OMB Number: 4040-0001
Expiration Date: 06/30/2011

APPLICATION FOR FEDERAL ASSISTANCE
SF 424 (R&R)

3. DATE RECEIVED BY STATE:

State Application Identifier:

1. * TYPE OF SUBMISSION

☐ Pre-application ☒ Application ☐ Changed/Corrected Application

4. a. Federal Identifier: DOE TOPIC 35f

b. Agency Routing Identifier:

2. DATE SUBMITTED: 09/19/2011

Applicant Identifier: SOLOMON 2611.01

5. APPLICANT INFORMATION

*** Organizational DUNS:** 627132913

* Legal Name: Luna Innovations Incorporated

Department:

Division:

* Street1: 1 Riverside Circle

Street2: Suite 400

* City: Roanoke

County / Parish:

* State: VA: Virginia

Province:

* Country: USA: UNITED STATES

* ZIP / Postal Code: 24016-4962

Person to be contacted on matters involving this application

Prefix: Ms.

* First Name: Shirley

Middle Name: D

* Last Name: Evans

Suffix:

* Phone Number: 540-961-6724

Fax Number: 540-769-8401

Email: submissions301@lunainnovations.com

6. * EMPLOYER IDENTIFICATION *(EIN) or (TIN):* 541560050

7. * TYPE OF APPLICANT: R: Small Business

Other (Specify):

Small Business Organization Type ☐ Women Owned ☐ Socially and Economically Disadvantaged

8. * TYPE OF APPLICATION:

☒ New ☐ Resubmission

☐ Renewal ☐ Continuation ☐ Revision

If Revision, mark appropriate box(es).

☐ A. Increase Award ☐ B. Decrease Award ☐ C. Increase Duration ☐ D. Decrease Duration

☐ E. Other (specify):

* Is this application being submitted to other agencies? Yes ☐ No ☒ What other Agencies?

9. * NAME OF FEDERAL AGENCY: Chicago Service Center

10. CATALOG OF FEDERAL DOMESTIC ASSISTANCE NUMBER: 81.049

TITLE: Office of Science Financial Assistance Program

11. * DESCRIPTIVE TITLE OF APPLICANT'S PROJECT:

Magnetic Field Probe (Field Sense)

12. PROPOSED PROJECT:

* Start Date: 03/01/2012

* Ending Date: 11/30/2012

*** 13. CONGRESSIONAL DISTRICT OF APPLICANT:** VA-006

14. PROJECT DIRECTOR/PRINCIPAL INVESTIGATOR CONTACT INFORMATION

Prefix: Mr.

* First Name: Joseph

Middle Name: A

* Last Name: French

Suffix:

Position/Title: Principal Investigator

* Organization Name: Luna Innovations Incorporated

Department:

Division:

* Street1: 3157 State Street

Street2:

* City: Blacksburg

County / Parish:

* State: VA: Virginia

Province:

* Country: USA: UNITED STATES

* ZIP / Postal Code: 24060-6604

* Phone Number: 540-552-0402

Fax Number:

* Email: frenchj@lunainnovations.com

15. ESTIMATED PROJECT FUNDING

a. Total Federal Funds Requested	149,996.00
b. Total Non-Federal Funds	0.00
c. Total Federal & Non-Federal Funds	149,996.00
d. Estimated Program Income	0.00

16. * IS APPLICATION SUBJECT TO REVIEW BY STATE EXECUTIVE ORDER 12372 PROCESS?

a. YES ☐ THIS PREAPPLICATION/APPLICATION WAS MADE AVAILABLE TO THE STATE EXECUTIVE ORDER 12372 PROCESS FOR REVIEW ON:

DATE:

b. NO ☒ PROGRAM IS NOT COVERED BY E.O. 12372; OR

☐ PROGRAM HAS NOT BEEN SELECTED BY STATE FOR REVIEW

17. By signing this application, I certify (1) to the statements contained in the list of certifications* and (2) that the statements herein are true, complete and accurate to the best of my knowledge. I also provide the required assurances * and agree to comply with any resulting terms if I accept an award. I am aware that any false, fictitious. or fraudulent statements or claims may subject me to criminal, civil, or administrative penalities. (U.S. Code, Title 18, Section 1001)

☒ *** I agree**

The list of certifications and assurances, or an Internet site where you may obtain this list, is contained in the announcement or agency specific instructions.

18. SFLLL or other Explanatory Documentation

Add Attachment | Delete Attachment | View Attachment

19. Authorized Representative

Prefix: Ms. * First Name: Shirley Middle Name: D

* Last Name: Evans Suffix:

* Position/Title: Sr. Contract Administrator

* Organization: Luna Innovations Incorporated

Department: Division:

* Street1: 1 Riverside Circle

Street2: Suite 400

* City: Roanoke County / Parish:

* State: VA: Virginia Province:

* Country: USA: UNITED STATES * ZIP / Postal Code: 24016-4962

* Phone Number: 540-961-6724 Fax Number: 540-769-8401

* Email: submissions301@lunainnovations.com

* Signature of Authorized Representative	* Date Signed
Shirley Evans	09/19/2011

20. Pre-application

Add Attachment | Delete Attachment | View Attachment

SBIR/STTR Information

OMB Number: 4040-0001
Expiration date: 06/30/2011

*** Program Type (select only one)**

☒ SBIR ☐ STTR
☐ Both *(See agency-specific instructions to determine whether a particular agency allows a single submission for both SBIR and STTR)*

*** SBIR/STTR Type (select only one)**

☒ Phase I ☐ Phase II
☐ Fast-Track *(See agency-specific instructions to determine whether a particular agency participates in Fast-Track)*

Questions 1-7 must be completed by all SBIR and STTR Applicants:

☒ Yes ☐ No	* 1a. Do you certify that at the time of award your organization will meet the eligibility criteria for a small business as defined in the funding opportunity announcement?
	* 1b. Anticipated Number of personnel to be employed at your organization at the time of award. 191
☐ Yes ☒ No	* 2. Does this application include subcontracts with Federal laboratories or any other Federal Government agencies? * If yes, insert the names of the Federal laboratories/agencies:
☐ Yes ☒ No	* 3. Are you located in a HUBZone? To find out if your business is in a HUBZone, use the mapping utility provided by the Small Business Administration at its web site: http://www.sba.gov
☒ Yes ☐ No	* 4. Will all research and development on the project be performed in its entirety in the United States? If no, provide an explanation in an attached file. * Explanation: Add Attachment Delete Attachment View Attachment
☐ Yes ☒ No	* 5. Has the applicant and/or Program Director/Principal Investigator submitted proposals for essentially equivalent work under other Federal program solicitations or received other Federal awards for essentially equivalent work? * If yes, insert the names of the other Federal agencies:
☒ Yes ☐ No	* 6. Disclosure Permission Statement: If this application does not result in an award, is the Government permitted to disclose the title of your proposed project, and the name, address, telephone number and e-mail address of the official signing for the applicant organization, to organizations that may be interested in contacting you for further information (e.g., possible collaborations, investment)?
	* 7. Commercialization Plan: If you are submitting a Phase II or Phase I/Phase II Fast-Track Application, include a Commercialization Plan in accordance with the agency announcement and/or agency-specific instructions. * Attach File: Add Attachment Delete Attachment View Attachment

SBIR/STTR Information

SBIR-Specific Questions:

Questions 8 and 9 apply only to SBIR applications. If you are submitting ONLY an STTR application, leave questions 8 and 9 blank and proceed to question 10.

[X] Yes [ ] No	* 8. Have you received SBIR Phase II awards from the Federal Government? If yes, provide a company commercialization history in accordance with agency-specific instructions using this attachment. * Attach File: 1234-Phase II list for DOE.pdf Add Attachment Delete Attachment View Attachment
[X] Yes [ ] No	* 9. Will the Project Director/Principal Investigator have his/her primary employment with the small business at the time of award?

STTR-Specific Questions:

Questions 10 and 11 apply only to STTR applications. If you are submitting ONLY an SBIR application, leave questions 10 and 11 blank.

[ ] Yes [ ] No	* 10. Please indicate whether the answer to BOTH of the following questions is TRUE: (1) Does the Project Director/Principal Investigator have a formal appointment or commitment either with the small business directly (as an employee or a contractor) OR as an employee of the Research Institution, which in turn has made a commitment to the small business through the STTR application process; AND (2) Will the Project Director/Principal Investigator devote at least 10% effort to the proposed project?
[ ] Yes [ ] No	* 11. In the joint research and development proposed in this project, does the small business perform at least 40% of the work and the research institution named in the application perform at least 30% of the work?

RESEARCH & RELATED Other Project Information

1. * Are Human Subjects Involved? ☐ Yes ☒ No

   1.a If YES to Human Subjects

   Is the Project Exempt from Federal regulations? ☐ Yes ☐ No

   If yes, check appropriate exemption number. ☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐ 6

   If no, is the IRB review Pending? ☐ Yes ☐ No

   IRB Approval Date:

   Human Subject Assurance Number:

2. * Are Vertebrate Animals Used? ☐ Yes ☒ No

   2.a. If YES to Vertebrate Animals

   Is the IACUC review Pending? ☐ Yes ☐ No

   IACUC Approval Date:

   Animal Welfare Assurance Number

3. * Is proprietary/privileged information included in the application? ☒ Yes ☐ No

4.a. * Does this project have an actual or potential impact on the environment? ☐ Yes ☒ No

4.b. If yes, please explain:

4.c. If this project has an actual or potential impact on the environment, has an exemption been authorized or an environmental assessment (EA) or environmental impact statement (EIS) been performed? ☐ Yes ☐ No

4.d. If yes, please explain:

5. * Is the research performance site designated, or eligible to be designated, as a historic place? ☐ Yes ☒ No

5.a. If yes, please explain:

6. * Does this project involve activities outside of the United States or partnerships with international collaborators? ☐ Yes ☒ No

6.a. If yes, identify countries:

6.b. Optional Explanation:

7. * Project Summary/Abstract 1235-Summary.pdf | Add Attachment | Delete Attachment | View Attachment

8. * Project Narrative 1236-Project Narrative.pdf | Add Attachment | Delete Attachment | View Attachment

9. Bibliography & References Cited | Add Attachment | Delete Attachment | View Attachment

10. Facilities & Other Resources | Add Attachment | Delete Attachment | View Attachment

11. Equipment | Add Attachment | Delete Attachment | View Attachment

12. Other Attachments | Add Attachments | Delete Attachments | View Attachments ☒

Project/Performance Site Location(s)

Project/Performance Site Primary Location

☐ I am submitting an application as an individual, and not on behalf of a company, state, local or tribal government, academia, or other type of organization.

Organization Name: Luna Innovations Incorporated

DUNS Number: 6271329130000

* Street1: 3157 State Street

Street2:

* City: Blacksburg

County:

* State: VA: Virginia

Province:

* Country: USA: UNITED STATES

* ZIP / Postal Code: 24060-6604

* Project/ Performance Site Congressional District: VA-009

Project/Performance Site Location 1

☐ I am submitting an application as an individual, and not on behalf of a company, state, local or tribal government, academia, or other type of organization.

Organization Name:

DUNS Number:

* Street1:

Street2:

* City:

County:

* State:

Province:

* Country: USA: UNITED STATES

* ZIP / Postal Code:

* Project/ Performance Site Congressional District:

RESEARCH & RELATED Senior/Key Person Profile (Expanded)

PROFILE - Project Director/Principal Investigator

Prefix: Mr. * First Name: Joseph Middle Name: A
* Last Name: French Suffix:
Position/Title: Principal Investigator Department:
Organization Name: Luna Innovations Incorporated Division:
* Street1: 3157 State Street
Street2:
* City: Blacksburg County/ Parish:
* State: VA: Virginia Province:
* Country: USA: UNITED STATES * Zip / Postal Code: 24060-6604
* Phone Number: 540-552-0402 Fax Number:
* E-Mail: frenchj@lunainnovations.com

Credential, e.g., agency login:

*** Project Role:** PD/PI **Other Project Role Category:**

Degree Type:
Degree Year:

***Attach Biographical Sketch** 1241-Joseph French - Bio Sket Add Attachment Delete Attachment View Attachment
Attach Current & Pending Support Add Attachment Delete Attachment View Attachment

PROFILE - Senior/Key Person 1

Prefix: Dr. * First Name: Sandra Middle Name: M
* Last Name: Klute Suffix:
Position/Title: Technology Director Department: OSG
Organization Name: Luna Innovations Incorporated Division:
* Street1: 3157 State Street
Street2:
* City: Blacksburg County/ Parish:
* State: VA: Virginia Province:
* Country: USA: UNITED STATES * Zip / Postal Code: 24060-6604
* Phone Number: 540-961-6725 Fax Number:
* E-Mail: klutes@lunainnovations.com

Credential, e.g., agency login:

*** Project Role:** Other Professional **Other Project Role Category:** Research Support

Degree Type:
Degree Year:

***Attach Biographical Sketch** 1242-Sandie Klute - Bio Sketc Add Attachment Delete Attachment View Attachment
Attach Current & Pending Support Add Attachment Delete Attachment View Attachment

RESEARCH & RELATED Senior/Key Person Profile (Expanded)

PROFILE - Senior/Key Person 2

Prefix:	Dr.
* First Name:	Stephen
Middle Name:	
* Last Name:	Kreger
Suffix:	
Position/Title:	Senior Optical Engineer
Department:	OSG
Organization Name:	Luna Innovations Incorporated
Division:	
* Street1:	3157 State Street
Street2:	
* City:	Blacksburg
County/ Parish:	
* State:	VA: Virginia
Province:	
* Country:	USA: UNITED STATES
* Zip / Postal Code:	24060-6604
* Phone Number:	540-951-1636
Fax Number:	
* E-Mail:	kregers@lunainnovations.com
Credential, e.g., agency login:	
*** Project Role:**	Other Professional
Other Project Role Category:	Research Support
Degree Type:	
Degree Year:	

***Attach Biographical Sketch**	1243-Steven Kreger - Bio Sket	Add Attachment	Delete Attachment	View Attachment
Attach Current & Pending Support		Add Attachment	Delete Attachment	View Attachment

BIOGRAPHICAL SKETCH

Provide the following information for the key personnel and other significant contributors.
Follow this format for each person. **DO NOT EXCEED TWO PAGES.**

NAME	POSITION TITLE
Sandie Klute	Technology Director
eRA COMMONS USER NAME	

EDUCATION/TRAINING *(Begin with baccalaureate or other initial professional education, such as nursing, and include postdoctoral training.)*

INSTITUTION AND LOCATION	DEGREE *(if applicable)*	YEAR(s)	FIELD OF STUDY
Virginia Polytechnic Institute	BS	1991	Engineering Mechanics
Virginia Polytechnic Institute	MS		Engineering Mechanics
Virginia Polytechnic Institute	Ph.D	1999	Engineering Mechanics

EXPERIENCE:

Technology Director	Luna Innovations, Inc.	June 2009-present
Principal Investigator	Luna Innovations, Inc.	May 2004- 2009
Senior Mechanical Engineer	Motion Control Systems, Inc.,	January 1999-2004
Graduate Research Assistant	Graduate Student Researchers Program / NASA Langley and VPI&SU,	1991-1999

Dr. Klute joined the Optical Systems Group at Luna Innovations in May 2004. While at Luna, Ms. Klute's responsibilities have included serving as Principal Investigator for various SBIR and non-SBIR government and commercial contracts, managing over $5.3 million in funding. More recently her responsibilities have included acting as Technology Director for the Optical Systems Group. Ms. Klute has managed several commercial programs utilizing Luna's Distributed Sensing System and Optical Backscatter Reflectometer, the technology proposed for this effort. Ms. Klute received a B.S., M.S. and Ph.D. (1999) in Engineering Mechanics from Virginia Polytechnic Institute and State University. Ms. Klute was a participant in the Graduate Student Researchers Program / Graduate Research Assistant, NASA Langley and VPI&SU, 1991-1999. She has extensive experience in: conventional and fiber-optic Laser-Doppler Velocimetry, high-speed Particle Image Velocimetry, the use and development of flow diagnostics/3-D imaging techniques in fluid dynamics and structures, six-component force balance strain gage systems, multi-hole pressure probes and scanning pressure systems, hot-wire anemometry, flow visualization, and extensive experience with wind and water tunnel testing. Ms. Klute's research experience includes steady and unsteady delta-wing and forebody/bluff-body aerodynamics, vortex dynamics, and active control of flow transition and separation. She has experience in computational fluid dynamics with FLUENT. Prior to Luna, Ms. Klute's background included lead role in management and design of rotating systems and brushless DC electric motor integration. She acted as *Project Manager and Lead Mechanical Engineer* for: Ingersol Milling, Navsea Mk8 Navy Seal Delivery Vehicle (SDV) Propulsion Motor, and *Lead Mechanical Engineer* on: Boeing Long-Term Mine Reconnaissance System Propulsion Motor (LMRS), Boeing Ballast & Trim Pump Motor.

SELECTED PUBLICATIONS

Scientific Journals and Proceedings

Klute, S. M., et. al "Fiber Optic Shape Sensing and Distributed Strain Measurements on a Morphing Chevron," AIAA 44th Aerospace Sciences Meeting, Paper No. AIAA-2006-0624.

Klute, S. M., " The Development and Control of Axial Vortices Over Swept Wings," Doctoral Dissertation, Virginia Polytechnic Institute & State University, December 1999.

