MILLENNITEK LLC
AN ADVANCED MATERIALS MANUFACTURER

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Vice President, R&D

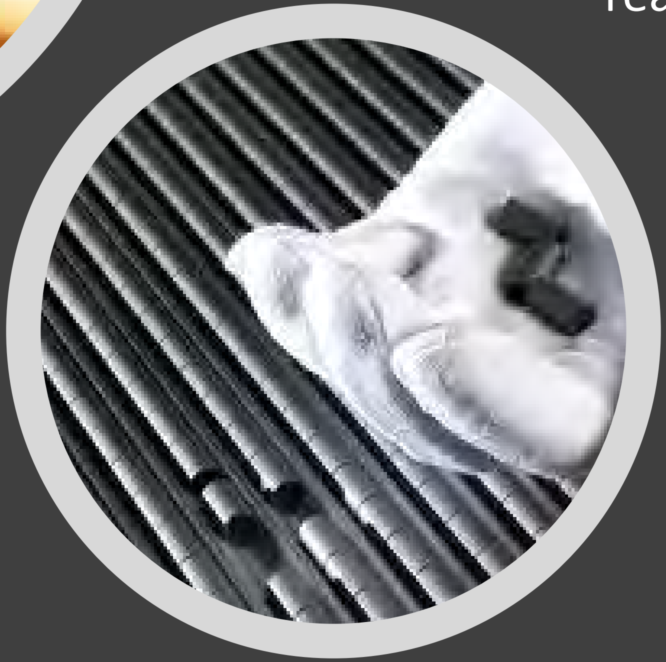
DOE SBIR Phase 2 Review

Cost Reduction Technology for Neutron Absorbers in Microreactor Applications

Contract No.
DE-SC0022822

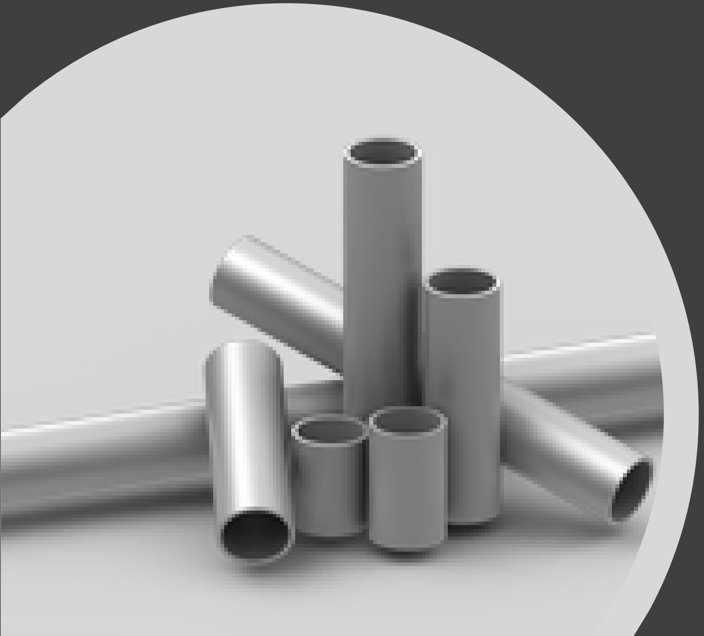
About MillenniTEK

- Founded 2010, currently 45 employees
- Based in Knoxville, Tennessee
- NQA-1 quality system
- Tier 1 Supplier for Safety Related Nuclear Components
- MillenniTEK products are currently in many worldwide reactors, with tens of millions delivered



PRODUCTS

- Neutron absorbers and other products made from boron carbide and other advanced borides and carbides
- Solid or thin wall annular configurations
- Density range from 65% to >99%
- Natural & Enriched
- Machined to exacting specifications



MillenniTEK Commercial Products and Pre-Commercial Products

Commercial

- B_4C based burnable neutron absorbers
  - Commercial PWRs
- Alumina spacers for nuclear start-up sources
- SiC components
- Erbia/Yttria coatings for uranium casting

