U.S. DEPARTMENT OF ENERGY | Office of NUCLEAR ENERGY

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Versatile Acoustic and Optical Sensing Platforms for Passive Structural Monitoring

Advanced Sensors and Instrumentation Annual Webinar

October 30, 2019

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Virginia Tech

Project Overview

- Goal
  - To develop an acoustic based distributed sensing system capable of monitoring phenomena such as strain, temperature, pressure and corrosion to better evaluate the aging and degradation of structural components in nuclear facilities
  - The first-of-its-kind sensing system will be developed with unprecedented resolution, versatility, reliability, and economic viability
- Objective(s)
  - Develop radiation tolerant silica and single crystal sapphire acoustic fibers waveguides (AFWs) and Bragg grating (AFBGs) sensors
  - Design and construct a fused silica and single crystal sapphire acoustic fiber Bragg grating sensing systems
  - Conduct testing of optimized acoustic fibers and sensors exposed to radiation and benchmark performance with optical fibers and sensors

Project Overview

- Participants (2019)
  - Virginia Tech (University Lead)
    - Materials Science and Engineering: Gary Pickrell (Lead PI), Dan Homa (Manager), Zach Hileman (Ph.D.), Steven Snider (M.S.)
    - Electrical and Computer Engineering: Anbo Wang (PI), Jiaji He (Ph.D.), Ruixuan Wang (Ph.D.)
  - Oak Ridge National Laboratories (National Lab Collaborator)
    - Nuclear Security and Isotopes Technology Division: Alexander Braatz
  - Prysmian Group (Industry Collaborator)
    - Materials Technology Group: Brian Risch

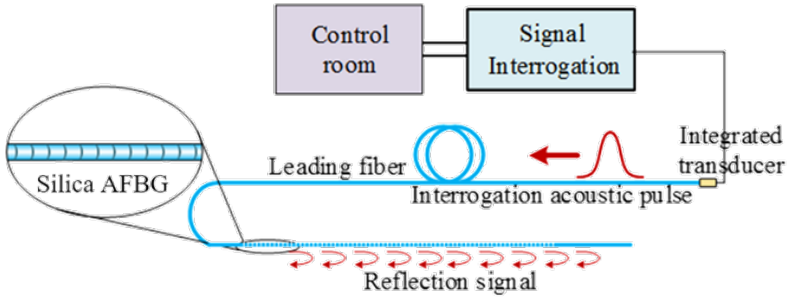
Project Overview

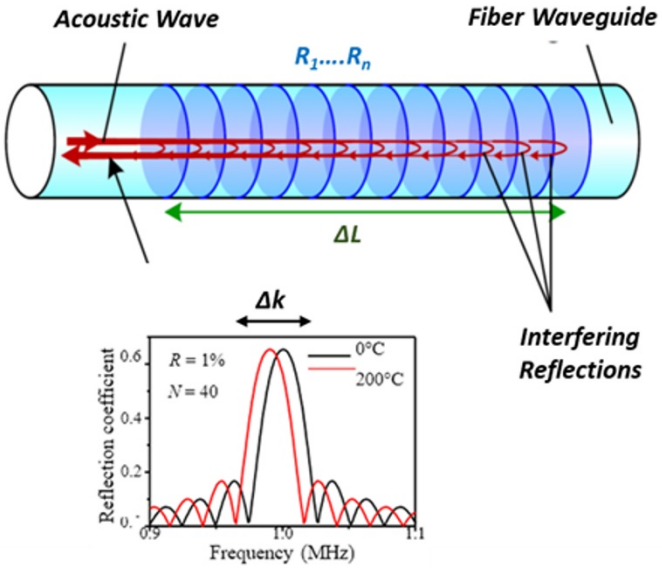
- Schedule
  - First- and second-year milestones completed on time
  - No changes/problems to report

