Thermo-Mechanically Stable Tungsten Powders as Solid Catchers for the Fast Release of Stopped Rare Isotopes

Nuclear Physics SBIR/STTR Exchange Meeting
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Program Officer: Dr. Manouchehr Farkhondeh
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Small Business
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Presentation Overview

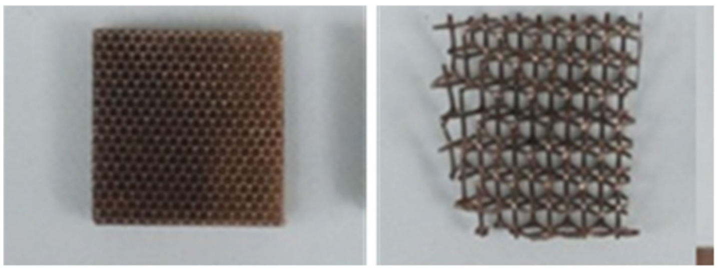
- About InnoSense LLC
- Commercialization Status
- Motivation
- Relevance to Nuclear Physics Programs
- Work Completed
- Summary
- Acknowledgments

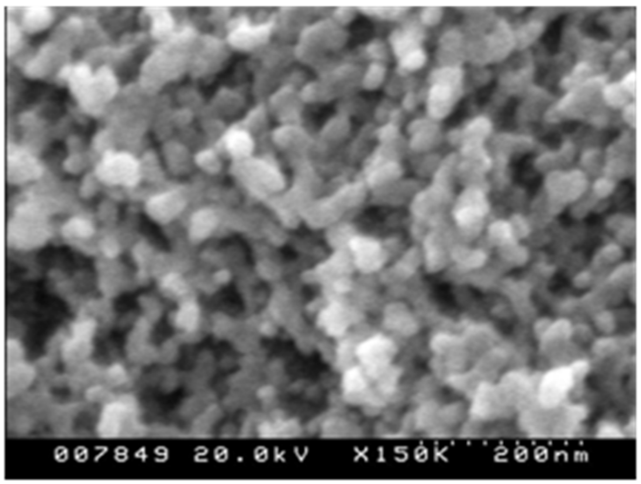
About InnoSense LLC

- Established in 2002 by private investment, R&D operations in 2004, housed in a 9,000 square feet laboratory facility located in Torrance, California. Core strengths – Nanotechnology, Chemical and Biosensing
  - Added 1400 sq. ft of space for testing and production capabilities – chemical sensors division
  - Planned expansion (~3000 sq. ft) for dedicated biotechnology/bioassay development
- Seven "wet" chemical facilities equipped with fume hoods, a clean room, a spectroscopy facility, BSL 2 hood, optical, chemical and biosensor testing laboratories, and two machine shops.
- Growth Phase - currently 28 employees, expanding to 30 soon
  - 7 PhD, 7 MS and 2 MBA degree holders; 4 issued patents, several pending
  - Dedicated business development team added in 2017.
  - Negotiating a large contract with MDA for production of 24/7 monitoring leak detectors
  - Gearing to spin-off divisions
  - Two Army funded efforts in preproduction/licensing activities

Commercialization – Building from ONP Funding

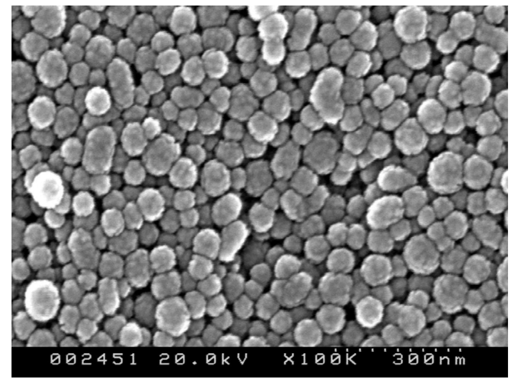
Silica aerogel coatings on metal lattices – $8,500 July 2015

