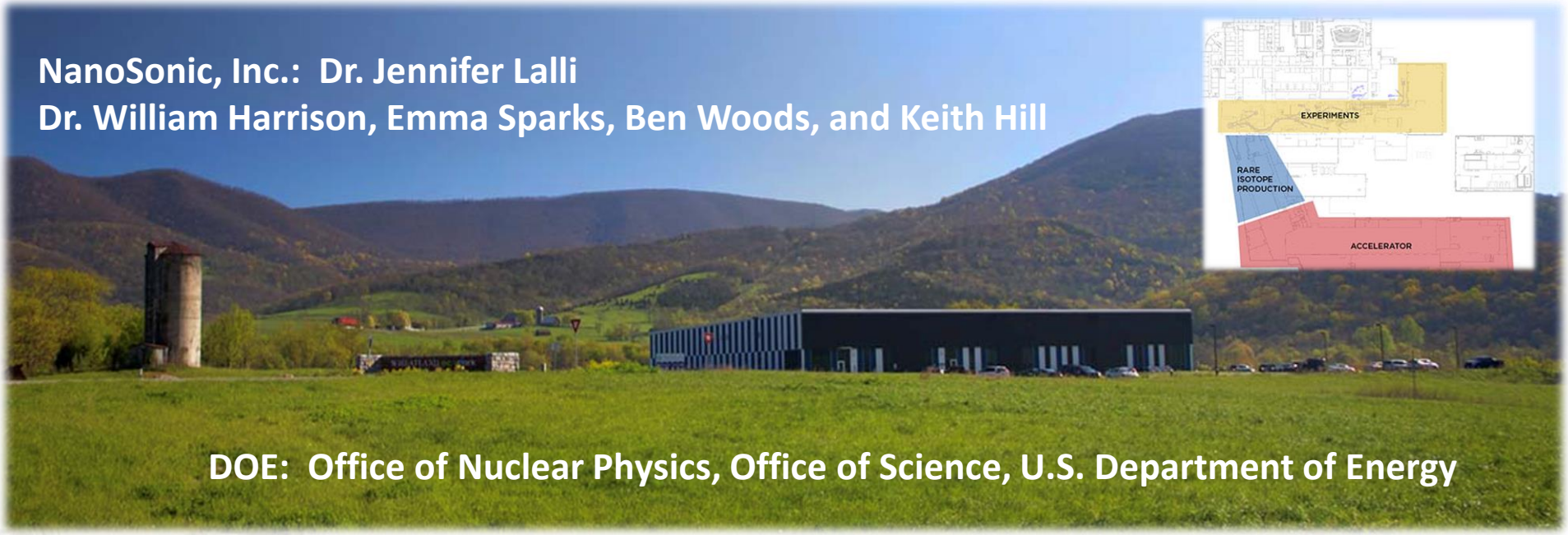
NanoSonic, Inc.

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 Keith Hill

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

August 17, 2021 - DOE SBIR Phase IIA NP SBIR Exchange

POCs: Dr. Michelle Shinn, Dr. Elizabeth Bartosz, Brenda May, John Motz, Christine Grady, Cassie Dukes, Linda Severs, Dr. Manouchehr Farkhondeh, and Dr. Manny Oliver

Overview

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

Phase IIA Timeline:

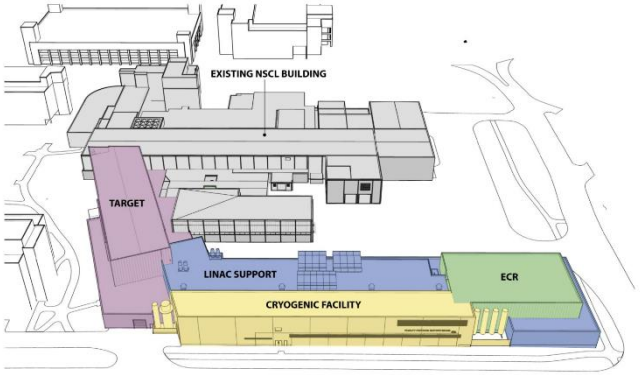
- **Project Start Date:** *5/21/2020*
- **Project End Date:** *9/20/2022*

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:

- Giles County Government
- BNL – NSRL and BLIP
- CSU
- MSU, FRIB
- Garlock

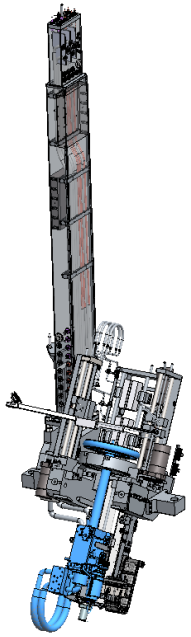


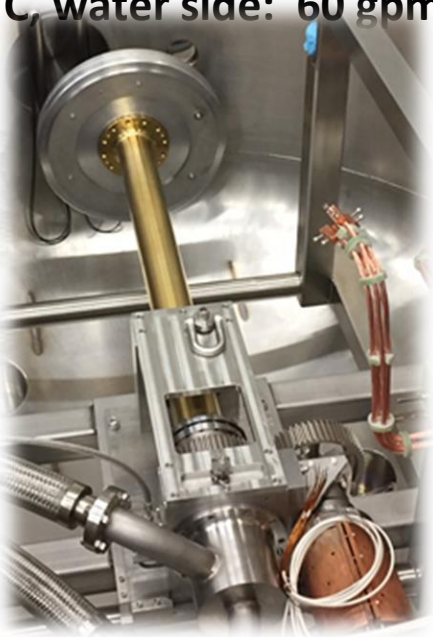
DOE Topic 26f – Technology for High Radiation Environments

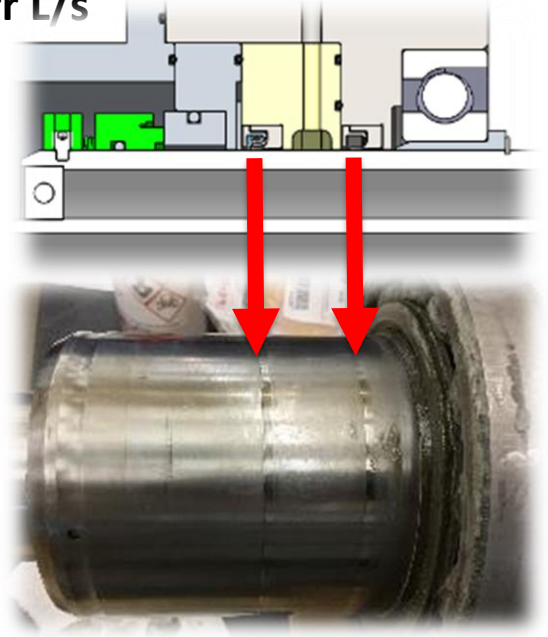
Grant # DE-SC0017107

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 [illegible]6 °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.