Klute, S. M., Telionis, D. P., “Experimental Investigation of Three-Dimensional Vortex Interaction over the F/A-18,” AIAA 32nd Aerospace Sciences Meeting, Paper No. AIAA-94-0623.

Traub, L. W., Rediniotis, O. K., **Klute, S. M.**, Moore, C. T., and Telionis, D. P., “Instabilities of Vortex Breakdown, Their Structure and Growth,” AIAA Paper No. 95-2308, 26th AIAA Fluid Dynamics Conference, San Diego, California, June 1995.

Klute, S. M., and Telionis, D. P., “The Unsteady Characteristics of the Flow over an F/A 18 at High Alpha,” AIAA 34th Aerospace Sciences Meeting, AIAA Paper No. 96-0824.

Klute, S. M., Rediniotis, O. K. and Telionis, D. P., "Flow Control Over a Maneuvering Delta Wing at High Angles of Attack," *AIAA Journal* Vol. 34, No. 4, pp. 662-668, April 1996.

Rediniotis, O. K., **Klute, S. M.**, Hoang, N. T. and Telionis, D. P., "Pitch-up Motion of Delta Wings," *AIAA Journal*, Vol. 32, pp. 716-725, April 1994.

Klute, S. M., Rediniotis, O. K., and Telionis, D. P., “Flow Control Over Delta Wings at High Angles of Attack,” AIAA Applied Aerodynamics Conference, August 1993, Paper No. AIAA-93-3494.

Klute, S. M., Rediniotis, O. K., Hoang, N. G., and Telionis, D. P., “Pitch-up Motion of Delta Wings,” presented at the AIAA Aerospace Sciences Meeting, Jan. 1992, Paper No. 92-0278.

Telionis, D. P., Rediniotis, O. K., **Klute, S. M.**, and Schaeffler, N. W., "Post-Stall Control of Swept Wings," VPI & SU Engineering Report No. VPI-E-92-25, November 1992.

Klute, S. M., Rediniotis, O. K., Stapountzis, H. and Telionis, D. P., "Vortex Shedding Over Non-Parallel Edges," Proceedings of the Third International Congress of Fluid Mechanics, Egypt, Vol. II, pp. 587-601, January 1990.

Rediniotis, O. K., **Klute, S. M.**, Stapountzis, H. and Telionis, D. P., "Vortex Shedding Over Nonparallel Edges," VPI & SU Engineering Report No. VPI-E-88-39, December 1988.

Patents

Current and Pending Support:

Current Project Name	Customer	Number	End Date	Hours/Month
Towed Arrays 0228401				
Fiber Twist II 0225201				
Management				remainder

Pending Project Name	Customer	Number
Towed Arrays Phase II		
Fiber Twist Phase II Option I		
SHM 400 Phase II		

BIOGRAPHICAL SKETCH

Provide the following information for the key personnel and other significant contributors.
Follow this format for each person. **DO NOT EXCEED TWO PAGES.**

NAME Stephen T. Kreger	POSITION TITLE Senior Optical Engineer
eRA COMMONS USER NAME	

EDUCATION/TRAINING *(Begin with baccalaureate or other initial professional education, such as nursing, and include postdoctoral training.)*

INSTITUTION AND LOCATION	DEGREE *(if applicable)*	YEAR(s)	FIELD OF STUDY
Rose-Hulman Inst. Of Tech, Terre Haute, IN	B.S.	1989	Physics
Inst. Of Optics, U. of Rochester, Rochester, NY	Ph.D.	1997	Optics

EXPERIENCE:

Luna Innovations March 2006 to Present Senior Optical Engineer
Responsible for new system design development for telecommunication optical component and network testing as well as distributed fiber optic sensing products, specializing in scanning laser optical frequency domain reflectometry and Rayleigh back scatter analysis. He is also heavily involved with the integration of Luna's Phoenix compact and rugged tunable laser design into Luna instrumentation, and shape sensing system development.

Blue Road Research May 2000 to Feb 2006 Optical Scientist / Chief Engineer
Developed advanced fiber optic Bragg grating sensors and sensor interrogation instrumentation.

National Institute of Standards and Technology Mar 1997- Apr 2000 Postdoctoral Fellow
Developed new high accuracy optical data storage substrate metrology techniques to aid manufacturers in improving yield and performance while lowering manufacturing cost.

Inst. Of Optics, University of Rochester Sept 1989- Mar 1997 PhD Candidate
Specialized in improving speed and sensitivity of advanced ultra low-light confocal scanning laser microscopy with video frame rate imaging.

Selected Publications

S. T. Kreger, D. K. Gifford , A. K. Sang, M. E. Froggatt, "Distributed strain and temperature sensing in plastic optical fiber using Rayleigh scatter," Proc. SPIE, Vol. 7316, 2009.
D. K. Gifford, S. T. Kreger, A. K. Sang, M. E. Froggatt, R. G. Duncan, M. S. Wolfe, and B. J. Soller,
"Swept-wavelength interferometric interrogation of fiber Rayleigh scatter for distributed sensing applications," Proc. SPIE, Vol. 6770, 2007.
M. Froggatt, D. Gifford, S. Kreger, M. Wolfe, B. Soller, "Characterization of Polarization-Maintaining Fiber Using High-Sensitivity Optical-Frequency-Domain Reflectometry," Journal of Lightwave Technology, Vol. 24, Issue 11, pp. 4149-4154, 2006.

S. T. Kreger, D. K. Gifford , M. E. Froggatt, B. J. Soller, M. S. Wolfe, “High Resolution Distributed Strain or Temperature Measurements in Single- and Multi-mode Fiber Using Swept-Wavelength Interferometry,” Proceedings of OFS 2006, Cancun, Mexico, ThE42, 2006.
S. Kreger, S. Calvert and E. Udd, “Optical frequency domain reflectometry for high density multiplexing of multi-axis fiber Bragg gratings”, Proceedings of OFS-16, Nara, Japan, p. 526, 2003.
S. Kreger, S. Calvert and E. Udd, “High pressure sensing using fiber Bragg gratings written into birefringent side hole fiber”, Proceedings of OFS-15, Portland, Oregon, IEEE, p. 355, 2002.
K. Rochford, S. Kreger, “Variation in optical disc birefringence measurements”, Technical Digest of the Joint International Symposium on Optical Memory and Optical Data Storage, Proc. SPIE, 3864, 223-225, (1999).
S. Kreger, T. G. Brown, "Solid state photon counters for scanned image acquisition: thermal and electronic saturation effects," Proc. SPIE, 2984, 178-89, (1997).

Current and Pending Support:

SOLOMON

Current Project Name	Customer	Number	End Date	Hours/Month
ISI Project Phase II	ISRG	1812.02		50%
Shape for Towed Arrays P I	NAVSEA	2284.01		<2%
Fiber Twist Phase II	ONR	2252.02		<2%

Pending Project Name	Customer	Number

BIOGRAPHICAL SKETCH

Provide the following information for the key personnel and other significant contributors.
Follow this format for each person. **DO NOT EXCEED TWO PAGES.**

NAME Joseph French	POSITION TITLE Optical Research Engineer
eRA COMMONS USER NAME	

EDUCATION/TRAINING *(Begin with baccalaureate or other initial professional education, such as nursing, and include postdoctoral training.)*

INSTITUTION AND LOCATION	DEGREE *(if applicable)*	YEAR(s)	FIELD OF STUDY
University of Maryland, Baltimore County, Baltimore, MD	B.S.	2005	Physics
University of Maryland, Baltimore County, Baltimore, MD	M.S.	2007	Applied Physics

EXPERIENCE:

Joseph joined the Optical Systems Group at Luna Innovations in August 2007. He has worked on many varied fiber optic projects during his time at Luna, he has been lead engineer on several DOD and DOE SBIR Phase I and II projects. Recently Joseph has become PI on several Phase I and Phase II SBIR contracts involving radiation insensitive sensors and dynamic distributed strain sensing. He has experience in several disciplines including computational modeling, hyperspectral imaging, fiber optic technology, non-linear optics, and terahertz spectroscopy. During his undergraduate studies at University of Maryland, Baltimore County, Joseph worked as a research assistant for Dr. L. Michael Hayden. He worked on multiple projects in non-linear optics and terahertz spectroscopy. As a graduate student, Joseph continued his studies in non-linear optics Dr. Hayden on various atomic modeling and waveguide design. His Masters thesis was a Tunable electro-optic Fabry-Perot resonator. Joseph is an expert in several computer languages including LabView, C++, Fortran, and MATLAB®.

PRESENTATIONS AND PUBLICATIONS:

Dr. Dickerson has more than a dozen technical publications and session presentations related to this work. The most relevant publications are listed below:

- Dickerson, Bryan D., Farmer, Justin R., French, Joseph A., Palmer, Matthew E., and Fielder, Robert S. "Fiber Optic Sensors Measuring Gamma Flux and Neutron Fluence," Transactions of the American Nuclear Society, 2008, vol 99: pp289-290.
- French J. "Tunable electro-optic modulated Fabry-Perot resonator," Masters Thesis, University of Maryland, Baltimore County, defended May 2007.

- L. Michael Hayden, Alexander M. Sinyukov, Megan R. Leahy, Joey French, Peter Lindahl, Warren N. Herman, Robert J. Twieg, Meng He, "New materials for optical rectification and electrooptic sampling of ultrashort pulses in the terahertz regime," J. Polymer Science B 41, 2492 (2003).

- Dhiraj K. Sardar, Joey A. French, Francisco Castano, Anthony Sayka, Felipe S. Salinas, "Temperature effectson the 1.0 and 1.3 □m emission lines of Nd3+ in LaSc3(BO3)4 host," J. Appl Phys. 91, 9629-9634 (2002).
- Dhiraj K. Sardar, Francisco Castano, Joey A. French, John B. Gruber, Thomas A. Reynolds, Theodore Alekel, Douglas A. Keszler, and Benjamin L. Clark, "Spectroscopic and laser properties of Nd3+ in LaSc3(BO3)4 host," J. Appl. Phys. 90, 4997-5001 (2001).

OMB Number: 4040-0001
Expiration Date: 06/30/2011

RESEARCH & RELATED BUDGET - SECTION A & B, BUDGET PERIOD 1

*** ORGANIZATIONAL DUNS:** 6271329130000

*** Budget Type:** ☒ Project ☐ Subaward/Consortium

Enter name of Organization: Luna Innovations Incorporated

Delete Entry *** Start Date:** 03/01/2012 *** End Date:** 11/30/2012 **Budget Period** 1

A. Senior/Key Person

	Prefix	* First Name	Middle Name	* Last Name	Suffix	* Project Role	Base Salary ($)	Cal. Months	Acad. Months	Sum. Months	* Requested Salary ($)	* Fringe Benefits ($)	* Funds Requested ($)
1.	Mr.	Joseph	A	French		PD/PI		2.72			15,245.00	0.00	15,245.00
2.	Dr.	Sandra	M	Klute		Research Support		0.62			5,192.00	0.00	5,192.00
3.	Mr.	Stephen		Kreger		Research Support		0.18			1,480.00	0.00	1,480.00
4.													
5.													
6.													
7.													
8.													
9.	Total Funds requested for all Senior Key Persons in the attached file												
												Total Senior/Key Person	21,917.00

Additional Senior Key Persons: Add Attachment Delete Attachment View Attachment

B. Other Personnel

* Number of Personnel	* Project Role	Cal. Months	Acad. Months	Sum. Months	* Requested Salary ($)	* Fringe Benefits ($)	* Funds Requested ($)
	Post Doctoral Associates						
	Graduate Students						
	Undergraduate Students						
	Secretarial/Clerical						
1	Project Engineer	3.01			16,755.00	0.00	16,755.00
1	Technician	3.40			12,201.00	0.00	12,201.00
2	**Total Number Other Personnel**					**Total Other Personnel**	28,956.00
						Total Salary, Wages and Fringe Benefits (A+B)	50,873.00

RESEARCH & RELATED BUDGET - SECTION C, D, & E, BUDGET PERIOD 1

* ORGANIZATIONAL DUNS: 6271329130000

* Budget Type: [X] Project [ ] Subaward/Consortium

Enter name of Organization: Luna Innovations Incorporated

Delete Entry * Start Date: 03/01/2012 * End Date: 11/30/2012 Budget Period

C. Equipment Description

List items and dollar amount for each item exceeding $5,000

	Equipment item	* Funds Requested ($)
1.		
2.		
3.		
4.		
5.		
6.		
7.		
8.		
9.		
10.		
11.	Total funds requested for all equipment listed in the attached file	
	Total Equipment	

Additional Equipment: Add Attachment Delete Attachment View Attachment

D. Travel

		Funds Requested ($)
1.	Domestic Travel Costs (Incl. Canada, Mexico and U.S. Possessions)	
2.	Foreign Travel Costs	
	Total Travel Cost	

E. Participant/Trainee Support Costs

		Funds Requested ($)
1.	Tuition/Fees/Health Insurance	
2.	Stipends	
3.	Travel	
4.	Subsistence	
5.	Other	
	Number of Participants/Trainees — Total Participant/Trainee Support Costs	

RESEARCH & RELATED Budget {C-E} (Funds Requested)

RESEARCH & RELATED BUDGET - SECTION F-K, BUDGET PERIOD 1

Next Period

* ORGANIZATIONAL DUNS: 6271329130000

* Budget Type: [X] Project [ ] Subaward/Consortium

Enter name of Organization: Luna Innovations Incorporated

Delete Entry * Start Date: 03/01/2012 * End Date: 11/30/2012 Budget Period 1

F. Other Direct Costs	Funds Requested ($)
1. Materials and Supplies	2,242.00
2. Publication Costs	
3. Consultant Services	
4. ADP/Computer Services	
5. Subawards/Consortium/Contractual Costs	
6. Equipment or Facility Rental/User Fees	900.00
7. Alterations and Renovations	
8.	
9.	
10.	
Total Other Direct Costs	3,142.00

G. Direct Costs	Funds Requested ($)
Total Direct Costs (A thru F)	54,015.00

H. Indirect Costs

	Indirect Cost Type	Indirect Cost Rate (%)	Indirect Cost Base ($)	* Funds Requested ($)
1.	Labor Overhead	93.04	50,873.00	47,332.00
2.	G&A	38.32	101,347.00	38,836.00
3.				
4.				
			Total Indirect Costs	86,168.00

Cognizant Federal Agency DCAA North Carolina Branch, Kathryn Conrad, 336-574-7904
(Agency Name, POC Name, and POC Phone Number)

I. Total Direct and Indirect Costs	Funds Requested ($)
Total Direct and Indirect Institutional Costs (G + H)	140,183.00

J. Fee	Funds Requested ($)
	9,813.00

K. * Budget Justification 1240-Budget Justification.pdf Add Attachment Delete Attachment View Attachment
(Only attach one file.)

RESEARCH & RELATED BUDGET - Cumulative Budget

		Totals ($)
Section A, Senior/Key Person		21,917.00
Section B, Other Personnel		28,956.00
Total Number Other Personnel	2	
Total Salary, Wages and Fringe Benefits (A+B)		50,873.00
Section C, Equipment		
Section D, Travel		
1. Domestic		
2. Foreign		
Section E, Participant/Trainee Support Costs		
1. Tuition/Fees/Health Insurance		
2. Stipends		
3. Travel		
4. Subsistence		
5. Other		
6. Number of Participants/Trainees		
Section F, Other Direct Costs		3,142.00
1. Materials and Supplies	2,242.00	
2. Publication Costs		
3. Consultant Services		
4. ADP/Computer Services		
5. Subawards/Consortium/Contractual Costs		
6. Equipment or Facility Rental/User Fees	900.00	
7. Alterations and Renovations		
8. Other 1		
9. Other 2		
10. Other 3		
Section G, Direct Costs (A thru F)		54,015.00
Section H, Indirect Costs		86,168.00
Section I, Total Direct and Indirect Costs (G + H)		140,183.00
Section J, Fee		9,813.00

BUDGET EXPLANATION FOR SBIR/STTR APPLICATIONS

Grantee: Luna Innovations Incorporated

Grant Application Number: TBD

DOE Requisition Number (DOE Use Only): ____________________

Please provide detailed information to support each element of the proposed budget. If an element is not applicable, please indicate. Please ensure that the figures provided in this explanation are consistent with those reflected on your proposed budget pages.

Luna Innovations Incorporated Proprietary
This proposal includes data that shall not be disclosed outside the University/government and shall not be duplicated, used, or disclosed—in whole or in part—for any purpose other than to evaluate this proposal. If, however, a contract is awarded to this offeror as a result of—or in connection with—the submission of this data, the government shall have the right to duplicate, use, or disclose the data to the extent provided in the resulting contract. This restriction does not limit the government's right to use information contained in this data if it is obtained from another sourcewithout-restriction.

Cost data is strictly confidential and cannot be shared with Luna personnel outside of Luna Contracts and Finance.

A/B. SENIOR/KEY PERSON & OTHER PERSONNEL $ 50,873

1. Identify each position ("Role in Project") to be supported under the proposed award, including the name of the Principal Investigator and other Key Personnel. Other personnel shall be identified by name to the extent possible.

   Joseph A. French, PI
   Sandra M. Klute, Research Support
   Stephen Kreger, Research Support
   Project Engineer, Research Support
   Technician, Research Support

2. Briefly justify the need for each individual proposed. (Note: If your budget includes any proposed labor that is primarily administrative or managerial in nature, particular effort should be made to support such labor, as these positions are not customarily proposed or recorded as direct labor charges to a specific award.)

