Long-Term Radiation Rugged Rotary Vacuum and Water Seals in Heavy-Ion Accelerators

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Office of Nuclear Physics U.S. Department of Energy

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TPOC: Dr. Michelle Shinn

Overview

Topic 26f: *Rotary Vacuum and Water Seals in Heavy-Ion Accelerators*

Needed for NP Experiments:

- Ultra-high vacuum and water-cooled seals
- Constant rotation 600 rpm, 5,000 hr, ~1 year
- Extremely high annual radiation dose (~15 MGy)
- Need to change seal as infrequently as possible

Partners:

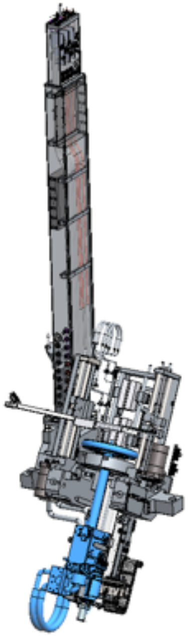
- BNL - NSRL and BLIP
- MSU - FRIB
- Garlock
- Cardinal Rubber & Seal

DOE Topic 26f – Technology for High Radiation Environments

Grant # DE-SC0017107

OBJECTIVE:

- **Develop new rotary vacuum and water seals for rotating targets and beam dumps for rare isotope beam production and beam strippers in high-power heavy-ion accelerators**
- **Durable performance for 0.5 – 1.5 MGy/month, 1 year (5,000 hours), at 600 rpm over 32 °C to 66 °C, water side: 60 gpm (25 psi), vacuum side: 1e^{-5} Torr L/s**



Need mechanical performance with enhanced Radiation & Less Abrasive
Investigating new material for new identified seal design

NanoSonic Team

& Our Commercial Partners/Investors

Dr. Jennifer Lalli, President, FSO, ITPSO
Ph.D. Chemistry, Virginia Tech

- > 20 years of adhesive/sealant and gasket/seal development
- Implemented ExoStar Distribution of Products to Defense Primes
- 2 R&D 100 Awards for HybridSil® & Metal Rubber™ (issued patent)
- Commercialized 15 SBIR products sold at www.nanosonic.com

Dr. William Harrison, Membrane and Seal Production Lead
Ph.D. Chemistry, Virginia Tech

- >20 years of laboratory safety and production expertise
- Leads NanoSonic scale-up and product certification
- Commercializing Zero Humidity Fuel Cell Membranes with LANL

Dr. Eric Gilmer, Chemical Engineering Production Lead
Ph.D. Chemical Engineering, Virginia Tech

- AM prototyping, modeling, and manufacturing expertise
- Leads production of parts for space and aeronautics systems

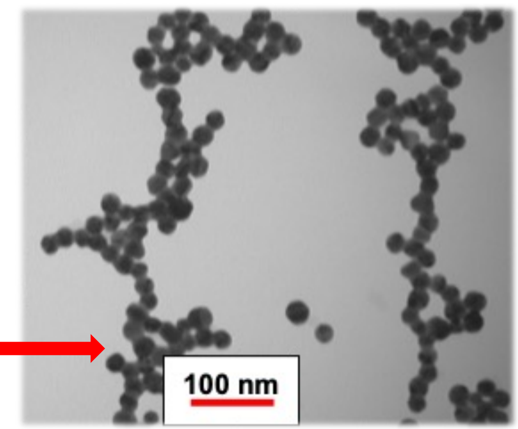
Facility for Rare Isotope Beams
at Michigan State University

Dr. Jie Wei, Accelerator Systems Division Director - Michigan State University, **Facility for Rare Isotope Beams**

- Design, fabrication, installation, commissioning, and operations of all aspects of FRIB accelerator systems
- 27 years of research, management, and teaching experience on particle accelerators, major science projects, and major user facilities
- Design, research and development, construction, and commissioning of the Relativistic Heavy Ion Collider interaction-region design of the Large Hadron Collider (LHC), the design, research and development, and c the Spallation Neutrino Source (SNS) ring, and the leadership of the China Spallation Neutron Source (CSN

Dr. Jeongseog Song, Target and Beam Dump Systems Group Leader
Drs. Philip Morrison, Michael Larmann, and Nicholas Reha

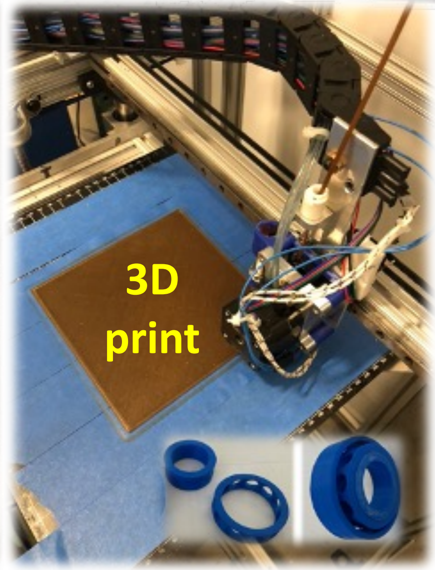
NanoSonic is now
ISO 9001:2015 Certified by NSF-ISR

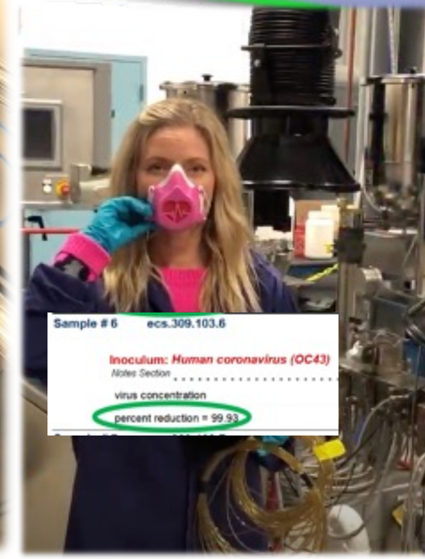


250-gal, 55-gal, 1-10 L in hood, two 20L, and one 100 L reactor

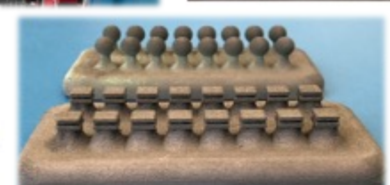
Au from 100 -L

NanoSonic Production Capabilities:
Extrusion and 3D Printing of Radiation Tolerant Polymers, Metals, & Ceramics