Dr. Jian Gao, Target and Beam Dump Systems Group Leader
Drs. Philip Morrison, Michael Larmann, and Nicholas Reha
Dr. Frederique Pellemoine, MSU FRIB Seal Integrator

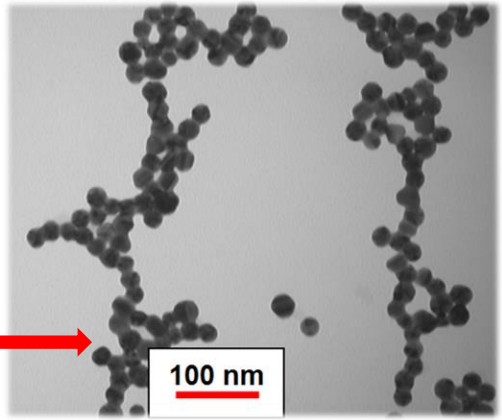
- Staff Physicist, Target and Beam Dump Systems Group Leader (FRIB)
- International Nuclear Target Development Society (INTDS)

Facility for Rare Isotope Beams
at Michigan State University

NanoSonic
Putting nanotechnology to work

Pembroke, VA
15 miles west of Virginia Tech

Scaling Nano

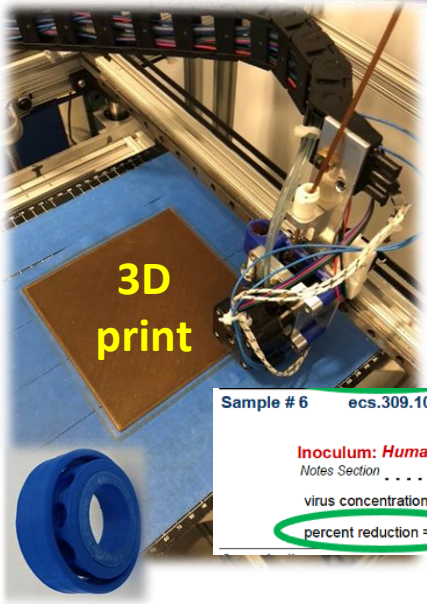


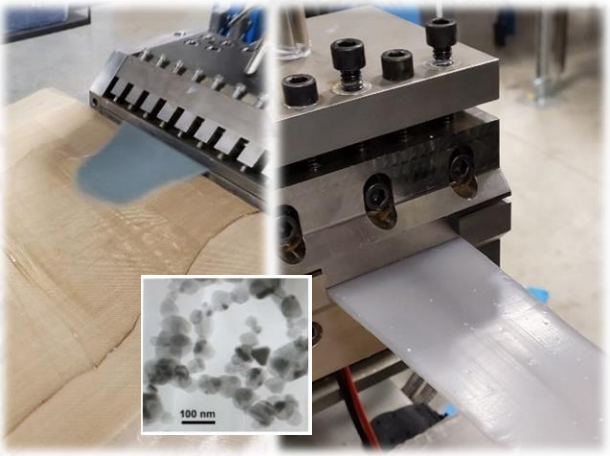
250-gal, 55-gal, 1-10 L in hood, two 20L, and one 100 L reactor

Au from 100 -L

NanoSonic Production Capabilities:

Extrusion and 3D Printing of Radiation Tolerant Polymers, Metals, & Ceramics

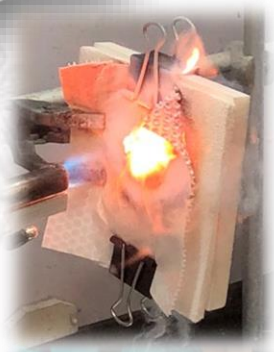


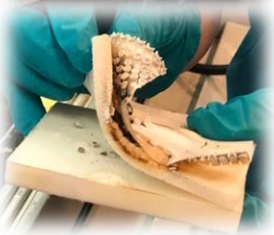


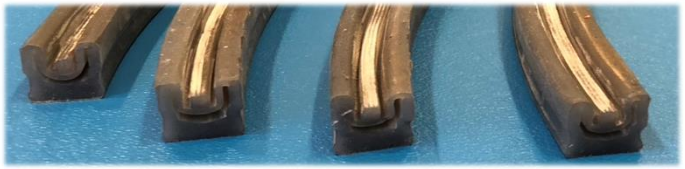
NanoSonic

Our Commercial Products

www.nanosonic.com





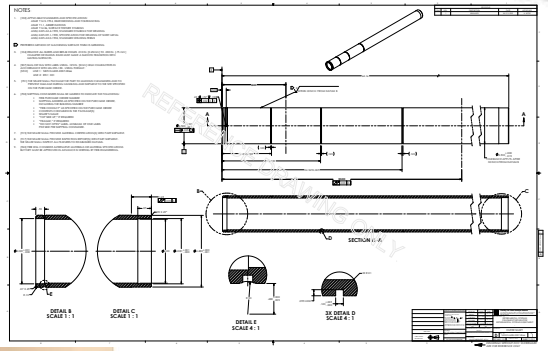


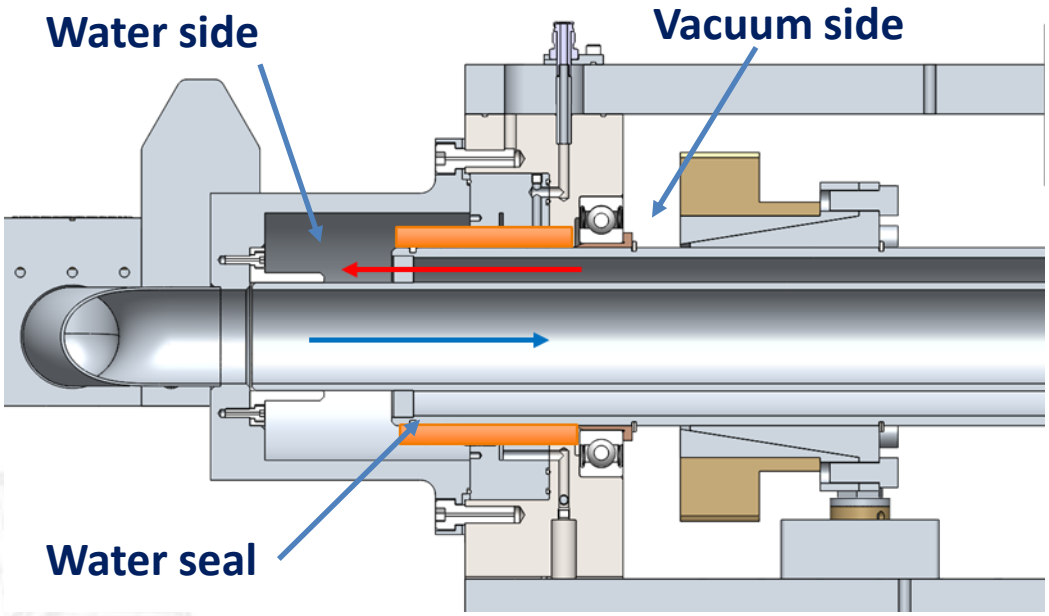
Goal:

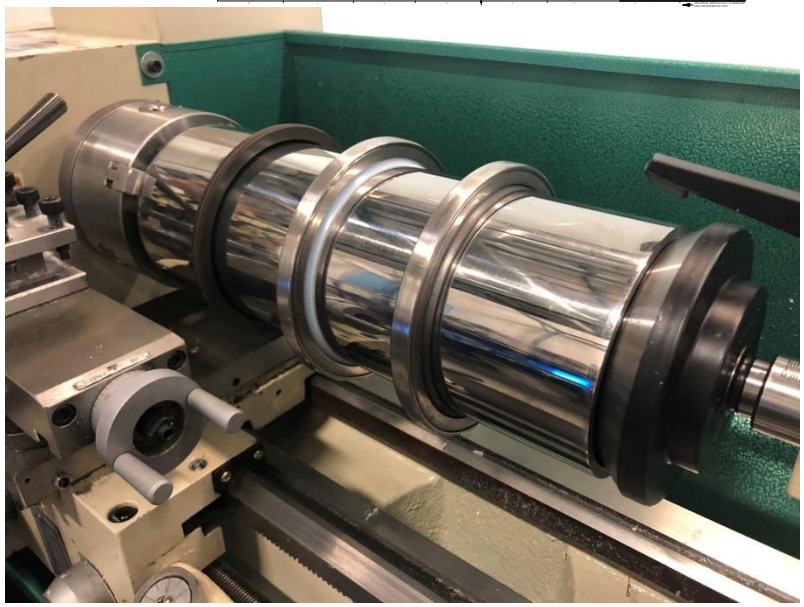
Develop New Materials and Seal Designs for FRIB Beam Dump