Pre-Commercial

- Neutron and gamma shielding
- Microreactor/SMR prototype components
- ^{10}B specialty ceramic powders
- Hard boride-based tooling and bearings
- SOFC tubular cells



SOFC tube and 250W bundle (Army)

R&D Laboratories

- Advanced Ceramic Processing Lab
- High Temp Atmosphere and Vacuum Furnaces
- SEM/EDS
- XRD
- Laser Particle Size
- Optical Microscopy
- Mechanical Testing

Phase 2 Project Scope (24-months) 8/28/23 to 8/27/25

Task 1 - Optimize and Scale-Up Manufacturing

- Synthesis optimization
- Jet milling development
- Nuclear purity analyses and refinement

Task 2 - Densified B_4C Manufacturing Scale-up & Optimization

- Graphite tooling design, based on customer target microreactor components
- Variation of the temperature and pressure ramp rates, dwell times, and cooling profiles between both hot pressing and SPS processes
- Microstructural analysis of billet samples to correlate density to powder and processing conditions
- Neutronic modeling in support of customer (s)

Task 3 - Microreactor Customer Component Completion and Property Testing

- Graphite tooling manufacturing
- SPS or hot-pressing to required density
- Diamond grinding of all surfaces to required dimensions and tolerances
- Chemical analysis
- Destructive mechanical and/or other property testing as specified by customer of component(s)
- Certification of components under NQA-1

Deliverables

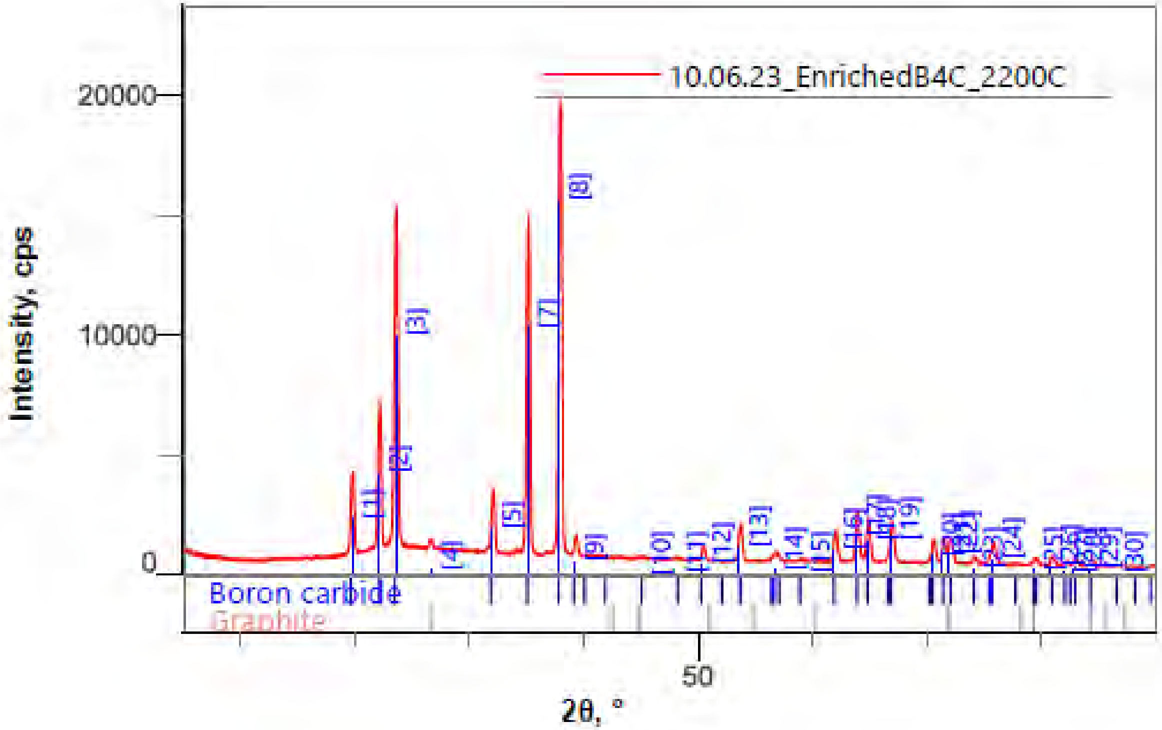
- Progress Reports
- Final Report
- Enriched B4C Microreactor Prototype to Customer

