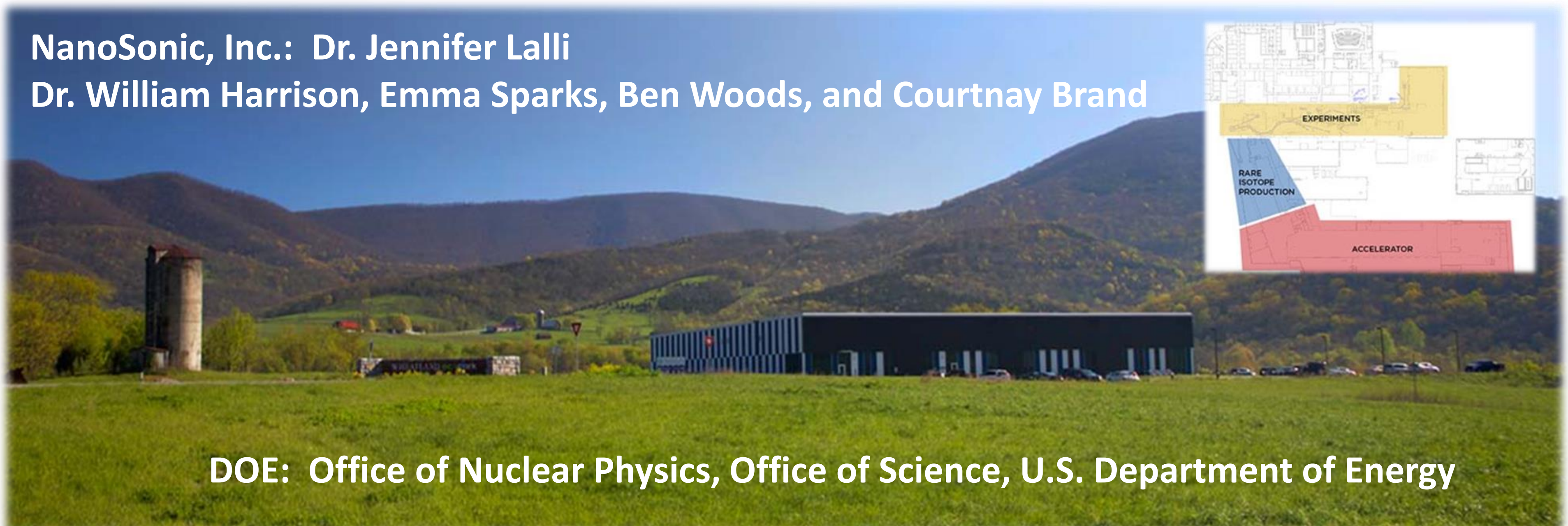
NanoSonic, Inc.

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



NanoSonic, Inc.: Dr. Jennifer Lalli
Dr. William Harrison, Emma Sparks, Ben Woods, and Courtnay Brand

DOE: Office of Nuclear Physics, Office of Science, U.S. Department of Energy

August 24, 2022 - DOE SBIR Phase IIA NP SBIR Exchange

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:

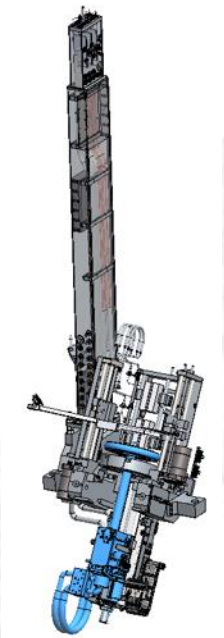
- BNL – NSRL and BLIP
- MSU, FRIB
- Garlock
- Cardinal Rubber & Seal

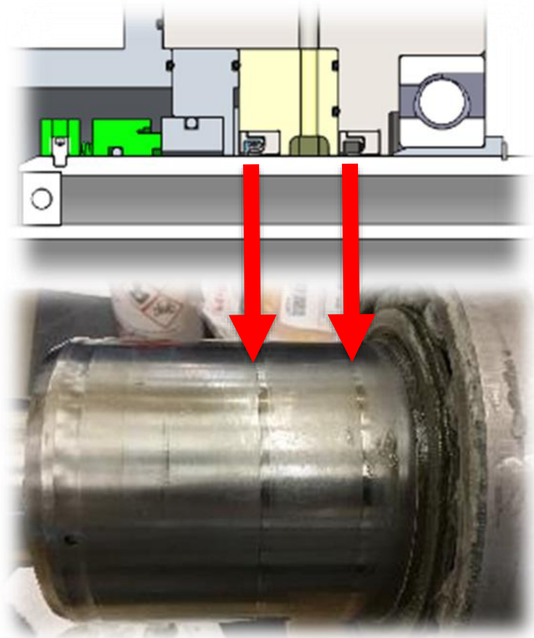
DOE Topic 26f – Technology for High Radiation Environments

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 the mechanical performance of Teflon with enhanced Radiation & Less Abrasive
Investigating new material for newly chosen design

NanoSonic Team

& Our Commercial Partners/Investors

Dr. Jennifer Lalli, Chief Development Officer
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, Gasket 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

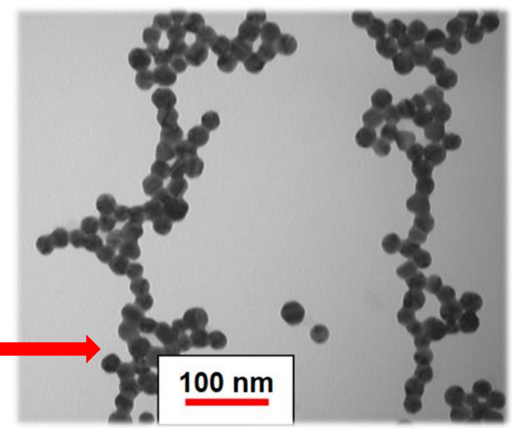
Dr. Jie Wei, Accelerator Systems Division Director - Michigan State University, **Facility for Rare Isotope Beams**

- 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 (RHIC), the interaction-region design of the Large Hadron Collider (LHC), the design, research and development, and construction of the Spallation Neutrino Source (SNS) ring, and the leadership of the China Spallation Neutron Source (CSNS) project.

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

Facility for Rare Isotope Beams
at Michigan State University

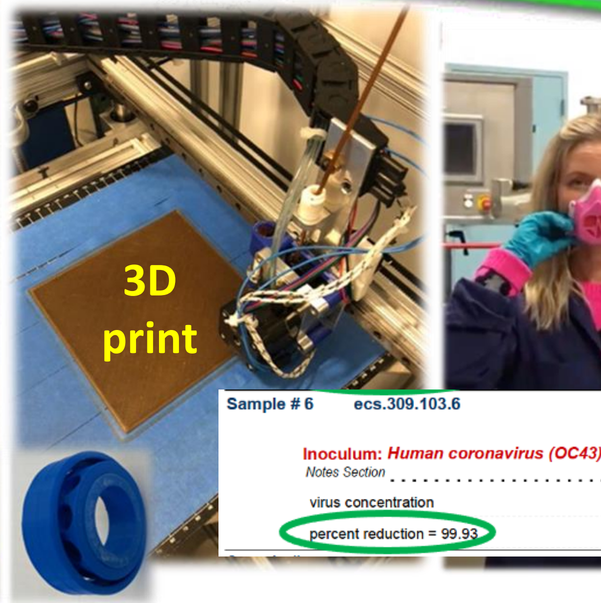
NanoSonic is now
ISO 9001:2015 Certified by NSF-ISR

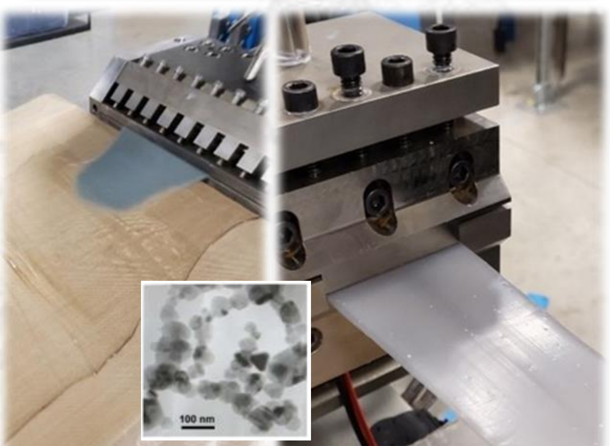


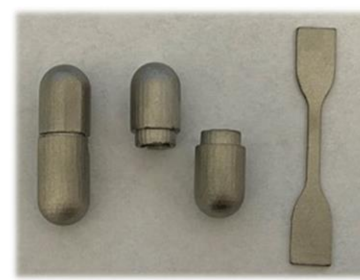
250-gal, 55-gal, 1-10 L in hood, two 20L, and one 100 L reactor