GANTT CHART		Project Year 1				Project Year 2				Project Year 3			
Task #	**Task Name**	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4
1	Project Management and Planning												
M1	**MILESTONE 1 [M3CA-17-VA-VT__-0702-042]**		√										
2	Acoustic Fiber Waveguide Realization and Improvement												
2.1	Waveguide Design by Acoustic Modelling												
2.2	Development of Acoustic Excitation and Detection Device												
M2	**MILESTONE 2 [M2CA-17-VA-VT__-0702-043]**				√								
M3	**MILESTONE 3 [M3CA-17-VA-VT__-0702-044]**				√								
3	Sensor Design and Fabrication on Fused Silica Fibers												
3.1	Sensor Design												
M5	**MILESTONE 5 [M3CA-17-VA-VT__-0702-047]**								√				
3.2	Reflector Element Fabrication and Tests												
M6	**MILESTONE 6 [M3CA-17-VA-VT__-0702-048]**							√					
3.3	AFBG Sensor Fabrication and Tests												
M7	**MILESTONE 7 [M2CA-17-VA-VT__-0702-049]**								√				
4	Radiation Exposure Testing of Fused Silica Based AFBG Sensors												
M9	**MILESTONE 9 [M3CA-17-VA-VT__-0702-0412]**									√			
5	Sensor Implementation on Sapphire Fibers												
5.1	Fabricating Sapphire Fiber Based AFBG Sensors												
5.2	High Temperature Sensing Capability Demonstration												
M10	**MILESTONE 10 [M2CA-17-VA-VT__-0702-0413]**											△	
6	Radiation Exposure Testing of Sapphire AFBG Sensors												
M11	**MILESTONE 11 [M3CA-17-VA-VT__-0702-0414]**												△
7	Laboratory Scale Performance Testing in Simulated Application												
M12	**MILESTONE 12 [M3CA-17-VA-VT__-0702-0415]**												△

Project Overview

- "System" design approach
  - Acoustic fiber waveguide (AFW)
  - Acoustic fiber Bragg grating (AFBG)
  - AFW and AFBG testing station
    - Acoustic excitation and detection
  - Sensor interrogation system
    - Acoustic excitation and detection
    - Signal demodulation and sensing algorithms
    - "User-friendly" interface
  - Acoustic coupling components
    - Transducer-horn assembly
    - Acoustic signal amplifier
  - Performance testing
    - Radiation exposure



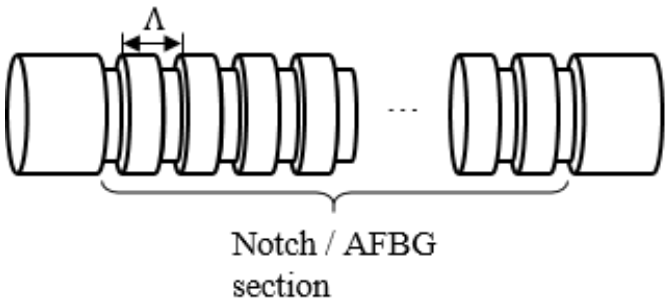


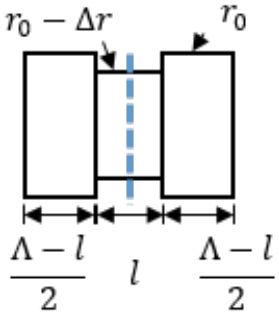
Accomplishments

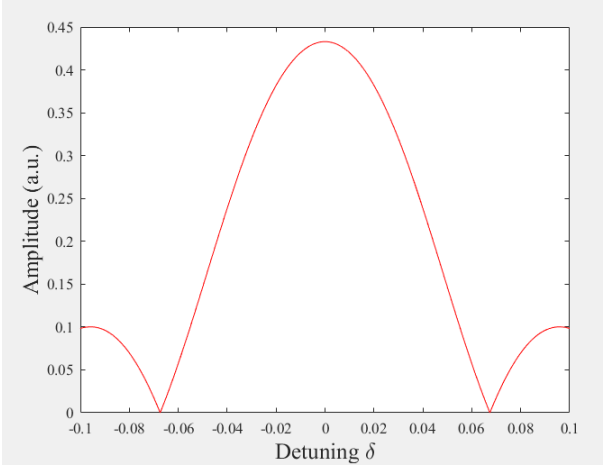
- M3CA-17-VA-0702-048: Reflector Element Fabrication and Testing
  - Completed on time (3/31/2019)
- M3CA-17-VA-VT-0702-047: Design of Single Reflector Element and Radiation Tolerant Fused Silica Acoustic Fiber Bragg Grating Sensor
  - Completed on time (6/30/2019)
- M2CA-17-VA-VT-0702-049: Construction and Testing of the Fused Silica Acoustic Fiber Bragg Grating Based Sensing System
  - Completed on time (6/30/2019)
- M2CA-17-VA-VT-07020412: Radiation Exposure Testing of Fused Silica Based Acoustic Fiber Bragg Grating Sensors
  - On schedule (12/31/19)
- *Three peer reviewed publications & one accepted for publication*