NanoSonic

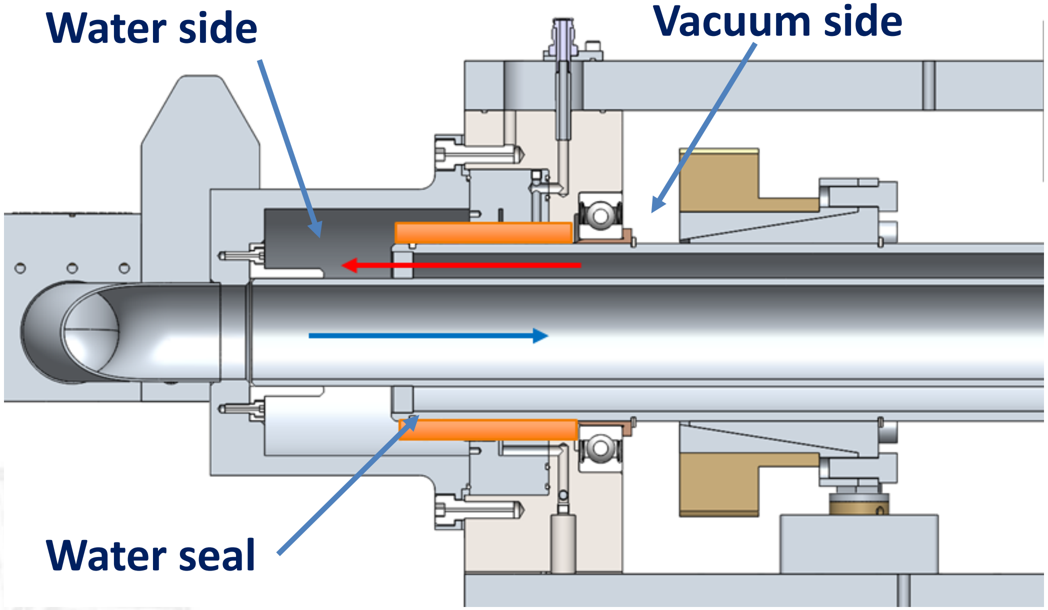


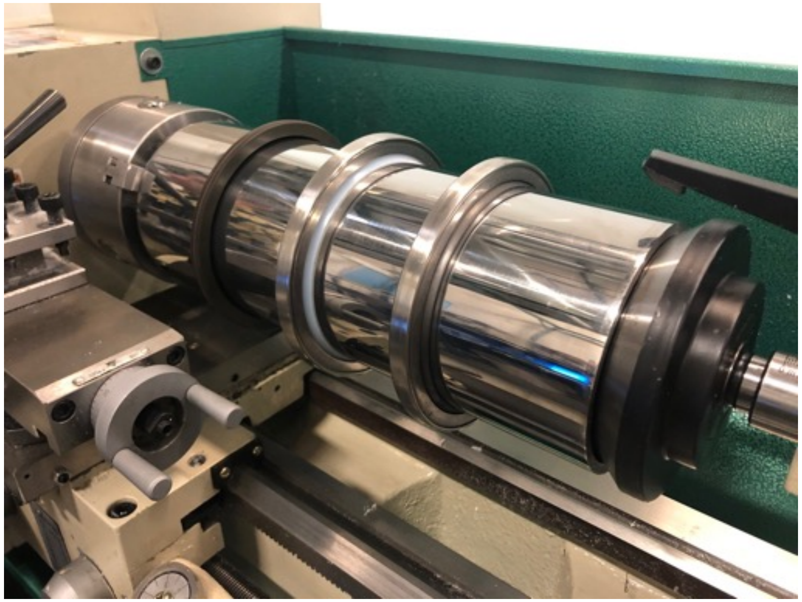
Goal:

Develop New Materials and Seal Designs for FRIB Beam Dump

GOALS:

- **Develop new polymers with radiation resistance**
- **Extrude compounded films not commercially available**
- **Implement new seal design**





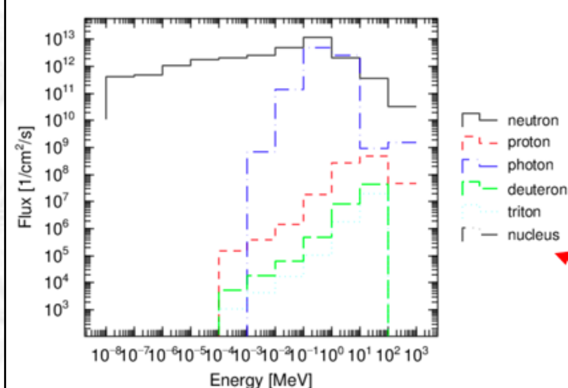
Reproduced 4.5" SS Shaft for Abrasion Testing of New Seal Materials to Mimic Beam Dump Water Seal

Goal: Survive High Dose Exposure

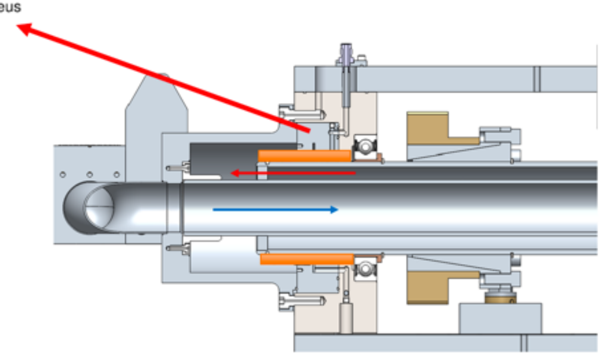
Particle Energy Spectra for Beam Dump's Rotating Water Seal

