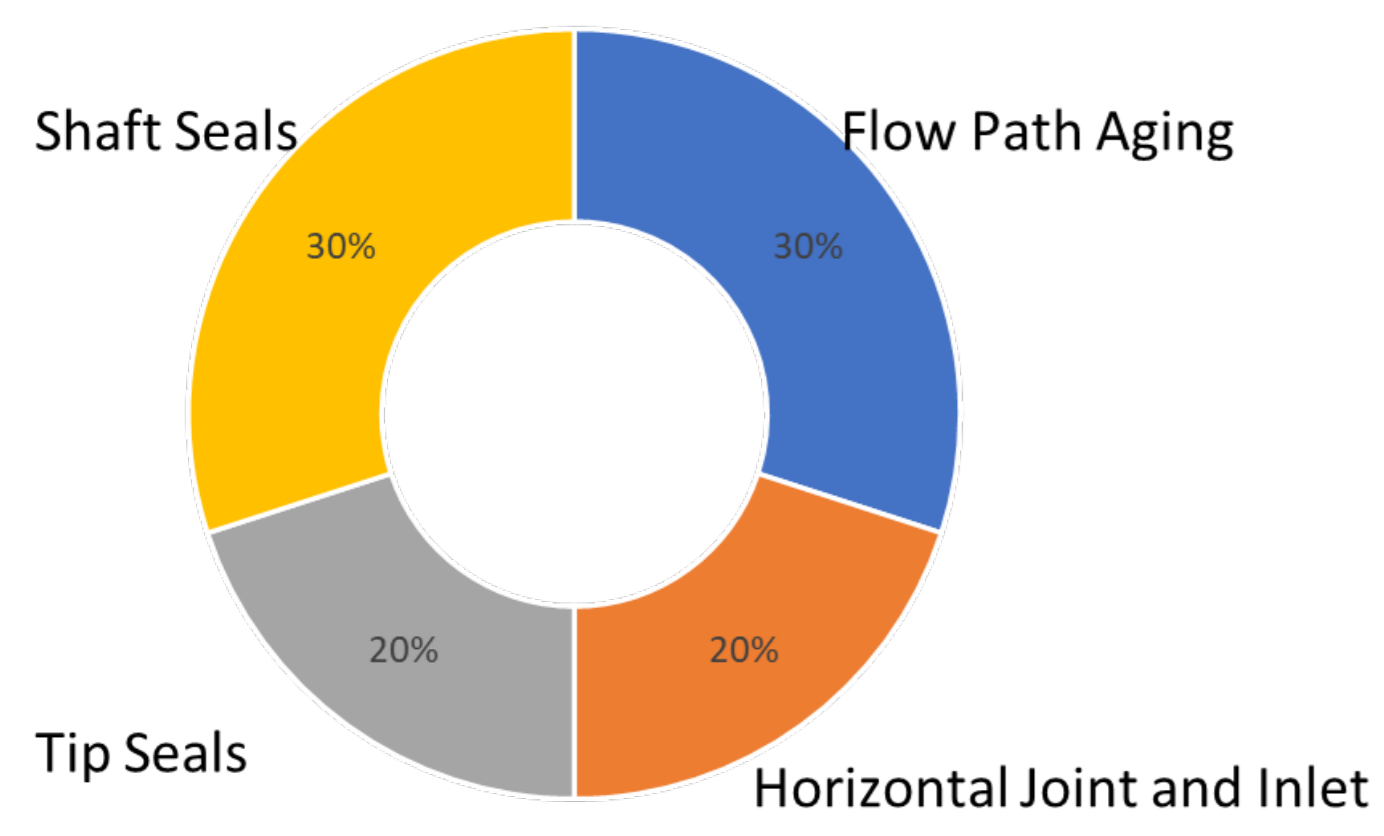
Clayton Grondahl (CMG Tech) and Rich Armstrong (Turbine Consultant)