Accomplishments

- Design of reflectors and AFBG sensors
  - Theoretical models developed for AFBG design and optimization
  - Simulation results were verified via experimentation
  - AFBGs can be tuned for selected operating frequencies
  - New analysis techniques were reported in a peer reviewed publication
    - *He, Jiaji, Daniel Homa, Gary Pickrell, and Anbo Wang. "Coupled Mode Analysis for 3D Stress-Free Elastic Acoustic Waveguide." IEEE Access 7 (2019): 117796-117803.*

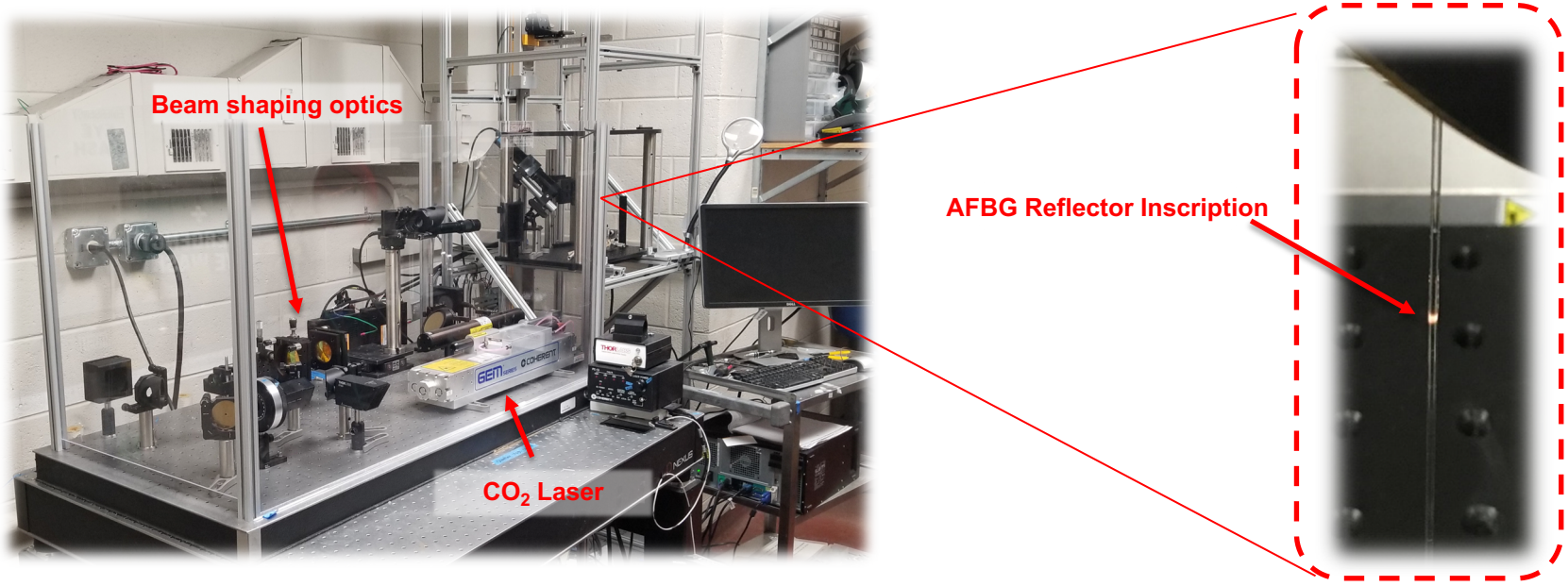






Accomplishments

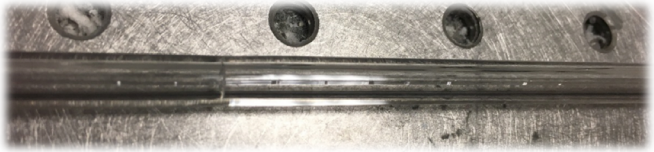
- Fabrication of reflectors and AFBG sensors
  - Demonstrated new and robust AFBG fabrication technique
  - Inscription via “modified” laser heated pedestal growth
    - Pair of axicons used to form a parallel ring beam
    - Parabolic mirror focuses the ring for uniform heating
    - A short taper (reflector) is created by placing the heated region under tension