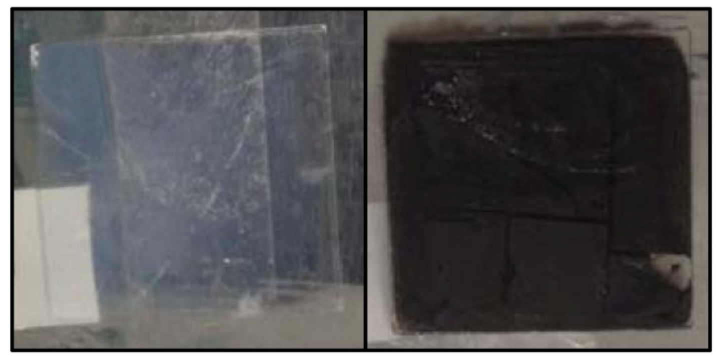




Porous Scaffolds for Refractory Solar Selective Coatings – SuNLaMP

$200 K (2016-2017)





Prior DOE ONP funding enabled us to develop the technology for porous monoliths and expand the application base for these materials

Company Commercialization Status

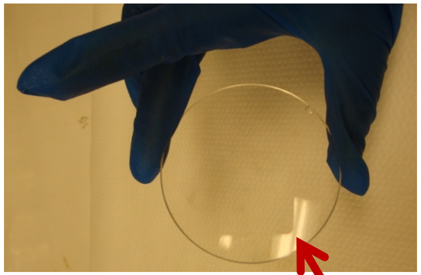
Army: W15QKN-09-C-0153

Passive Temperature Dosimeter

- Ongoing Phase III Funding ~$1M
- Correlation Testing completed at Yuma Proving Grounds 2018
- Expanding customers in the Army to ramp up production

Army: W911NF-11-C-0056

Permanent anti-fog coating



PC lens and PU visor

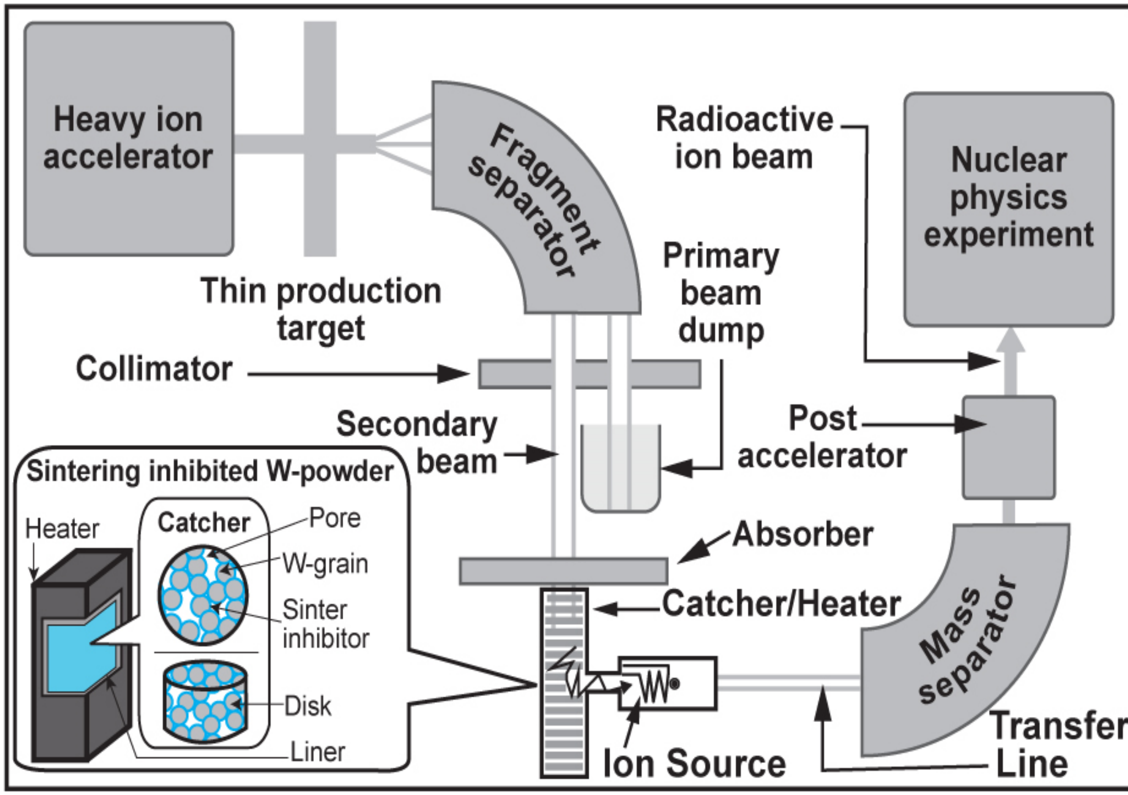
- DOD DTRA RIF award – 2015
- Nanomaterials in coating
- Negotiations with Company who supplies DOD and other markets for licensing