GOALS:

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



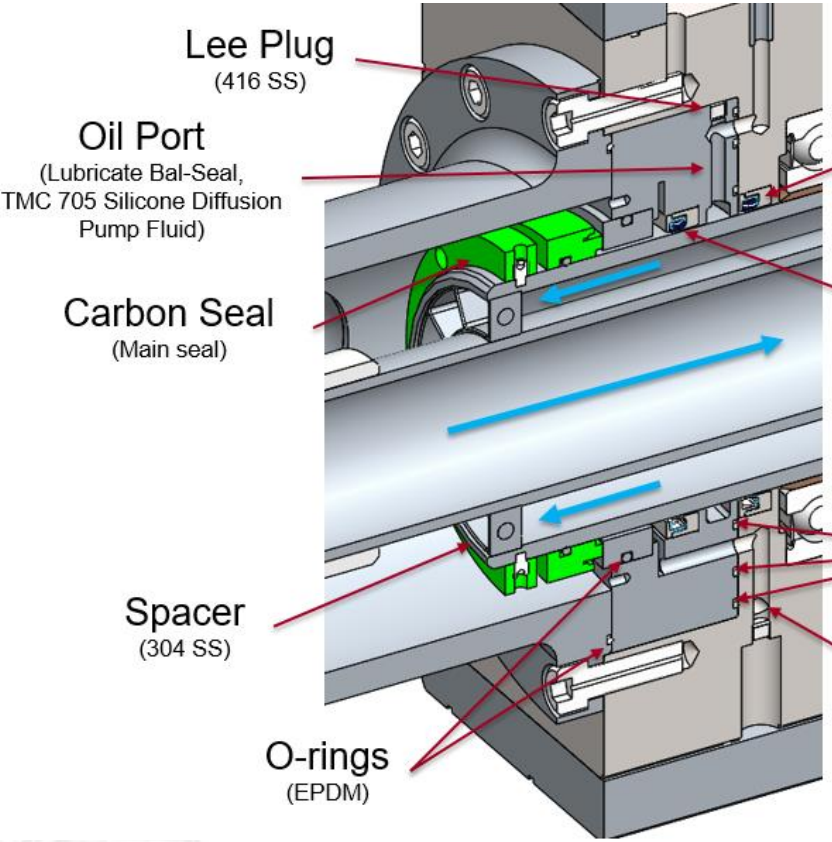


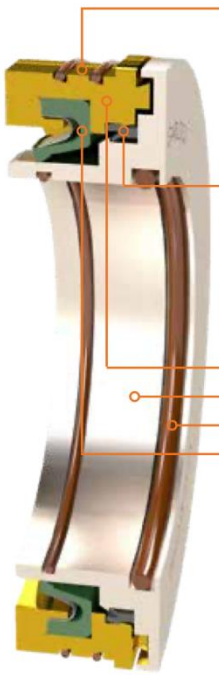


Reproduced 4.5” SS Shaft for Abrasion Testing of New Seal Materials to Mimic Beam Dump Water Seal

New Design and Materials:

Develop New Materials for Flood-Gard Design





PATENTED CAM-LOCK O-RING GROOVE DESIGN

The patented Cam-Lock design of FLOOD-GARD™ provides excellent bore retention while allowing easy installation by hand, without the need for an arbor press.

GARLOCK PATENTED UNITIZING RING

FLOOD-GARD™ bearing isolators employ a patented unitizing ring to eliminate metal-to-metal contact between the rotor and stator.

MATERIAL OF CONSTRUCTION

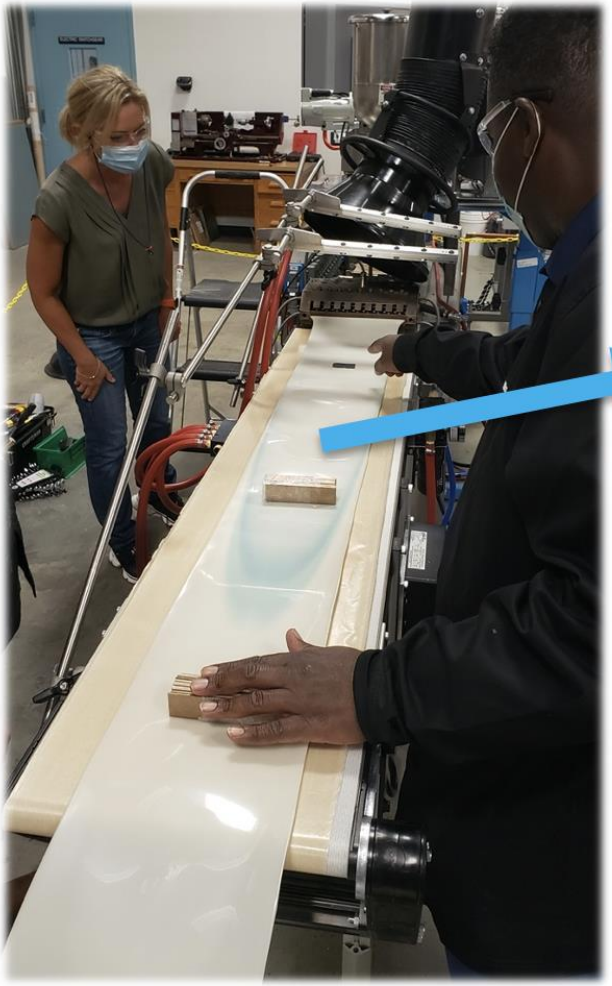
- Bronze stator
- 316 stainless steel rotor
- FKM o-rings
- MILL-RIGHT® V internal seal