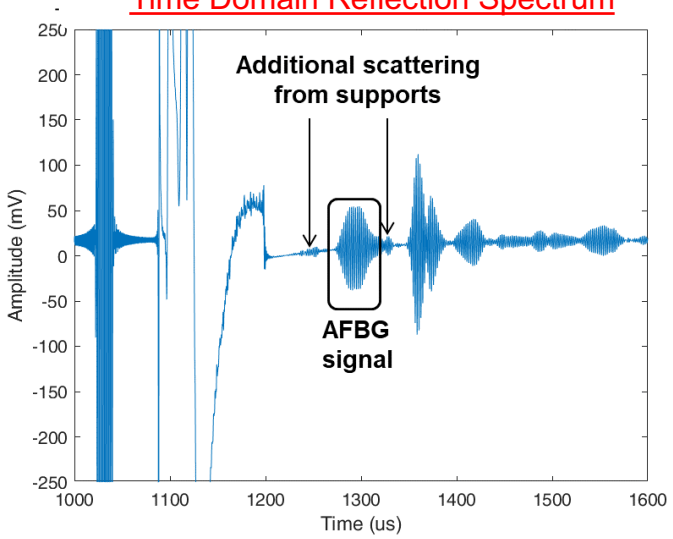
Accomplishments

- Performance characterization of AFW and AFBG sensors
  - AFBG in “suspended core” AFW
    - AFBG inscribed in the core rod and then inserted into the cladding tube
    - Core supported with internal struts
  - Sensor stabilization via thermal annealing
    - Process developed and reported in an accepted peer reviewed manuscript
  - High quality AFBG spectrum
    - Well defined AFBG signal envelope
    - AFBG/end reflection amplitude ratio was improved significantly (0.48 vs 0.30)
  - Scattering due to struts was minimized