MDA: HQ0147-14-C-7012

Hypergolic Leak Detector for THAAD

- Drop-in replacement Leak Detector for MDA THAAD missiles
- $200K production order from Lockheed in 2017-2018
- New contract under negotiation

Refractory Hot Catchers for Rare Isotopes (no primary beam power)



Features

- Sintering inhibited W-powders
  - Maintains porosity at high temperature for long time
- Stable in energetic radioactive beams
- Supplementary to the gas catcher

Advantages

- Higher stopping power (~100 to 1000 times) over gas catcher
- Allows diffusion/effusion of short-lived isotopes as atoms or molecules
- Versatile and cost-effective processing
- Does not have the intensity limits of gas catchers for rare isotope beams

Collaborator

Dr. Jerry Nolen
Argonne National Laboratory

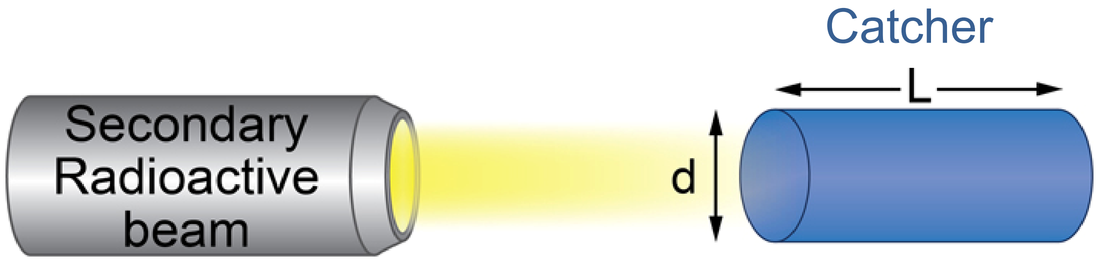
- Porous solid catchers with thicknesses in the range of ~20 g/cm^2 will complement gas catchers which are the FRIB base-line concept for stopping energetic rare isotopes and delivering them for stopped beam research or for reacceleration.
- Tungsten catcher to stop and release ^{11}Li and ^{6,8}He isotopes

Catchers/Targets Being Studied at ISL and ANL

Refractory Catcher/Target	Production beam	Collected Isotopes
Tungsten-coated SiO_2 Aerogel	^{18}O (typical)	^{8-11}Li $^{6,8}He$
Carbon Aerogel	^{16}O, ^{48}Ca, etc.	$^{12}C^{14}O$–$^{12}C^{24}O$ $^{12}C^{14}O_2$–$^{12}C^{24}O_2$
Yttria-Stabilized Zirconia (YSZ) and Hafnia (HfO_2) Porous Monolith	^{12}C, ^{48}Ca, etc.	$^{9}C^{16}O$–$^{22}C^{16}O$ $^{9}C^{16}O_2$–$^{22}C^{16}O_2$
Sintering-inhibited Disks of Tungsten, Tungsten + ALD-Hafnia and Tungsten Carbide	^{18}O, ^{48}Ca, etc.	"All of the above"
Nanoporous CaO Monolith Nanoporous Metal Oxide (M_2O_3) Thin Films* (M = ^{209}Bi, ^{75}As, ^{121}Ab)	^{40}Ca ^{4}He, $^{6,7}Li$	$^{31-35}Ar$ $^{211}Rn/^{211}At$, $^{77}Kr/^{77}Br$, $^{123}Xe/^{123}I$ $t_{½}$ [14 h/7.4 h]; [1.24 h/2.78 d]; [2.08 h/13.4 h]

* Thin film targetry for medical isotope production

Catcher Thickness Considerations



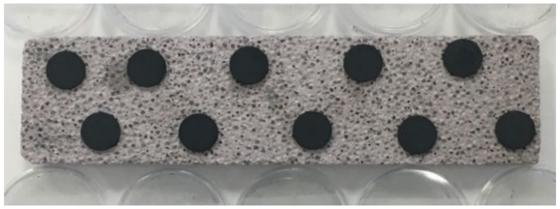
- Desired areal density (η) or thickness for efficient isotope capture can range from 3–20 g/cm^2 depending on the material used.
- Areal density can be related to the apparent volumetric density as:
  - $\eta = \rho L$
- This value is used to screen catcher disks after the 1000–1500 °C vacuum heat treatment