   - Mr. French will serve as Principal Investigator
   - Dr. Sandra Klute will guide sensor development in addition to overseeing the project development.

- Mr. Kreger will assist in development of the optical system and provide support for the optical instrumentation.
- The Project Engineer will perform optical, electrical and mechanical design.
- The Technician will provide developmental support, assembly and testing.

3. State the number of hours to be expended, and the hourly labor rate, for each position proposed.

   Mr. French, 425 hours, $35.87
   Dr. Klute, 97 hours, $53.53
   Mr. Kreger, 28 hours, $52.84
   Project Engineer, 470 hours, $35.65
   Technician, 530 hours, $23.02

4. Identify the basis for the labor rate(s) proposed and explain why it is reasonable for the market (e.g., education, skills, experience, salary survey, etc.). **Please note it is not sufficient to state only that the proposed compensation is an individual's actual salary; however, that should be addressed.**

   Salary Determination – Salaries are determined based upon stratification of our employees, ranking within the strata of individuals and periodic direct reference to several available local and regional market rate sources. This is done by the Director of Human Resources per a Compensation program and salary administration system.

   Proposed compensation for the Project Engineer and Technician is based upon the current average compensation for comparable positions within the Company. As we often do not know which particular individual will be available to work on a project at the time of proposal submission, this practice allows for flexibility in utilizing various personnel on any given project. In developing the category rates, Luna adds the effective hourly rate of each employee in the appropriate "pool" and divides the sum by the number of people in the pool.

   Annual salary increases take effect on January 1 of each year. Accordingly, the proposed rates incorporate a 4% escalation effective January 1, 2012 which is the beginning of our fiscal year.

5. FRINGE BENEFITS **-** If separately proposed, indicate the basis for the rate used or the computation applied, including the types of benefits to be provided. If the rate or computation protocol used has been approved by a Federal agency, provide a copy of the agreement.

   N/A, Luna utilizes a Labor Overhead rate.

C. EQUIPMENT **$0.00**____________________________

1. Briefly itemize and justify the need for each item of equipment to be purchased.

2. Indicate the estimated unit cost for each item to be purchased.

3. Provide the basis for the cost estimates (e.g., vendor quotes, catalog prices, invoices, past experience purchasing similar or like items, etc.). Attach any written vendor quotes, catalog pages, etc., supporting the proposed cost.

D. TRAVEL **$0.00__________________________**

1. Briefly justify the need for all proposed travel.

2. Indicate the estimated number of travelers, number of trips, dates, points of origin and destination.

3. For each trip, itemize the transportation and/or subsistence costs for each individual traveling.

4. Specify the basis for computation of each type of travel expense (e.g., current airline ticket quotes, past trips of a similar nature, federal government or organizational travel policy, etc.).

F. OTHER DIRECT COSTS **$3,142___________________________**

1. Materials and Supplies
   a. Itemize materials and supplies estimates by type/nature of expense.

Item	Source	Units	Per Each	Extended
Quartz block	Technical glass Products	10	$10.30	$103.00
Machining	Various	1	$1,200.00	$1,200.00
Polarization Paddles	Thorlabs	3	$313.00	$939.00
	TOTAL			**$2,242.00**

   b. Provide the basis for cost estimates or computations (e.g., vendor quotes, prior purchase of similar or like items, etc.).

   Costs are based on past purchases for similar items.

2. Publication Costs
   a. Itemize publication cost estimates by type/nature of expense.

   b. Provide the basis for cost estimates or computations (e.g., vendor quotes, prior purchase of similar or like items, etc.).

3. Consultant Services
   a. Identify the individual/firm proposed and the professional services to be provided.

   b. Provide a brief justification for the use of the party selected.

   c. State the number of hours to be devoted to the project, and the hourly rate to be charged to this award. **(Note: Consultant documentation should include a signed letter from the consultant confirming his/her agreement to perform the labor hours proposed, at the payment rate listed, and should provide verification that this rate is consistent with, or more favorable than, recent billings for similar work, e.g., copies of paid invoices.)**

4. ADP/Computer Services
   a. Briefly itemize and justify the need for funds to support computer services.

   b. Provide the basis for cost estimates or computations (e.g., vendor quotes, prior purchase of similar or like services, etc.).

5. Subawards/Consortium/Contractual Costs (Including Research Institutions and any Other Subcontractors)
   a. Describe the support and/or the services to be acquired.

   b. Provide a brief justification for the use of the research institution or other subcontractor selected.

   c. State the amounts of time to be devoted to the project, and the costs that will be charged to this award.

   d. For professional services contracts, state the number of hours to be devoted to the project, and the costs that will be charged to this award.

   e. A budget and budget support documentation, formatted in the same or similar manner as your own, must be obtained from the research institution or other subcontractors**.** Submit the research institution or other subcontractor documentation together with your written review comments confirming your determination of the reasonableness and acceptability of each element of the proposed budget.

   Also, if the research institution is a DOE National Laboratory, DOE Order O 481.1C "WORK FOR OTHERS (NON-DEPARTMENT OF ENERGY FUNDED WORK)" Section 4.c. requires that a determination be made by and certified in writing by the laboratory's cognizant DOE Contracting Officer indicating that the laboratory is in compliance with the cited order. Generally the DOE Contracting Officer will issue a letter containing their determination. This process can take several weeks. It is suggested that you contact the laboratory and begin the approval process as soon as possible.

6. Equipment or Facility Rental/User Fees $900
   a. Briefly itemize and justify the need for each item of equipment or facility to be rented or otherwise utilized.

      NMR Facility at Virginia Tech will provide the strong magnetic field for proof of concept testing. $900

   b. Indicate the estimated unit cost (rent or user fee) for each item of equipment or facility.

      10 hours @! $90.00/hour for a total of $900.00

   c. Provide the basis for the cost estimates (e.g., vendor quotes, catalog prices, invoices, past experience with similar or like items or facilities, etc.). Attach any written vendor quotes, catalog pages, etc., supporting the proposed cost.

      Cost is based o previous quote from the facility dated November 2010.

7. Other
   List items by major type and provide justification for the proposed cost (e.g., vendor quotes, prior purchase of similar or like items, etc.).

H. INDIRECT COSTS $86,168____________________

1. State the rate(s) and base(s) proposed in your budget. The base should be described (for example, "Total Direct Costs") and listed as a dollar amount.

   Labor Overhead: 93.04%, Base of Total Direct Labor ($50,873) = $47,332.

   General & Administrative (G&A): 38.32%, Total Cost Input ($101,347) = $38,836.

   a. Are the rate(s) and base(s) provided above approved by a Federal agency for the period of performance proposed for this award?

      Yes

   b. If yes, identify the source of approval and provide a copy of the agreement.

      Our Cognizant Federal Auditor is DCAA North Carolina Branch. Our contact is Ms. Kathryn Conrad,

(336) 574-7904. DCAA accepted our rates in 2010 with an overhead rate of 93.04% and a G&A rate of 38.32%. Our provisional rate proposal for 2011 has been submitted to DCAA for review and acceptance and is consistent with the rates proposed. Luna does not expect significant changes to our indirect rates over the next twelve months. In addition, our rates were negotiated with DOE for 2009 and 2010 and a courtesy copy of our provisional rate proposal has been submitted to DOE for review. For questions, please contact Jamie Gotchie at (630) 252-2278.

c. If no, state whether the amount requested is based on a rate(s) and base(s) which have been accepted for estimating purposes by DOE or another Federal agency for the period of performance for this award. If so, identify the agency, and office, and provide any correspondence indicating acceptance and/or contact information for the agency.

   (Note: DOE will have to determine whether this is a sufficient basis for accepting your proposed rate(s) and base(s). More information may be required, possibly including the information requested under 2, below.)

2. If the rate(s) and base(s) proposed in your budget are not approved by a Federal Agency or accepted by a Federal Agency for estimating purposes, state the basis for the amount requested. Provide documentation supporting the computation of the rate(s) proposed. **(Please see the "Guidance for Indirect Rate Submission" for guidance.)**

LEVEL OF EFFORT WORKSHEET

For calculating the percent of the research and analytical effort performed by the small business, the research institution, if any, and other consultants or subcontractors.

	Small Business	Research Institution (if any)	Other Consultants and/or Subcontractors	TOTAL
(1) Total Value of Project	**(A+B+C+D+F1+F2+F6+ F8+H+J)** $147,754	**(F5)** $0	**(F3+F4)** $0	**(Equals line I + line J from budget page)** $147,754
(2) Value of leased, purchased, or in-kind equipment, and materials & supplies	**(lines C+F1+F6 from budget page)** $2,242	**(Applicable portion of Research Institution's subcontract)** $0	**(Applicable portion of consultant and/or other subcontracts)** $0	$2,242
(3) = (1) - (2) Research or analytical effort	$145,512	$0	$0	$145,512
(4) Percentages (Divide entries on line (3) by total for line (3).)	100%	0%	0%	100%

Luna Innovations Incorporated
Title: Fiber Optic Magnetic Field Probes for Accelerator Beam Facilities
Principal Investigator: Joseph French
Topic # 35f.3

PROJECT SUMMARY/ABSTRACT

Statement of the problem or situation that is being addressed (1 – 3 sentences):
The proposed Facility for Rare Isotope Beams (FRIB) at Michigan State University utilizes several magnetic quadrupole lenses and magnetic dipoles to transport and separate ions respectively; each magnetic system generates a large magnetic field. Due to the isotope production, the environment is extremely harsh for conventional magnetic field sensors, which results in extremely short sensor lifetimes or only offline sensor operation. Effectively monitoring the magnetic field requires the development of radiation resistive probes to overcome the limited lifetimes of conventional field sensors.

General statement of how this problem is being addressed (1 – 2 sentences):
Luna Innovations Incorporated will develop a radiation resistive magnetic field probe for monitoring intense magnetic fields in harsh environments based on an all optical design. Using a fiber optic approach, Luna will develop a sensing system capable of monitoring the magnetic fields, improving efficiency and providing a reliable interrogation of magnetic dipoles used during the production of rare isotopes.

Commercial applications and other benefits:
The field sensors have several applications in research and commercial businesses. The large colliders and magnetic containment facilities for plasma would benefit from the resistant monitoring probe. Space platforms, where instrumentation is in harsh environment due to solar radiation, could use these resistant probes as well. Using an all fiber optic approach lends several beneficial qualities to the measurement of magnetic fields. Fiber optic leads are EMI resistive, can operate in high temperature and extremely low temperatures, small profiles, and are cost effective and easy to produce. The proposed probe can be used singly or provide a distributed measurement of the magnetic field which would lead to better characterization and modeling of magnetic fields improving efficiency and lowering cost.

Key Words:
Fiber Optic, Magnetic Field, Radiation, Harsh Environment, Rare Isotope Beam, Accelertors

Summary for members of Congress (layman's terms, two sentences maximum, 50 words max).
Monitoring magnetic fields in harsh environments will provide a more reliable interrogation of containment magnets and field sources. By providing the developed Luna sensors, the Rare Isotope beam facilities will be able to explore novel materials as well as reactors and other high radiation facilities will be able to increase efficiency.

A. Company & Project Information

Contractor Name:	Luna Innovations Incorporated
Principle Investigator:	Joseph French
Business Address:	1 Riverside Circle, Suite 400, Roanoke, VA 24016
Project Title:	Fiber Optic Magnetic Field Probes for Accelerator Beam Facilities
Short Title:	Field Sense
Topic Number & Letter:	35f

B. Proprietary Data Rights Statement

The technical data contained in pages 2-21 of this application have been submitted in confidence and contain trade secrets or proprietary information, and such data shall be used or disclosed only for evaluation purposes, provided that if this applicant receives an award as a result of or in connection with the submission of this application, DOE shall have the right to use or disclose the data herein to the extent provided in the award. This restriction does not limit the Government's right to use or disclose data obtained without restriction from any source, including the applicant.

C. Identification and Significance of the Problem and Technical Approach

1. Introduction and problem statement

Researchers are increasingly trying to push the boundaries with respect to observing rare elemental isotopes. However, these rare elements are typically only found in nature as a result of large violent events such as supernovae or the resultant effects of the beginning of the universe (i.e. big bang) which are hard to reproduce in a laboratory setting. These hard to produce, rare isotopes, could provide improvements to many current technologies. Medical treatments, such as treatments for cancer, would benefit from the new isotopes and the research on how they interact with nuclei. Rare isotopes may be able to provide safer, enhanced imaging and medical diagnostic tools. To produce these rare isotopes and to begin intensive studies of their properties, the Department of Energy (DOE) has funded a new facility at Michigan State University, the Facility for Rare Isotope Beams (FRIB). This new facility will enable unprecedented research to be performed on how these rare isotopes interact and how the cosmos evolved.

The FRIB is currently slated to be built in 2012 and will employ several large magnetic fields to control and separate the varied ions that are produced through irradiation. Focusing and divergence of these beams is performed through the use of several magnetic quadrupole lenses which manipulate the magnetic field to concentrate or disperse the ions. Additionally, the FRIB separates different ions and directs where they travel based on their mass charge ratio as they move. This is done through the intense field (0.5-2.5T) generated by magnetic dipoles. To be used effectively, each magnetic field from the quadrupoles or the dipoles must be carefully monitored to determine exactly where the ions are being directed while the beams are online. The current method of monitoring the fields invloves quantifing the field as the beams are being brought online using a field probe and removing these field probes once the beam has been configured and begins to stream. The dipoles are then assumed to remain in this state throughout the irradiation period. The probes are removed due to the induced radiation changes incurred as the beams interact with the probe. This irradiation degrades their lifetime and their accuracy. Measurement in-situ and dynamic field feedback will be critical to experimental accuracy.

The rare isotopes produced through nuclear interactions, such as neutron capture or proton collisions, can generate several radioactive byproducts through decay. The combination of the gamma, neutron, and proton particles create a relatively harsh environment for any material. Unfortunately, the magnetic fields which control the beams throughout the facility are in locations where there exist large flux rates of this radiation (2E10 n/cm^{2}s, mostly thermal neutrons). Conventional magnetic field probes used to monitor the magnetic fields have a reduced lifetime and effectiveness due to the neutron fluxes experienced in these areas which is why they need to be removed once the beam is brought online. This is the limiting factor that requires the NMR probes which are currently being used in these facilities to be used offline.

Development of a radiation resistant magnetic field probe would enable careful monitoring and control of the magnetic fields in-situ. This technology will reduce operational cost while increasing safety by limiting the amount of recalibration and costly downtime caused by removing or replacing damaged magnetic field probes. A new probe will also provide more accurate field data that can be used to precisely control the particle separation enabling high quality research.

**** Proprietary Information Starts Here****

2. Solution

Luna Innovations Incorporated will develop a radiation resistive magnetic field probe based on an all fiber optic design to be used with the FRIB and similar facilities. This technology will provide a reliable measurement of the magnetic fields within radiation environments enabling advanced control and high quality research at a reduced cost. The probe design will incorporate a specially designed radiation resistant optical fiber and use the intrinsic magneto-optic effect of the optical fiber to accurately measure and control the existing fields. Using Optical Frequency Domain Reflectometery (OFDR) to demodulate the sensor signal, the probes will be able to make thermally compensated measurements of strong magnetic fields (0.500T – 2.500T) with an accuracy of better than 0.01%. These probes will be able to withstand greater than 10^18 n/cm^2 fast neutron fluence environments, which is equivalent to one year of constant irradiation in the FRIB. Cabling to the sensor made from COTS components, will be inherently EMI resistant and will not experience any signal degradation over extended lengths. This will provide increased access to remote areas of these facilities as well as reduce the need for complex and expensive signal conditioning instrumentation. Figure 1 shows a preliminary design of the radiation resistant magnetic field probe.

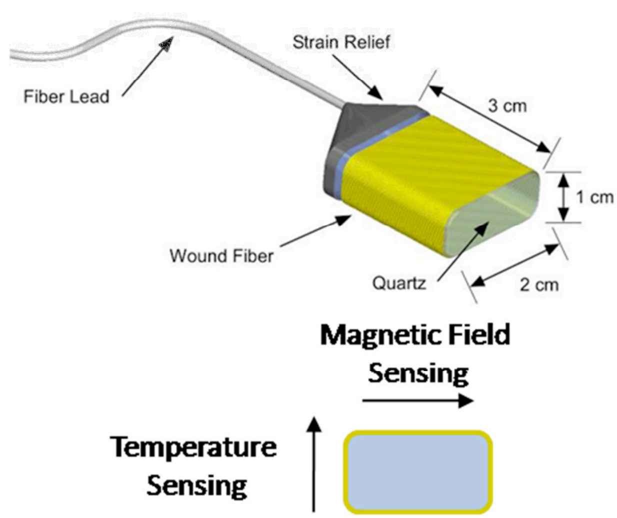


Figure 1. Preliminary radiation resistant magnetic field probe

Optical fiber can be wound multiple times around a quartz block with the long linear section of the fiber wrap oriented parallel with the magnetic field. The fiber wrapping provides >5 meters of sensing length in a miniature 1 x 2 x 3 cm package. A quartz block is used to provide structural support with matched thermal coefficients to limit the induced strain of the fiber as a result of to thermal effects. A single optical fiber will provide information on the temperature and magnetic field based on the sections orientation. The portions of fiber parallel with the magnetic field will have induced polarization change of the light's electric field coupled with the temperature's strain effect. The portions of the fiber that are perpendicular will have induced strain from any temperature changes while maintaining a constant polarization. The close coupling of the temperature sensing portions with the magnetic field's sensing portions allow very accurate thermal compensation. Off axis misalignment will only affect the magnetic field sensing while the temperature sensing will be unaffected.