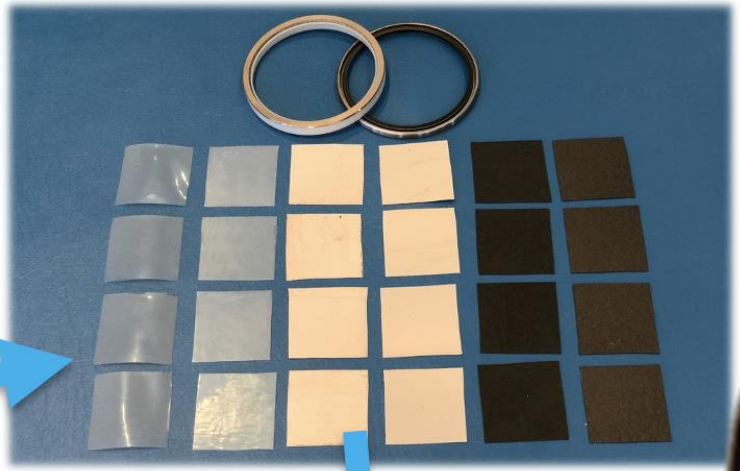
KLZ 2-118 09.2019

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

Technical Approach

Extrude New Compounded Materials for use in New Lip and Flood-Gard Seals



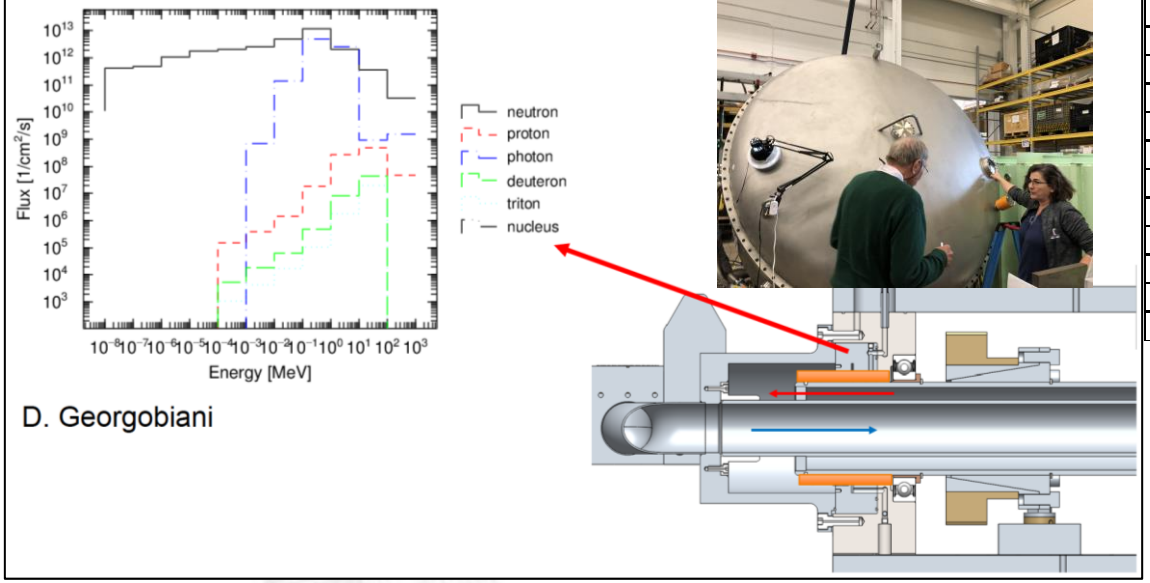


Extrude NanoSonic Modified Polymer for High Dose Exposure at BNL BLIP and Integration with Garlock Housing

High Dose Exposure

Particle Energy Spectra for Beam Dump's Rotating Water Seal

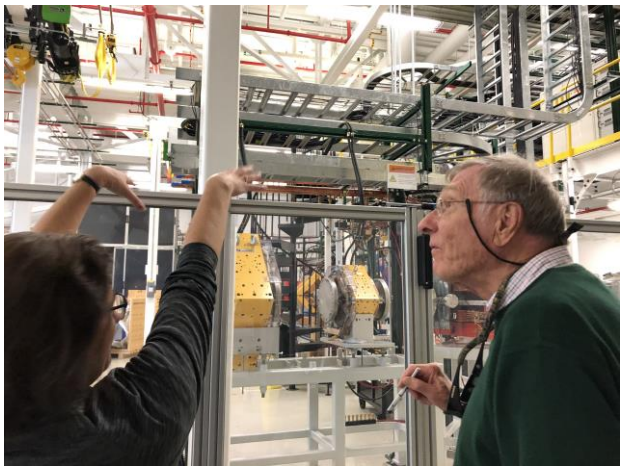
- 48Ca at 400 kW, 261 MeV/u → 40Mg



D. Georgobiani

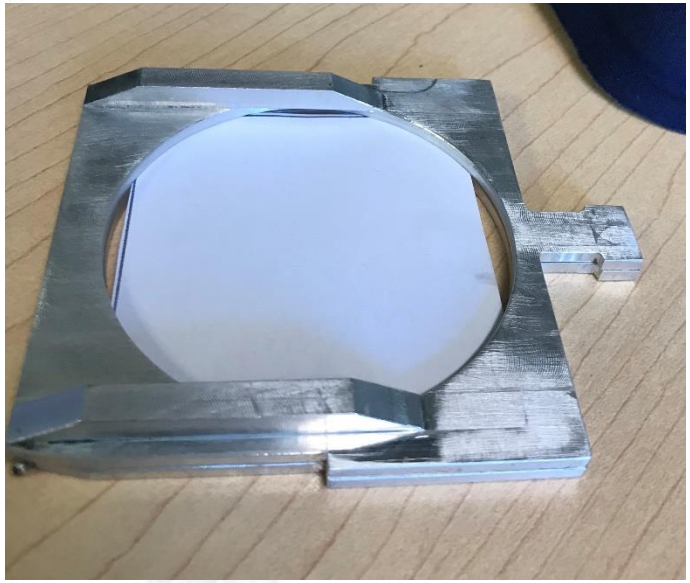
Energy, MeV		Flux, particles/cm2/second				
E_low	E_high	Neutrons	Protons	Photons	Deuterons	Tritons
1.0E-09	1.0E-08	5.1E+06	0.0E+00	0.0E+00	0.0E+00	0.0E+00
1.0E-08	1.0E-07	1.9E+08	0.0E+00	0.0E+00	0.0E+00	0.0E+00
1.0E-07	1.0E-06	2.3E+08	0.0E+00	0.0E+00	0.0E+00	0.0E+00
1.0E-06	1.0E-05	4.9E+08	0.0E+00	0.0E+00	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

Will expose candidate seal materials to electron irradiation using 4 passes of 50 kGy high dose medical sterilization techniques for 200 kGy at Steris



Will Conduct 0.2 kGy exposure at Steris and 0.2 - 20 MGy at BLIP

High Dose Exposure at BNL BLIP



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

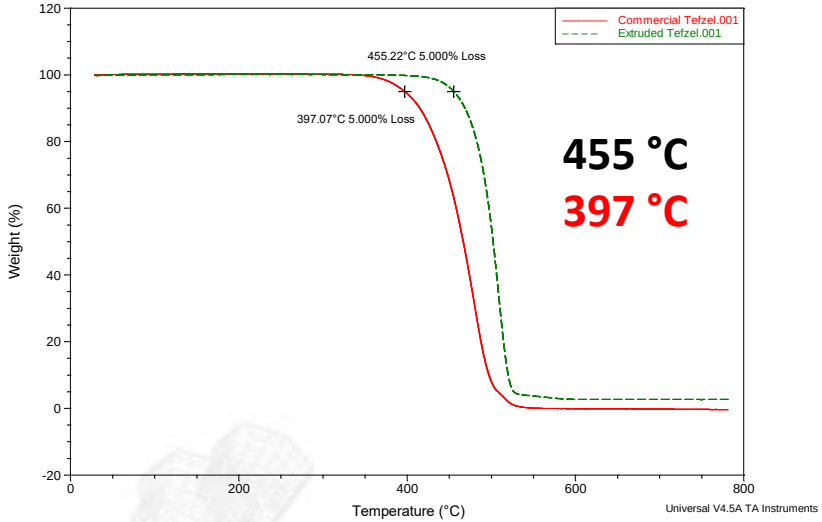
Three rotary feedthroughs were immersed in cold water and irradiated under static conditions at the Brookhaven Linac Isotope Producer (BLIP) at the Brookhaven National Laboratory (BNL). An 112 MeV proton beam was stopped in several thick solid isotope production targets made of rubidium chloride and 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.