Must be thick to stop high energy radioactive beams at FRIB

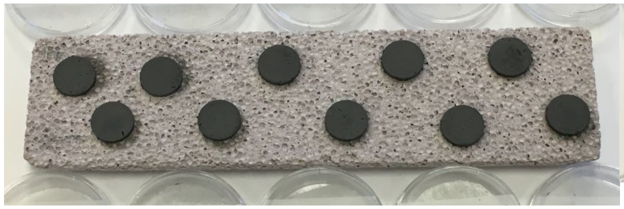
Refine Processing of Candidate Powders

- **0.6–1 µm Tungsten**
- **150–300 nm Tungsten Carbide**
  - **Porogens - open pores in disks**
  - **Diameter ~12.6 mm**
  - **Thickness ~1.5 mm**
  - **Stacked for x g/cm^2 (catcher thickness)**

Before Firing



600 °C/4h; 1400 ° C/2h in Ar



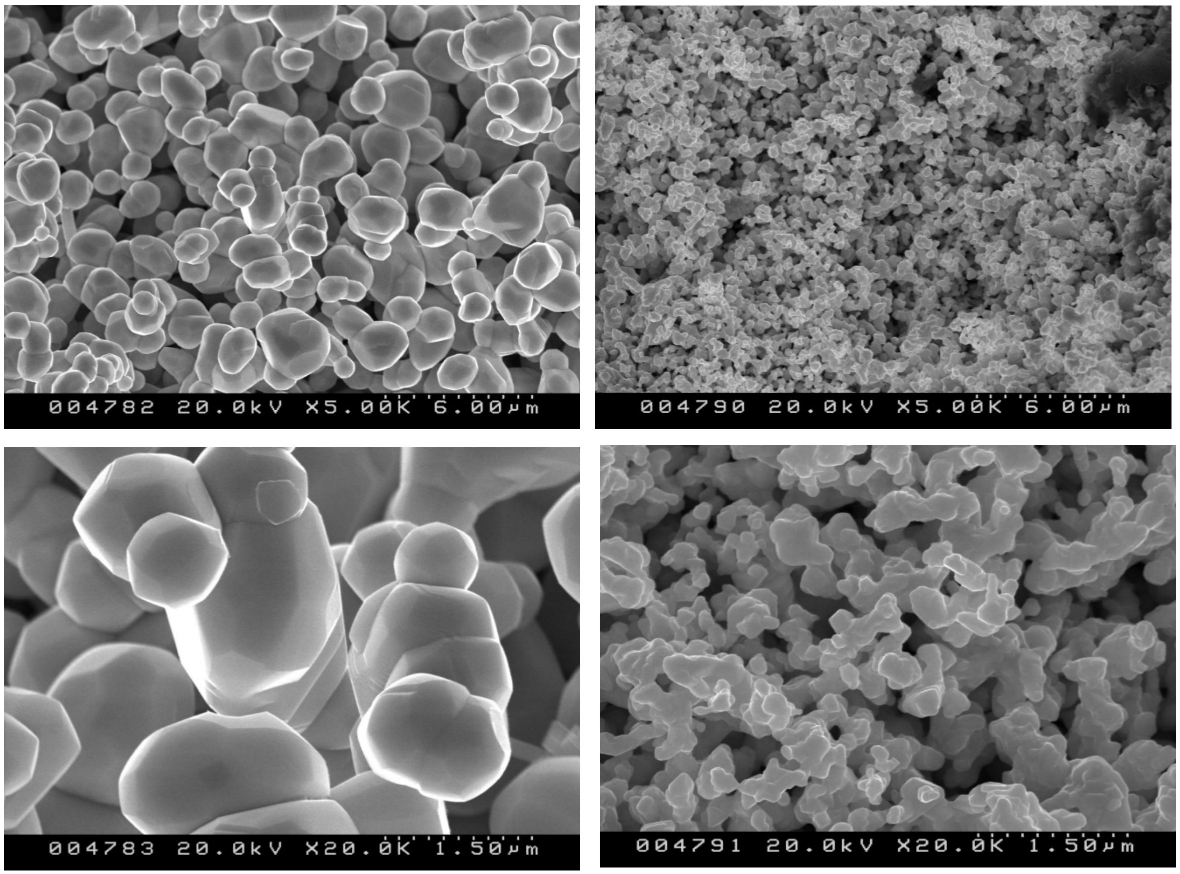