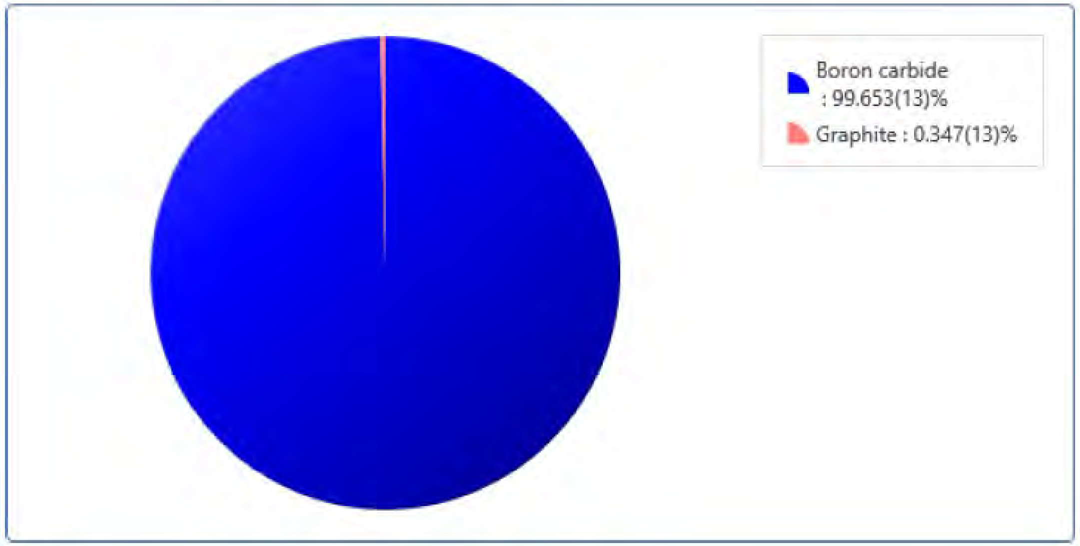
Phase 2 Project Schedule

24-Month Project Schedule									
TASK	**Q1**	**Q2**	**Q3**	**Q4**	**Q5**	**Q6**	**Q7**	**Q8**	
Task 1 - Optimize and Scale-Up Manufacturing									
Synthesis Development									
Jet Milling Trials									
Extensive Pilot-Scale Characterizations									
Milestone: ^{10}B enriched B_4C produced meeting nuclear specifications after jet milling					•				
Task 2 – Densified B_4C Component Manufacturing Scale-up & Optimization									
Scale-up of SPS Billet Size									
Scale-up of Hot-Pressing Billet Size									
Milestone – MillenniTEK successfully installed/operated 200-ton Hot Press			✓						
Milestone – Down-selection of optimized billets for final property characterizations						•			
Task 3 - Microreactor Customer Component Completion and Property Testing									
Component geometries identified & designed for manufacturing for customers/teaming partners									
Manufacturing									
Property Testing/Certifications									
Customer Case Study/Process Qualification Activities									
Milestone – At least one actual-scale microreactor B_4C component delivered to customer for testing/qualification activities									•
Reporting									
Progress Reports		✓		xx		xx			
Final Report									X

Task 1

- Successfully scaled to kilogram quantities
- Phase purity and chemical composition successfully meet typical nuclear quality requirements





Jet Milling Development

0.5 kg/hr. jet mill at Millennitek

Challenges:
- Wear liner and jet nozzle materials lead to impurities
- Oxygen pickup