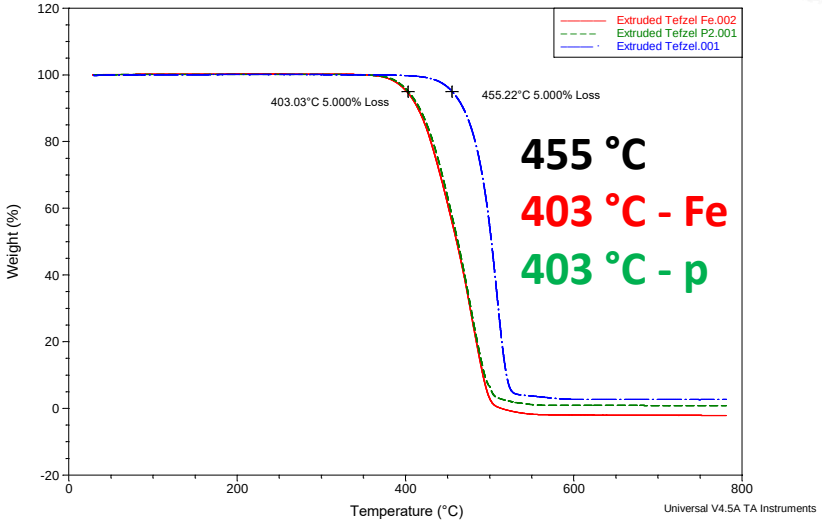
0.2 MGy ~ 2h
2 MGy ~ 21 h
20 MGy ~ 9 days

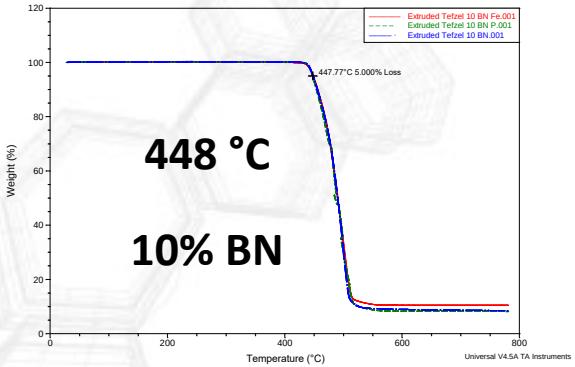
Run Scheduled upon Targetry Housing Construction

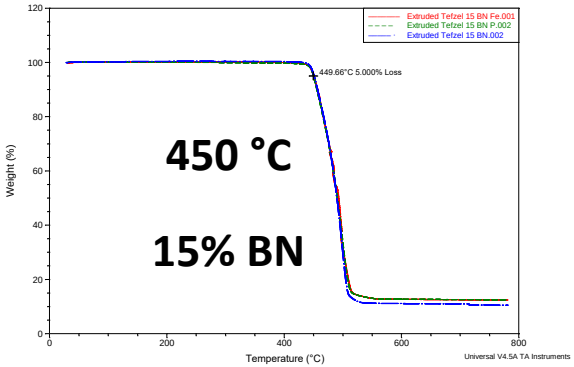
TGA for Tefzel and NanoSonic ETFE 5%

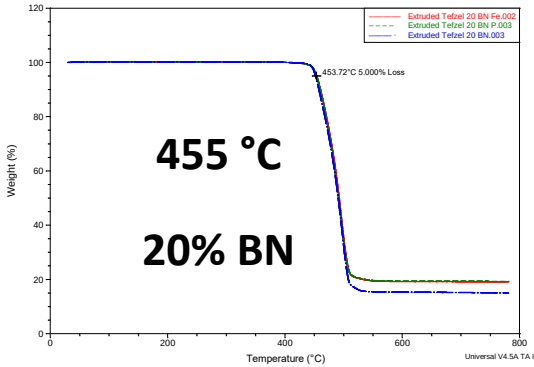
ETFE Extruded with BN – pre- and post- Fe and proton







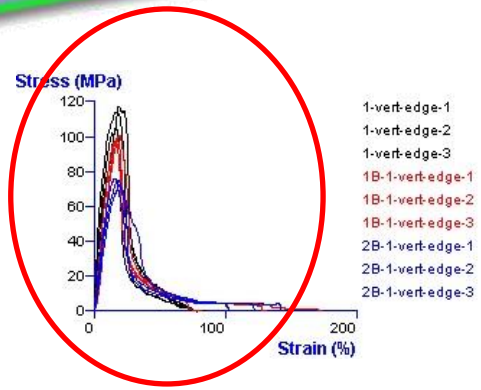


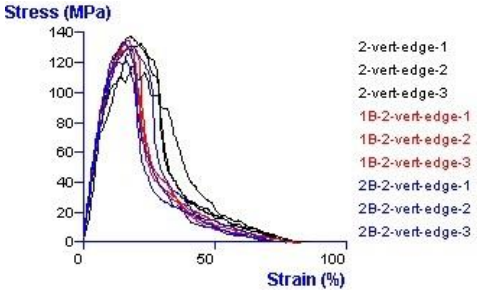


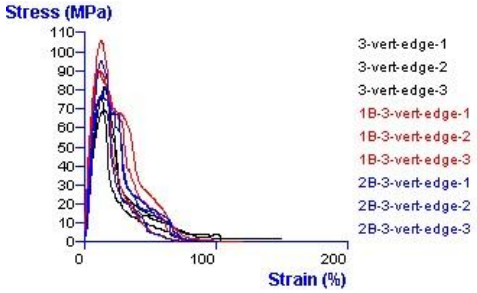
NanoSonic-ETFE ~60 °C increase over Commercial ETFE

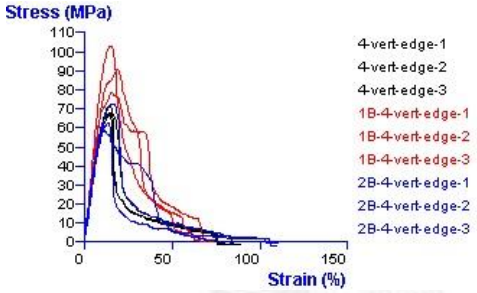
Increasing BN Provides Increasing Enhancements in Radiation Resistance 45 - 52 °C increase

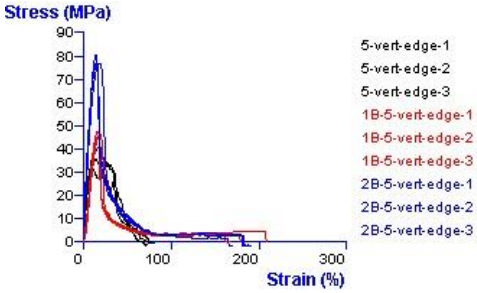
NanoSonic Vertical
Pre- and Post- Irradiation