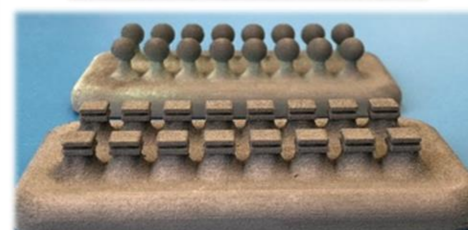
Au from 100 -L

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









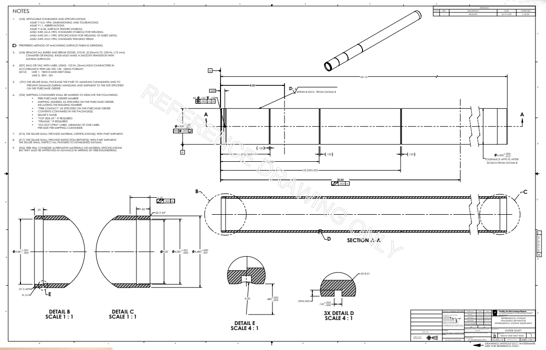
NanoSonic

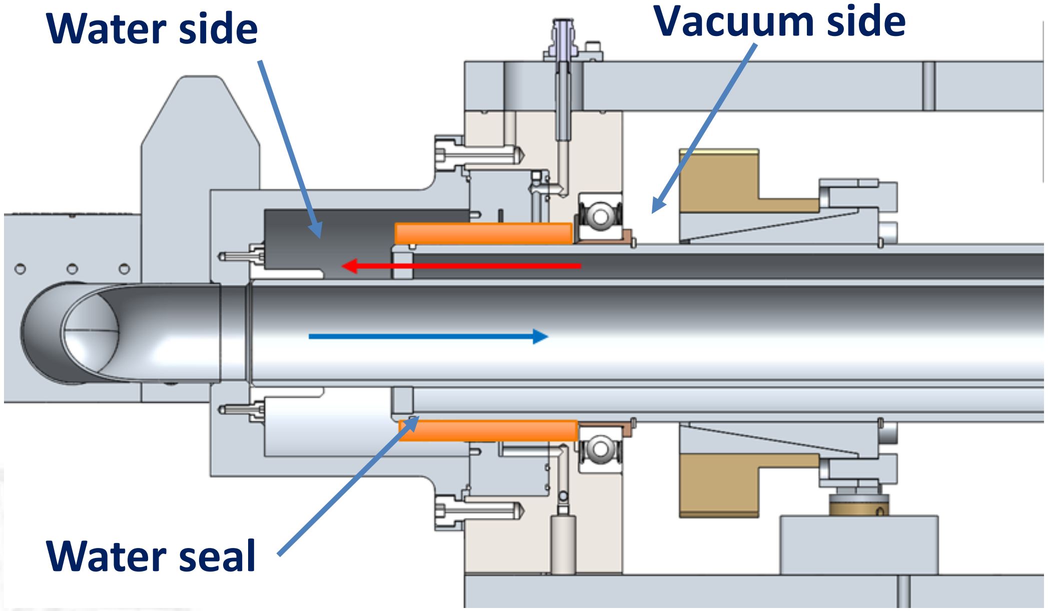
Goal:

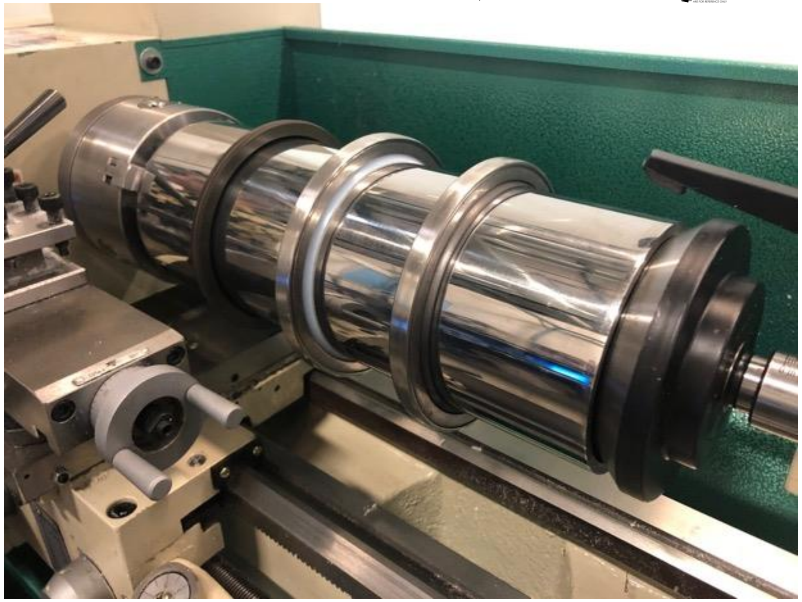
Develop New Materials and Seal Designs for FRIB Beam Dump

GOALS:

- **Develop new PTFE like polymers with radiation resistance**
- **Extrude compounded films not commercially available**
- **Implement new seal design – Flood-Gard® bearing isolator**







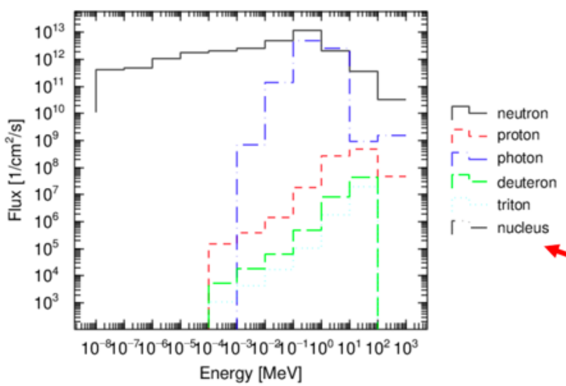
Reproduced 4.5" SS Shaft for Abrasion Testing of New Seal Materials to Mimic Beam Dump Water Seal

High Dose Exposure

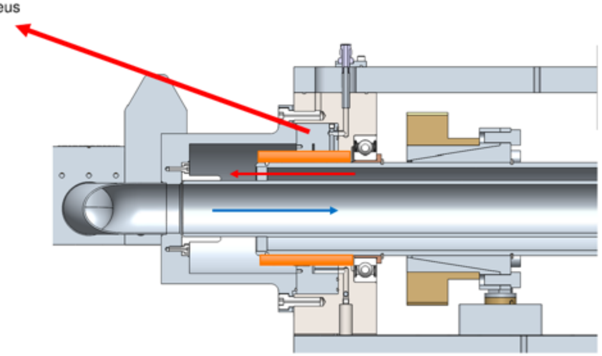
Particle Energy Spectra for Beam Dump's Rotating Water Seal