Energy, MeV		Flux, particles/cm2/second				
E_low	E_high	Neutrons	Protons	Photons	Deuterons	Tritons
1.0E-09	1.0E-08	5.1E+06	0.0E+00	0.0E+00	0.0E+00	0.0E+00
1.0E-08	1.0E-07	1.9E+08	0.0E+00	0.0E+00	0.0E+00	0.0E+00
1.0E-07	1.0E-06	2.3E+08	0.0E+00	0.0E+00	0.0E+00	0.0E+00
1.0E-06	1.0E-05	4.9E+08	0.0E+00	0.0E+00	0.0E+00	0.0E+00
1.0E-05	1.0E-04	8.3E+08	0.0E+00	0.0E+00	0.0E+00	0.0E+00
1.0E-04	1.0E-03	9.7E+08	6.8E+01	0.0E+00	2.4E+00	5.0E-01
1.0E-03	1.0E-02	1.2E+09	1.8E+02	3.2E+05	8.3E+00	2.0E+00
1.0E-02	1.0E-01	2.3E+09	6.7E+02	6.7E+07	3.0E+01	7.9E+00
1.0E-01	1.0E+00	5.3E+09	8.2E+03	2.3E+09	2.3E+02	4.8E+01
1.0E+00	1.0E+01	9.5E+08	1.2E+05	1.2E+09	3.8E+03	8.1E+02
1.0E+01	1.0E+02	1.6E+08	2.3E+05	4.3E+05	2.0E+04	9.3E+03
1.0E+02	1.0E+03	1.5E+07	2.1E+04	7.3E+05	0.0E+00	0.0E+00

- 48Ca at 400 kW, 261 MeV/u → 40Mg



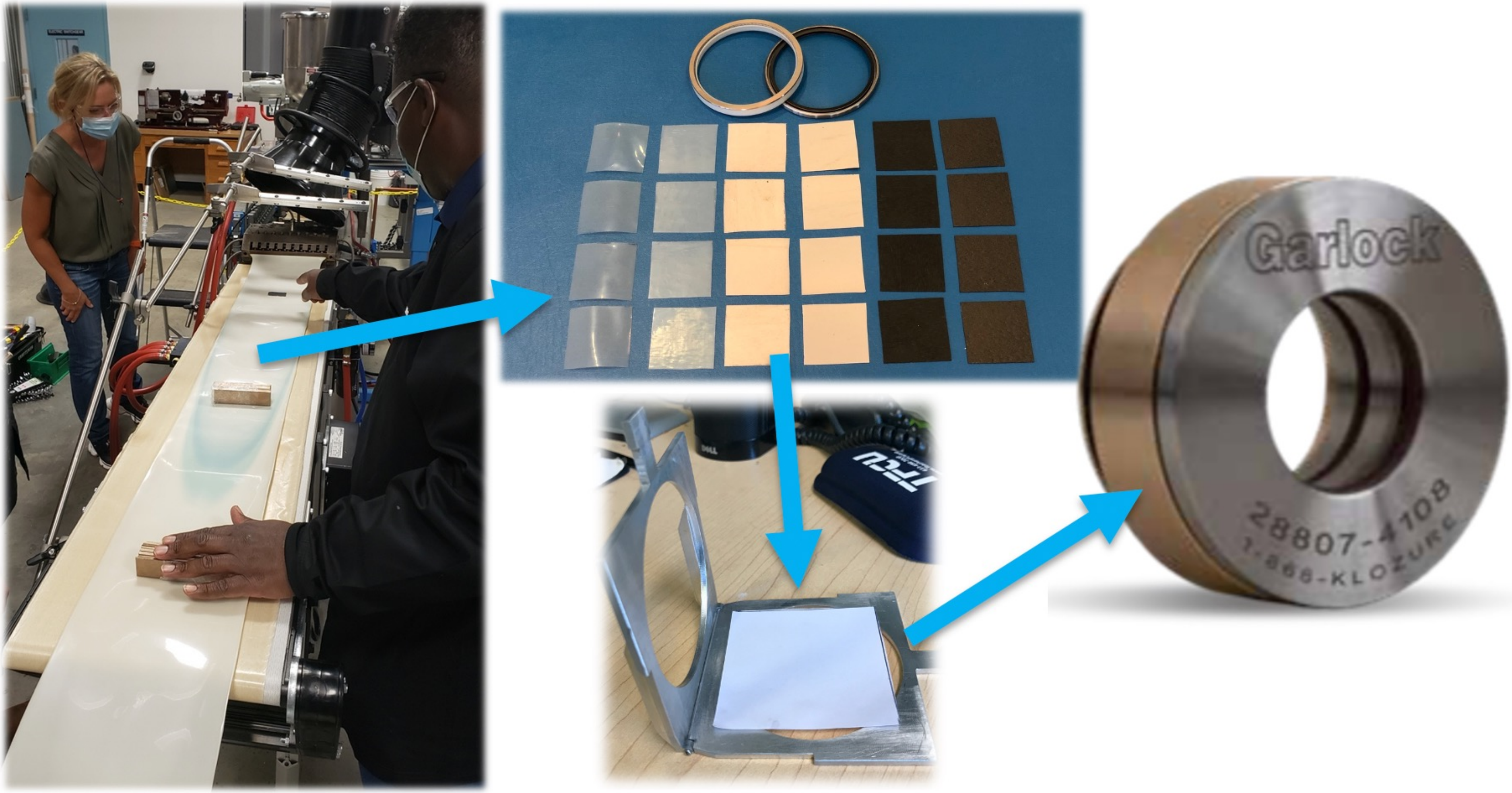
D. Georgobiani



High Energy 260 MeV when operated at 400 kW

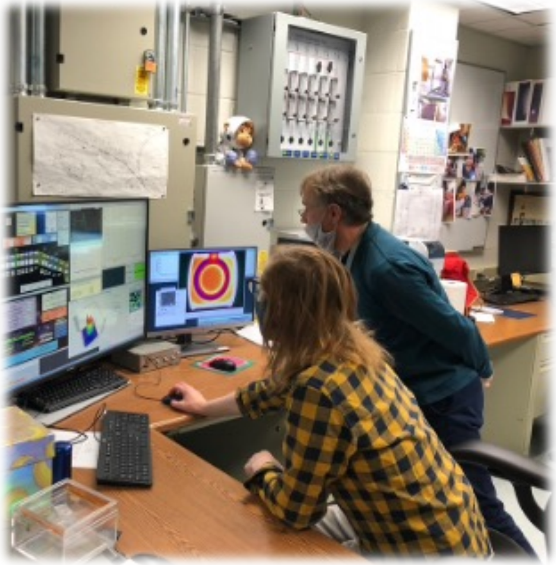
Technical Approach

Extrude New Compounded Materials for use in New Seal Designs
Expose Materials to High Energy and High Dose Radiation for Durability Study