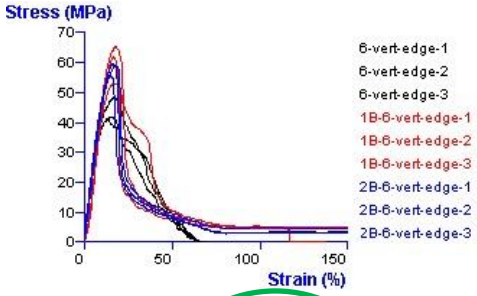


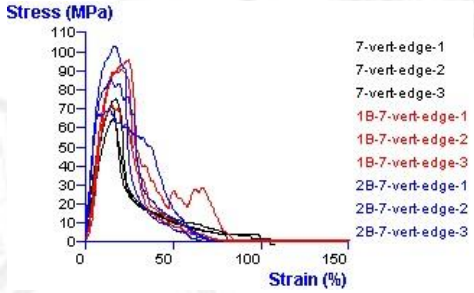


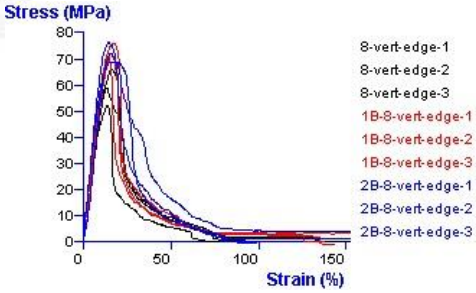


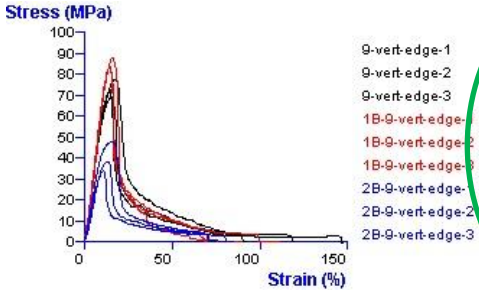


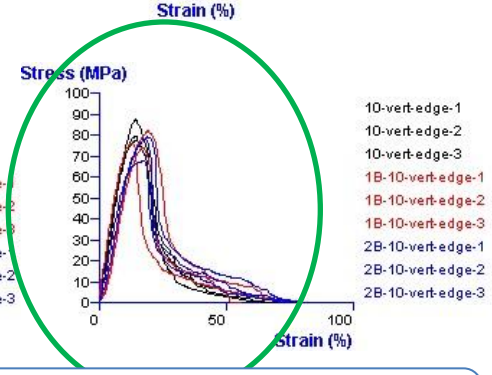








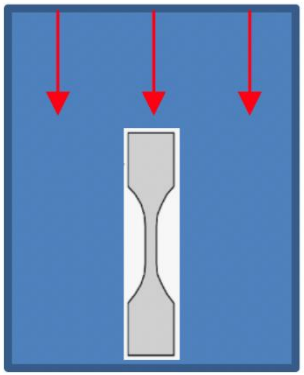


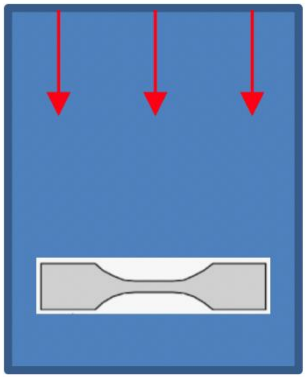


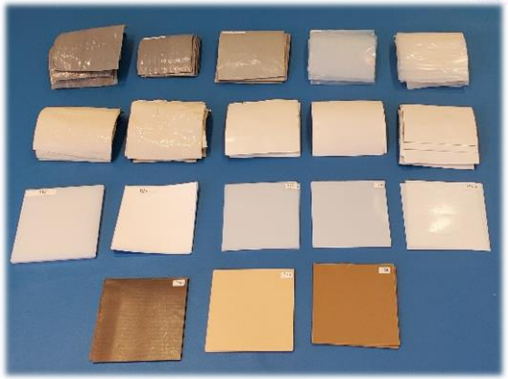
Note Tensile Strength Variations or Stability Post Fe and Proton Exposure

Materials Development

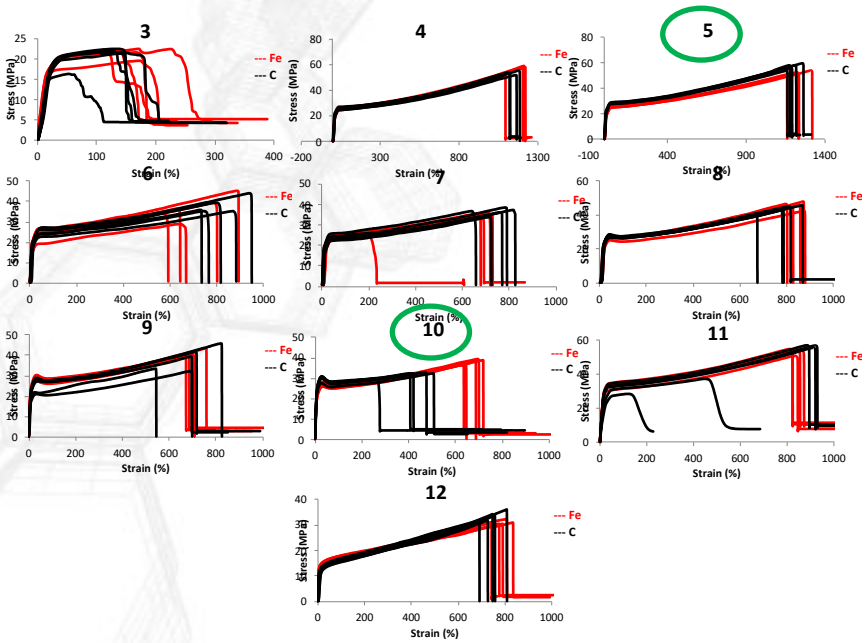
Preliminary Exposure at NSRL to Fe for Down-Selection

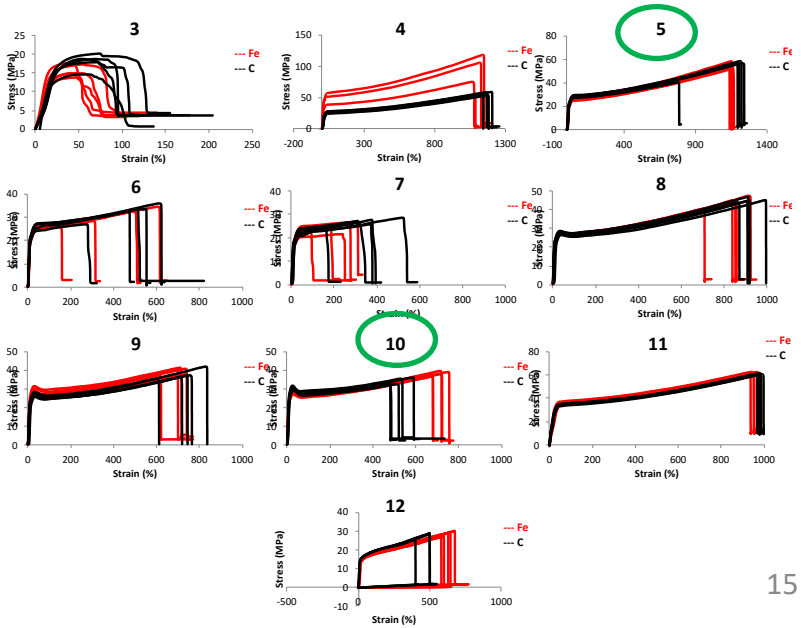




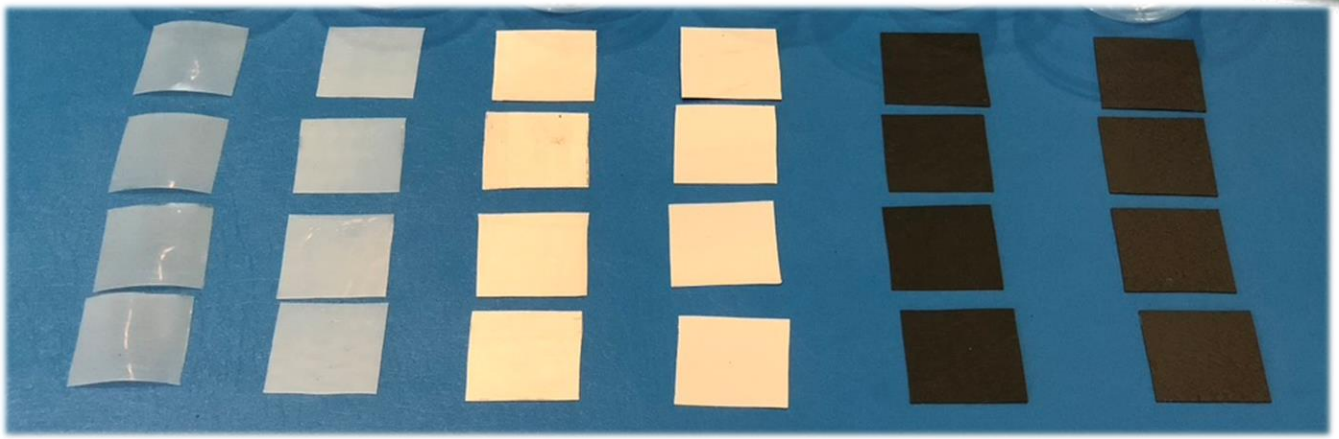


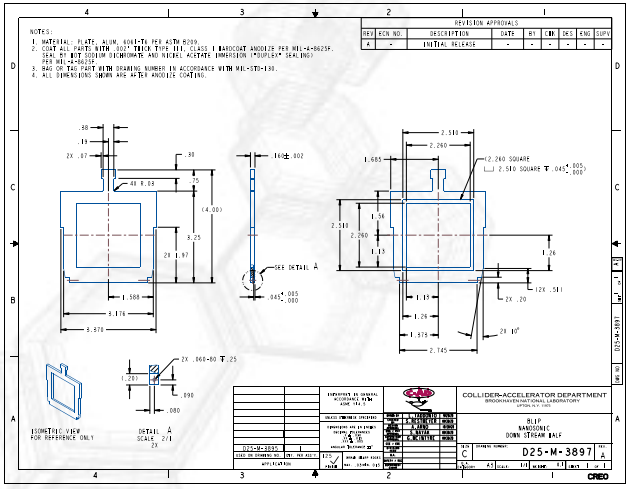
Mechanical Properties for All NanoSonic Films in Parallel and Perpendicular Directions