Supercritical CO₂ Power Cycles Symposium

Shaft Sealing is Critical to Turbomachinery Performance

Area of Performance Loss in Steam Turbines



Source: Ethos Energy Public Document Based on Steam Path Audits

sCO₂ Seal Development Testing at Sandia Brayton Energy Laboratory



- Test facility capability :
 - 4000psi (275bar) sCO₂ pressure
 - 40,000 RPM shaft speed
 - 1300°F (700°C) temperature
 - Steady state leakage make-up capacity 30 g/sec
- Charter to assist in commercialization of sCO₂ power conversion cycles for advanced nuclear reactors

PALS for Sandia

- PALS Identified as the most promising shaft sealing candidate for:
- Large clearance rub avoidance before actuation on startup / shutdown.
 - Does not induce cross-coupling as with labyrinth seals
 - Requires only a short axial length for design of shorter, more stable, rotors

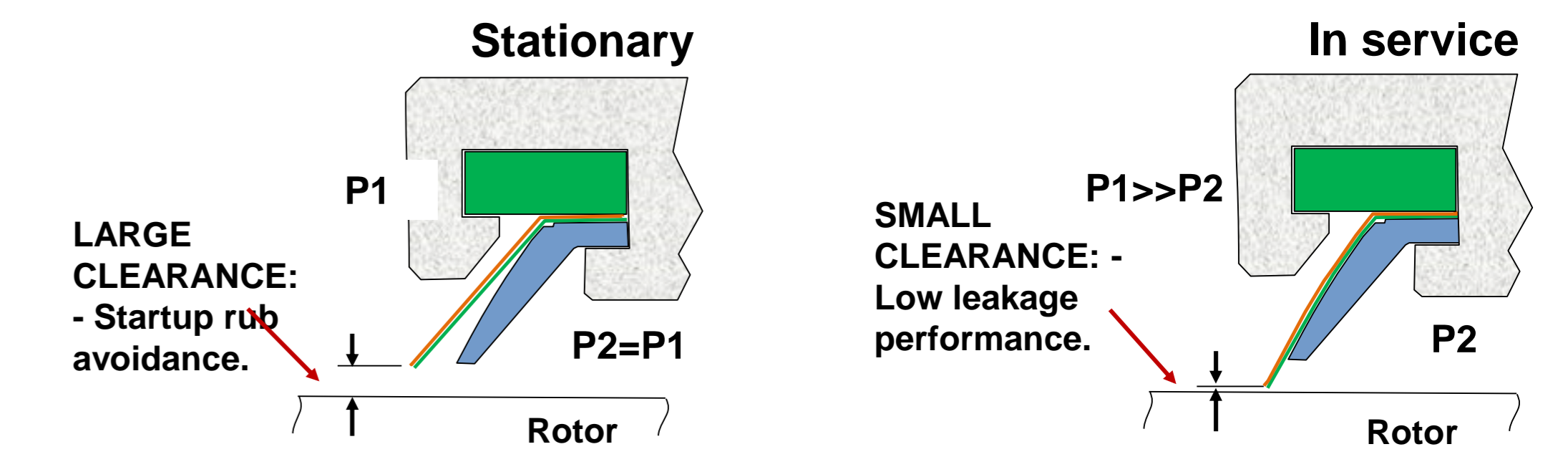
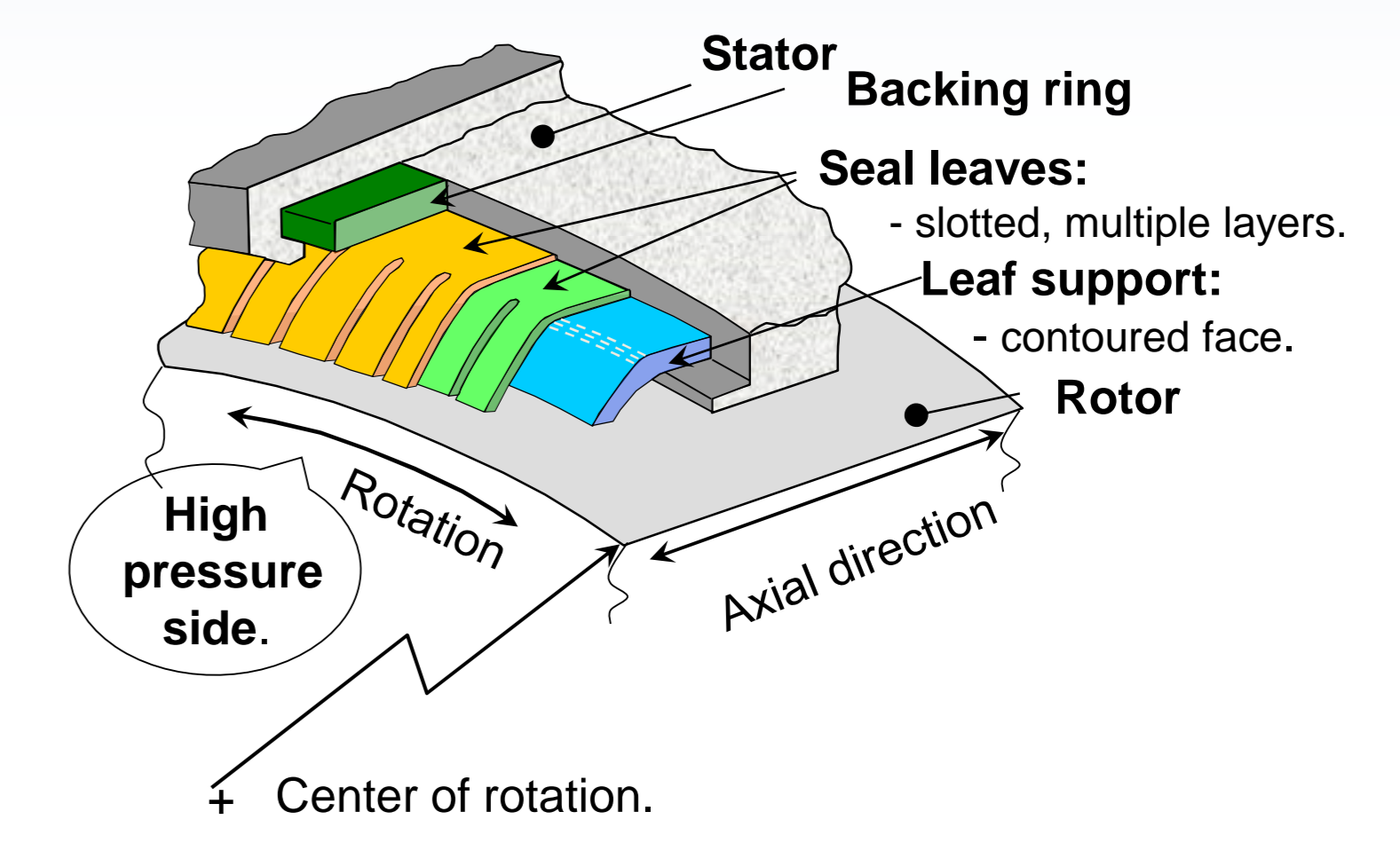
Sandia plan: modify sCO₂ DGS pocket for PALS test:

- Replace DGS radial seal runner with a cylindrical spacer
- Test 2 PALS back-to-back same as DGS
- Enlarge sCO₂ passages for flow to close PALS

PALS design specifications:

- 2.3in (58.4mm) seal diameter
- 3000psid (207bar) differential pressure
- 0.015in (0.38mm) fence height
- Seal tip closure of 0.010in (0.25mm) at ~500psid (34bar)
- Ambient temperature