1000 °C/1 h in 10^{-5} HPa

- **Change in disk dimensions <3% post processing**
- **Mass change ~ 3-4%**

Open Porosity Retained Post Heating in Argon and Vacuum

Tungsten (W) | **Tungsten Carbide (WC)**

x5K / **x20K**

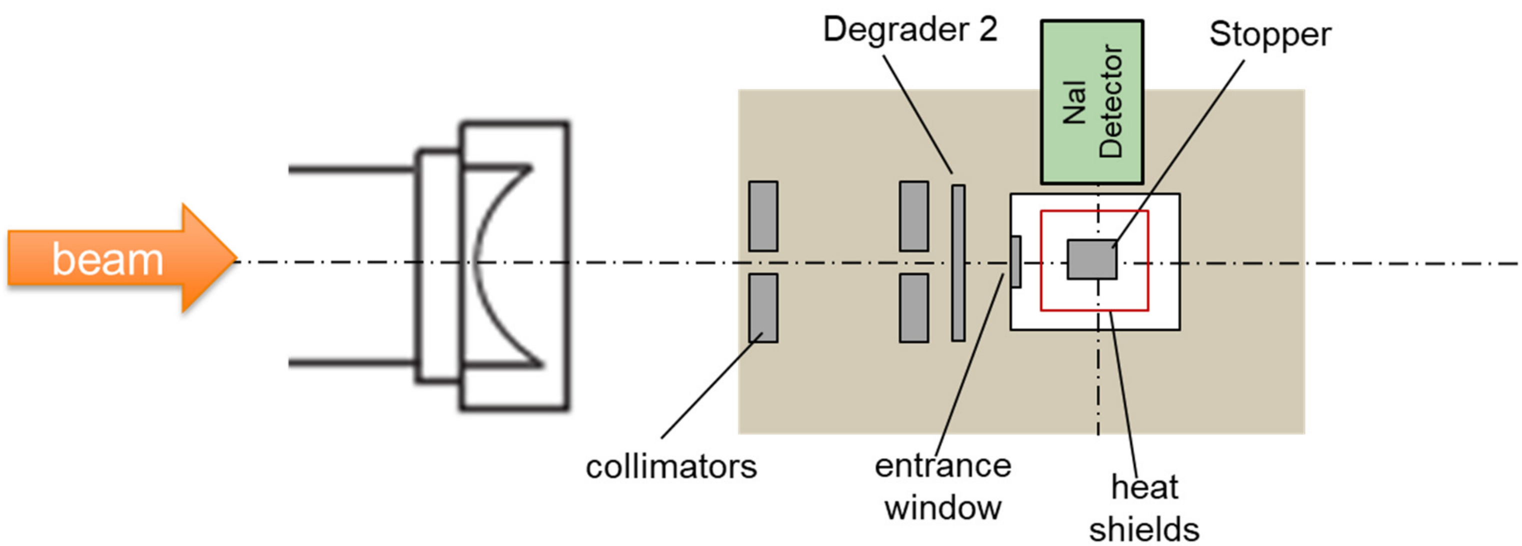


Avg. Pore Dia.: ~1.25 µm | **~500 nm**

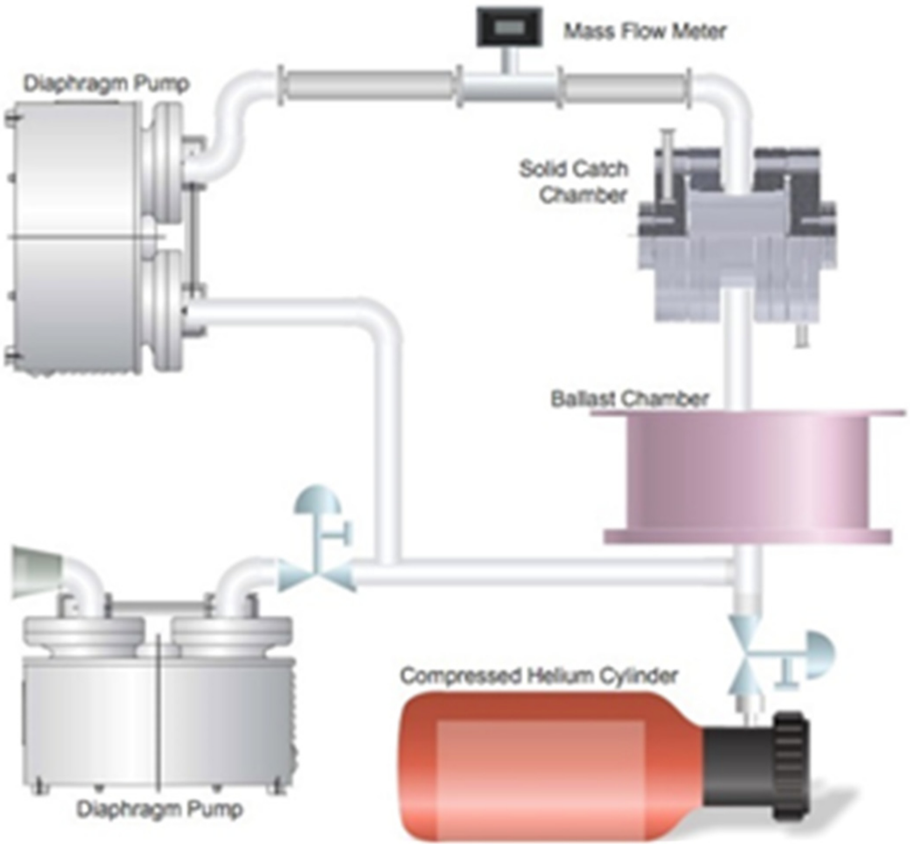
- Minimal grain growth and sintering achieved
- Open porosity retained
- Apparent density (g/cm^3)