AFBG in “Suspended Core” AFW

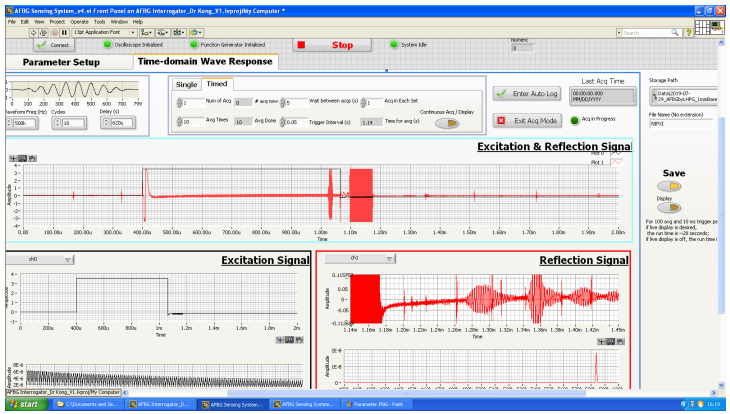


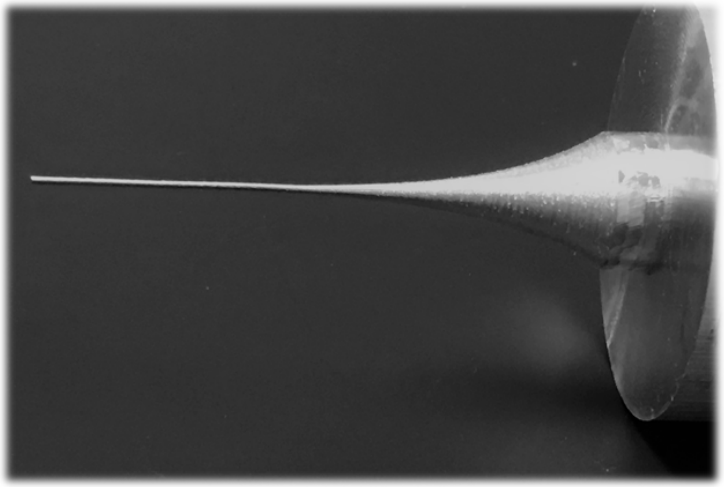
Time Domain Reflection Spectrum



Accomplishments

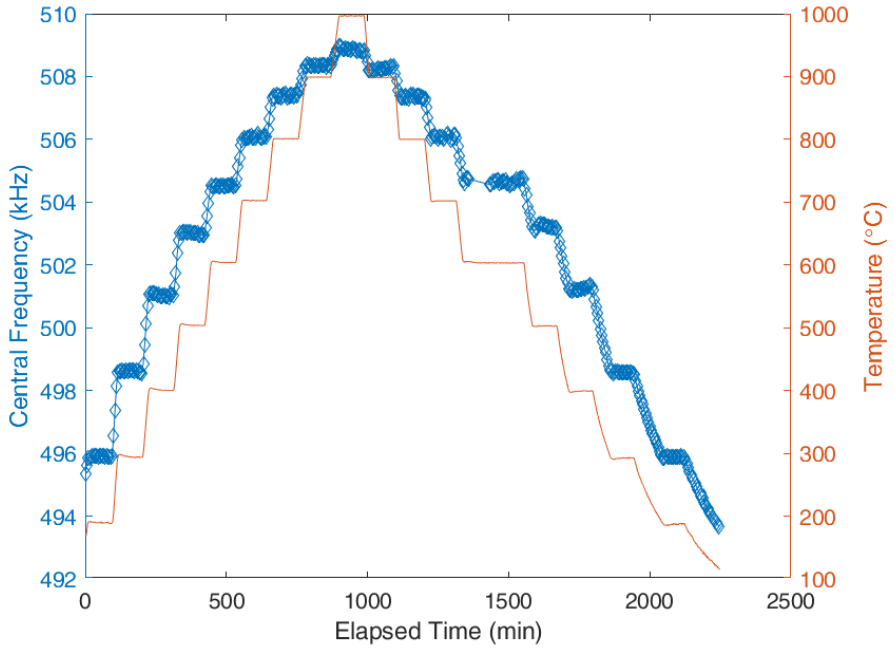
- Development of fused silica based AFBG sensing system
  - Interrogation system
    - Compact and transportable
  - User-friendly interface
    - Parameter setup and signal generation
    - Real-time high-speed data acquisition
  - Acoustic transducer(s)
    - System accepts an array of commercially available transducers
    - Wide range of frequencies (kHz-MHz)
  - Acoustic horn/amplifier
    - Design methodologies and theoretical models have been developed
    - Enables efficient coupling, signal amplification, and design flexibility

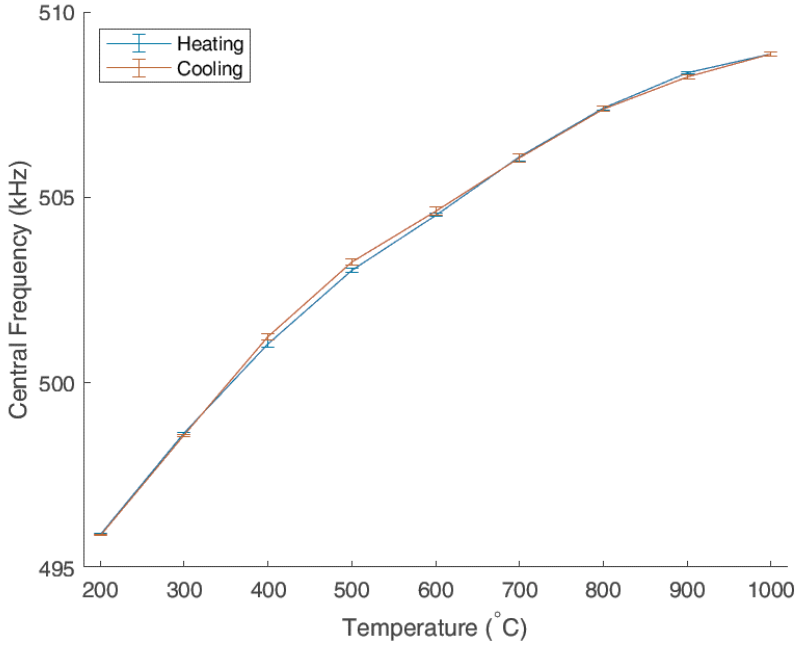




Accomplishments

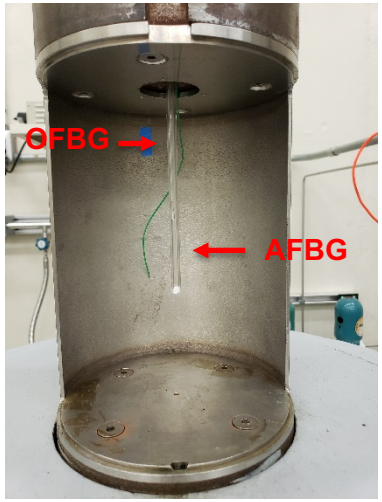
- Performance testing of AFBG temperature sensing system
  - Thermal cycling conducted to a maximum temperature of 1000ºC
    - ~1.3 kHz per 100 ºC / ~ 6 ºC resolution.
    - Minimal thermal hysteresis