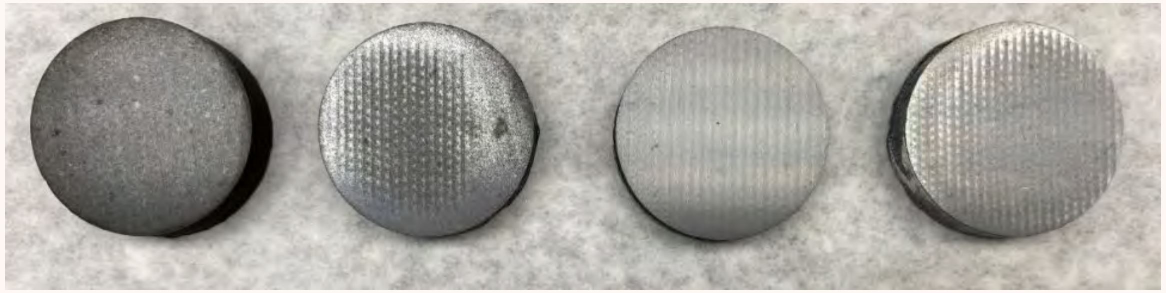
Hot-Pressing Scale-Up

- Millennitek cost-share commitment to purchase
- Commissioned 2/26/2024
- 200T, 2200 °C capability
- Completed 3 cycles last week, successfully producing natural enrichment B_4C neutron absorber prototypes

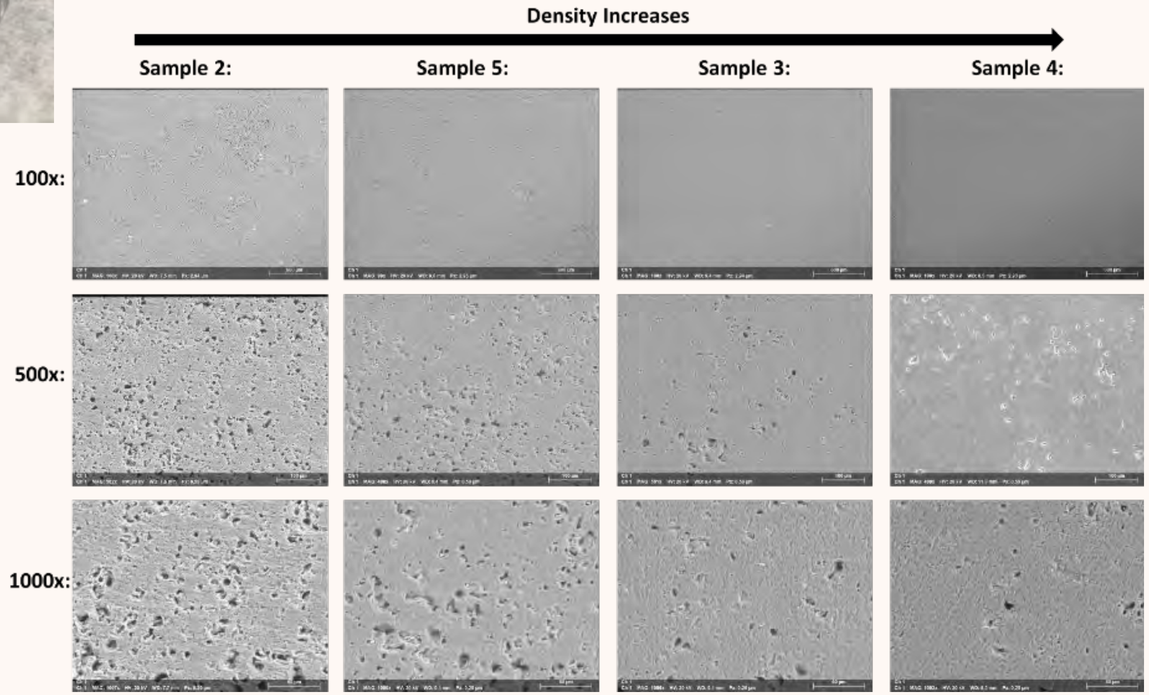
Spark Plasma Sintering Development

- Working with Thermal Technology (Minden, NV)
  - Phase 1 utilized DCS 25
  - Phase 2 utilizing DCS 200
- Evaluating cored mold designs as well as thick, high aspect-ratio geometries

SPS Results



SPS B_4C disks from lowest density produced, left, to highest density, right.