3. Significance of the Innovation

Luna has extensive experience using fiber optic sensing devices within high radiation reactor environments. To date all fiber optic magnetic field probes have a dopant within the core and cladding of the fiber to provide enhanced sensitivity to the magnetic field, these dopants are typically rare earth metals. These rare earth metals possess large neutron capture cross sections. For example, the most sensitive fiber to magnetic fields is optical fiber doped with Terbium which has a thermal neutron cross section of 23.5 barns[1]. However, Cerium (also a rare earth with a high Verdet constant) has been shown to have a low neutron cross section and is ideal for a dopant of the optical fiber core. Luna is planning to design a radiation resistant polarization maintaining optical fiber consisting of a silica core doped with ceria (Cerium oxide) surrounded by an inner cladding doped with flourine. Stress regions will be used to provide high birefringence and bend insensitivity. High birefringence is needed for maintaining the polarization and the bend insensitivity facilitates a tightly wrapped fiber and minimizes associated bend loss. The outer cladding used will consist of Borate doped silica. This extra cladding will provide additional thermal neutron absorption providing shielding of the core. Figure 2 is a diagram of the radiation resistive optical fiber with the doped Ceria core for enhanced magnetic field sensitivity. A magnetic field probe consisting of just the pure silica core fiber would be approximately 50 times less sensitive than terbium to magnetic fields which limit the minimum field that could be measured by the pure silica fiber, but has the benefit of being radiation resistant. The addition of the Ceria to the core raises the sensitivity at least an order of magnitude allowing a small package size while maintaining sensitivity. Table 1 below summarizes the optical fiber materials' Verdet and thermal neutron cross-sections.

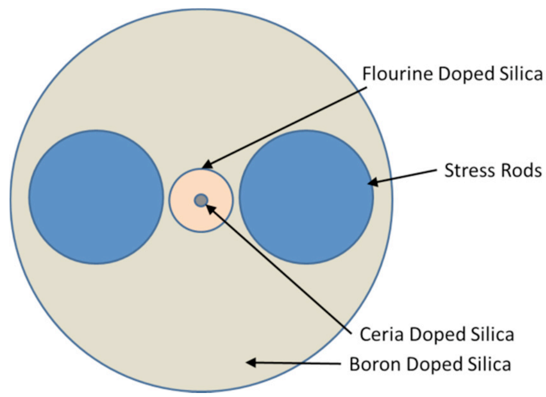


Figure 2. Radiation Resistant Polarization maintaining optical fiber with enhanced Magnetic Field sensing (2RPMF).

[1] *Neutron News*, Vol. 3, No. 3, 1992, pp 29-37

Table 1. Verdet Constant and Thermal Neutron Absorption Cross-Sections for the 2RPMF Fiber

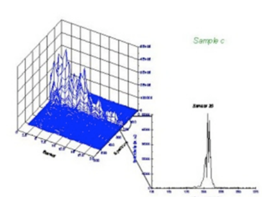
Material	Verdet* (rad/m*T)	Thermal Neutron Cross-Section (barns)
Silicon	-0.56	0.177
Oxygen	n/a	0.000
Flourine	n/a	0.010
Boron	n/a	767.000
Cerium	~-10	0.630
Terbium	-20	23.40
* In fused silca		

To demodulate the slight signal from the pure silica core fiber, Luna will use its OFDR system which has been commercialized and provides a sensing platform capable of measuring the Rayleigh backscatter and associated distributed temperature and polarization change along the entire length of optical fiber.[2]

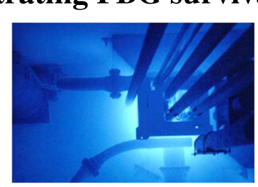
4. Luna is a recognized leader in harsh environment sensing and instrumentation development.

Luna has over 9 years of fiber optic sensor research in radiation environments. Previously, Luna has developed radiation hardened sensors which measure temperature, strain, pressure, neutron energy, neutron fluence and gamma flux. Luna has logged over 450 reactor hours and has more than 100 hours scheduled over the next 3 years in research reactors at both The Ohio state University, MIT and INL. Along with the radiation environment, Luna has developed sensors which can withstand temperatures from 3 to >1473 K. The table below represents some of the harsh environment testing that Luna has performed.

Luna has demonstrated fiber Bragg grating (FBG) survivability to $2x10^{19} n/cm^2$ and 87GRad during a NASA Phase I/II SBIR, far exceeding previously-held limitations of fiber optic sensors. Additinally, distributed FBG sensors were demonstrated up to 1000°C, another technological breakthrough.



Demonstrating FBG survivability



Combined environments

During a DOE Phase I/II SBIR, Luna demonstrated extrinsic Fabry-Perot interferometer (EFPI) based sensor operability up to $6.9x10^{17} n/cm^2$. EFPI-based pressure and temperature sensors have been developed by Luna for operation up to 1000°C and 1400°C respectively. EFPI pressure sensors also allow combined P/T sensing

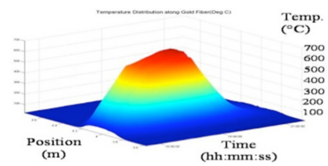
[2] Gifford, D., Soller, B., Wolfe, M., Froggatt, M., "Distributed Fiber-Optic Temperature Sensing using Rayleigh Backscatter." Opical Communication, 2005. ECoC2005. 31st European Conference. Sept 24-29 2005. **3**:511-512.

in a hybrid transducer, enabling highly robust temperature correction in extreme environments.

In non-radiation environments, Luna is also pushing the limits on extreme temperature pressure sensing up to 1400°C in a current DOE Phase II SBIR. Robust temperature compensation and advanced packaging methodologies are being developed to enable continued reactor plant measurements during an accident condition.

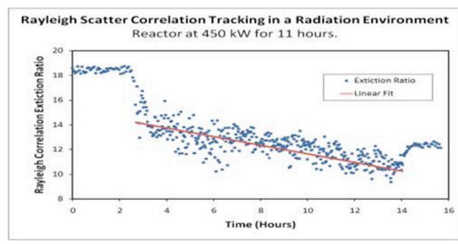
Pressure and temperature calibration

Luna delivered a **distributed temperature mapping system using Rayleigh scatter** to NASA Marshall. The system provided temperature distributions up to 800°C at ±2% full scale accuracies. An Optical Backscatter Reflectometer was delivered along with probes designed for use in a NaK cooled reactor fuel element simulator.



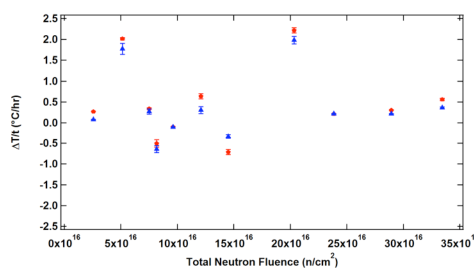
Rayleigh Scatter based distributed temperature map

Luna showed **sensitivity of Rayleigh scatter correlation extinction ratio to radiation** in the Ohio State University Nuclear Reactor Laboratory. Data at each point along the length of a fiber demonstrated a smooth trend in correlation of the Rayleigh scatter pattern with time as the reactor was powered on from a time of 3 hours to 14 hours. These data are sensitive to radiation but independent of temperature and axial strain.



Sensitivity of Rayleigh scatter correlation within a radiation environment

Luna has received a DOE Phase III Xcelerator grant for a radiation resistant temperature probe for application in Gen-IV reactor environments. Luna is transitioning the technology to a TRL 7 during this grant and is working with BEA at INL to instrument their Advanced Test Reactor.



Drift in radiation resistant thermal probes with neutron fluence

Luna has also licensed the OFDR technology that was first developed by NASA. Since the OFDR's the initial licensure, Luna has continually pushed the technology further to achieve unprecedented sensitivity over long lengths of fiber. Current OFDR technology produced by Luna has dynamic ranges of 70 db and spatial resolution of 30 um over long lengths of fibers. These OFDR devices can measure the Rayleigh backscatter of optical fiber which can be used to find temperature or strain at each location 30 um location.

D. Anticipated Public Benefits

The result of this work will enable improved monitoring of the strong magnetic fields which control the transport and dispersion of ion beams in a high radiation flux environment. This will allow the FRIB to provide research opportunities to the scientific community and advance the state of the art in medical imaging, diagnostic techniques, and provide insight to the evolution of the cosmos. By providing accurate magnetic field sensing, the proposed technique constitutes a significant and innovative advance for other facilities such as CERN, LHC, and researchers concentrating on the advancement of superconductors for… . Additionally the design can be adapted to provide measurement of the magnetic field within other harsh environments such as high or low temperatures and high pressure. These are limiting with current electrical magnetic field detection such as Hall and NMR probes. Also by utilizing the OFDR technology sensor health can be monitored as well providing improved feedback to the users of the field probes' state of health, increasing the confidence of the magnetic field measurement.

E. Phase I Technical Objectives

The overall goal of this three-phased development is to advance the state of the art for radiation resistant magnetic field probes. The demonstration of feasibility during the Phase I will be guided by four main objectives:

1. **Develop a magnetic field probe that is compatible with high radiation flux facilities,**
2. **Develop algorithms for temperature compensation and magnetic field determination,**
3. **Demonstrate the probes effectiveness in laboratory testing,**
4. **Develop commercialization / transition to manufacturing strategy.**

Figure 3 provides an overview of the strategic plan for this research in Phases I, II, and III.

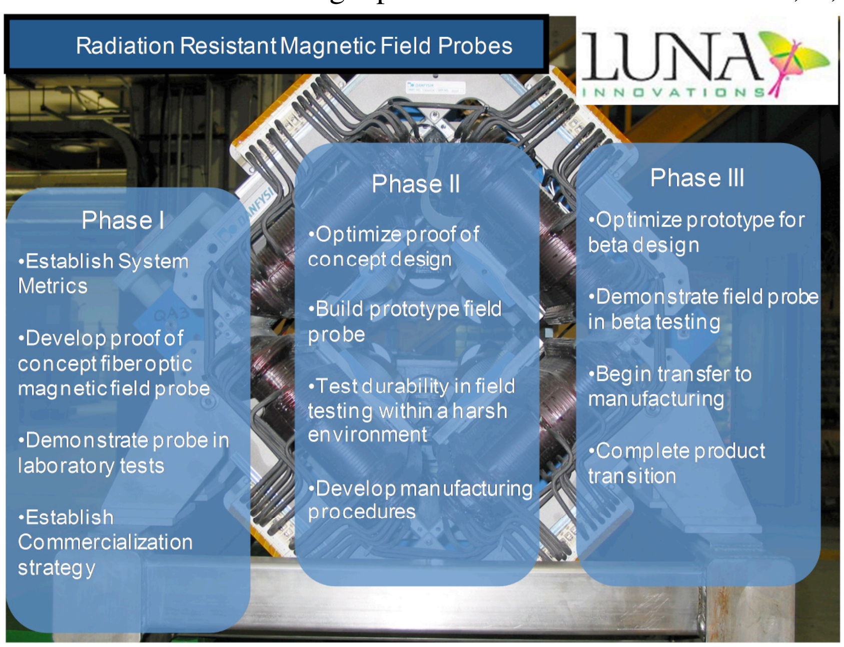


Figure 3. Overview of the objective for Phases I, II, and III

Objective 1: Develop a magnetic field probe that is compatible with high radiation flux facilities

Luna plans to work directly with DOE and industry leaders to determine sensor requirements which will meet real needs in the FRIB and similar facilities as well as harsh environments where current technology is limited. The effort will focus on determining a sensor design that is able to achieve the magnetic field sensing metrics to determine the viability within the desired range of magnetic field locations. Experimental verification of durability and accuracy will also be based on the FRIB requirements. The Luna team will consider the tradeoffs of probe design and accuracy. At the completion of this objective, Luna will have a proof of concept probe capable of measuring

Objective 2: Develop algorithms for temperature compensation and calculation of the magnetic field

Luna has several demodulation systems that will act as a base for this project. Each system has different capabilities with respect to sample rate (0.33 Hz – 300 Hz), sensing length (0-300m), and sensitivity (0.003-6 ns). Selection of the most appropriate will enable the highest fidelity measurements within the acceptable cost limitations. During the course of this development effort, algorithms which calculate the magnetic field intensity from these profiles as well as compensate for temperature will be needed for the selected system. Additionally, these algorithms will need to be tested and verified. Completion of this would result in the ability to meet the projects goals for interrogating the field sensor.

Objective 3: Demonstrate the probes effectiveness in laboratory tests

The third objective of this Phase I effort is to demonstrate the feasibility of the technology to make precision field measurements in a radiation environment. This will heavily rely on experimental verification of accuracy and sensitivity based on the needs of the DOE and FRIB. The magnetic field testing will be performed without radiation in Phase I. The design of the experimental methods will need to be determined to verify that there is limited cross-sensitivity with environmental stimuli. Testing will likely include: vibration, thermal shock, thermal cycling, pressure cycling, etc. Additional modeling and literature review will be performed to provide information on the probes effectiveness in relevant radiation environments. Once completed, the data will verify that the sensor and system are capable of meeting the measurement needs of the DOE and industry leaders. Data from testing will also provide useful information to refine the design of the sensor during the Phase II project. Radiation testing is cost prohibitive and will be performed during Phase II, if financing allows this may be done during Phase I

Objective 4: Develop commercialization / transition to manufacturing strategy

The initial market will be FRIB research and testing, which will provide a logical technology insertion point to build confidence for magnetic field testing within the radiation environment in the future. Prototype construction methods will focus on improving the manufacturability of the sensors. The instrumentation system will be designed for turn-key operation to facilitate rapid acceptance. During the Phase I quantity manufacturing steps will be identified for future outsourcing, where applicable, to reduce future cost. Luna will also offer the sensors and signal conditioning system directly to university, government and commercial R&D labs as part of Luna's R&D instrumentation product line. Luna will also discuss the system performance with its contacts throughout the nuclear industry to determine the applicability of the proposed sensors to other radiation testing facilities, current and under development. Additional markets that could utilize the magnetic field probes include harsh environments such as turbine manufacturers, plasma facilities and space platforms.

F. Phase I Work Plan and Phase I Performance Schedule

1. Technical Background

1.1 Magneto-optic effect

In the presence of a magnetic field parallel to the direction of light travel within a medium, light will rotate its polarization linearly proportional to the magnitude of the magnetic field, the medium becomes birefringant. This rotation referred to as Faraday rotation, is used in several optical components such as Faraday rotators and optical isolators. The degree of induced rotation in the polarization arises from the different indices of refraction that the orthogonal components of the electric field experience in the medium. Similar to wave plates with a fast and slow axis, one polarization will lag behind the other in time, thus the electric field vector will rotate. Figure 4 below shows a representation of the rotation with an applied magnetic field

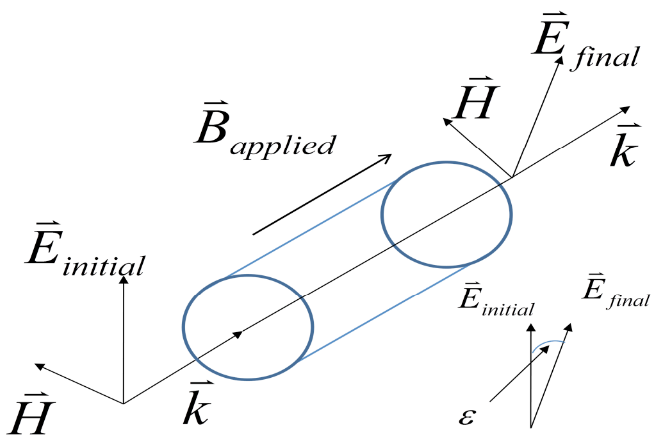


Figure 4. The Electric field is rotated by ε when magnetic field is applied to an optical medium parallel to the light's travel.

The degree of rotation is given by ε, which is defined as

$$\varepsilon = \nu BL \qquad \textbf{Eq. 1}$$

where *v* is the Verdet constant, *B* is the magnitude of the magnetic field and *L* is the length of interaction of the magnetic field. For pure silica core optical fiber, the Verdet constant at 1540 nm is 0.56 rad/T/m. This is comparatively low when compared to Terbium Gallium Garnet of ~40 rad/T/M at 1540nm. The rotation is independent of the direction of the magnetic field so multiple passes either forwards or backwards, will result in additional rotation without unwinding. Time resolved systems that can demodulate the signal would experience a measurable lag between the S and P polarizations to corresponds to the magnitude of the magnetic field given a Verdet constant and fiber interaction length. The Verdet constant, however, is both temperature sensitive and wavelength dependant, careful compensation is needed to calculate the magnetic field over a given sensor length to account for thermal effects.

1.2 Optical Frequency Domain Reflectometry

Optical Time Domain Reflectometry (OTDR) is based on transmitting a pulse of laser light through the fiber and tracking the time at which the reflected signals are detected, thereby distinguishing the spatial location of the sensors. Although this technique works very well over great distances (kilometers), spatial resolution tends to be coarse. With this technique, achieving spatial resolution better than 1 m is very challenging.