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

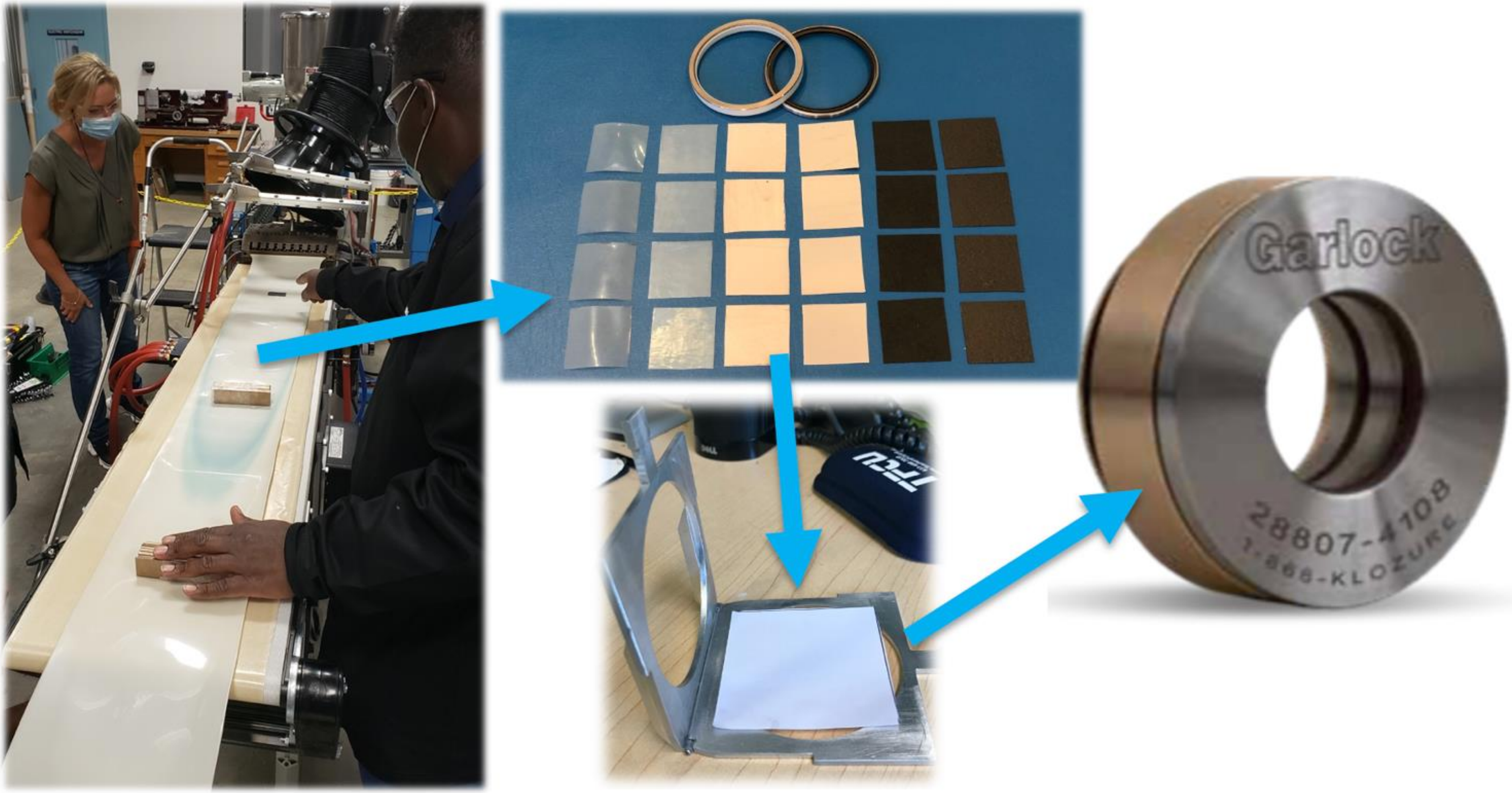


High Energy 260 MeV when operated at 400 kW

Technical Approach

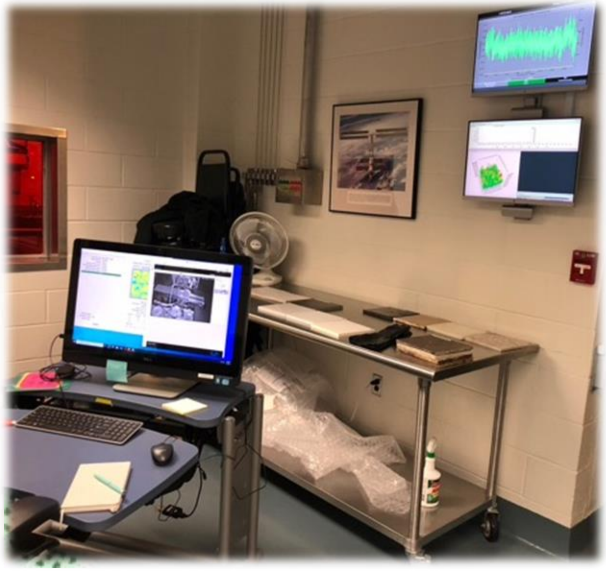
Extrude New Compounded Materials for use in New Seal Designs

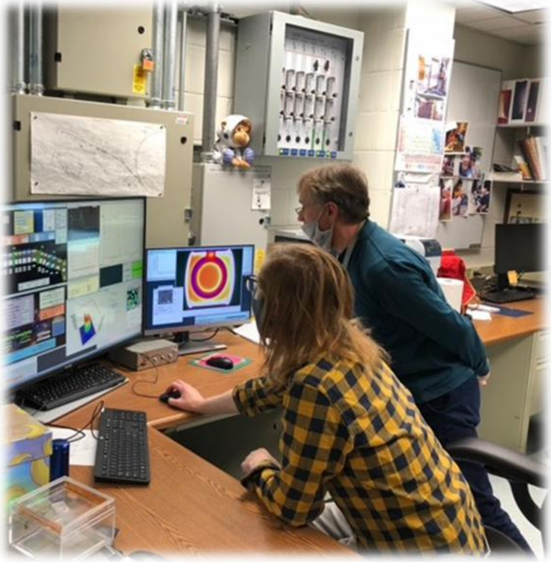
Expose Materials to High Energy and High Dose Radiation for Durability Study



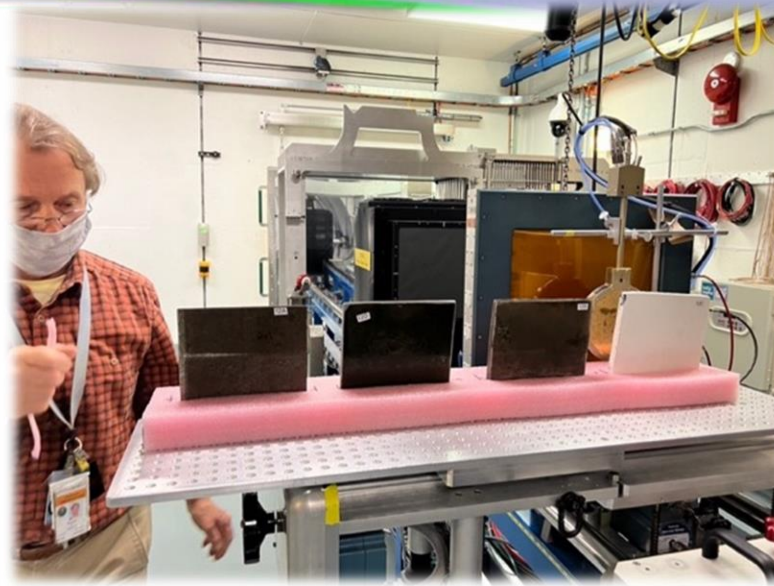
Extrude NanoSonic Modified Polymer for High Dose Exposure at BNL BLIP and Integration with Garlock Housing

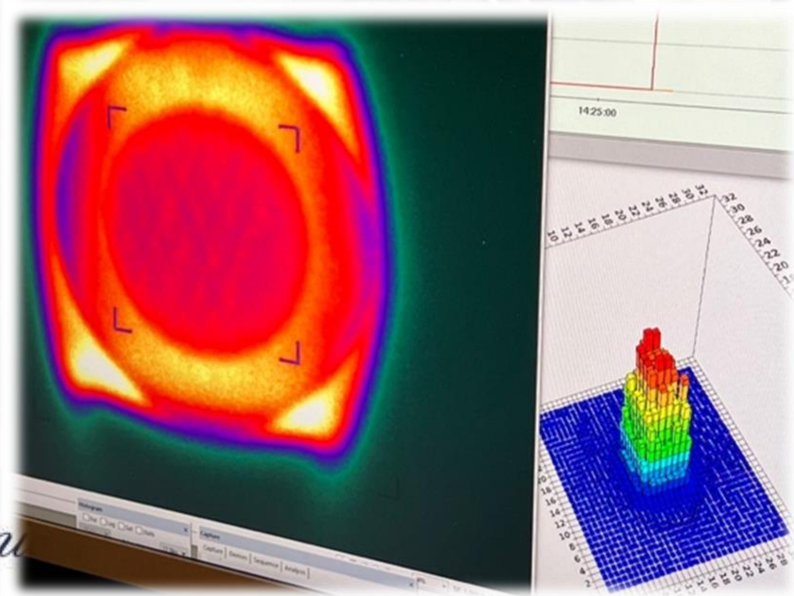
Radiation Exposure Run 1 - May 7, 2021
High Energy – 1 GeV Fe / 1 GeV proton