SEM micrographs of the four SPS B_4C trials showing increased density from left to right in 100x, 500x, and 1000x magnification (top to bottom).

SUMMARY OF PHASE 2 SBIR CONTRACT

- Just completed 2nd Quarter and successfully meeting milestones
- Significant investment completed at Millennitek for scaling up hot pressing of enriched neutron absorbers
- Manufacturing process standup of enriched B_4C components including complex geometry forming have been successful
- Seeking to determine if SPS can further reduce costs
- Progressing rapidly with several customers, with first deliveries of enriched B_4C neutron absorbers anticipated in Summer 2024, and significant commercial sales by end of 2024

- Synthesis of natural and enriched Tungsten Tetraboride (WB_4) powder
- Developed layered shielding design for microreactor and delivered subscale prototype
  - NASA SBIR Phase 2
- Exploring cermets of WB_4 via reactive hot pressing
  - Hard tooling for industrial applications
    - DOE SBIR Phase 2
  - Dust and radiation resistant bearing for lunar applications
    - NASA SBIR Phase 2
    - Currently working with INL to irradiate and characterize bearing roller component (NRAD and IMCL)

Related Work

NASA SBIR Phase 2: Tungsten Tetraboride (WB_4) Integral Shielding

FISSION SURFACE POWER (NASA/DOE)

- Integral Gamma & Neutron Shielding Material
- Low density
- Stable to 2000 °C
- >50% dose reduction of current NASA shield design (LiH/DU) at same mass
- Patent Issued June 2022