PALS Design and How it Works



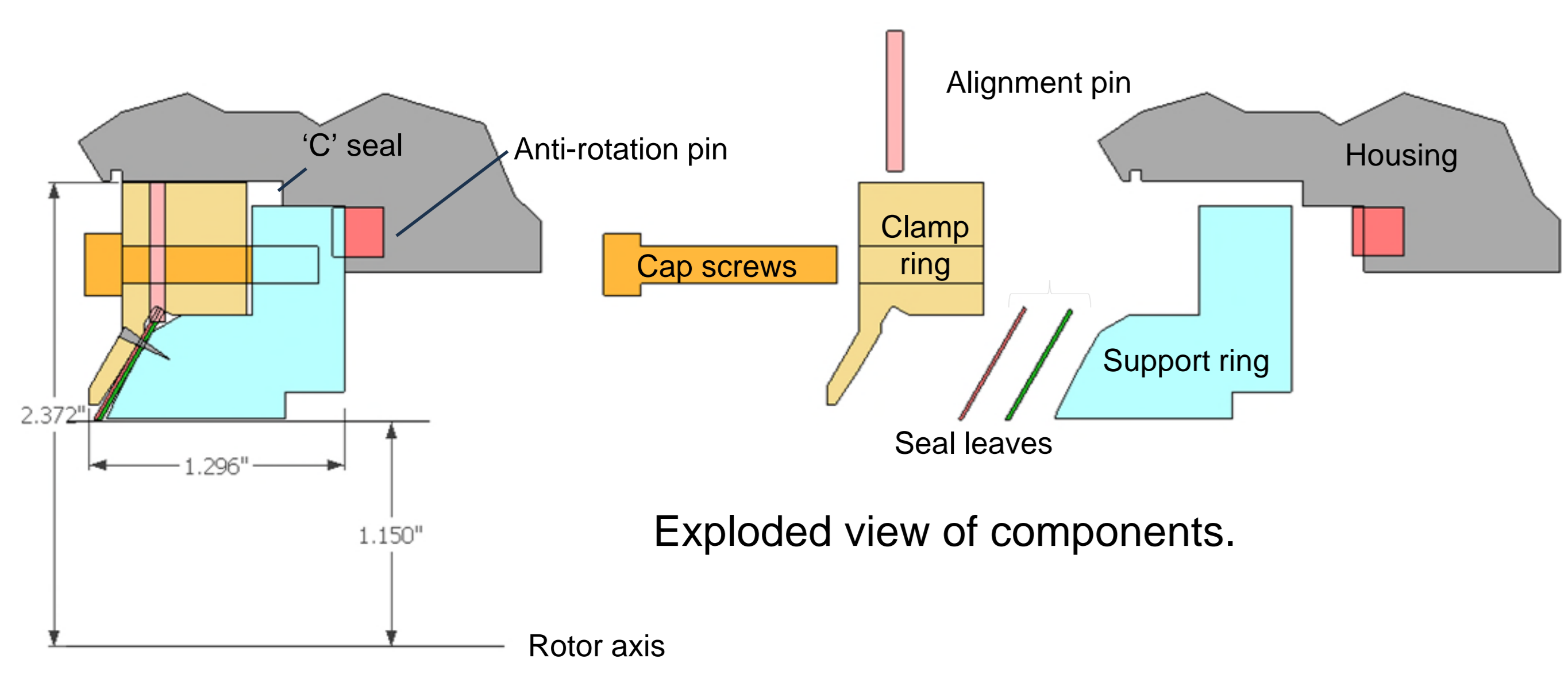
sCO₂ Applications Challenge Shaft Sealing at High Delta-pressure and Shaft speed

Dedicated Facility for sCO₂ Seal Testing at Extreme Pressure and Shaft Speed

Supply 'Strip' Style and 'Conical' PALS Designs with Static Verification Testing

Seal Clearance Closure with Pressure Bending of Leaves and Compliant Shaft Seal Operation with Initial Wear-in