  - W = 7.71±0.22 (n=15)
  - WC = 4.51±0.16 (n=20)
- Apparent Porosity
  - W = 60%
  - WC = 71%
- **Intrusion Porosity**
  - **W ~60%**
  - **WC ~71%**

Setup for solid stopper tests at NSCL

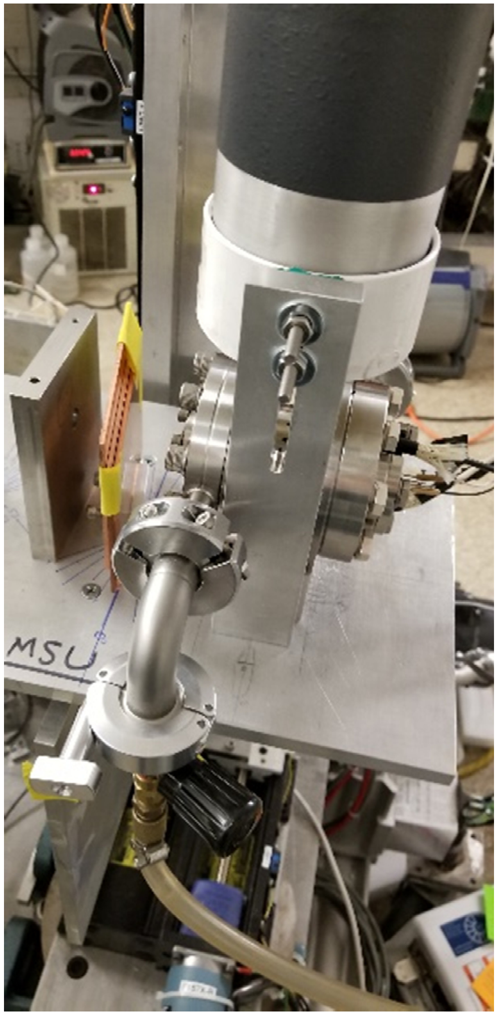
- First on-line test of the porous solid tungsten WC catchers at NSCL using a very short-lived isotope (^{8}He, 119 msec)
  - Collaboration of Argonne and NSCL scientists in May, 2018