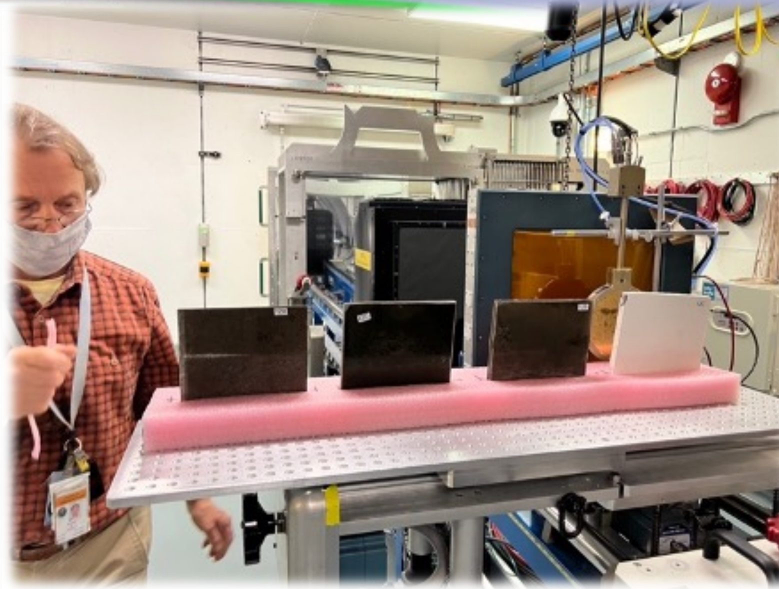


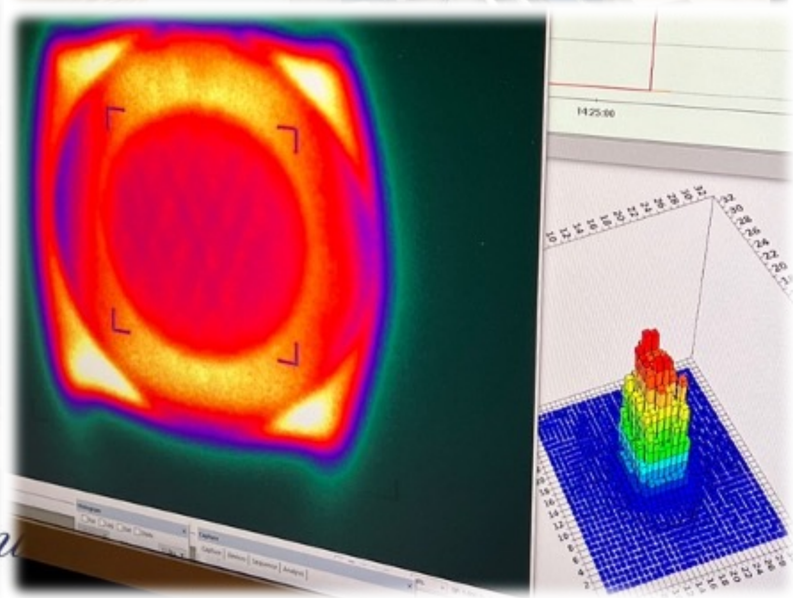
Extrude NanoSonic Modified Polymer for High Dose Exposure at BNL BLIP and Integration with Garlock Housing

Radiation Exposure Run 1 - May 7, 2021
High Energy – 1 GeV Fe / 1 GeV proton



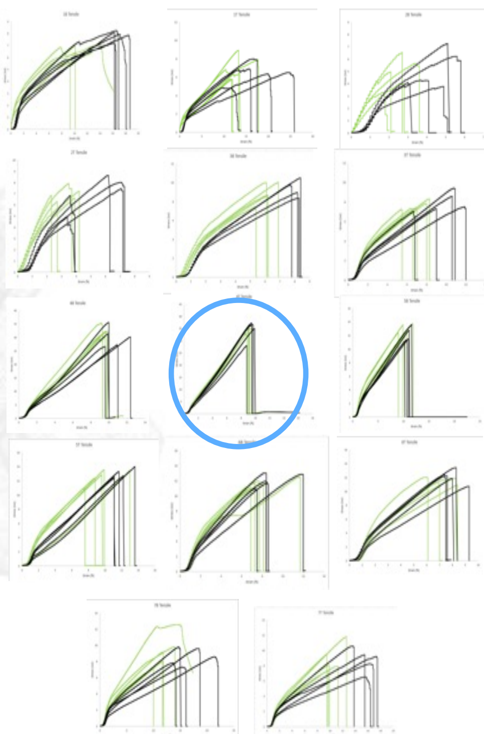
Radiation Exposure Run 2 - June 13, 2022
Lower Energy – 400 MeV Fe / 100 MeV proton

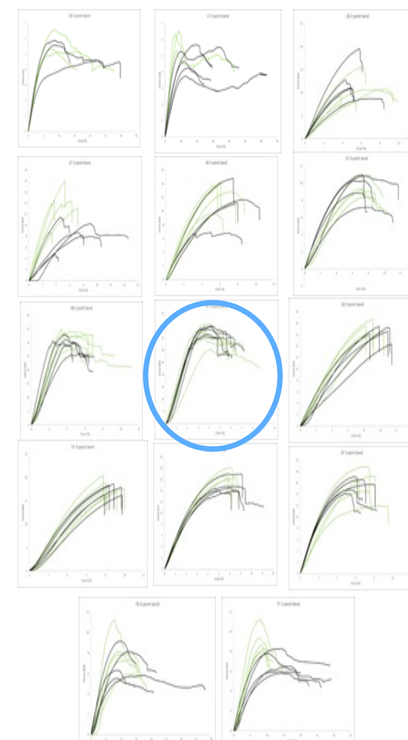




Pre- and Post- Irradiation Tensile and 3-pt Bend
54 Gy dose: *1 GeV proton + 1 GeV Fe*

The composite sample was first irradiated using a beam of Fe ions at an energy of 1000 MeV/nucleon at the NASA Space Radiation Laboratory (NSRL) at Brookhaven National Laboratory. The beam was prepared with a uniform radiation field that spanned 20 x 20 cm^2. The dosimetry was performed with a 1 cm^3 ion chamber with a NIST-traceable calibration for dose delivered in water. After calibration, the composite sample was placed on the beamline and exposed for 67.62 minutes for a total dose of 27 Gray. The beam came in “spills” that were ~400 milliseconds long with a period of 6.6 seconds. The sample was then irradiated with a proton beam of 1000 MeV energy where the exposure of 27 Gray took 24.36 minutes.