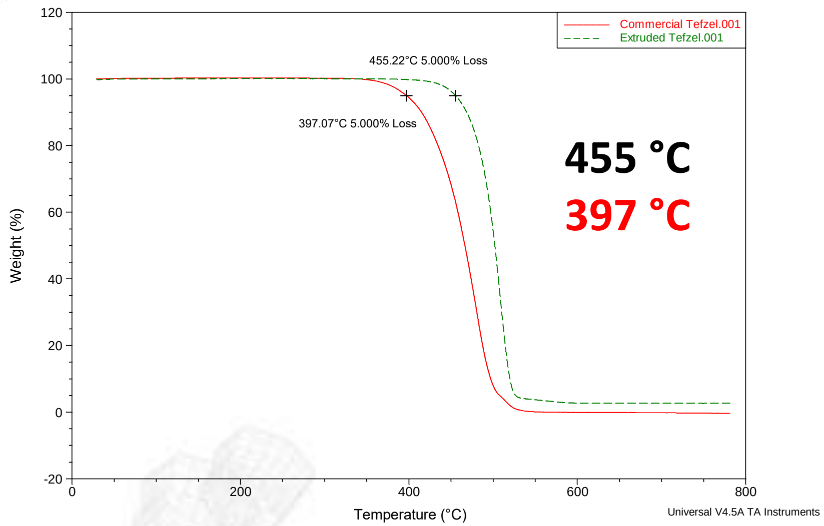
Radiation Exposure Run 2 - June 13, 2022
Lower Energy – 400 MeV Fe / 100 MeV proton

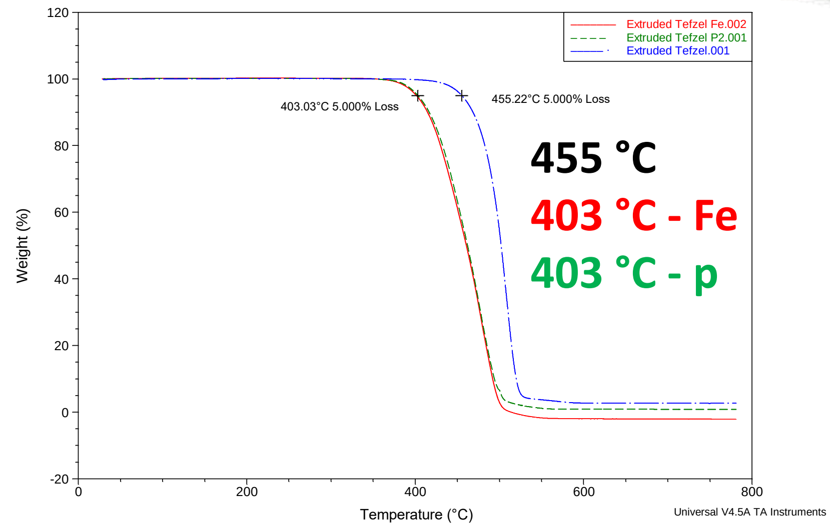


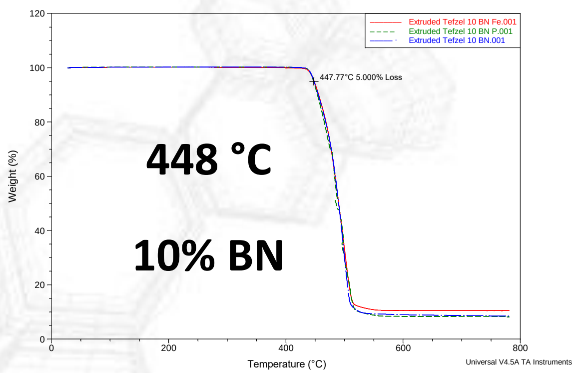


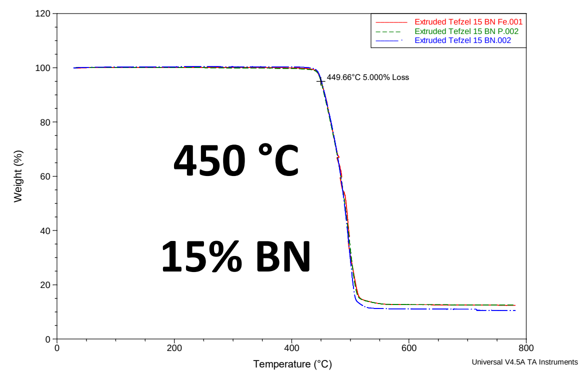
TGA for COTS and NanoSonic Polymer

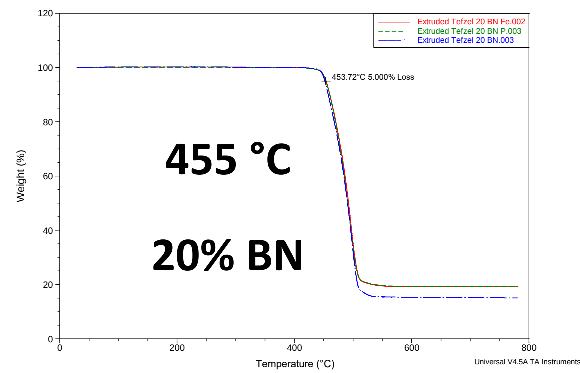
pre- and post- 1 GeV Fe and 1 GeV proton







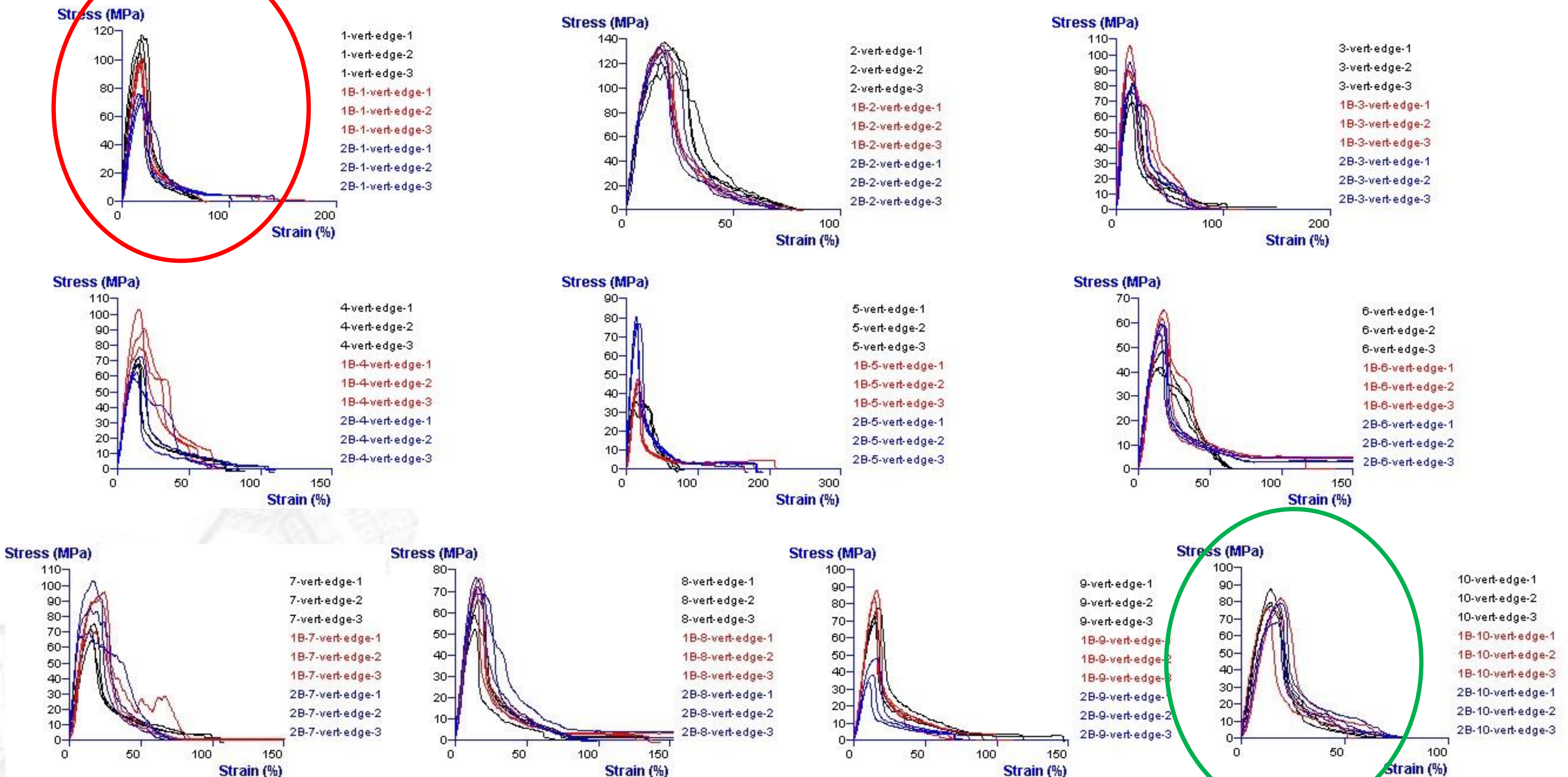




NanoSonic-polymer ~60 °C increase over Commercial

Increasing BN Provides Increasing Enhancements in Radiation Resistance 45 - 52 °C increase