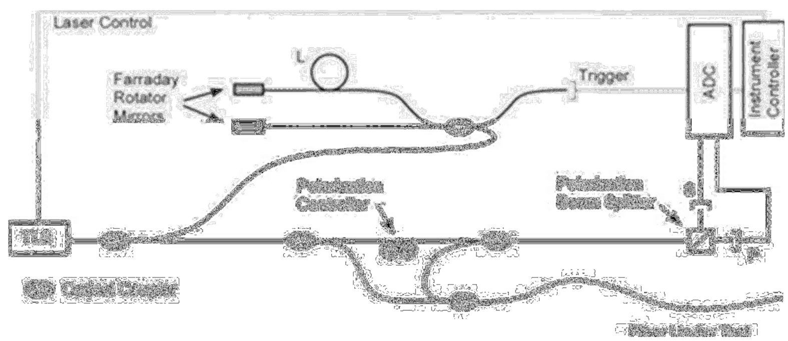


Figure 5: Set-up used in the OBR to measure the reflection events in a fiber network under test.

Perhaps even more popular is the Wavelength Division Multiplexing (WDM) technique in which a small number of Fiber Bragg Grating (FBG) sensors are placed in the fiber with each reflecting a different wavelength of light. Though relatively high spatial resolutions on the order of a centimeter may be achieved with this technique, the number of sensors tends to be limited to tens due to the finite bandwidth of broadband or swept-wavelength laser sources and the need to allocate significant portions of that bandwidth to each sensor to accommodate the dynamic range of the application. With the shape and position sensing technique, dynamic ranges of ± 10,000 με are expected which is equivalent to nearly 20 nm of spectral bandwidth. Using a WDM-based technique would require either that each Fiber Bragg Grating (FBG) be allocated the full spectral bandwidth expected or that the dynamic range of the measurements be constrained. Furthermore, WDM sensor fabrication is very labor intensive and thus very costly.

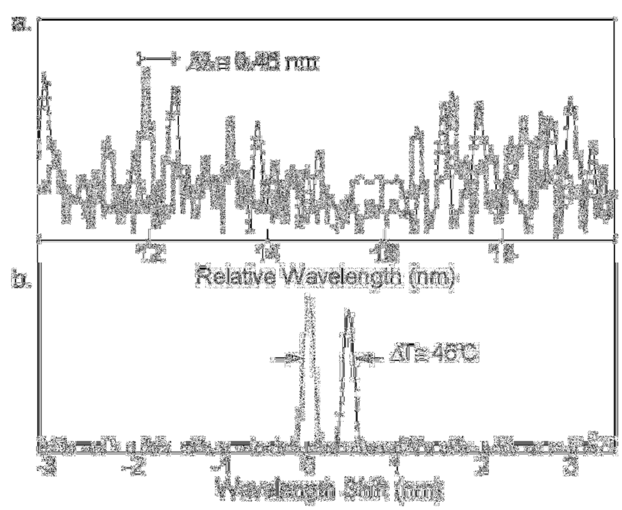


Figure 6 (a) Rayleigh scatter spectra along a 5 mm fiber segment for a heated (solid) and reference (dotted) scan. (b) Cross-correlation of the two spectra.

An attractive alternative to these techniques is Optical Frequency Domain Reflectometry (OFDR). The OFDR technique was originally developed by researchers at NASA Langley Research Center for testing on the X-33 and the shuttle, but has been commercialized by Luna through license from NASA for numerous monitoring applications. OFDR allows thousands of sensors with overlapping spectra to be read with very high spatial resolution on the order of sub-millimeter giving the most complete picture of any of the viable distributed fiber optic sensing techniques[3]. This technology is at the fundamental core of Luna's telecommunication diagnostic and distributed sensing platform: the Optical Backscatter Reflectometer or OBR™.

A representation of the optical network of an OBR™ is shown in Figure 5. An external-cavity tunable laser source (TLS), controlled by an instrument controller, is swept through a specified wavelength range. The laser's frequency is extremely stable with a repeatability of 4 MHz. A gas cell (not pictured) is used to correct every scan of the laser, thus maintaining extremely high absolute wavelength accuracy. The wavelength range determines the spatial resolution of the measurement, with longer scan ranges resulting in higher spatial resolutions. A 40 nm scan centered at 1550 nm, for example, results in 20 micron spatial resolution, while a 20nm scan range will result in a 40 micron resolution.

The light from the source is split by an optical coupler between two fiber interferometers. The upper interferometer in the diagram acts as an optical frequency monitor: every time the intensity at the trigger detector passes through one full fringe the laser optical frequency has changed by a set amount determined by the inverse of the trigger interferometer delay. The delay is determined by the path length difference L. The lower interferometer is the measurement interferometer. The light from a reference branch interferes with the light returning from the fiber under test (FUT). A polarization controller in the reference path is used to ensure that the reference light is split evenly through a polarization beam splitter to polarization diverse detectors, S and P. In this way a consistent interference signal can be obtained regardless of the polarization state of the light returning from the FUT. The signals from the S and P detectors are digitized and sent to an instrument controller for processing. The vector sum of the S and P signals results in a consistent measure of the optical backscatter. Luna's High Speed Distributed Sensing System (HS-DSS) is equivalent to the system described above except that one laser is shared by up to four parallel channels and the laser can be swept as fast as 20,000 nm/s, instead of the 20 nm/s more typical of the OBR. This allows interrogation of four independent sensing fibers concurrently and at very high rates. The sensitivity of the technology allows the use of distributed sensing via Rayleigh scattering, or interrogating thousands of Bragg sensors all with the same center wavelength.

1.3 Strain Sensing using Rayleigh Scatter

Luna's distributed sensing technology is capable of measuring strain over a range of ± 12,000 $\mu\epsilon$. This wide range combined with optical fiber that can be as small as 80 microns in diameter provides a high performance sensing solution. Similar to interrogating Fiber Bragg Gratings (FBG), the Rayleigh backscatter of a fiber creates a unique pattern that is measured by the instrument. Instead of a clear peak or set of peaks, however, the reflected amplitude, phase, and spectrum of the scatter are random patterns. Figure 6(a) shows the reflected spectrum of a

[3] Duncan, R., Childers, B., Gifford, D., Petit, D., Hickson, A., Jackson, A., Duke, J., Brown, T., "Use of a Fiber-Optic Distributed Sensing System for Nondestructive testing of Aerspace Structures," Materials Evaluation 61, 838 (2003).

segment of scatter from a piece of standard telecommunication fiber (SMF-28), calculated by windowing a segment of scatter data in the distance domain and performing an inverse Fast Fourier Transform (FFT). Just as with an FBG, applied temperature or strain shifts the reflected spectrum of the scatter in the fiber at the location it is applied. Nominally, the shift in reflected spectrum in an FBG is found by measuring the shift in its spectral peak. Finding the frequency shift of the scatter spectrum is slightly more complicated as the spectrum is random. This is accomplished by performing a cross-correlation of the scatter spectrum from a measurement data set with that from a reference data set taken with the FUT in some nominal temperature or strain state. Figure 6(b) shows the cross-correlation of a reference scatter spectrum with one that was perturbed by a temperature change. The correlation peak is shifted from center by a frequency shift resulting from the temperature change.

The following process yields a distributed measurement of temperature or strain applied to a fiber. First, a reference measurement of the Rayleigh scatter is made with the fiber in a nominal known temperature and/or strain state. Second, a measurement of the scatter is made with some temperature or strain applied along the fiber. The complex scatter pattern as a function of distance is calculated via a FFT for both data sets. The Rayleigh scatter spectrum of a segment of a length, Δx, at one point in the fiber for both sets of data is calculated by windowing each segment in the distance (or optical delay) domain and performing an inverse FFT. A cross-correlation of the reference and measurement spectra yields a peak that is shifted from center by the frequency shift induced by the applied stimulus at the selected location. This frequency shift is converted to temperature or strain using calibration coefficients appropriate to the fiber type. This process is repeated for segments of scatter along the entire length of the fiber to yield temperature or strain as a function of distance.

Very small strains can be detected with high precision by comparing the phase changes along the length of the fiber. Figure 7 shows the local displacement of the fiber core, from its original length. In this case the strain field was oscillating with a period of 15mm, providing a good demonstration of the high spatial resolution that the technology is capable of. Note the Y axis scale in Figure 7 is in nanometers (1×10^{-9} meters). For reference 250 nm = 10 millions of an inch.

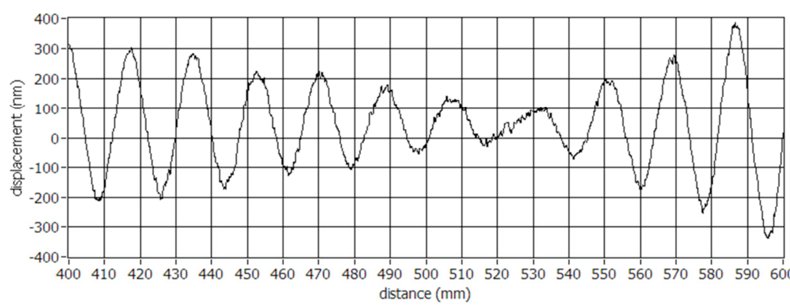


Figure 7: Using Rayleigh scatter very small displacements can be tracked in optical fiber (on the order of 10nm) over long distances and at high resolution. This figure shows the measurement of a rapidly changing strain field in an optical fiber with millimeter spatial resolution along the fiber and tens of nanometers resolution measurement of the displacement.

1.4 Magnetic field induced time lag of the S and P polarization within an optical fiber

Similar to the strain induced by temperature or stress, the magneto-optic effect will shift in time the reflected S and P polarization states as measured by the OFDR system. By setting up a simple experiment to determine feasibility, this has been shown. A standard jacketed fiber was place within a solenoid capable of producing a magnetic field of 0.04 T when 22 volts is applied across it. The fiber was stretched to lie parallel with the magnetic field inside the solenoid at approximately the middle where the field is the strongest. A gaussmeter probe was placed at the same level to estimate the field the fiber was experiencing. Additionally, a K type thermocouple was placed next to the fiber to measure the temperature rise as the wire in the solenoid heats.

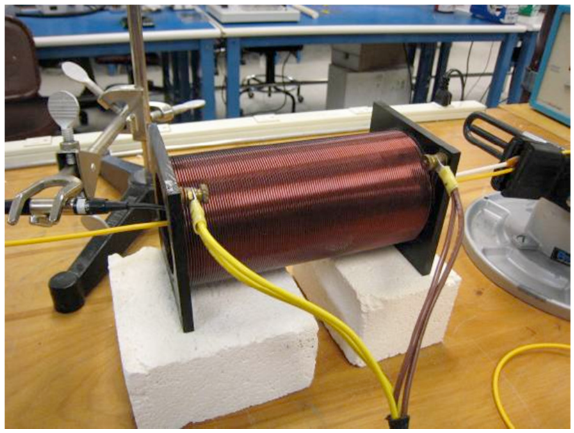


Figure 8. Magnetic Field test with a standard jacketed fiber. The optical fiber is the yellow jacketed wire in the center of the solenoid, a gaussmeter probe is on the left side of the solenoid and a K type thermocouple is on the right inside a white alumina tube.

The field was cycled six times over approximately 30 minutes. The field was switched on for 6 seconds for interrogation then switched off for 5 minutes to prevent any temperature rise of the fiber. The optical backscatter of the S and P polarization of the fiber was monitored with an OBR using a 44 nm scan range. The 44 nm scan range provides a 20 um step change in the distance or a time step of 95 fs. Figure 9 below shows the average relative peak shift with an applied magnetic field.

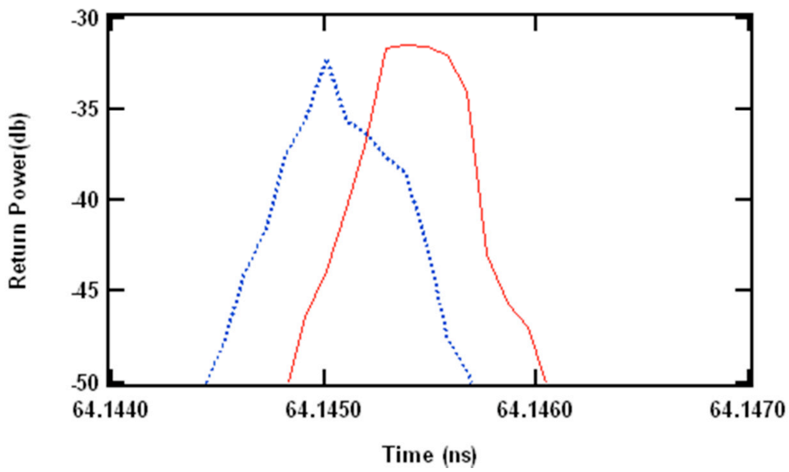


Figure 9. Average magnetic field induced time lag in a standard fiber. The blue dashed line shows the reflected power when the magnetic field is applied, the read solid line represents the reflected power when the field is off. The magnetic field applied was 0.04T with an interaction length of 6.7 inches.

When the field is applied, on average we see a shift of 380 fs from when the field is not applied. Increasing length of interaction and magnitude of the magnetic field applied will increase the time lag between the peak positions. This will raise the sensitivity of the sensor proportionally to the number of fiber wraps used.

2. Detailed Technical Task Descriptions

Task 1: Develop the system metrics for a radiation resistant magnetic field probe.

During this Task Luna will focus on finalizing the magnetic field probe metrics for the Phase I effort and complete preliminary determination of the Phase II goals. To accomplish this task, Luna will work with the DOE and the staff at FRIB to develop performance goals for the probe so that it can be easily integrated in the FRIB and other commercial applications. The table below summarizes the preliminary goals for the Phase I and II efforts. Optimization of the probes performance compared to the goals outlined during this task will be completed in Task 6.

Table 2. Preliminary goals for the Phase I and II system metrics

Metric	Phase I Goal	Phase II Goal
Magnetic Field Strength	0.5 - 2.5 T	0.5 – 2.5 T
Accuracy	0.1%	<0.01%
Sensor size	3 cm x 2 cm x 1 cm	TBD
Harsh Environment Survivability	1E17 n/cm^2	TBD
Sampling frequency	0.1 Hz	1 Hz
Distance between sensor and electronics	~9 feet	>100 feet
Electronics size	Bench top system	TBD
Self-calibrating	No	Yes

During this task Luna will consult with the DOE and the FRIB for details on the expected environment where this system will operate. Factors such as temperature range, shock, vibration, and electromagnetic interference (EMI) requirements will be quantified. Preliminary discussions on system size and weight will also be discussed. The required electronics package size will be evaluated in detail during Task 5. This task will also define the testing that will be required to demonstrate the technology being developed. Luna will examine different standard test procedures that are appropriate and identify those key to qualification of the final product for use within the FRIB and other similar facilities. Tests will also be identified to quantify the metrics identified during this task. The result of this task will be a solid set of metrics, as well as tests to determine performance with regard to the metrics.

Task 2: Design and build a proof of concept probe

Several proof of concept magnetic field sensors will be constructed by Luna to demonstrate the performance of the technology using COTS PM optical fiber. Calibration and testing of the probes constructed during this task will be performed during Task 4. The result of this task will be prototype sensors and construction methods that will be reviewed during the optimization task as part of the Phase II project. This task will be conducted by Luna Innovations in Blacksburg, Va.

Off the shelf PM fiber will be used for the proof of concept due to the cost limitation of the specially designed optical fiber shown in Figure 2. A custom draw is ~$25000 for 1-2 km of optical fiber. For the basis of proof of concept, the off the shelf PM fiber will provide mechanical and optical properties similar to that of the 2RPMF fiber without the magnetic field sensitivity of the ceria doped core. The PM fiber will have the same structure as the 2RPMF fiber and will provide information on the capabilities of the enhanced fiber to be used later. During Phase II, the custom fiber will be drawn using the design developed in Phase I.

Initial designs of the probe will be based on increasing the interaction length of the fiber with the magnetic field while keeping the size minimal. Due to the low sensitivity of the Verdet constant for the pure silica fiber in the off the shelf PM fiber, long interaction lengths are needed to achieve the accuracy identified in Task 1. The quartz block support structure will be optimized though modeling to determine the radius of curvature of the edges and thickness to mitigate the bend loss the fiber will experience. Modeling will also be conducted for thermal and structural response with respect to the radiation environment. Previously, Luna has used computer aided design and modeling software as well as analytical models to determine the expected performance of prototype sensors in reactor applications. For a separate DOE project (DE-FG02-07ER84686), Luna developed a model to predict the gamma heating profile of a capsule put into the OSU research reactor. In Figure 10 below, the heating profile is simulated based on the gamma radiation profile for several locations and along the capsule axis.