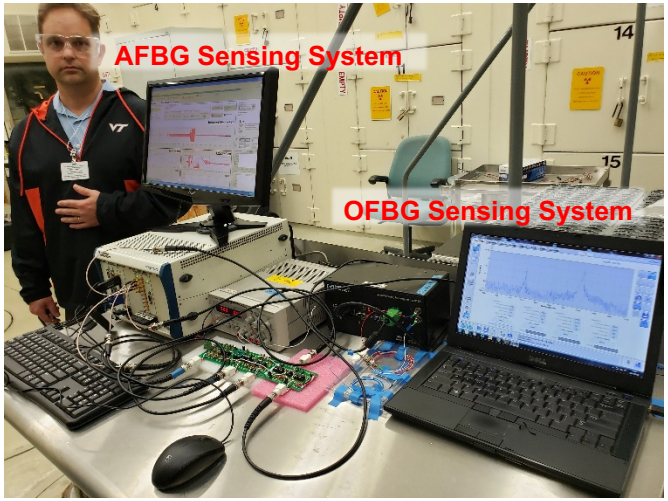




Accomplishments

- Radiation exposure testing of prototype sensing system
  - Performed at Oak Ridge National Laboratories (ORNL)
    - High-intensity gamma ray field from a ^{60}Co source
  - Successful installation of prototype AFBG sensing system
  - Benchmark testing with OFBG in radiation tolerant optical fiber
    - Prysmian “Super RadHard” single mode fiber
    - Femtosecond laser inscription of FBGs performed at VT





Technology Impact

- *The successful demonstration of the first-of-a-kind, low-cost, fully-distributed, multi-parameter sensing platform will contribute to the advancement of 3D sensor network monitoring solutions for nuclear energy systems.*
- *The versatile and commercially viable sensing system fill the gap between low cost electronic sensors and high-performance fiber optic sensors.*
- *The research products generated from this project will provide technologies that support the efficient and clean energy production necessary for energy independence.*
- *The diverse and multi-disciplinary research setting provides both faculty and students with the opportunity to cultivate a broad and diverse skillset that will provide benefit to the nuclear sciences, as well as the overall scientific community.*

Conclusion

- *Accomplishments for the second project year*
  - *Successfully designed and constructed an AFBG temperature sensing system with a user-friendly interface that is fit for use*
  - *Demonstrated the performance of the AFBG temperature sensing system up to 1000ºC*
  - *Developed methodologies and techniques for the fabrication of acoustic horn/amplifiers*
  - *Successfully installed a prototype AFBG sensing system and radhard OFBG sensing system at ORNL for radiation exposure testing*
- *The accomplishments are consistent with the project goals, objectives and schedule.*

Questions?

Contact information

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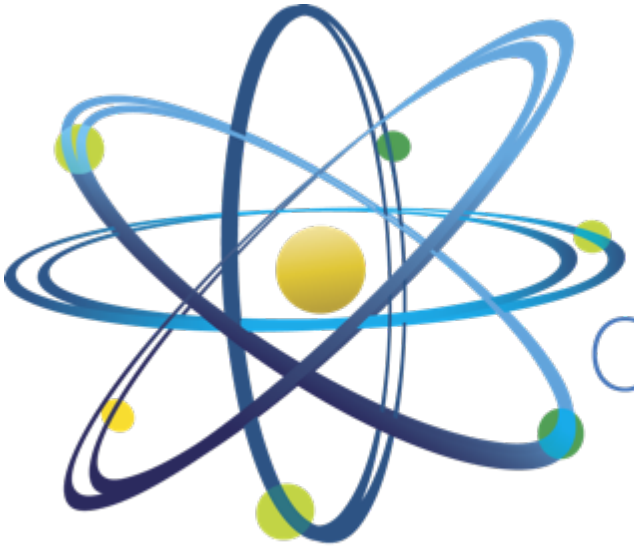

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