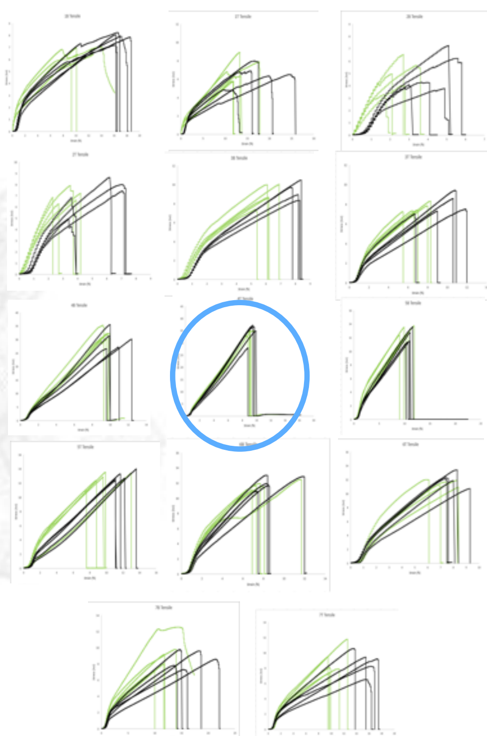
Pre- and Post- Irradiation – 27 Gy
1 GeV Fe and 1 GeV proton - separate

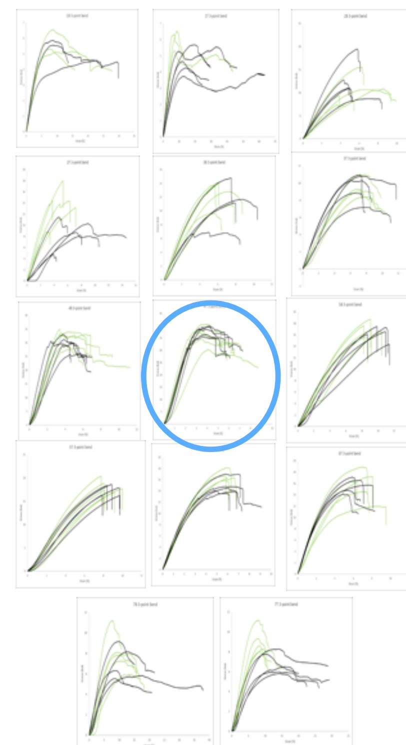


Note Tensile Strength Variations or Stability Post Fe and Proton Exposure

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.

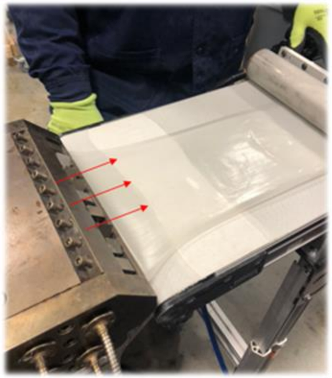


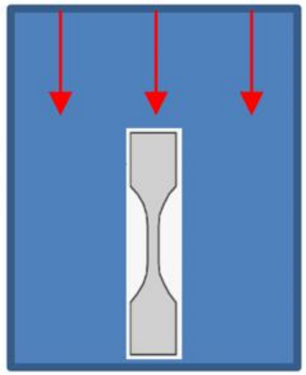


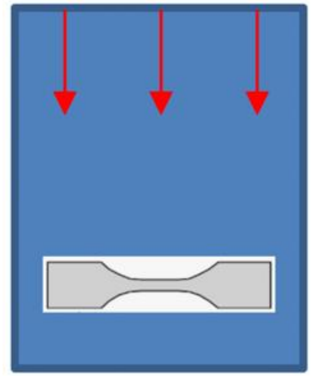
Composites with High-Z Layer Exhibits Trend for Enhanced Durability

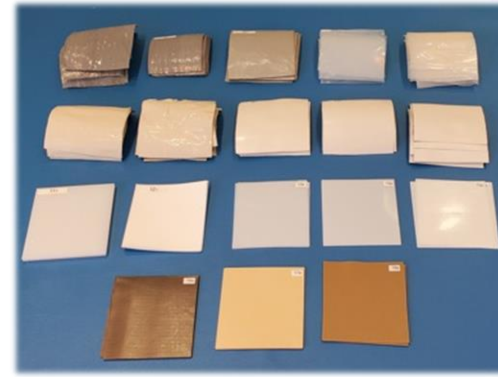
Increased Dose – 214 Gy

Exposure at NSRL to Fe 1 GeV for Down-Selection

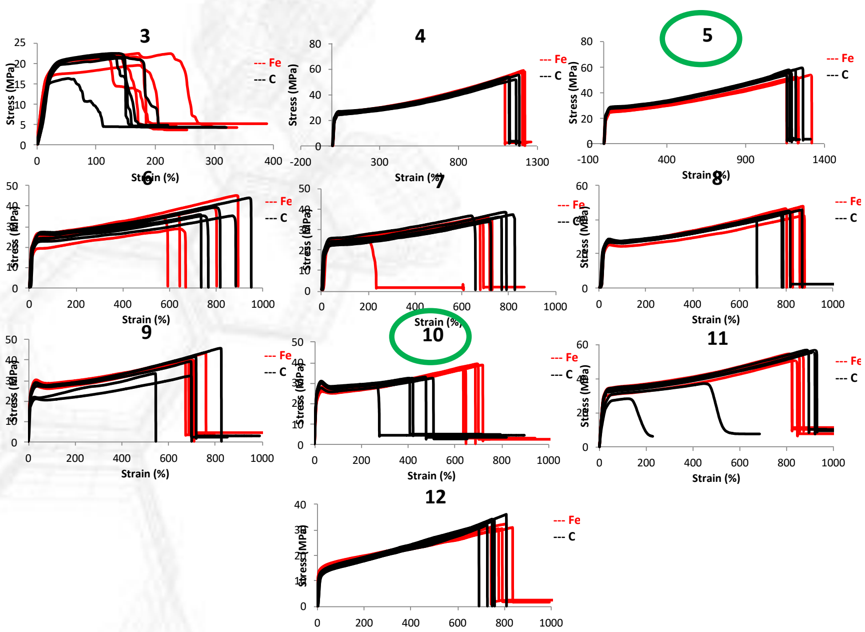


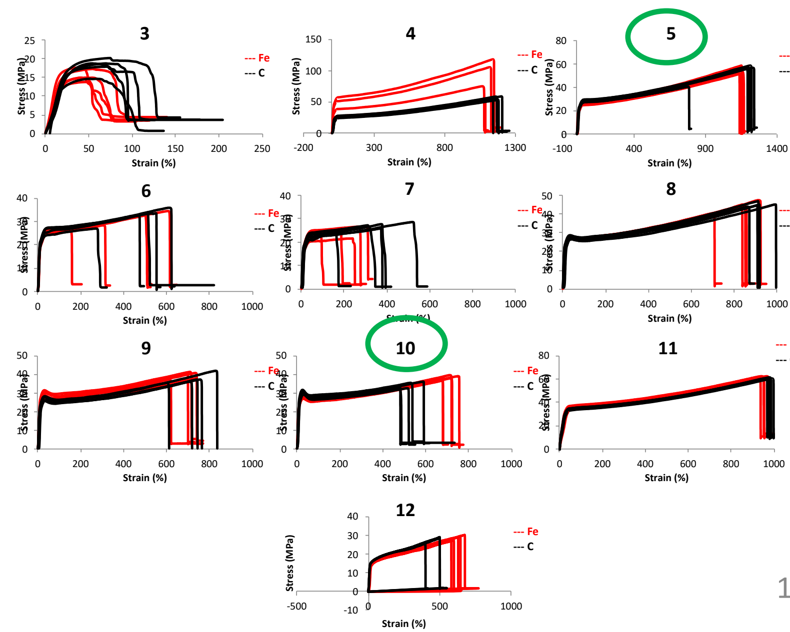






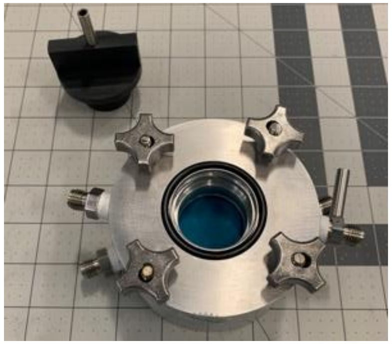
Mechanical Properties for All NanoSonic Films in Parallel and Perpendicular Directions