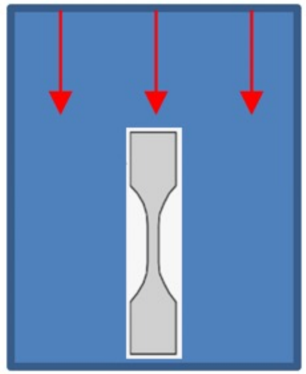


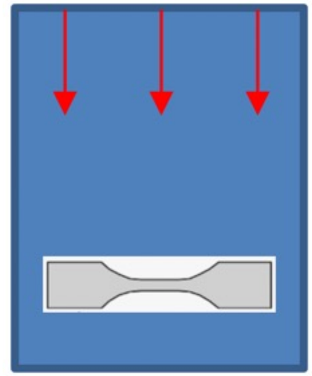


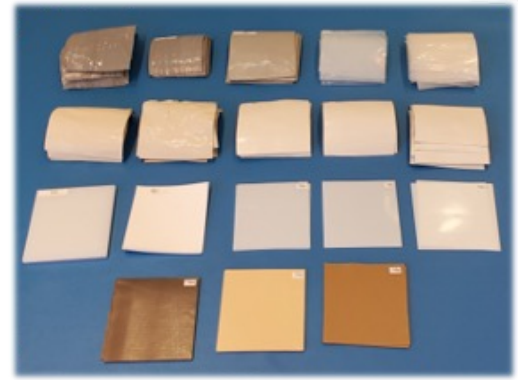
Composites with High-Z Layer Exhibits Trend for Enhanced Durability

Increased Dose – 214 Gy

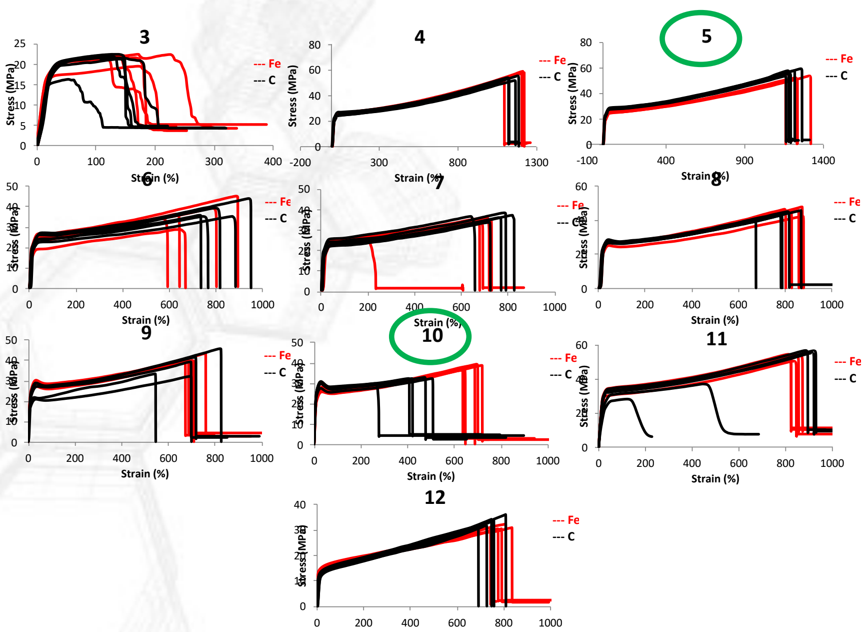
Exposure at NSRL to Fe 1 GeV for Down-Selection – Chain Scission vs. Embrittlement