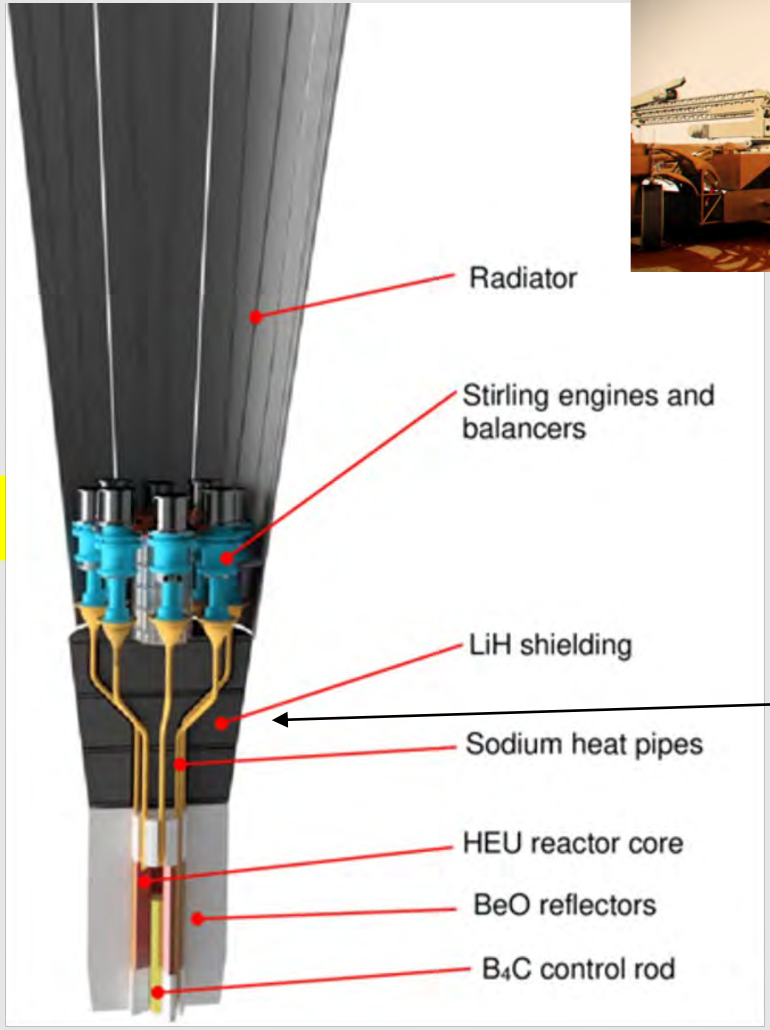


Image credit: NASA

Image credit: NASA

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DOE SBIR Phase 2: Tungsten Tetraboride (WB_4) Hard Tooling

78% less Tungsten, and 0% Cobalt for WB_4 Tooling

- Reduction of Tungsten & Cobalt Strategic Materials
- WB_4 cemented with other metals to form superhard cermet
- Lower density/cost
  6.5 g/cc for WB_4
  (14.2 g/cc for Co-WC)
- >60% harder than Co-WC
- Patent Pending

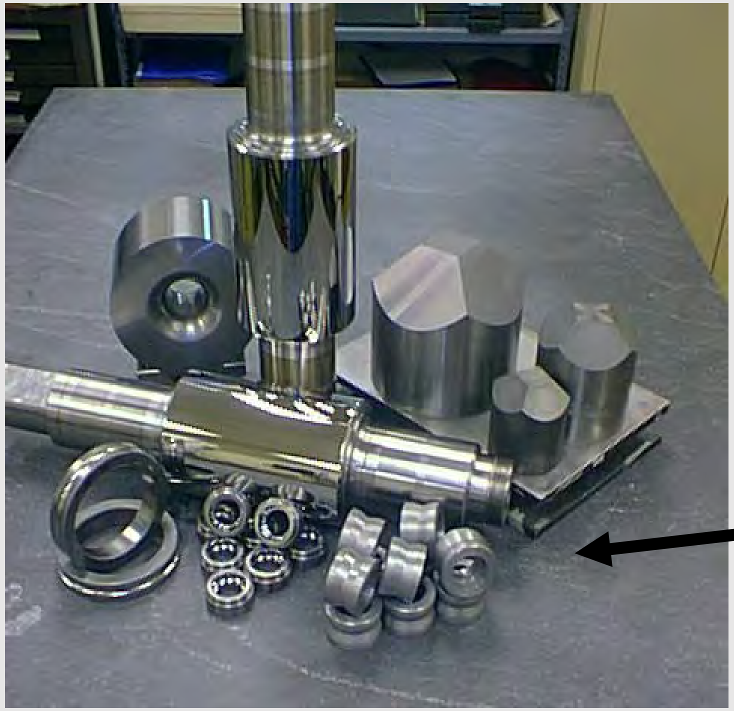
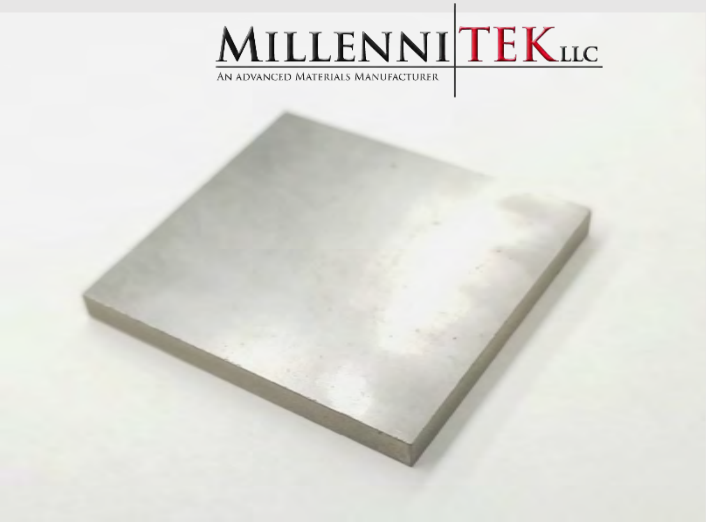