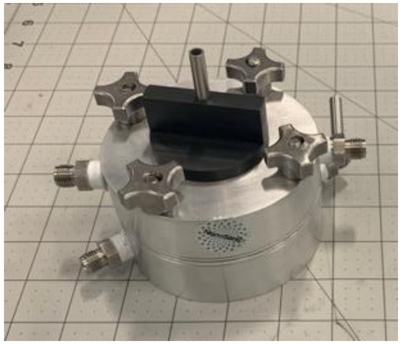


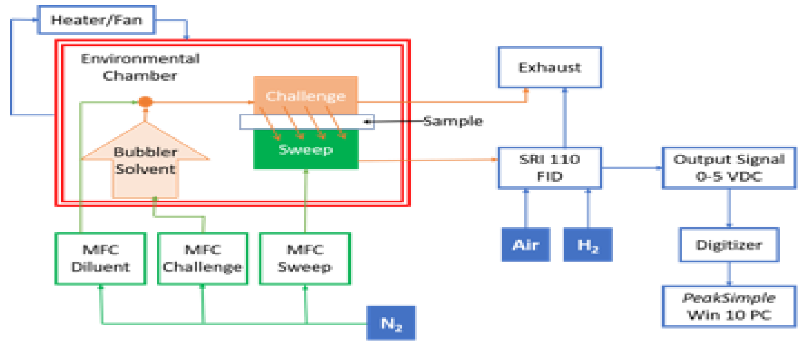


Permeation Testing at NanoSonic Before and After Radiation

I / II	Chemical permeation resistance: NFPA 1994 Class 1	20 g/m^2 challenge over 1 hour	20 g/m^2 challenge over 6 hours







Permeation Testing at Intertek for Related Materials – CBRN Gloves

Intertek and Avarint results verify that Dimethyl sulfate, Soman (GD), and Distilled Mustard (HD) are “non detectable” when tested for 60 min against NanoSonic’s FKM at a thickness of 0.23mm

SECTION 7.1.2.1

LIQUID TOXIC & GASEOUS INDUSTRIAL CHEMICAL PERMEATION RESISTANCE TEST

CONDITIONING: In Accordance with Section 8.7.7.1.1

CHALLENGE CHEMICAL:	Dimethyl sulfate	**CONCENTRATION:**	20 g/m^2
SAMPLING METHOD:	Universal Sorbent Tube	**ANALYSIS METHOD:**	GC-MS
MINIMUM DETECTION LIMIT:	0.20		

intertek
Total Quality. Assured.

TEST RESULTS	SAMPLE 1	SAMPLE 2	SAMPLE 3	AVERAGE
Cumulative Permeation Mass (μg/cm^2) - T_{0-15}	<0.20	<0.20	<0.20	<0.20
Cumulative Permeation Mass (μg/cm^2) - T_{15-60}	<0.20	<0.20	<0.20	<0.20
Cumulative Permeation Mass (μg/cm^2) - T_{0-60}	<0.20	<0.20	<0.20	<0.20

Avarint

NFPA TEST REPORT

Method: NFPA 1994; Class 1 (2018 ed)
Customer: Intertek, 3933 US Route 1, Cortland, NY 13045
Material ID: Nanosonic CRT2109020947-001 G104796074
Material Type: Tan MM335-131 Fabric (P)
Test Date: 9/22/2021
Report Date: 9/30/2021

Test Trial Summary Information

Test Trial: A0226-003
Chemical: HD
Test Duration: 60 minutes
DCR Response: 101%
Temperature: 90.2°F
Relative Humidity: 77.6%
Pass Criteria: < 1.33 μg/cm^2 (15 min); 4.0 μg/cm^2 (60 min)
Detection Limit: 0.1 μg/cm^2

Test Results

Tan MM335-131 Fabric (P)

Avarint Sample Control Number	Sample Type	Permeation (μg/cm^2) t = 15 min	Permeation (μg/cm^2) t = 60 min
A0226-0025	Replicate 1	ND	ND
A0226-0026	Replicate 2	ND	ND
A0226-0027	Replicate 3	ND	ND
A0226-0028	Neg. Ctrl	ND	ND
Pos. Ctrl	Average recovery (%)	95%	ND

Avarint

NFPA TEST REPORT

Method: NFPA 1994; Class 1 (2018 ed)
Customer: Intertek, 3933 US Route 1, Cortland, NY 13045
Material ID: Nanosonic CRT2109020947-001 G104796074
Material Type: Tan MM335-131 Fabric (P)
Test Date: 9/22/2021
Report Date: 9/30/2021

Test Trial Summary Information

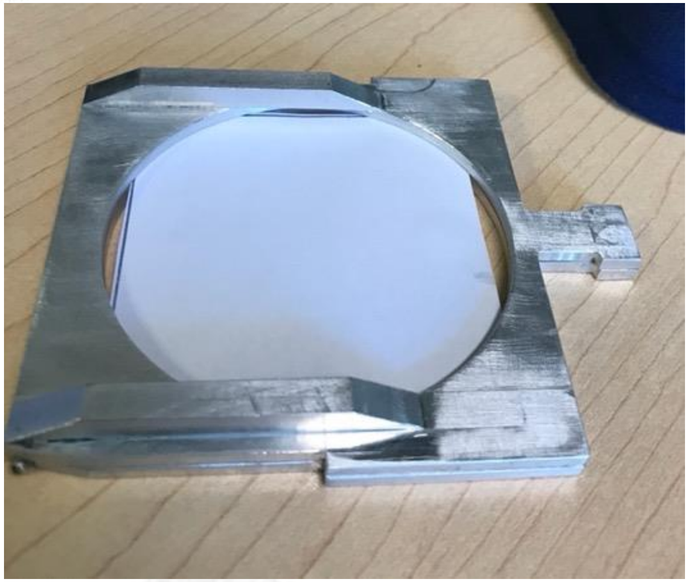
Test Trial: A0226-004
Chemical: GD
Test Duration: 60 minutes
DCR Response: 100%
Temperature: 90.0°F
Relative Humidity: 79.0%
Pass Criteria: < 0.43 μg/cm^2 (15 min); 1.25 μg/cm^2 (60 min)
Detection Limit: 0.05 μg/cm^2

Test Results

Tan MM335-131 Fabric (P)

Avarint Sample Control Number	Sample Type	Permeation (μg/cm^2) t = 15 min	Permeation (μg/cm^2) t = 60 min
A0226-0029	Replicate 1	ND	ND
A0226-0030	Replicate 2	ND	ND
A0226-0031	Replicate 3	ND	ND
A0226-0032	Neg. Ctrl	ND	ND
Pos. Ctrl	Average recovery (%)	96%	ND