This page contains proprietary information that Luna Innovations Incorporated requests not be released to persons outside the Government, except for purposes of review and evaluation

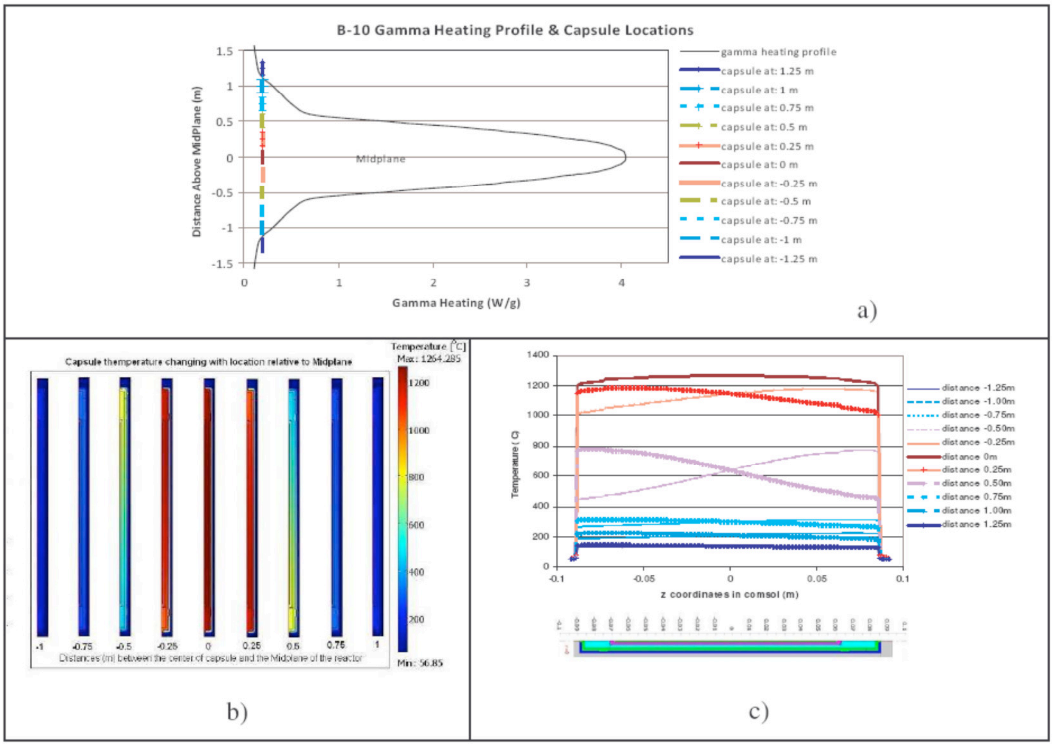


Figure 10. Gamma heating profile and simulation results. a) Capsule locations and heating profile. b) Simulated cross section results. c) Temperature profile along the capsule axis.

The probe housing and construction will take into account the harsh environment it will be placed in. The high neutron flux environment will restrict any strong radiation absorbers and plastics for consideration in the housing and strain relief. Additionally, metallic strain reliefs and structural components will not be used for the probe design. Fiberglass sheathing and fiberglass braids will be employed to protect both the sensor and lead during handling. Embedment of the windings will be investigated to provide the best compromise of radiation compatibility and structural support. Modeling of the proposed geometry will be used to guide additional consideration to increase probe lifetime and increase signal to noise of the magnetic field measurement. The result of this task will be a robust radiation resistant probe to be constructed and used in testing in Task 4, verifying the capability of measuring high magnetic fields in radiation environments.

Task 3: Construct the algorithms to calibrate and calculate the magnetic field from the probe data

Luna will develop the necessary algorithms for thermally compensating, calibrating, and calculating the magnetic field magnitude from the demodulation of the sensors signal. Two systems (both based on the OFDR technology) will be employed from measuring the magnetic fields affect on the polarization of the light propagating through the optical fiber. The first is the OBR which will give the distributed change in time of flight for the two polarizations. This system was used in the preliminary experiment to show the sensitivity of the demodulation system. The second instrument that will be tested is the Optical Vector Analyzer (OVA). The

OVA measures the Jones matrix of the optical fiber directly and will give the time lag between the S and the P states. For an arbitrary birefringent material, the Jones matrix is given as the expression below.

$$\begin{pmatrix} e^{i\phi_x}\cos^2(\theta)+e^{i\phi_y}\sin^2(\theta) & (e^{i\phi_x}-e^{i\phi_y})\cos(\theta)\sin(\theta) \\ (e^{i\phi_x}-e^{i\phi_y})\cos(\theta)\sin(\theta) & e^{i\phi_y}\cos^2(\theta)+e^{i\phi_x}\sin^2(\theta) \end{pmatrix}$$

Where ϕ_x and ϕ_y are the phase in the x and y polarization of the electric field, θ is the angle of the fast axis of the birefringent medium to the x axis. Solving the system of equations using the real and imaginary components of the measured Jones matrix using the OVA, will provide $\phi_x - \phi_y = \varepsilon$, the rotation due to the applied magnetic field. The rotation for the off the shelf PM fiber will be less sensitive than the 2RPMF fiber but will allow for proof of concept and probe improvement.

Thermal compensation will be accomplished by monitoring the temperature induced strain in the fiber perpendicular to the magnetic field. The time shifts in these regions correspond to the temperature of the fiber and supporting block without interference of the magnetic field. This shift will be compensated for in the measured shifts in Rayleigh backscatter of the portions of fiber within the magnetic field. To compensate for thermal effects the lag induced by thermal stimuli will be subtracted from the lag induced by the magnetic field. The result of this task will be a stable alpha version of the algorithm to be used in Phase II. Careful consideration to the memory and speed requirements of the signal demodulation will be conducted. The algorithms developed during this task will be applied directly to the 2RPMF fiber in Phase II due to the universality of the algorithms independence of the fiber type. This task will begin after the completion of Task 1 and span the balance of the program. The work will be conducted in Luna's Blacksburg facility by the Luna team.

Task 4: Conduct laboratory tests to characterize the probes effectiveness

During this task Luna will demonstrate the performance of the proof of concept sensor constructed during Task 2. This task will take one month to complete and begin after completion of Task 2. Testing will be performed at Luna's Blacksburg facility by the Luna research team. Testing will be performed using either Luna's OBR™ 4400 single channel system or Luna's OVA™. These units will be made available as needed for the duration of the testing.

Initial testing will be conducted with a magnetic field similar to the preliminary testing done for this proposal. The field will be relatively low 0.02-0.04 T and will provide accuracy characterization at a stable temperature. The probe will be co-located with a thermocouple to ensure a stable temperature environment. Initially thermocouples will be used to measure the thermal environment of the probe, once the thermal compensation approach is verified this will be done with the optical fiber in the probe which is perpendicular to the magnetic field. The thermocouples will provide accurate measurement within stable magnetic fields, any time varying field will induce an EMF in the thermocouple that would provide erroneous measurements.

Thermal calibration will be performed using a controlled environmental chamber. The controlled temperature will be ramped at stages from 0°C to 60°C while the fiber is in a stable magnetic field. This thermal calibration will determine the amount of compensation needed for the temperatures seen at the FRIB and other facilities. Additionally mechanical vibration, EMI, and humidity will be investigated to gather information on any extra noise sources interfering with the optical fiber's signal. Additional testing to higher extremes of environment will be conducted based on the projects available resources. Thermal cross-sensitvity to off-axis misalignment will be evaluated through rotating the probe within a magnetic field at a stable elevated temperature. The cross-sensitivity test will be performed at Luna using Luna's Tenny Environmental Chamber.

Once these initial test have been performed, the probes will be placed in a strong magnetic field to monitor there range capabilities. To achieve this, Luna will use an NMR magnetic field supplied by Virginia Tech's chemistry department. Also available is Luna's NMR equipment located in the Danville Virginia location. Each facility will be considered and used based on availability. The probe will be slowly translated through the 7 T field provided by the NMR. This will provide data in fields from 0.5 – 2.5 T which is what is in use at the FRIB. Higher fields will also be considered for testing once the metrics in Task 1 have been met. All the data gathered from these experiments will be used in Task 5 to improve the design to accomplish the goals of Phase II set in Task 1.

Radiation testing will be performed in Phase II or if resources permit during Phase I. The probes will be placed in an environments comprising of neutrons, protons, and gamma rays. A design of experiment will performed to minimize the test matrix such that information on the probes effectiveness within radiation environments can be gathered to provide predictions of the probes survivability. This will be done by Luna in conjunction with a subcontract with facilities that would be able to provide the radiation environment such as Michigan State University's National Superconducting Cyclotron Laboratory. Additionally, Luna has several grants which utilize the OSU research reactor and there exists the possibility of piggy-backing a reactor test. The research reactor would provide a large flux of thermal neutrons that can simulate the flux rates seen at beam facilities through careful shield and moderation.

Task 5: Improve the probe's design for prototyping and field testing in Phase II

This task will serve as a transition to Phase II. During this task Luna will evaluate the testing conducted in Task 4 and potentially conduct further testing where deemed appropriate. After evaluating the proof of concept data Luna will revisit the sensor design to evaluate improvements that can be implemented early in the Phase II effort. Luna will also explore hardware options for the Phase II instrument based on the Phase II metrics, such as speed accuracy, etc. This work will be require three months to complete and will be conducted at the Luna Blacksburg facility by Luna researchers.

Luna will evaluate optical network changes that might be needed such that the resulting system is tailored specifically for this application. If for example the distance between the sensor and instrument needs to be hundreds of feet then part of the optical network may need to be moved close to the sensor to improve performance. Material consideration of the structural support and possible embedment of the fiber will be evaluated for performance. Due to a small size, the optical fiber will have a tendency to flex away from the probe which will lower the magnitude of the field measurement. By carefully embedding the fiber to the probe block, the sensor will have increased accuracy. Noise sources, such as vibration and humidity, will be considered in optimizing the probe housing to limit the interference. Additionally the optical design of the 2RPMF fiber will be discussed with preform manufacturers to provide design challenges and cost analysis for the Phase II effort. Initial evaluation of these changes will be made during this task. The work in this task will provide a foundation for and a solid transition to Phase II.

Task 6: Begin commercialization strategies and develop a plan for manufacture

During this task Luna will develop a plan for transition to commercial product. This task will span the entire 9 month effort. This task will be conducted by Luna researchers with input from the DOE, FRIB, and other industry contacts. The goal of this task will be to develop relationships for easier market entry as well as perform research to facilitate quick integration with current facilities

Luna will work with the DOE to expand upon the probe requirements established in Task 1. As a result Luna will be able to quickly identify the market's need and adapt the prototype design to minimize the time for acceptance. Additionally, this effort will develop a preliminary test plan for execution in the Phase II and Phase III effort. Initial estimates on the testing breakdown between the Phase II and Phase III efforts will be included in the plan. Preliminary quotations will be obtained to assist in Phase II planning and to support a Phase III transition plan early in the Phase II effort.

Luna will also explore the commercial and general markets as additional avenues for marketing the technology as a condition based monitoring tool. Luna will also work with FRIB and contacts within other high magnetic field production facilities to market the technology as a field development and verification tool. Additionally the probe can be used in areas where traditional magnetic field probes are limited such as high temperature and high pressure applications. Space platforms could also be considered with tailored sensitivity to measure the relatively low magnetic fields in outer space.

G. Related Research or R&D

Research done by others

Typically, Hall effect probes are used to monitor the strong magnetic containment fields. These have an increased degradation of accuracy with neutron fluence. Recently, there has been an effort to improve the Hall Effect probe to be radiation resistant for use in accelerators.[4] These radiation resistant hall probes did see an improvement over traditional probes. There are drawbacks to using these. The semiconductor material is sensitive to damage due to radiation as opposed to pure silica fiber.[1] Additionally the Hall Effect probes are very sensitive to EMI without compensation, they have a bias voltage due to imperfections in manufacture, and are difficult to manufacture due to the exactness of the pad construction and wire connections. A commercially available Hall probe was rated to 1E15 n/cm^2 at 0.1 MeV, our proposed probes will be designed to last longer.

NMR probes are also used to measure the large magnetic fields. These consist of measuring the inducted voltage in a coil from the precession of a diamagnetic particle. The precession is

[4] I.Bolshakova, R.Holyaka, I.Duran, S.Kulikov, M.Kumada, C.Leroy, "Radiation Resistant Magnetic Sensors For Accelerators," *Proceedings of EPAC 2004,* Lucerne, Switzerland, pg 733-735.

highly dependent on the material any additional transmutation of degradation of the material characteristics makes the probe inaccurate.

Related Luna work

1. *Temperature sensors for reactor monitoring up to ~800°C*

Project : Low-Drift Ultra-High Temperature Thermal Sensors (Phase I & II),

PI: Matt Palmer

Co-PI: Joseph French

Short Title: Ultratherm II, Department of Energy (DOE) Phase II SBIR, Period: 8/15/2008 – 8/14/2011. Contract No. DE-FG02-07ER84686,

Contact: Dr. Madeline A. Feltus, US DOE, Germantown, MD, Ph: (301) 903-2308, Email: Madeline.Feltus@hq.doe.gov

The long-range goal of this project is to provide the Department of Energy with sensor instrumentation for their Advanced Test Reactor and for commercial Gen III and Gen IV reactors. To reach this goal, Luna will develop fiber optic temperature sensors and testing technology that will meet the following objectives:

Luna will systematically optimize the design and demonstrate the performance of the temperature sensors in realistic target environments. Luna aims to achieve a long-term operation temperature of 800ºC while minimizing radiation-induced temperature drift to less than 1ºC, surpassing the reactor performance of type-K thermocouples. Through rigorous thermal and nuclear pretesting, Luna will show that the temperature sensor and readout system technology are mature enough to warrant high-fluence high-temperature testing in the ATR or other similar irradiation facilities.

Luna aims to show that its temperature sensors can survive a total neutron fluence of 1 x10^{20} n/cm^2. Practice encapsulated and instrumented experiments will be performed at OSU with design constraints based on high flux test reactor requirements, to test and refine procedures such as separating unactivated sensors from the activated capsule, and testing sensor performance before and after irradiation. A high flux test reactor capsule test will be designed, certified for thermo-nuclear safety, and irradiated by MIT during the Phase II period. Post irradiation evaluation of the sensors will be performed by Luna using test methods that were refined and verified earlier in the project

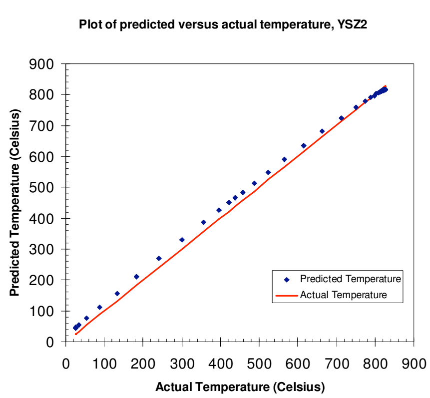


Figure 11. Plot of temperature predicted by previous calibration data (blue) and temperature recorded by K-type thermocouple. Higher than expected predictions are most likely due to timestamp errors or lag in thermocouple response in comparison to the optical sensor.

2. Demonstrated Distributed Temperature Measurement Using Rayleigh Backscatter at High Temperatures

Abbreviation:Safe-100 II

Title: Advanced Fiber-Optics Instrumentation for Early Flight Fission Research

PI: Bryan Dickerson

NASA Phase II SBIR, Contract # NNM05AB19C, 5/20/2005 – 4/15/2008

George Marshall Space Flight Center, Al

Contact: Thomas Godfroy (256) 544-1104, Thomas.Godfroy.@nasa.gov

During Phase II, Luna developed the analysis technology to replace written FBGs with intrinsic Rayleigh scattering profiles in single-mode optical fiber. Temperature distributions up to 800°C were read accurately (±2% of full scale). Annealing protocols were developed to minimize high temperature drift. A full system was demonstrated and delivered to NASA, with Luna's Optical Backscatter Spectrometer (OBR), real-time distributed temperature characterization software, and special probes for insertion into a NaK cooled reactor fuel element simulator as shown in the following figure.

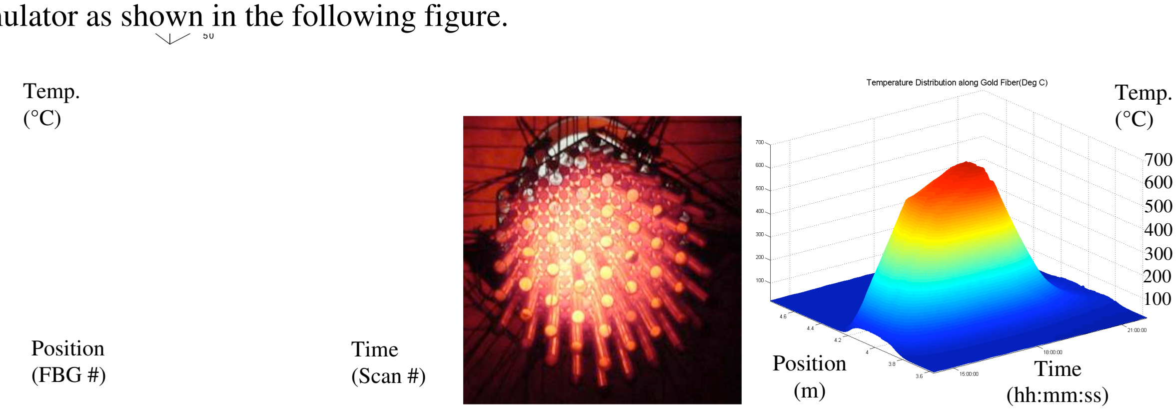


Figure 12. SAFE-100 II distributed temperature histories: Phase I Results using FBGs (LEFT), NASA's radiation free thermal simulator of a space reactor core fuel assembly (CENTER), and Phase II results using Rauleigh scattering without FBGs.