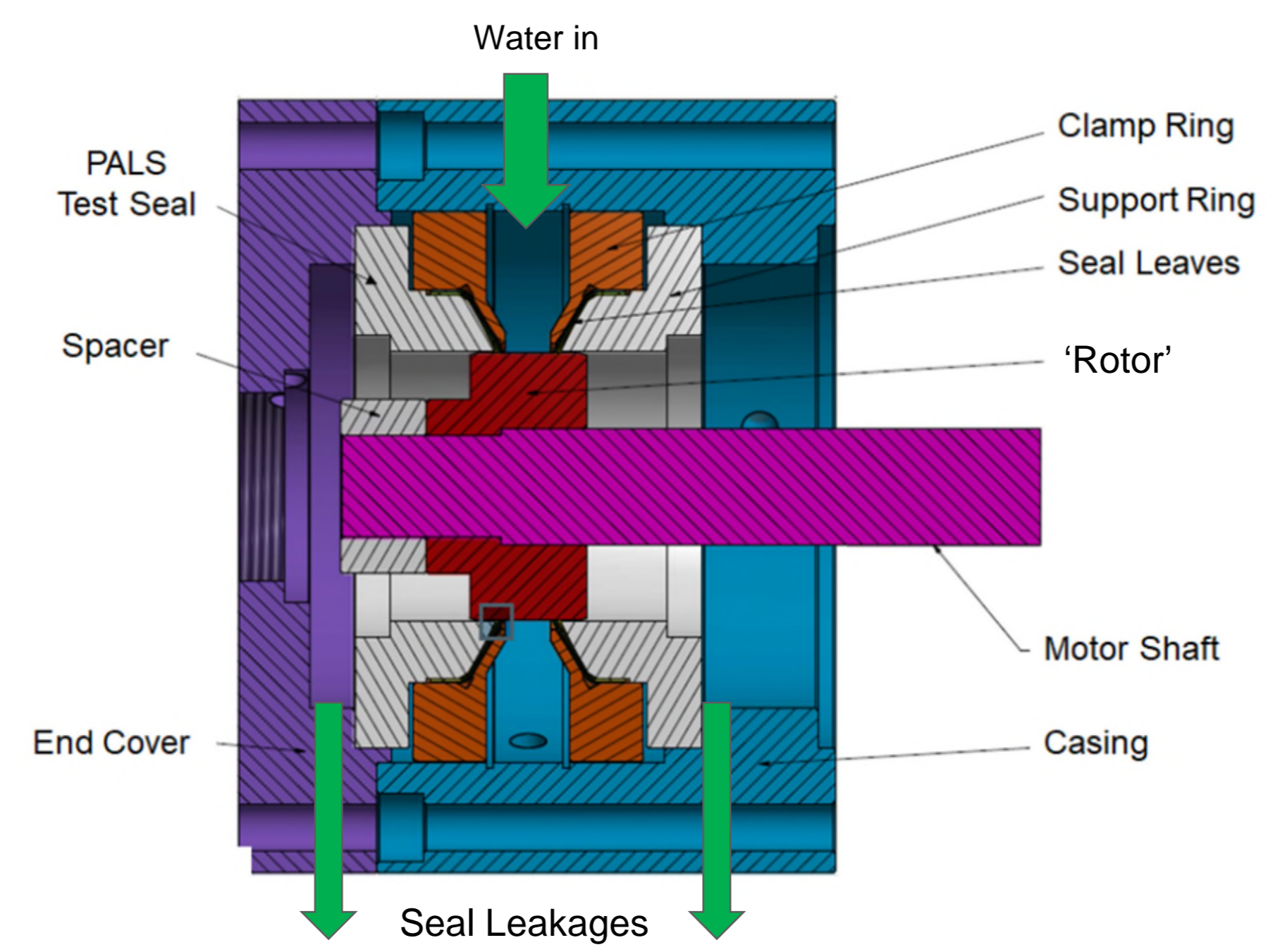
Sandia PALS Design – 'Conical' Seal Leaves:



Assembly and Seal Envelope Dimensions

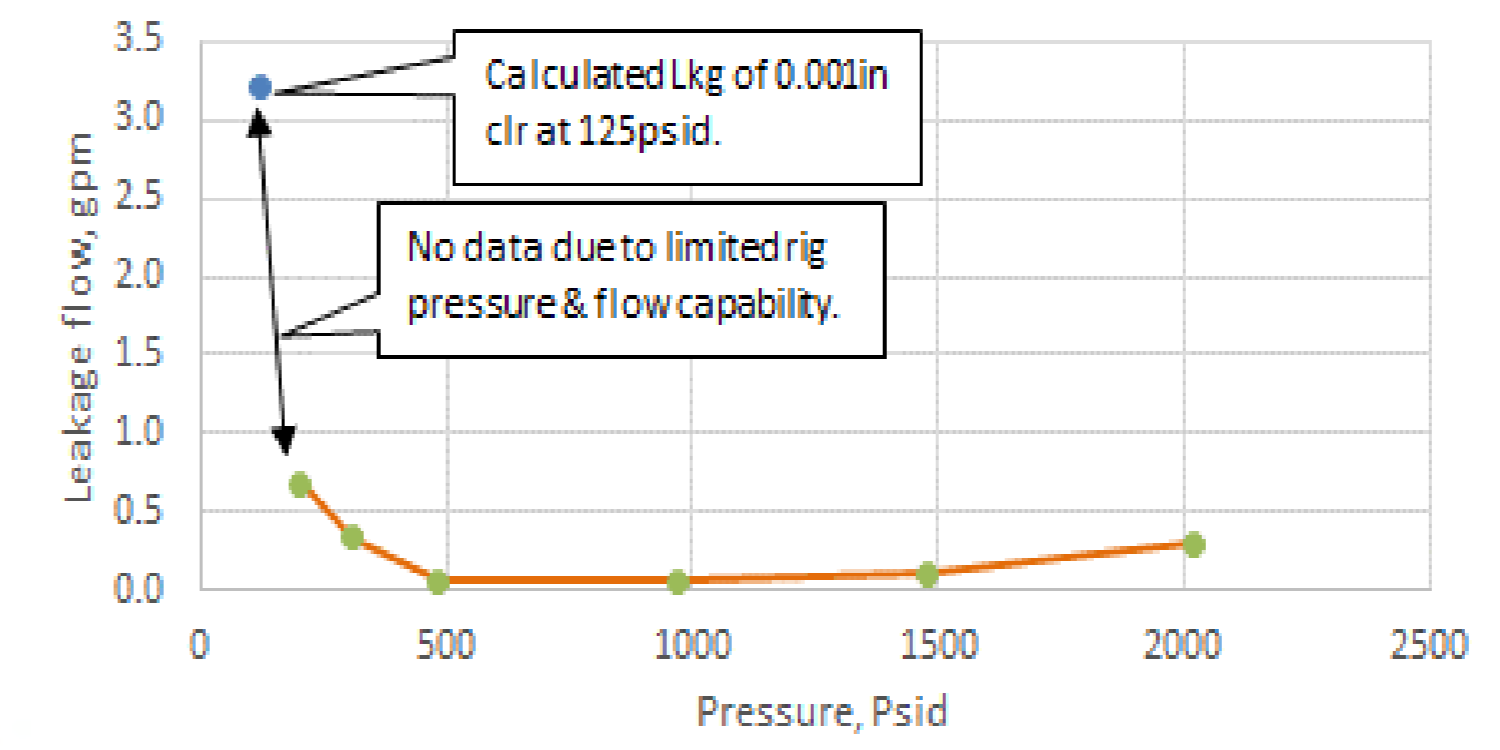
Design Verification Testing:

- Confirm PALS closure in non-rotating water rig.
- Duplicate features of Sandia seal test pocket.
- Assess PALS inter-leaf leakage with 0.002in (~50µm) leaf tip – 'rotor' interference.