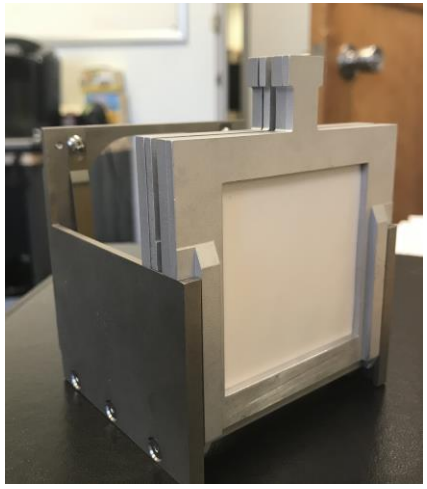


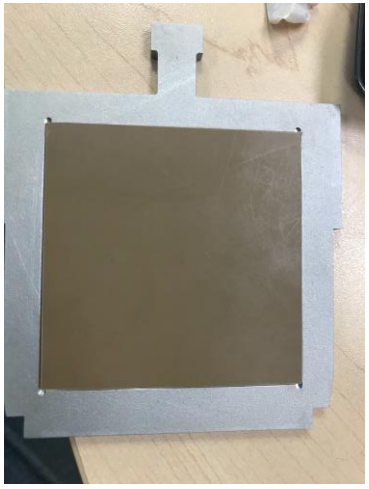


High Dose Exposure at BNL BLIP
Extruded and Delivered Films – 3/22/2021



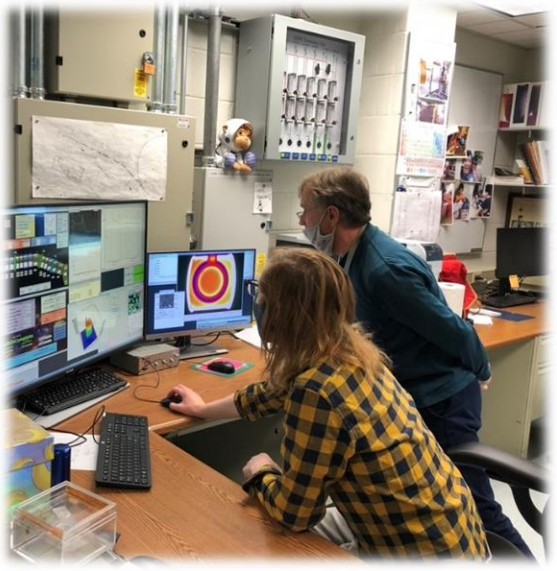




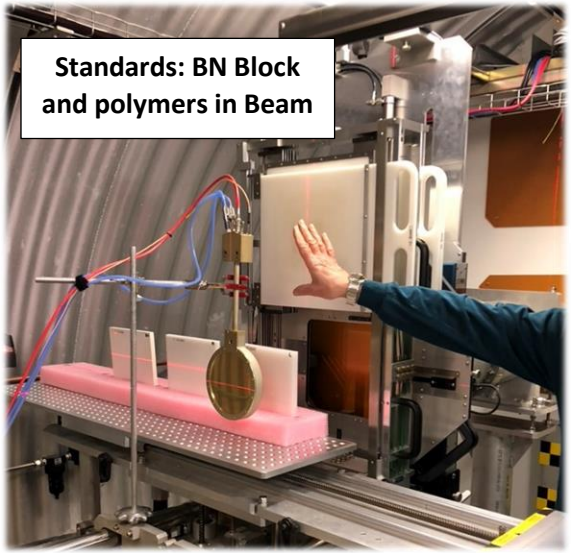


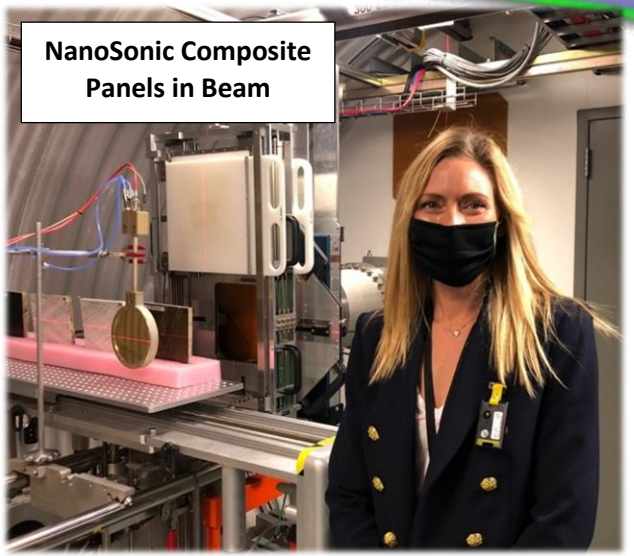
Run Scheduled for April 2021 upon Targetry Housing Construction

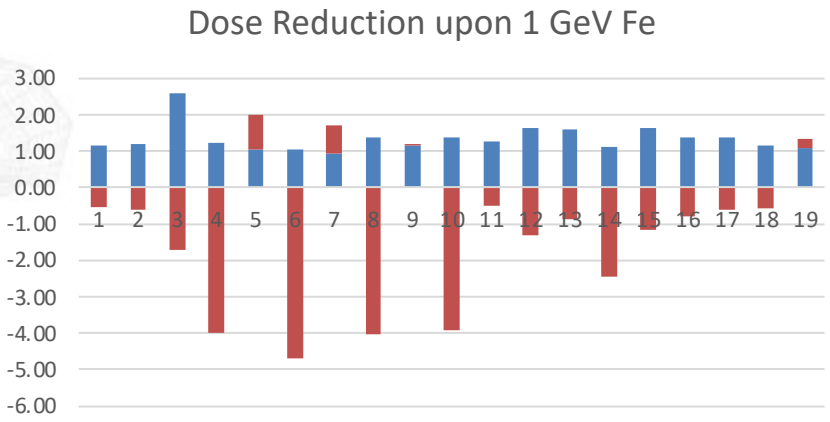
Radiation Shielding Run May 7, 2021



New Materials Development Testing
NSRL Testing in May 2021 Run







NanoSonic Composite #6 (1.0g/cm³) Exhibits >2x Dose Reduction over Solid BN #3 (2.6 g/cm³)

Accomplishments in Abrasion

On Taber Abrader per ASTM D-1003

Taber Abrasion for Water/Vacuum Seals

CS17 Diameter

Material	L (mm)	R (mm)	Pretest weight (g)	Post-test weight (g)	cycles	Loss (g)
Tefzel 3mil	51.19	50.88	1.0513	1.0408	4	0.0105
Tefzel 5mil	51.06	50.68	2.4301	2.407	1000	0.0231
Tefzel .093"	50.94	50.62	47.1957	47.1734	1000	0.0223
Daikin PFA	48.78	47.84	101.8792	101.8357	1000	0.0435
Dupont PFA	48.69	47.81	101.4681	101.4392	1000	0.0289
McMaster PTFE	48.59	47.79	53.83	53.44	1000	0.3900
C-Plastics PTFE	48.49	47.58	55.9317	55.6309	1000	0.3008