3. Testing of Fiber Optic Sensors during an Instrumented Test in a High Flux Reactor Simulating HTGR Conditions

Abbreviation: Gen-IV SIM I & II

Title: Low-Drift Temperature Sensor Gen-IV Simulation Test Planning and Hardware Development

PI: Matt Palmer

Co-PI: Joseph French

DOE STTR Phase I with Luna and INL, (8/2008 - 4/2009)

DOE STTR Phae II with Luna and MIT, (8/2009 – 9/2011)

Department of Energy, Germantown, MD

Contact: Dr. Madeline A. Feltus, (301) 903-2308, madeline.feltus@DOE.gov

This program developed a plan for testing low drift fiber optic temperature sensors in Gen-IV reactor fuel and coolant conditions at the Idaho National Lab Advanced Test Reactor. During the Phase I, reactor test capsule designs were initiated and flux, fluence, and temperature estimates were based on the ATR test position selected. During Phase II, the lead out hardware will be developed to test prototype optical fiber sensors in an ***instrumented test*** designed to reach a neutron fluence of 1E20n/cm^{-2}. Fiber optic sensors from Ultratherm II, and Neutron Spectrometer II Plus are planned to contribute to the array of sensors to be tested in this coordinated project.

*** Proprietary Information Ends Here***

H. Principal Investigator and other Key Personnel

1. Joseph French, Principal Investigator

Mr. Joseph French joined the Optical Systems Group at Luna Innovations in August 2007. Joseph French received a B.S. in Applied Physics from the University of Maryland, Baltimore County (UMBC) in 2004 and in 2007 graduated with a M.S. in Applied Physics from UMBC. During his undergraduate and graduate studies, Mr. French gained extensive experience with laser characterization, free space optical design, non-linear optics, waveguide analysis, THz spectroscopy, and computational analysis. During his work at Luna, Mr. French has worked on several DOE, DOD and NASA projects as an engineer and lead engineer. For these projects, he has developed a multitude of software interfaces and analysis tools for several DOE projects including programming for: data acquisition modules, temperature controllers, pressure controllers, motion controllers, hyperspectral imaging, machine vision, and USB interfaces. Recently, Mr. French has been lead PI on several Phase I and Phase II grants, most recently DOD's "Aircraft Tire Contact Patch Force and Shear Sensor FA9201-10-C-0113". Additionally, Mr. French is the PI on the DOE Phase III Xcelerator for Low Drift Ultrahigh Temperature thermal sensors. Mr. French has 7 publications related to optics, instrument interface design, and sensor design. **Mr. French, as the PI for this program, will assure effective planning and directing, as well as the technical success of the effort.**

2. Dr. Sandra M. Klute, Technical Director, Optical Systems Group

Dr. Klute joined the Optical Systems Group at Luna Innovations in 2004. While at Luna, Dr. Klute's responsibilities have included serving as PI and co-PI for various SBIR and non-SBIR government and commercial contracts, managing over $4.3 million in funding. Dr. Klute received a B.S., M.S. and Ph.D. in Engineering Mechanics from Virginia Polytechnic Institute and State University. Dr. Klute was a participant in the Graduate Student Researchers Program / Graduate Research Assistant, NASA Langley and VPI&SU, 1991-1999. She has extensive experience in: the use and development of flow diagnostics/3D imaging techniques in fluid dynamics and structures, conventional and fiber-optic Laser-Doppler Velocimetry, high-speed Particle Image Velocimetry, six-component force balance strain gage systems, multi-hole pressure probes and scanning pressure systems, hot-wire anemometry, flow visualization, and extensive experience with wind and water tunnel testing. Dr. Klute's research experience includes steady and unsteady delta-wing and forebody/bluff-body aerodynamics, vortex dynamics, and active control of flow transition and separation. Prior to Luna, Dr. Klute's background included lead role in management and design of rotating systems and brushless DC electric motor integration. She acted as Project Manager and Lead Mechanical Engineer for: Ingersol Milling, Navsea Mk8 Navy Seal Delivery Vehicle (SDV) Propulsion Motor, and Lead Mechanical Engineer on: Boeing Long-Term Mine Reconnaissance System Propulsion Motor (LMRS), Boeing Ballast & Trim Pump Motor. **Dr. Klute has 11 technical publications and session presentations related to her field of study.**

3. Dr. Stephen T. Kreger, Senior Optical Engineer

Dr. Stephen T. Kreger earned his Ph.D in Optics at the Institute of Optics at the University of Rochester in 1997 where he specialized in advanced ultra low-light high-speed confocal scanning laser microscopy. He next developed new high accuracy optical data storage substrate metrology techniques at NIST Boulder under a National Research Council Postdoctoral position. From 2000 to 2006 he served as an Optical Scientist and later as Chief Engineer at Blue Road Research in Portland Oregon where he developed advanced fiber optic Bragg grating sensors and sensor interrogation instrumentation. In early 2006 he joined Luna Technologies as a Senior Optical Engineer where contributes to new optical network analysis and distributed fiber optic sensing product development based on scanning laser optical frequency domain reflectometry and Rayleigh back scatter analysis. He is also heavily involved with the integration of Luna's recently purchased tunable laser design into Luna instrumentation and shape sensing system development.

I. Facilities/Equipment

1. Luna Innovations Facilities

Luna Innovations Incorporated occupies approximately 100,000 sq. ft. of research, development, manufacturing and administrative space for the development of healthcare, instrumentation, test & measurement solutions. Our headquarters facility located in the new Riverside Corporate Center in Roanoke, Virginia occupies 20,000 sq. ft. and houses our corporate team and the Secure Communications and Computing team.

Luna maintains a 32,000 sq. ft. state-of-the-art space in Blacksburg, Virginia for research, manufacturing, and product development that includes specializing in advanced materials, life sciences and optical systems. This location also includes our Luna Technologies Division.

Luna's research laboratories include extensive electronic, optical, and computer-based instrumentation that is used for advanced materials development and measurement instrumentation. The manufacturing facility houses a dedicated area for assembly of current optical fiber sensor products and signal processing systems, with other dedicated areas containing specialized equipment for the manufacturing of fiber optic gratings and thin films. Luna Innovations Incorporated is a cleared SECRET facility with SECRET storage capabilities through the Defense Security Service. Luna Charlottesville is collaborating with universities, industry, and government to develop intelligent systems, material systems, pharmaceuticals, and biomedical technologies, in a 16,800 sq. ft. technology development facility. Luna Danville (Luna nanoWorks division) located in a renovated historic tobacco warehouse, is developing and manufacturing carbonaceous nanomaterials. The 24,000 sq. ft. facility includes an 8,000 sq. ft. manufacturing floor with an additional 8,000 sq. ft. available for future manufacturing growth. Luna's Danville location is breathing new life into the Southside Virginia economy by bringing high tech manufacturing and higher education initiatives to the area.

Luna maintains an extensive set of advanced facilities to perform advanced fiber optic and materials research and development. Four labs in Luna's Blacksburg facility are dedicated to optical systems. The main optics lab includes Vytran hi-birefringence fusion splicing systems, Fujikura polarization maintaining fiber splicing system, Sumitomo and Power Technology portable fiber splicers, low temperature laboratory freezer, computer controlled nanometer resolution translation stages, multiple high resolution microscopes and three axis translation stages, MWPC-600 plasma cleaner, and two ANDO AQ-6315 Optical Spectrum Analyzers.

In Luna's **Systems Development Lab** the team uses a wide variety of state-of-the-art software and hardware tools to produce system solutions for interrogation of Luna sensors. Development simulation is accomplished using electronic workbench and PSPICE. Many system design tools are available including: Code Composer, Lab View, C and C++, Xilinx ISE, and ModelSim. ChipProbe is used for rapid implementation of Xilinx FPGA solutions to high speed, real-time system requirements as well as the ME Labs IDE and programmer for Microchip Technology devices. Luna retains the equipment and personnel to do complete PCB design, assembly and testing in house using ORCAD and PCADD software. Mechanical design and fabrication is also available using the Solid Works 3D CADD suite. A complete inventory of test equipment is maintained including Tektronix and Agilent oscilloscopes, an optical spectrum analyzer, optical power meter, signal generation and analysis equipment, lab grade powers supplies and Fluke multimeters.

The **Harsh Environment Metrology and Instrumentation (H.E.M.I.) lab** is used for processing and characterization of materials, optical fiber, sensors, sensor components, electronic systems and optical components to support sensor and system development. Equipment in this lab includes several high-temperature furnaces capable of 1500°C, a Tenney environmental chamber, Ruska high pressure calibration system, Ruska digital pressure controller, shock tube which provides high frequency pressure pulses for fast response pressure sensor characterization, and vibration exciter (shaker table).

J. Subcontractors/Consultants

Luna will not be using any subcontractors or consultants during the Phase I effort.

K. Prior, Current, or Pending Support of Similar Proposals or Awards:

No prior, current or pending support for proposed work.

L. Letter of Support

MICHIGAN STATE
UNIVERSITY

September 15, 2011

Joseph French
Luna Innovations
3157 State St.
Blacksburg, VA 24060

Dr. Georg Bollen
Professor
Experimental Systems
Division Director

FRIB
FACILITY FOR RARE ISOTOPE BEAMS

Michigan State University
East Lansing, MI
48824-1321
Tel: 517/908 7715
bollen@frib.msu.edu

Dear Mr. French:

I would like to express our interest and support of your Phase I proposal to DOE entitled "***Fiber Optic Magnetic Field Probes for Accelerator Beam Facilities***". Your proposed technology could be an advantage in the operation of the Facility for Rare Isotope Beams (FRIB), which is being designed and constructed at MSU.

The particular challenge at FRIB are the very high radiation levels present in the frontend of the fragment separator, caused by the 400 kW primary beam interacting with the rare isotope productions target and the primary beam dump. An accurate knowledge of the magnetic field of the first dipoles in the fragment separator is needed for selecting the isotopes desired. Conventional NMR field probes would not survive the radiation fields for any reasonable time once full-power operation of FRIB is achieved. The presently planned approach for FRIB is to turn off the beam for every field measurement, to insert the probe, and then to retract it into a shielded position after the magnetic field is measured and before the beam is turned on. This is very inefficient and will lead to long beam tuning time. Your proposed magnetic field sensing technology has the potential to provide continuous field measurements even in high radiation environment and is therefore of very high interest to the FRIB project.

With the operational Coupled Cyclotron Facility at NSCL/MSU we would be able to provide Luna the possibility to test the proposed technology in radiation field similar to those at FRIB. We would like to continue working with you throughout this project to assist in the specification of performance metrics and integration considerations necessary to transform this Phase I effort into a successful product.

We wish you the best of success in your proposal process. Please contact me if you need any additional information.

Sincerely,

G. Bollen

Georg Bollen

VirginiaTech
College of Science

Chemistry Department, Analytical Services
Hahn Hall (0212)
Blacksburg, Virginia 24061
540/231-6578 Fax: 540/231-3255
E-mail: genoi@vt.edu
www.vt.edu

11/4/10

To whom it may concern,

Luna Innovations has been granted access to the NMR laboratory and instrumentation to perform experiments to expose test materials to intense magnetic fields. The current rate for use of our facility is $90.00/hr.

Geno Iannaccone
Dir Analytical Services

G Iannaccone

Commercialization Plan

The data contained in pages 1-11 of this commercialization plan have been submitted in confidence and contain trade secrets or proprietary information, and such data shall be used or disclosed only for evaluation purposes, provided that if this applicant receives an award as a result of or in connection with the submission of this application, DOE shall have the right to use or disclose the data herein to the extent provided in the award. This restriction does not limit the government's right to use or disclose data obtained without restriction from any source, including the applicant.

1 Introduction

Luna Innovations Incorporated (Luna) proposes to develop a radiation resistant magnetic field probe based on an all optical fiber approach to monitor magnetic fields in high neutron flux environments. The development of the fiber optic sensing system under this program can address several monitoring applications including superconducting magnets (>7000 MRI machines in the US)[1], nuclear reactors (>100 reactors Licensed by the NRC in the US), high temperature environments (jets, turbines, etc.), high pressure environments, plasma facilities, and space platforms (23 satellites launched in 2010). If just the reactors and a small portion of the superconducting magnet facilities employed a single field probes this would be recurring revenue of $300K for the probes with instrumentation revenue of $10M. Initially, the magnetic field probe will be marketed to government and university research facilities for use in basic scientific research and DOE guided applications. Additionally, the market can be expanded to include superconducting magnets which have a need for the field probe integrated into their complex control loops.

2 Company Information

The Luna Business Model --- ***inspired by ideas…driven by markets***

Luna Innovations develops and manufactures new-generation products for the healthcare, telecommunications, energy and defense markets. Our products are used to measure, monitor, protect and improve critical processes in the markets we serve. Through its disciplined commercialization business model, Luna has become a recognized leader in transitioning science to solutions (see Figure 1).

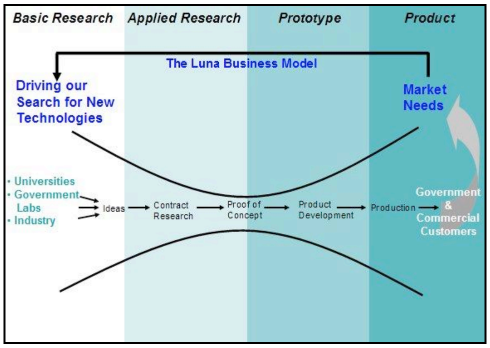


Figure 1. Luna's model for driving technologies to commercialization.

[1] **OECD Health Data 2011 http://www.oecd.org**

Nearly 200 professionals are employed in basic research, development, administration and production. We have offices strategically located throughout Virginia in Blacksburg, Charlottesville, Danville and Roanoke.

2.1 Technology Development

Luna's innovation engine lies in its Technology Development Division. Engineers and scientists located throughout Luna collaborate with a network of experts in academia, federal labs and business to identify technologies and develop ideas with market potential. Technology development is focused in four areas: sensors and systems, health sciences, materials, and secure computing & communications. Luna continues to develop technology and expand the sensing product portfolio. The depth and breadth of sensing technology that exists at Luna is a solid foundation for future developments and provides a high potential opportunity and focus for the company. Luna has a reputation for excellence and outstanding performance in R&D. Luna has been recognized three times with a national *Tibbetts Award* (2006, 2002 and 1998), which is presented to companies that best exemplify the philosophy and doctrine of the Small Business Innovation Research (SBIR) program.

2.2 Investment in Optical Sensor Products

Luna is committed to developing SBIR research into commercial products using internal investment to supplement external funding. Luna is investing > $5M/yr of a combination of our own and commercial contracts in commercializing the sensors and instrumentation which have originated from SBIR or other government funding.

2.3 Optical Products and Emerging Solutions

Commercialization of SBIR technology has been focused through product sales and licensing agreements in sensing & instrumentation. In 2010 Luna had nearly $9M in sales of optical instrumentation sensors resulting from SBIR funded technologies. This includes solutions for federal markets, healthcare, telecommunications, energy, industry, and university research organizations. Historical optical sensing products that have been developed through the SBIR/STTR program and offered by Luna Innovations include the FOSS-1, FOSS-3, AFSS, FiberPro2 USB, MUX-8 (8 channel fiber optic multiplexer), Aeroscan, FiberScan 2000, Hyperscan, and Lunascan 3000 (chemical and biological sensing).

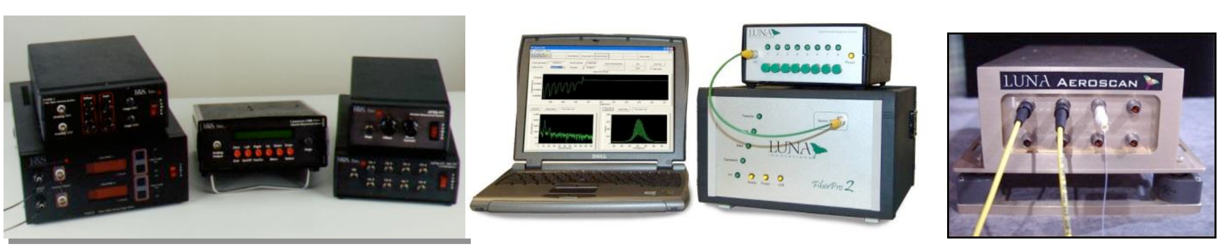


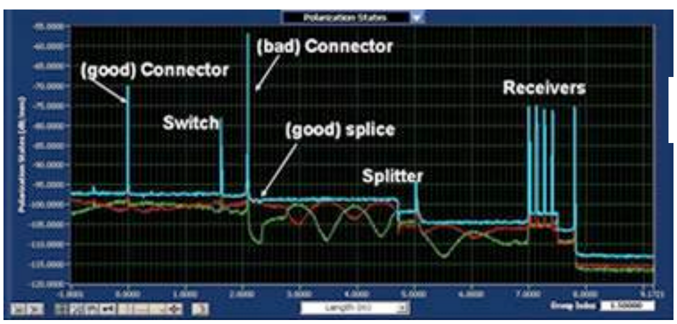
Figure 2: Historical Luna Products

Luna Technologies is the name of the company's current offering of branded products for fiber optic test & measurement and sensing instrumentation. This business unit of Luna Innovations began in 2000 and is today attaining its goal of becoming a premier supplier of optical instrumentation to customers worldwide. Luna's fast, accurate, flexible, and cost-effective instrumentation is used for process and control monitoring in telecommunications manufacturing, power generation and distribution, down-hole oil and gas production, aerospace and defense applications.