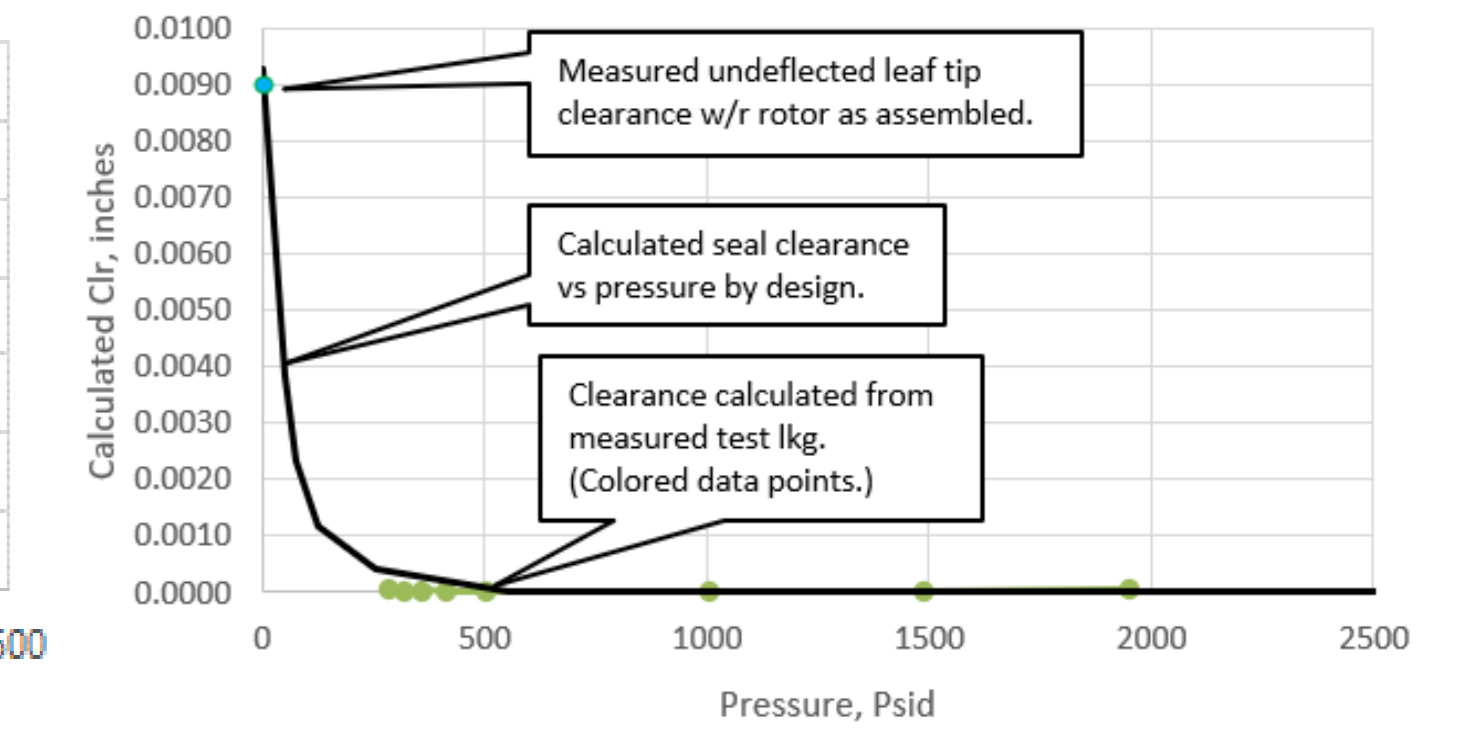


Verification Test Results - 'Conical' Seal Leaves:

• Seal leakage vs pressure:



• Effective seal clearance vs pressure:



- ✓ PALS seal clearance closed with pressure at less than 500psid (35bar).
- ✓ Seal inter-leaf leakage less than 0.5gpm (1.9lpm).
- ✓ Effective inter-leaf seal clearance is less than 0.0001inch (0.0025mm) at pressure above 300psid (20bar).
- ✓ PALS verified ready for Sandia sCO₂ dynamic testing

* Ref ASME GT2023-102258 source material and copyright.

Results Continue to Verify PALS a Viable Technology for sCO₂ Application.