Image credit: Dura-Metal



Z13.02-1981 - Regolith Dust and Radiation-Tolerant Bearing

SBIR · STTR America's Seed Fund POWERED BY NASA

PI: Drew Spradling , MilleniTEK, LLC - Knoxville, TN

NON-PROPRIETARY DATA

IDENTIFICATION AND SIGNIFICANCE OF INNOVATION

A radiation-resistant and superhard material for dust-resistant mechanical bearing applications on the lunar surface will be tested and demonstrated under this project. This highly incompressible ceramic material is able to be formed into intricate bearing geometries to create dense, hard, geometrically precise, and wear-resistant bearing surfaces. This new material is more than 30% lighter than the chrome steel commonly used for bearings, and about 15% lighter than Nitinol, which NASA has been recently investigating for bearing applications. A roller bearing using this new material that is tolerant of regolith dust will be designed, fabricated, and performance tested. Radiation resistance testing of this material will also be performed with INL. Performance testing of assembled bearings from this material will be tested for lunar dust resistance, and at temperature extremes ranging from -240 C to 130 °C. At the conclusion of the Phase II, a functioning roller bearing would have been tested in the simulated conditions and delivered to NASA for further evaluation.

TECHNICAL OBJECTIVES AND PROPOSED DELIVERABLES

The goal of the Phase II effort is to engineer and manufacture complete, assembled, roller bearings using our material, and perform extensive testing under relevant conditions simulating the lunar surface. To accomplish these objectives, we will also further develop the microstructure to optimize the density, strength, and surface finish of the material. Phase I demonstrated the technical feasibility of producing bearing geometry components from the material formulation. These samples were characterized for surface roughness, hardness, wear resistance, coefficient of friction, and thermal conductivity/CTE. Demonstrated values appeared promising, and significant further improvements seem probable in the Phase II effort. The manufacturing of the bearing material billets will be scaled and we will perform detailed engineering, fabrication, and testing of assembled bearings for performance. Also, a significant effort to study the new material in a radiation environment that meets the target lunar surface environment, side by side with baseline materials of other mature bearing materials, will be useful result of this effort to NASA as they seek to qualify new materials for bearings and radiation shielding for Human's return to the Moon. A complete assembled bearing made from this new material will be delivered to NASA at the conclusion of the project.

TRL

Estimated

1	2	3	4	5	6	7	8	9
			■	■				

IMAGE TITLE: Dust-Resistant Bearing

NASA APPLICATIONS

The new bearing being developed will be applicable to small, precision mechanical bearing applications that can operate reliably without environmental protection housing in the extreme environments of NASA missions. Many conventional bearing materials and required lubricants are not tolerant of these environments. The proposed material is radiation-resistant and capable of operation without lubricant, at a significantly lower mass than current bearing metal alloys.

NON-NASA APPLICATIONS

This fully-ceramic bearing material technology has the potential to be utilized in high temperature and corrosive bearing applications in the oilfield, refinery, chemical processing, and metal processing industries. Additionally, non-bearing uses include exploiting the high hardness of the material within the industrial forming, cutting, and grinding tool industries.

FIRM CONTACTS

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Commercialization Activities

- Working with many of the micro- and small-modular reactor companies
- Have successfully produced and delivered prototype natural enrichment, nuclear-grade hot-pressed B_4C components such as solid cylinders, cored hexagons, annular cylinders, and other geometries to customers
- Contributing to Design for Manufacturing for neutron absorbers/shielding with several microreactor developers
- Anticipate first significant commercial sales of enriched B_4C neutron absorbers by late 2024
- Presenting and exhibiting at tradeshows
    - Come see us next at NETS 2024 in Sante Fe, NM and the Nuclear Opportunities Workshop 2024 in Knoxville, TN