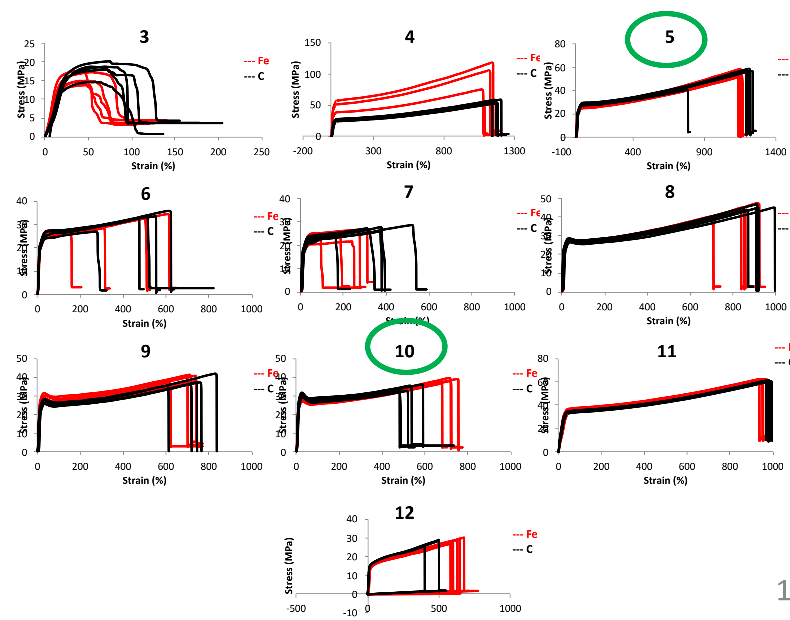




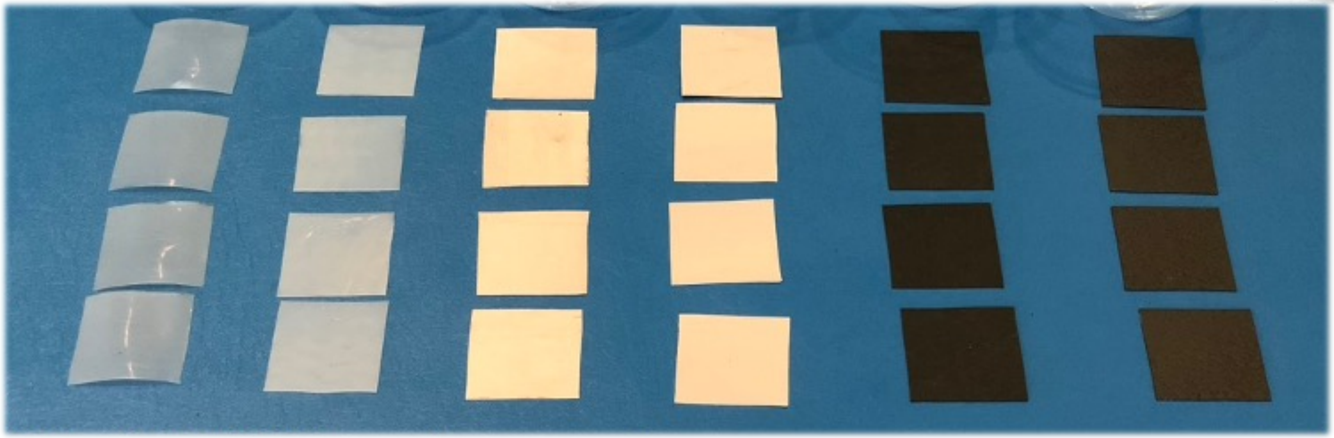


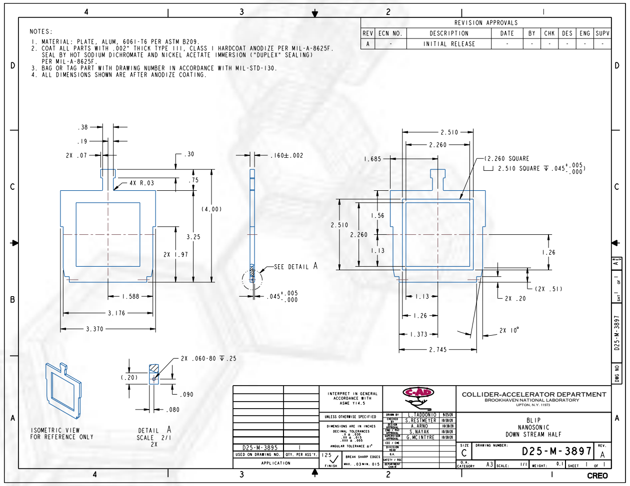
Mechanical Properties for All NanoSonic Films in Parallel and Perpendicular Directions