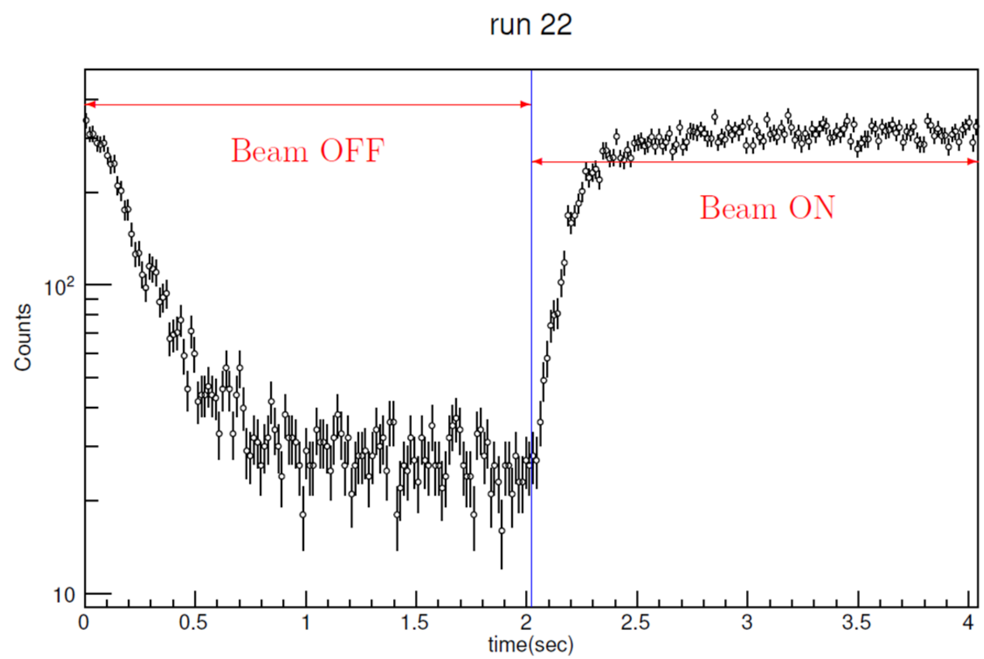


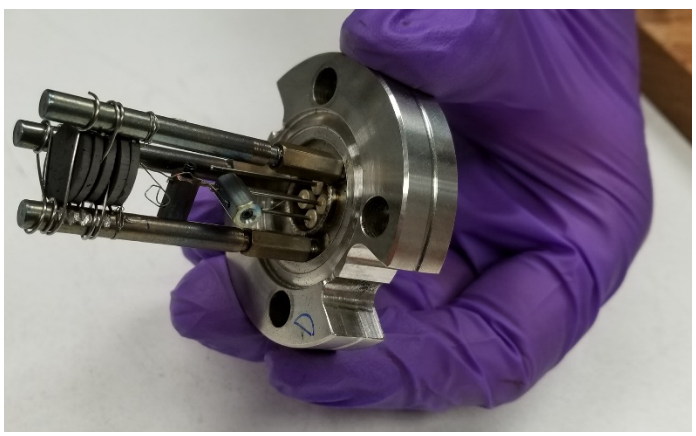
Setup for solid stopper tests at NSCL



Sample Chamber and Count Rate in NaI Detector







"Effective" half-life of ^{8}He decreased with heater power up to present limit of 400 W, ~500 ^{o}C. Release estimate ~20% - very good for a noble gas at this low temperature

Summary

- Processing methods developed for refractory nanoporous tungsten and tungsten carbide powders for use as solid catchers
  - 12.5 mm diameter, 1.5 mm thick disks stacked for 1 cm thick catcher
  - Apparent density
    - Tungsten ~7.7 g/cm^3
    - Tungsten carbide ~4.5 g/cm^3
  - Open (intrusion) porosity; **Pore size ⇔ particle size**
    - Tungsten ~60%
    - **Tungsten carbide ~71% (tested on-line at MSU/NSCL)**
- Successful on-line test conducted at NSCL in May 2018
  - ~20% release of very short-lived ^{8}He (119-msec half-life) already at relatively low temperature, ~500 ^{o}C

The participants in this test at the NSCL were: Jeongseog Song, Ravi Gampa, Jim Specht, John Greene, Matt Gott, and Jerry Nolen from Argonne, and Mauricio Portillo, Antonio Villari, Mathias Steiner, and Tom Ginter from MSU/NSCL.

Future Plans

- Initial results are promising
- Further testing is dependent on FRIB interest and resources being made available
  - Variety of materials have been processed into disks and waiting to be tested (backlog from multiple projects)
    - Tungsten
    - Tungsten Carbide
    - ALD-Hafnia coated Tungsten
    - Carbon
    - ALD-Tungsten Coated Silica Aerogels
    - Carbon Aerogels
  - Feedback, required to refine the materials processing
  - Potential users – RIBF at RIKEN; RISP in South Korea; GANIL in France

Acknowledgments

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Dr. Michelle Shin

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