High Dose Exposure at BNL BLIP



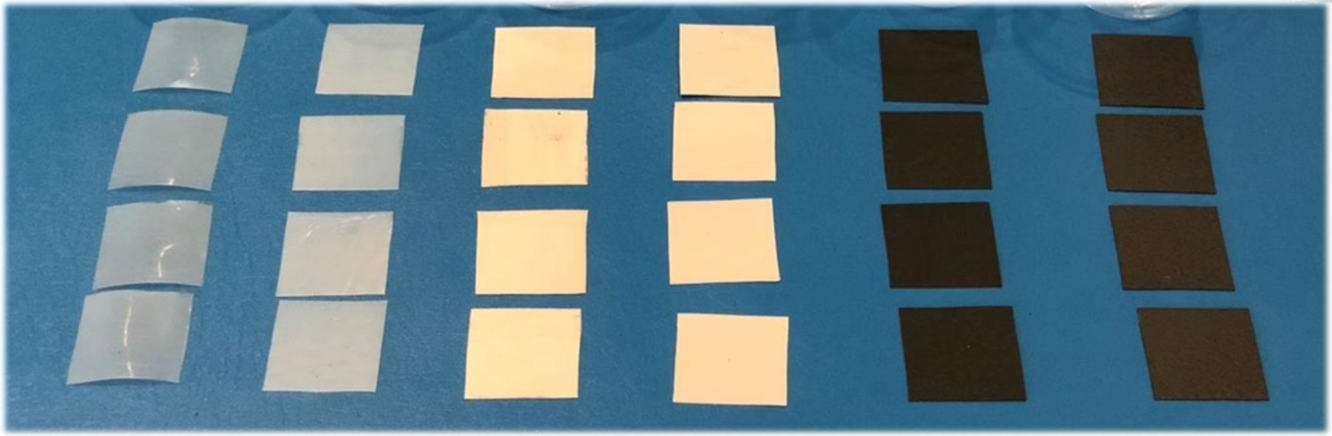
Dr. Dmitri Medvedev
Dr. Cathy Cutler
Dr. Dohyun Kim

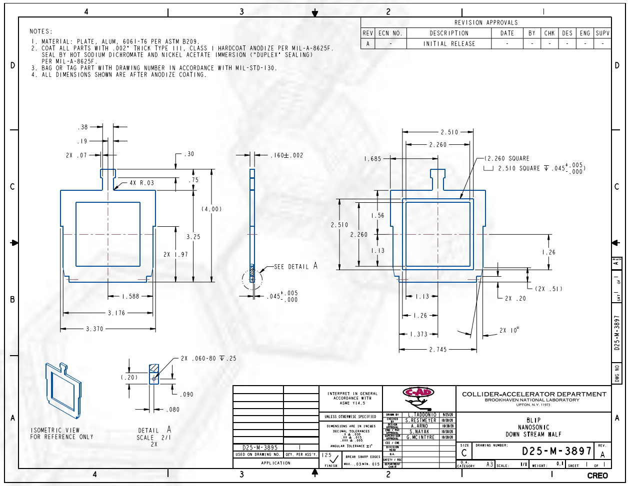
Three rotary feedthroughs were immersed in cold water and irradiated under static conditions at the Brookhaven Linac Isotope Producer (BLIP) at the Brookhaven National Laboratory (BNL). An 112 MeV proton beam was stopped in several thick solid isotope production targets made of rubidium chloride and gallium and provided the feedthrough radiation absorbed dose. The average absorbed dose rate was 2.24 MGy/day for different radiation doses: 0.2, 2 and 20 MGy. The radiation consisted primarily of fast neutrons (mean energy 8.5 MeV), protons (mean energy 20 MeV), gamma rays and electrons. These radiation types, their intensity and energy are close to the ones expected under FRIB conditions in the target and beam dump systems area.

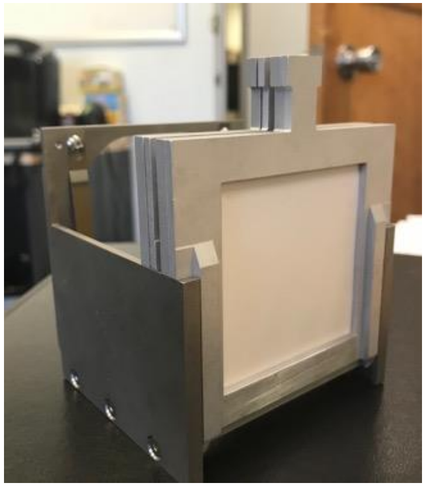
0.2 MGy ~ 2h
2 MGy ~ 21 h
20 MGy ~ 9 days

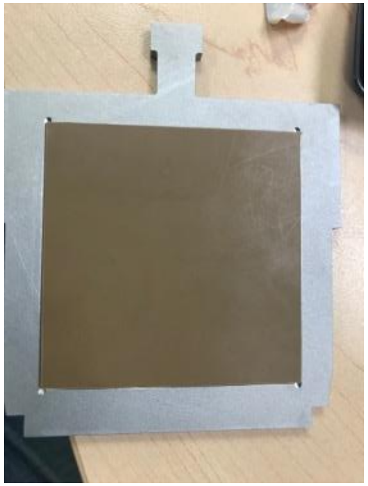
Run Scheduled upon Targetry Housing Construction

High Dose Exposure at BNL BLIP Extruded and Delivered Films





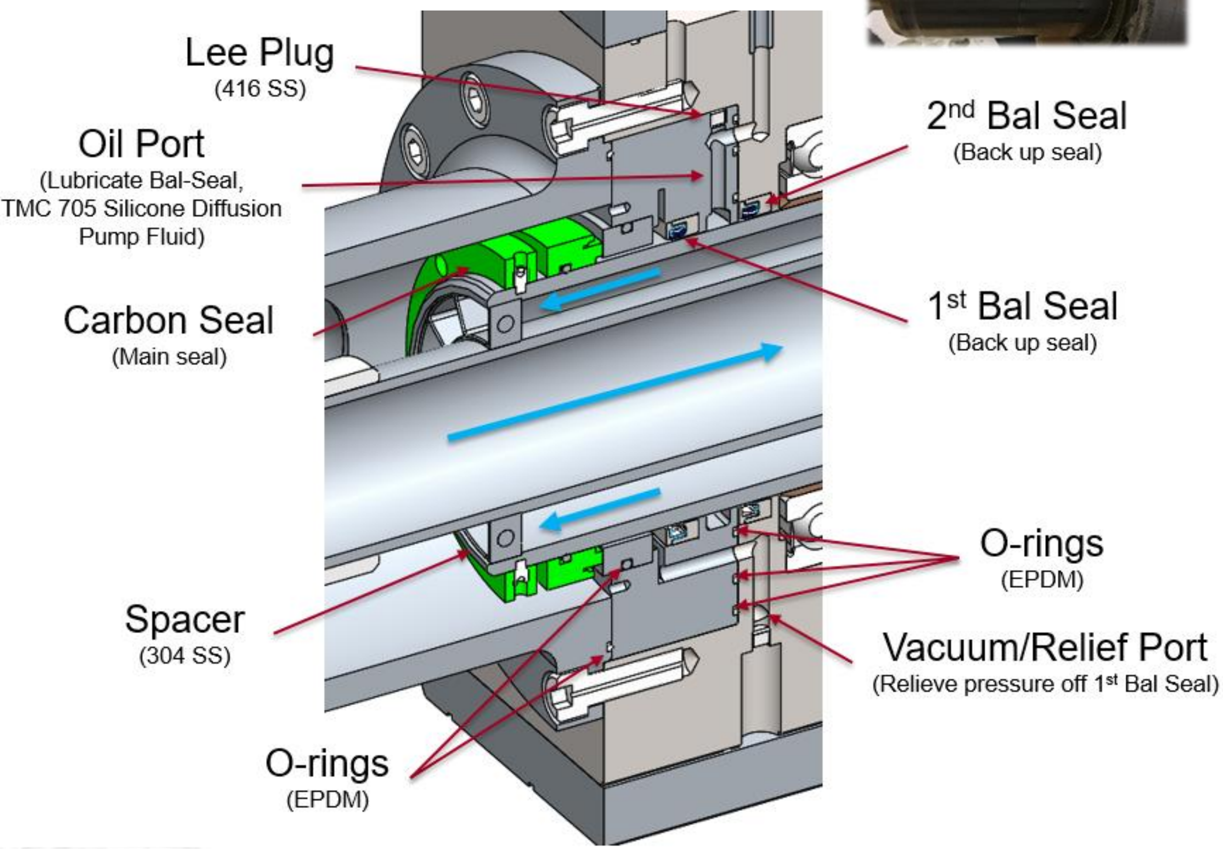


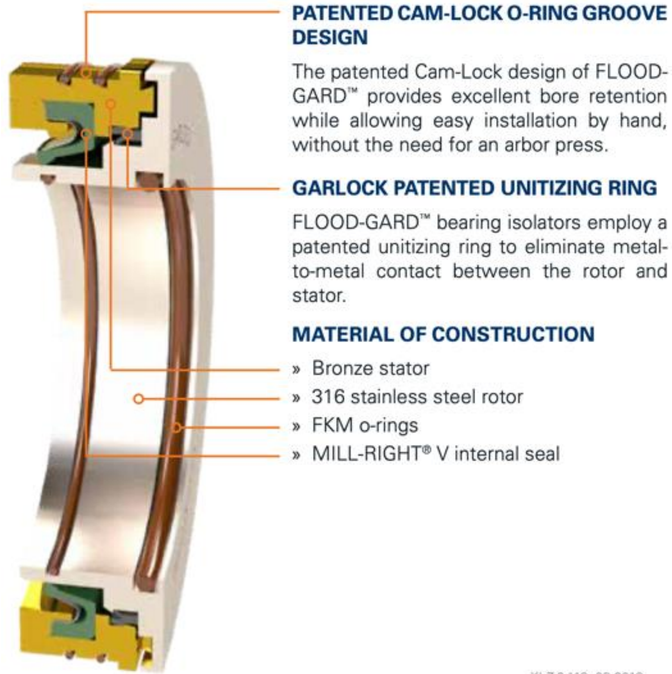


Run Scheduled for 2022

New Design and Materials:

Develop New Materials for Pseud-Flood-Gard Design

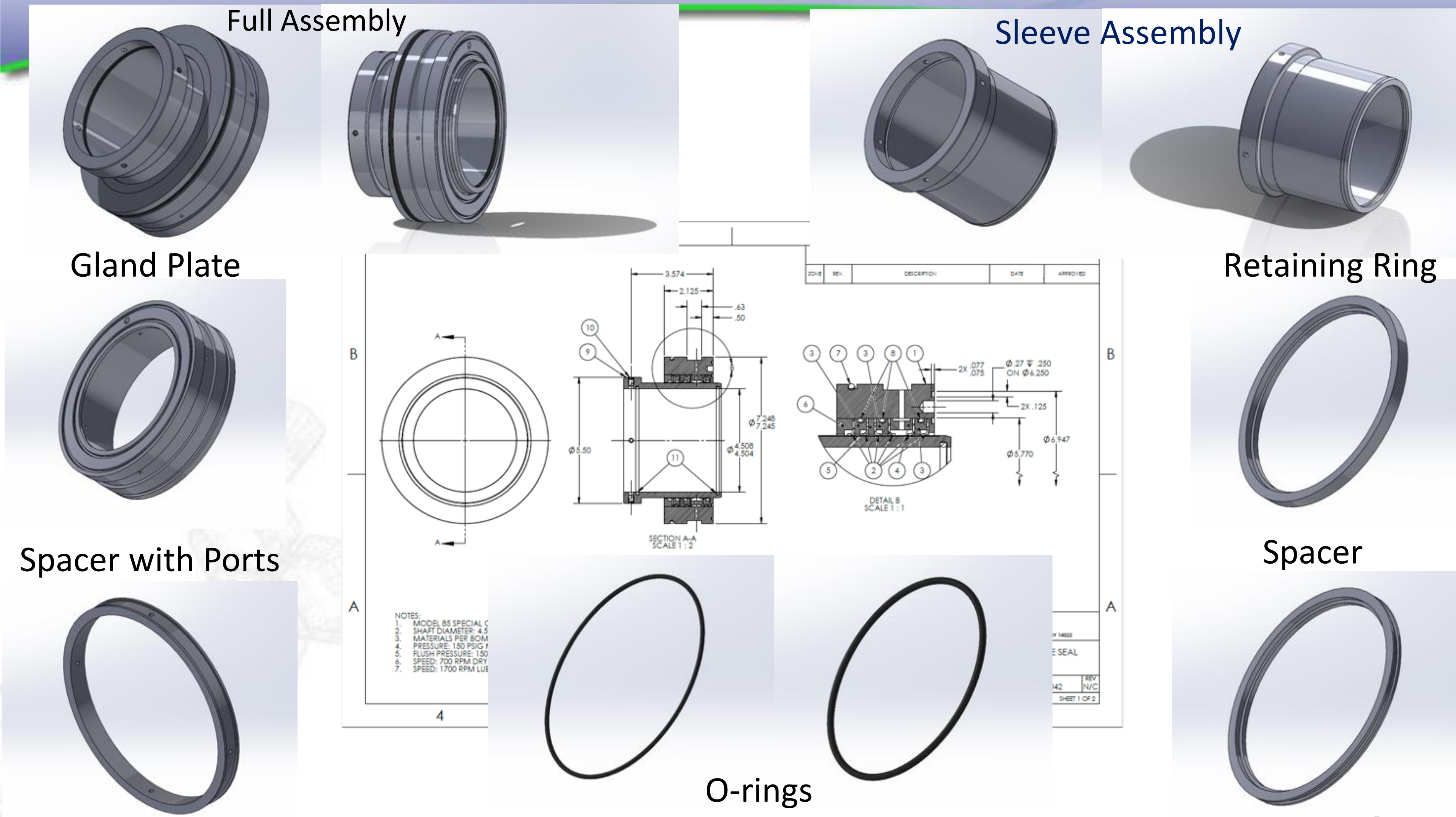




Delivering Flood-Gard Commercial Seals and NanoSonic Modified Seals
o-rings, unitizing ring, and V internal seal

Final Design

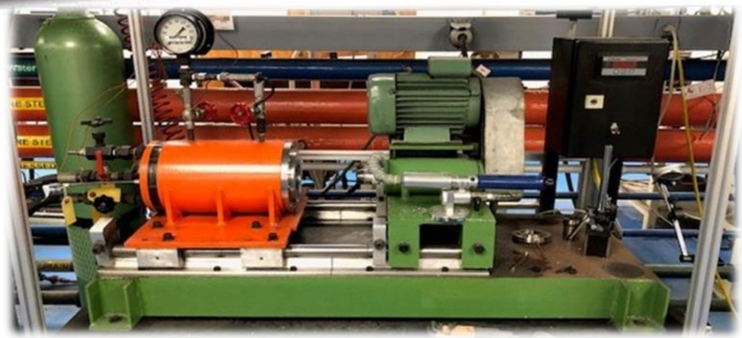
for Delivery to MSU September 2022

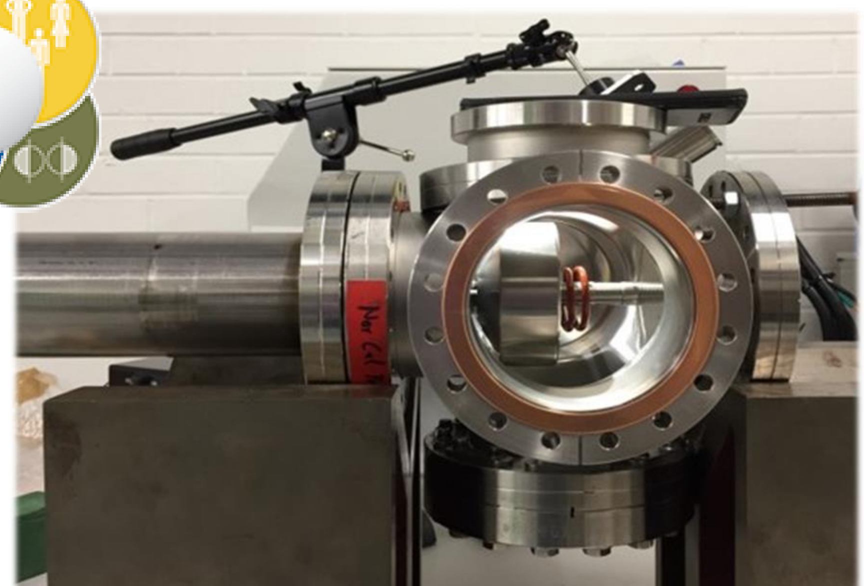


1. The seal assembly shall isolate water at 27 PSIG nominal from oil at 0 PSIG nominal and isolate the oil from ambient vacuum at 10^{-5} Torr
2. The rotating surface outer diameter is 4.500” Nominally with a 4.350” maximum axial length available
3. The rotational speed is not to exceed 700 RPM and temperature not to exceed 200° C
4. The seal must mate with existing oil flush geometry to minimum hardware modification required.

Garlock Test and MSU FRIB Test Plan

Deliver Final Material to Garlock for Introduction into Flood-Gard Housing





Test Bench to Evaluate the Water Seal for the Beam Dump Assembly under Thermomechanical Environment Close to FRIB Operating Conditions

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