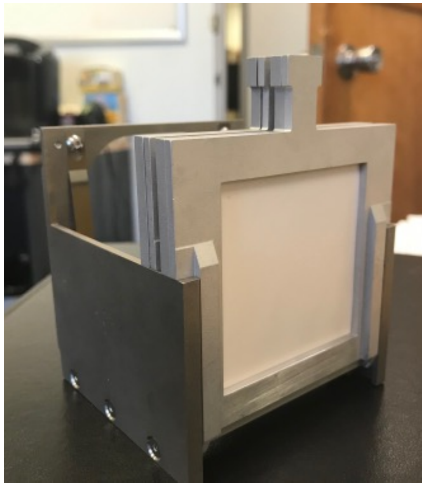


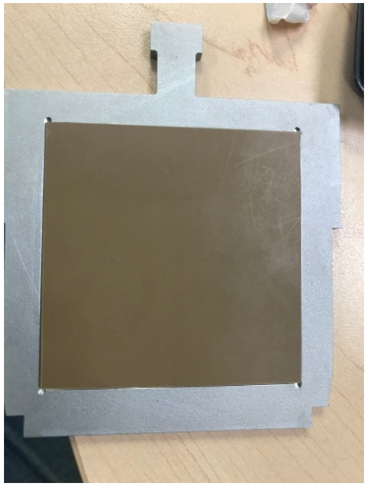


High Dose Exposure at BNL BLIP
Delivered Films





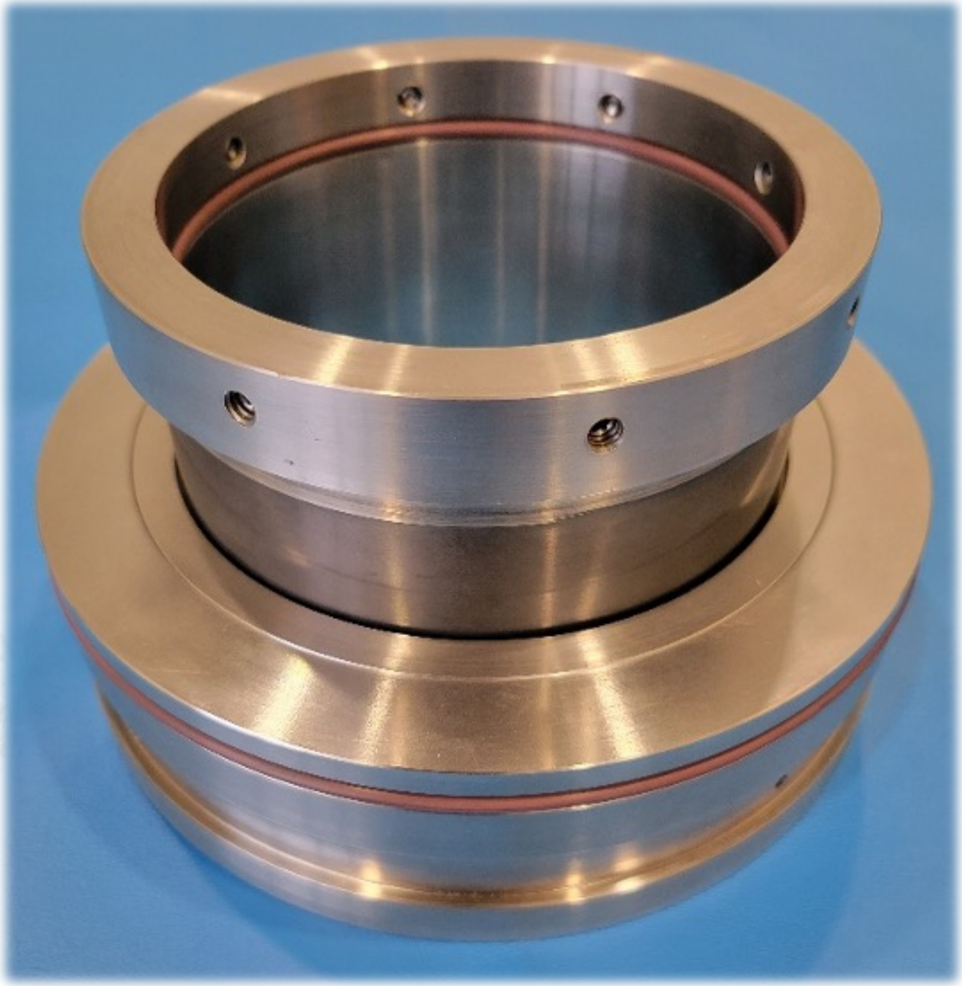




First Run in 2022 – New Run Pending

Status

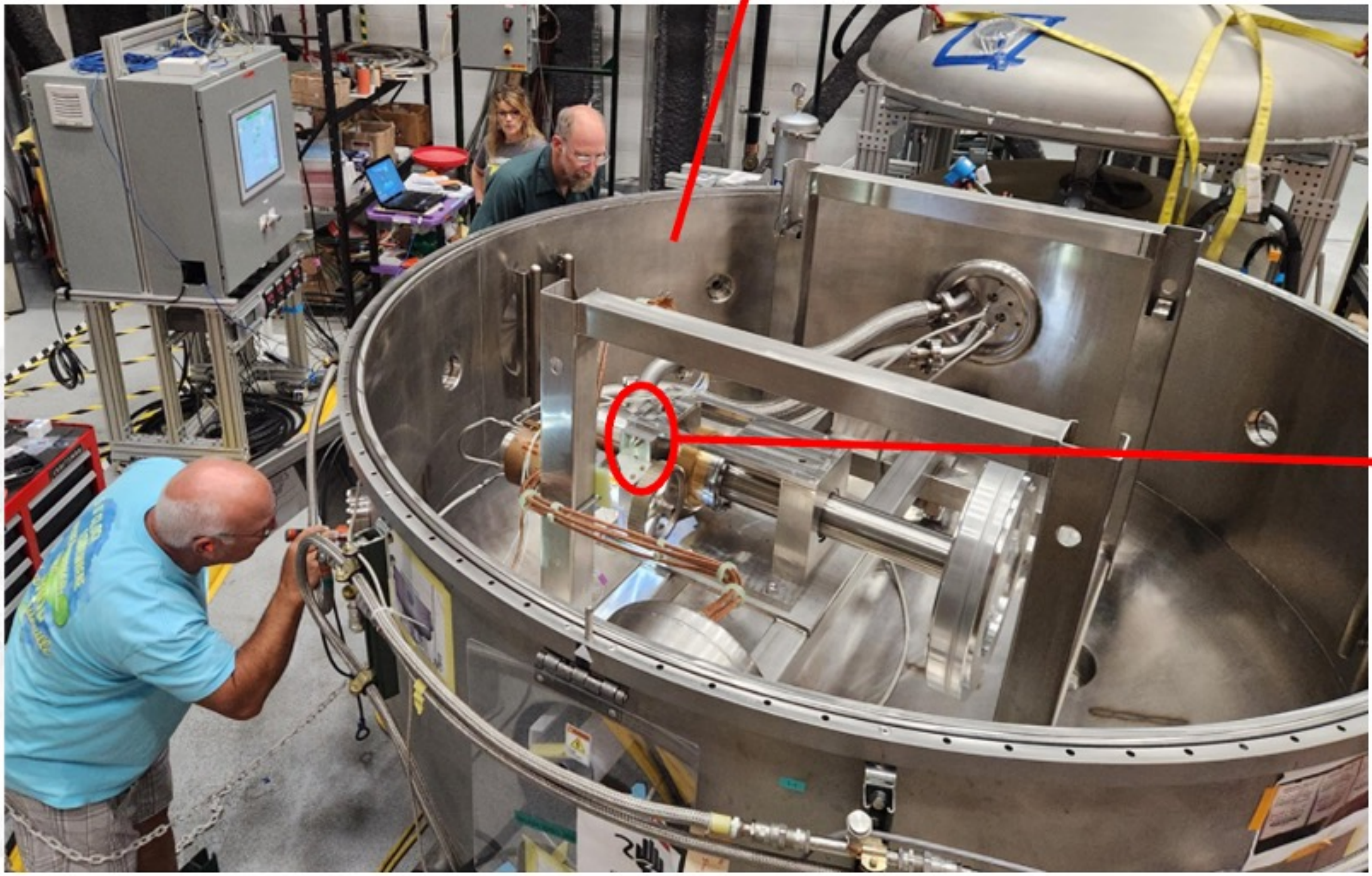
Delivered Fully Assembled Seals to MSU for Initial Testing



NanoSonic Delivered Custom Seal Housings with COTS inner lip seals and o-rings

System
Water Seal Test Vessel

Vacuum vessel



Water seal inside

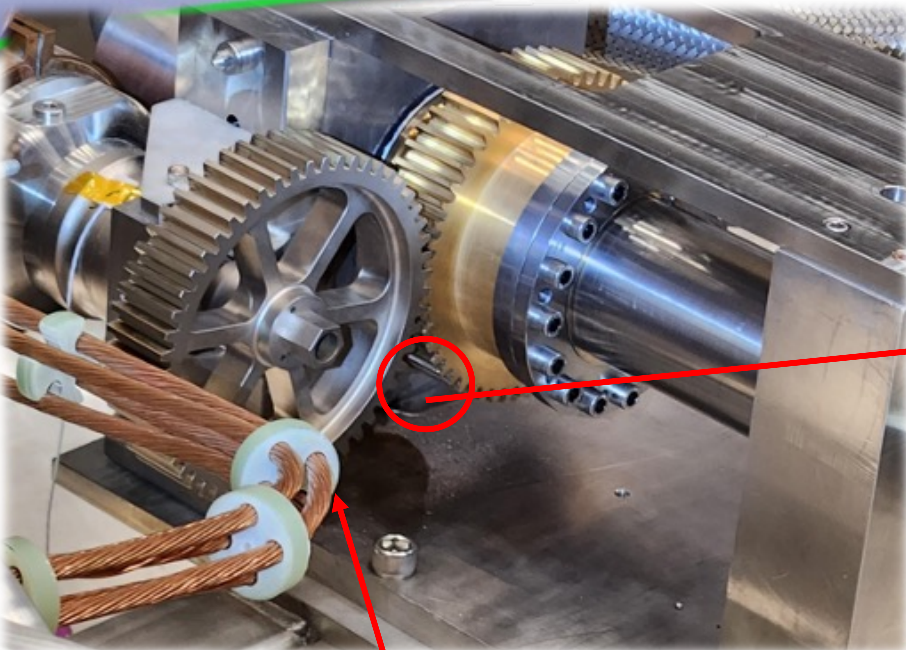
DRM test

- Rotating and water flow test at target truck bay area on 6/28/2023
  - Water flow rate for DRM
  - Inlet: 57.5 gpm
  - Outlet:62.81 gpm
  - Water pump rotating speed: 3500 rpm
  - Flowmeter not exactly in center
  - Water cooling for motor, ~ 2 gpm