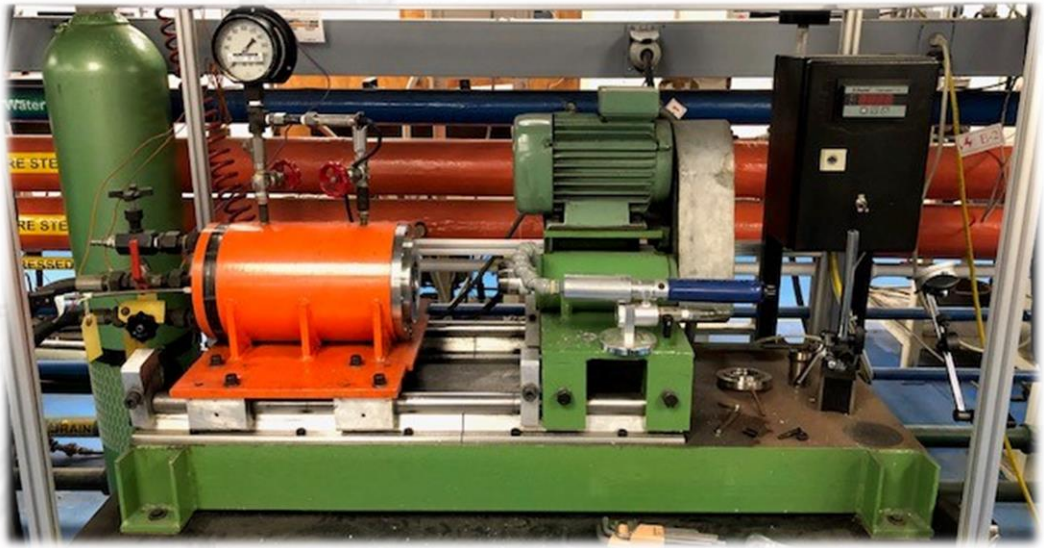
Tefzel offers lower weight loss relative to Teflon as expected

Rockwell Hardness of 50 is Important as SS 304l is 30 vs. SS 304 of 70

Garlock Test and Production Plan

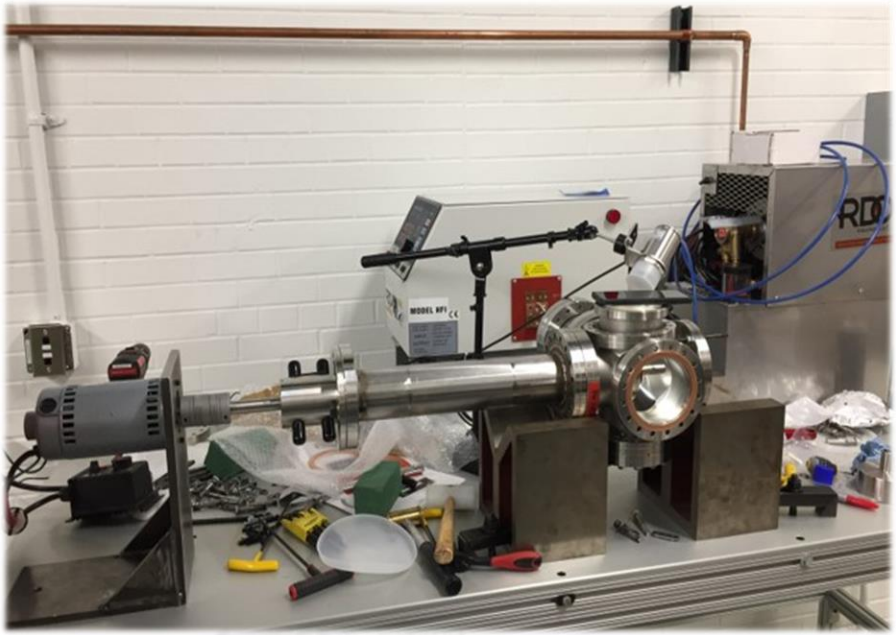
Deliver Final Material to Garlock for Introduction into Flood-Gard Housing

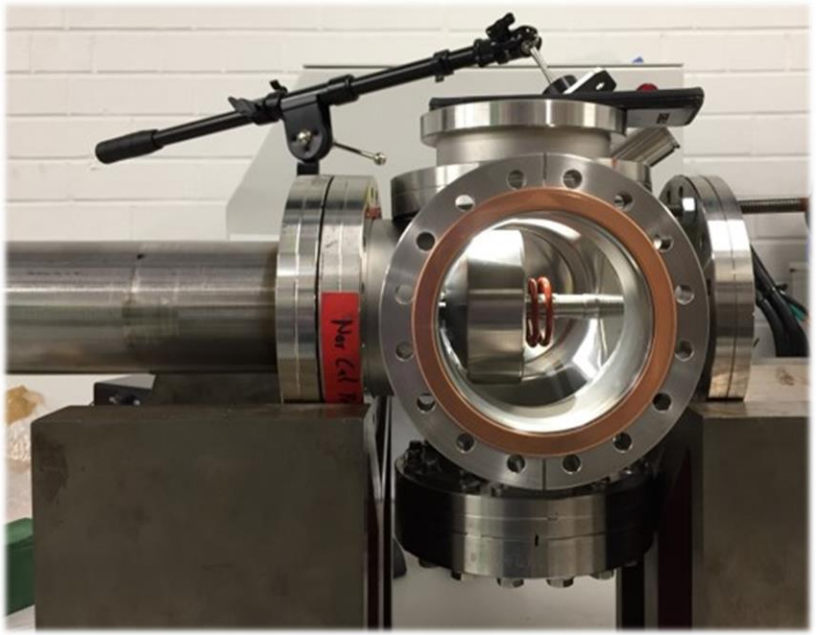
PROCEDURE STANDARD	TEST DESCRIPTION	ACCEPTANCE CRITERIA	TARGET REQUIREMENTS
Wear/ Leakage Test	**- Pressure: 3 bar/43.5 psi - Cycle duration: 15 hours - Temperature: ambient - Misalignment: 0.1mm MAX - Media: dry run - Speed: 4 m/s - Sleeve: 40mm INA EGS**	**Wear: Less than 5% WEAR RATE and no obvious chips takes out of lip.**	**- Complete entire test cycle - Final visual inspection of lips show acceptable wear and no "chips" torn out**



Remaining Challenges and Barriers:

High Dose Testing and Final Seal Integration/Testing at MSU





FRIB

Facility for Rare Isotope Beams

640 S. Shaw Lane
East Lansing, MI 48824

dump being developed within Michigan State University's (MSU) Facility for Rare Isotope Beams (FRIB). The housing of the seal and the formats for the material will be redesigned, optimized, and tested at MSU.

Task 1 - Support quarterly meetings (via telecon and annual site visit from NanoSonic at MSU). The purpose of the meetings is to provide input to NanoSonic pertinent drawings and input relative to dimensions, materials, and integration constraints and needs.

Task 2 – Evaluate NanoSonic report input and data, and provide feedback regarding down-selection.

Task 3 – Evaluate and provide a test bench to test the water seal for the beam dump assembly under thermo-mechanical environment close to FRIB operating conditions.

Acknowledgements

This material is based upon work supported by the Department of Energy, Office of Science, under Award No. DE-SC0017107

Dr. Jie Wei, Dr. Jian Gao, Dr. Frederique Pellemoine and Dr. Georg Bollen MSU FRIB
Dr. Thomas Borak, CSU
Drs. Michelle Shinn and Elizabeth Bartosz, DOE
Brenda May and Linda Severs, DOE