Rot speed (rpm)	Time	Motor current (A)	Δp (psi)	Motor temp (C)	Flow (gpm)	Water leak
200	10:30 – 10:50					X
300	10:50 – 11:10	3.85	7 (83-76)	29.11	In:55.3 out:59.26	O

NanoSonic

Water Leak Found during Rotation



New Materials Production Status

Calender New Compounded Materials for use in New Seal Designs

Expose Materials to High Energy and High Dose Radiation for Durability Study

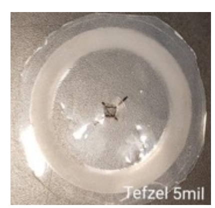
Calender NanoSonic Modified Polymer Materials for Integration with New Housing

Accomplishments in Abrasion

On Taber Abrader per ASTM D-1003

Taber Abrasion for Water/Vacuum Seals

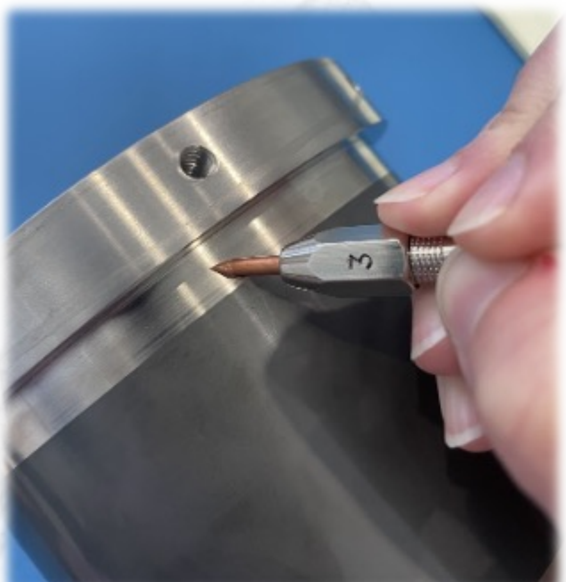
Material	L (mm)	R (mm)	Pretest weight (g)	Post-test weight (g)	cycles	Loss (g)
	CS17 Diameter					
	51.19	50.88	1.0513	1.0408	4	0.0105
	51.06	50.68	2.4301	2.407	1000	0.0231
	50.94	50.62	47.1957	47.1734	1000	0.0223
	48.78	47.84	101.8792	101.8357	1000	0.0435
	48.69	47.81	101.4681	101.4392	1000	0.0289
	48.59	47.79	53.83	53.44	1000	0.3900
	48.49	47.58	55.9317	55.6309	1000	0.3008



Rockwell Hardness Important as SS 304l is 30 vs. SS 304 of 70

Technical Approach

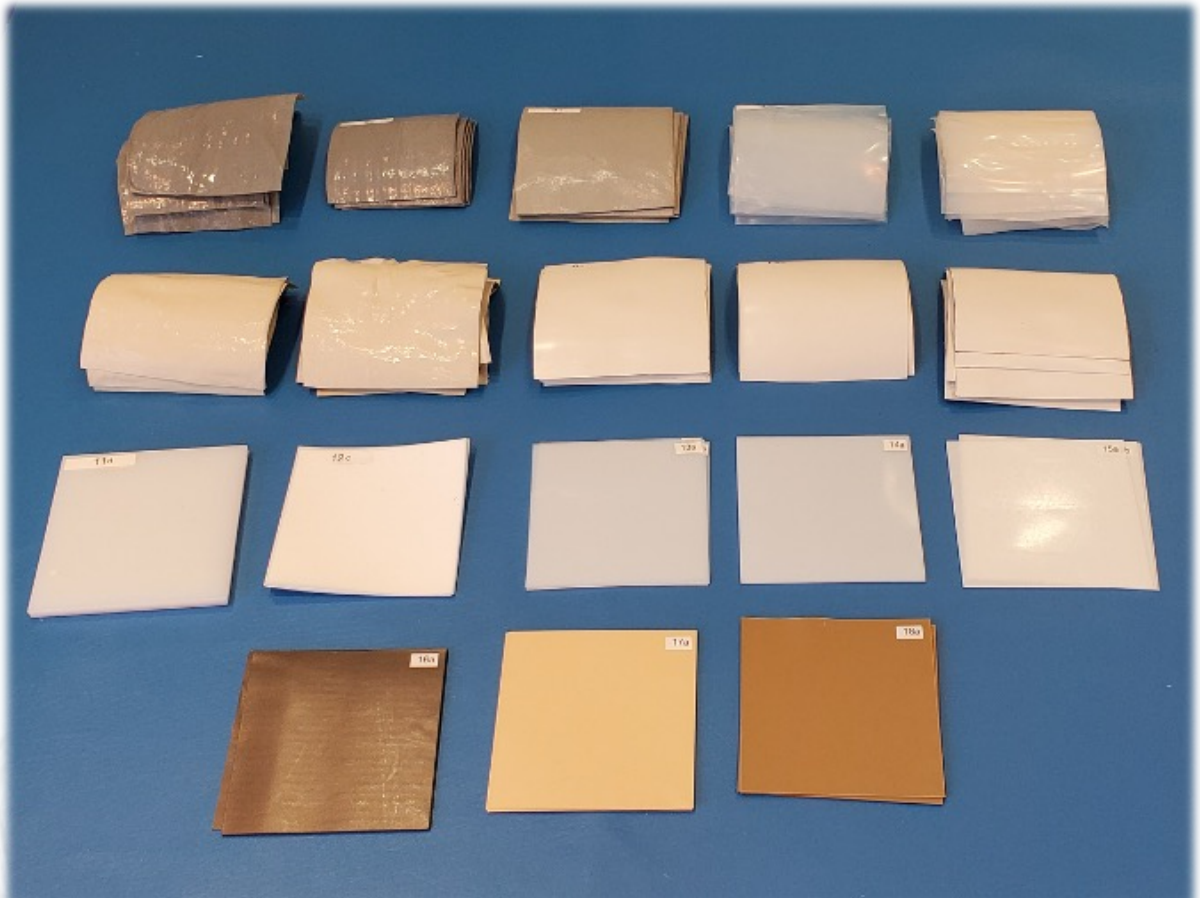
Seal Housing and Lip Hardness



Lip Seal Hardness Shall be Tailored for Housing

Integration Status

Radiation Exposed Materials Down-Selected for Seal Testing



Radiation Exposed Seal Materials Down-selected and formed as Lip Seals for Integration within Housing

Acknowledgements

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