2.4 Fiber Optic Test Products:

- Optical Vector Analyzer™ (OVA) Platform
- Optical Backscatter Reflectometer™ (OBR) Benchtop
- Optical Backscatter Reflectometer™ (OBR) Portable
- Tunable Laser Platform (Phoenix Laser)
- Optical Manufacturing Solutions
- Fiber Optic Switches
- Lightpath Analysis software

Portable OBR



OVA

Figure 3: OVA Data

2.5 Fiber Sensing Solutions:

- Distributed Sensing System™ (DSS 4300) – strain and temperature profile sensing with Fiber Bragg Gratings (FBG)
- Optical Backscatter Reflectometer™ (OBR 4600) with distributed sensing of strain and temperature (with fiber fingerprinting)

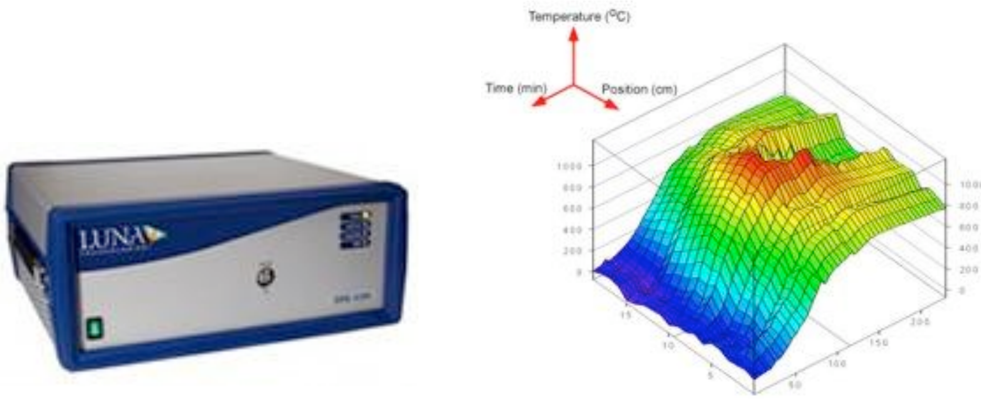


Figure 4: DSS 4300 and distributed temperature measurement data (Temperature, Time and Position)

Planned product releases this year include the DSS 8600, a high speed (+500 Hz), distributed sensing system for strain. Industries that are expected to be the first adopters of this technology are automotive and aerospace testing and R&D and motorsports. Additionally, the ODiSI (Optical Distributed Sensing Instrument) is in the early stages of production and has improved user interfaces and sensing fiber locating software to improve ease of use.

2.6 History of Success

Luna has successfully negotiated business agreements (e.g. licenses, license options, etc.) for the commercialization of various materials and sensing technologies. Fiscally, Luna has experienced extensive revenue growth since 2000. For every $1 of SBIR funding awarded, Luna has generated over $2.48 in non-SBIR funding, not including the revenue generated at our spinout companies. A recognized leader in technology transfer, government-funded research has enabled Luna to develop concepts into commercial reality. We have developed more than a dozen products serving various industries including energy, telecommunications, life sciences and defense all tracing origination to government funded research.

Luna Technologies, a division of Luna Innovations Incorporated, manufactures and markets test & measurement equipment and integrated sensing solutions. Luna Technologies is recognized as a technology leader offering revolutionary products through a well-established global distribution network. Its award-winning products provide all-parameter analysis of optical component and sub-assemblies allowing manufacturers and suppliers to reduce costs and time-to-market by improving component characterization and production schedules. Luna has also developed version of the technologies for integration with standard instruments such as those from fiber optic leader JDSU aimed at field-deployable platforms for installation and maintenance testing of modern fiber optic networks.

Luna Energy was helped by the NIST Advanced Technology Program (ATP) to fund research on real-time, state-of-health pipeline monitoring using fiber optic sensors. The company was acquired in December 2004 by Baker Hughes Incorporated, a leader in oil field services.
Luna's shape sensing platform, the basis of the navigational system under development with Intuitive Surgical for robotic surgical devices, was developed using an estimated $5 million of government contracts.

Since the generation and protection of intellectual property (IP) is critical to our future success, we continuously seek to expand our IP portfolio by applying our disciplined processes to generate know-how and intellectual property through our external network of relationships with industry, academia, and Federal Labs and internal research and development efforts. By continuing to expand our IP, we will seek to enhance our competitive position and develop additional products in these new product areas.

Involvement outside of the traditional work environment to advance technology and economic development includes Luna employees serving on state and national boards and committees that establish policies and action plans to promote technology-based economic growth; build partnerships between industry, government and academia; improve the environment for growth of technology-based industry; and mentor entrepreneurs and the future technology workforce to stimulate technological innovation. These boards/committees include: the National Research Council and the National Academies SBIR Steering Committee; the Alliance for Science and Technology Research in America; the Virginia Research and Technology Advisory Commission; the Virginia Joint Commission on Technology and Science; and the Task Force on the Future of American Innovation.

In conclusion, Luna has been very successful at bringing SBIR technology to market earning a Commercialization Achievement Index of 80. Fiscally, Luna has experienced extensive revenue growth since 2000. For every $1 of SBIR funding awarded, Luna has generated over $2.48 in non-SBIR funding, not including the revenue generated at our spinout companies. Our research continues to produce new products, technologies and jobs - all proof that Luna is exceeding the returns envisioned by our Federal R&D partners.

3 Market

Market overview

According to a recent BCC market research study,[2] the global market for superconductivity applications was worth an estimated $1.7 billion in 2009, a figure that is expected to reach nearly $2 billion in 2010 and nearly $3.4 billion in 2015, a compound annual growth rate (CAGR) of 11.3% over the next 5 years as shown in Figure 5. Superconducting magnets, particularly those used in science, research and technology development, and healthcare applications dominate the market. This sector is estimated at $1.9 billion in 2010 and is expected to be worth nearly $2.4 billion in 2015, a compound annual growth rate (CAGR) of 4.2%. Superconducting electrical equipment (e.g., transformers, generators, motors, fault current limiters, power storage, cable) is expected to capture nearly 25% of the market by 2015. This sector was estimated at $23 million in 2010 and is expected to reach $889 million in 2015, a compound annual growth rate (CAGR) of nearly 107%. Included in these estimates are the costs of the control instrumentation that is necessary to ensure safe performance and operation. If 150 superconducting facilities used has several field probes at a cost of $2000 each with an associated demodulation system currently estimated at $100K this is a $15M market with $0.9M in recurring revenue every year.

[2] http://www.bccresearch.com/report/AVM066B.html

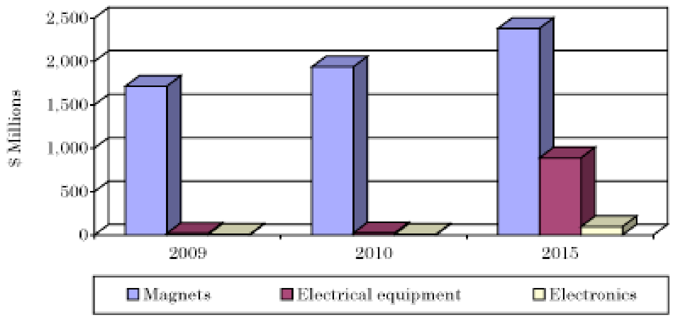


Figure 5: **Global market for superconductor technologies**

Superconducting magnets are necessary for a number of applications from scientific research (e.g. x-ray diffraction, scanning tunneling microscope, and particle accelerator) to medical field (e.g. Magnetic Resonance Imaging). Superconducting magnets also have been applied in nuclear power and propulsion systems. The development of the novel and low cost magnetic field probes under this program can be applied for the health monitoring of superconducting magnets. The main application areas are expected to be Nuclear Magnetic Resonance (NMR) and Magnetic Resonance Imaging (MRI) due to the size of the commercial market and the applicability of the technology to reduce installation, operation, and maintenance costs.

Potential applications

Traditionally the first market for superconducting magnets is for science, research and technological development (RTD) which covers a broad range of different types of applications: from rather small laboratory magnets up to huge and sometimes quite complex structures for big science projects in high-energy physics like high-energy particle colliders or fusion experiments. The biggest market for superconducting magnets is Magnetic Resonance Imaging (MRI) which experienced significant growth beginning of the 1980's. It has become a well established diagnostic tool routinely used in hospitals. The ability to provide real-time information for superconducting magnets is an important diagnostic tool for the effective design, construction and protection of the superconducting magnets. Due to the optical characteristics of the optical probe, distributed sensing is a natural extension of the probe technology. By providing a distributed magnetic field profile, MRI machines could modify their output to provide enhanced imaging and increase their signal to noise ratio.

The development of the system under this program can address several markets such as superconducting magnet for cryogenic application, nuclear reactors, and accelerator facilities. Luna's initial market focus will be on the harsh environment application market (accelerators and reactors), with secondary focus on the cryogenic superconducting markets with lower temperatures. Additional markets will also be space platforms and plasma facilities.

The first product to be introduced resulting from this project, a magnetic sensing system for containment monitoring, will be marketed for use in the Facility for Rare Isotope Beam (FRIB) and similar facilities. The benefits of the use of this proposed sensing system are expected to minimize the need for replacement probes and provide reliable information of magnetic field strength. Luna will be working closely with DOE to develop a system with relevant performance specs that will be easily integrated into the existing magnet fields at the beam facilities and cooperate with industrial partners to gain rapid market acceptance for other applications.

4 Commercialization Strategy

Luna Innovations' mission is to identify significant problems, apply innovative science and technology to generate unique solutions, and provide the launch pad to fully develop their commercial potential. Luna is a next-generation, employee-owned company that has built a complete network for driving innovative technologies through the development cycle all the way to fully functioning commercial products. Luna produces and distributes products that address billion dollar markets.

While the focus of this project is to develop a fiber optic sensing system for monitoring the magnetic field of containment magnets, a greater market potential includes superconducting magnet monitoring applications to provide magnetic field information at the low temperatures and has the possibility to be used as a distributed sensor. Once beta prototypes and a market opportunity have been demonstrated, Luna typically transitions product development to a subsidiary company or to Luna's Product Division. Somewhat similar platforms and system development have already been transitioned to the Product's Division. The Products Division has a healthy revenue stream from product sales and internally funds final-stage product development, marketing, and production ramp-up. For the proposed system, final product development is estimated to cost $1.5M. Since there already exists a Product Division for fiber optic systems, transitioning the magnetic field sensing system to a commercial product would be relatively straightforward. Luna is intentionally structured to create a Products Division for each category of technology under development to facilitate rapid transition. Examples of previous technologies that have been brought to market and the methods used to obtain product development funding include:

Figure 6: Luna's OBR 4400.

Telecommunications test and measurement:

In 2000, Luna Innovations launched Luna Technologies to commercialize OFDR technology in the telecom industry, Figure 6. This award-winning company maintained and expanded a profitable product portfolio throughout the telecom down-turn and is now a world leader in the industry. Luna recently re-acquired Luna Technologies and their three separate product lines.

Pressure and temperature instrumentation for oil exploration:

Luna teamed with Baker Hughes to develop a fiber optic pressure and temperature instrumentation system for down-hole monitoring in off-shore drilling applications. Luna Energy was formed which deployed the system on field rigs and was ultimately acquired by Baker Hughes.

Emboli detection system for surgical applications

Luna recently formed a partnership with Carillion Health Systems to launch a series of biomedical product. The EDACTM Quantifier blood circuit monitor uses advanced ultrasound technology to non-invasively count and classify emboli in the bloodstream, greatly increasing patient safety during surgery. This award-wining product (Figure 7) is currently in production with increasing sales projected as the technology gains acceptance.

Figure 7: Luna's EDAC-card.

Wireless networking and instrumentation: Luna Innovations formed a joint venture, Luna iMonitoring, with IHS Energy to launch a wireless network product which provides instrumentation to oil well pumping operations. The system is used to monitor pump productivity in real time via satellite link allowing the user to optimize operations based on market demand. Luna Wireless was acquired by IHS Energy.

Competitors, and Luna's price and quality advantages

There is a small number of researchers developing or offering radiation resistant magnetic field sensing, though to date these are all non-optical in nature. To our knowledge, no one has developed or is developing a complete integrated radiation resistant magnetic field detection system based on an all optical approach. Luna is the world leader in the fiber optic sensor and instrument. Luna has been successfully developing sensing systems for over 16 years and is well aware of the limitations of our own and competing platforms. Luna has extensive experience in harsh environments as well with >450 reactor hours. The proposed system will address all of the shortcomings of previous instrumentation and will be a highly competitive product.

The proposed system is based on an approach conceived specifically to provide:

i) Large magnetic field sensing with high accuracy

ii) Radiation tolerant

iii) Real time monitoring. The proposed fiber optic sensing system provides temperature and magnetic field monitoring in real time

iv) Operation in Harsh environment with electromagnetic interference (EMI) cross sensitivity immunity along the lead length.

v) Small foot print with a single lead from demodulation system to probe.

vi) Provide sensor health monitoring of the field probes.

The magnetic field monitoring system of containment fields developed under this program will be the most competitive fiber optic magnetic field monitoring and management system on the market. Additionally, this system will not suffer from the typical instabilities found in other sensing systems. It will truly be a turn-key system that is robust and operable by untrained technicians. Therefore, this system will be highly competitive ensuring successful commercialization. Development of this system into a turn-key instrument will enable its rapid acceptance in the accelerator facilities and superconducting magnet markets.

Luna has a well-staffed sales and marketing team which conducts market analysis for new technology introduction, establishes and maintains contact with key customers including commercial and government customers, and provides guidance to the R&D Division to help focus technology development towards significant market demands. Luna's Commercial Projects Group will follow the ongoing work to complete the Phase II effort, and be involved in building relations with the customer companies. Manufacturing will provide guidance on production costs for the system and assure that the configuration being developed is properly controlled and is producible at the volumes required. Marketing will provide market assessments and guidance on other companies/industries to approach for potential sales and will develop appropriate marketing strategies. All of the relevant business development expertise and staffing requirements are currently in place. No additional key technical personnel are required, although additional technician support may be added as workloads increase.

Table 1: Skills and Experience of Key Management and Technical Personnel Relevant to Bringing Innovative Technology to Commercial Application

Name/Title	Experience Summary
Mr. Joseph French, PI	Mr. Joseph French joined the Optical Systems Group at Luna Innovations in August 2007. Joseph French received a B.S. in Applied Physics from the University of Maryland, Baltimore County (UMBC) in 2004 and in 2007 graduated with a M.S. in Applied Physics from UMBC. Mr. French has extensive experience with laser characterization, free space optical design, non-linear optics, waveguide analysis, THz spectroscopy, and computational analysis. During his work at Luna, Mr. French has worked on several DOE, DOD and NASA projects as an engineer and lead engineer. For these projects, he has developed a multitude of software interfaces and analysis tools for several DOE projects including programming for: data acquisition modules, temperature controllers, pressure controllers, motion controllers, hyperspectral imaging, machine vision, and USB interfaces. Recently, Mr. French has been lead PI on several Phase I and Phase II grants, most recently DOD's "Aircraft Tire Contact Patch Force and Shear Sensor FA9201-10-C-0113". Additionally, Mr. French is the PI on the awarded DOE Phase III for Low Drift Ultrahigh Temperature thermal sensors.
Dr. Sandie Klute Technology Director, Optical Systems Group	Dr. Klute joined the Optical Systems Group at Luna Innovations in 2004. While at Luna, Dr. Klute's responsibilities have included serving as PI and co-PI for various SBIR and non-SBIR government and commercial contracts, managing over $4.3 million in funding. She has extensive experience in: the use and development of flow diagnostics/3D imaging techniques in fluid dynamics and structures, conventional and fiber-optic Laser-Doppler Velocimetry, high-speed Particle Image Velocimetry, six-component force balance strain gage systems, multi-hole pressure probes and scanning pressure systems, hot-wire anemometry, flow visualization, and extensive experience with wind and water tunnel testing. Prior to Luna, Dr. Klute's background included lead role in management and design of rotating systems and brushless DC electric motor integration. She acted as

	Project Manager and Lead Mechanical Engineer for: Ingersol Milling, Navsea Mk8 Navy Seal Delivery Vehicle (SDV) Propulsion Motor, and Lead Mechanical Engineer on: Boeing Long-Term Mine Reconnaissance System Propulsion Motor (LMRS), Boeing Ballast & Trim Pump Motor.
Dr. Stephen Kreger Senior Optical Researcher	Dr. Stephen T. Kreger earned his Ph.D in Optics at the Institute of Optics at the University of Rochester in 1997 where he specialized in advanced ultra low-light high-speed confocal scanning laser microscopy. He next developed new high accuracy optical data storage substrate metrology techniques at NIST Boulder under a National Research Council Postdoctoral position. From 2000 to 2006 he served as an Optical Scientist and later as Chief Engineer at Blue Road Research in Portland Oregon where he developed advanced fiber optic Bragg grating sensors and sensor interrogation instrumentation. In early 2006 he joined Luna Technologies as a Senior Optical Engineer where contributes to new optical network analysis and distributed fiber optic sensing product development based on scanning laser optical frequency domain reflectometry and Rayleigh back scatter analysis. He is also heavily involved with the integration of Luna's recently purchased tunable laser design into Luna instrumentation and shape sensing system development.
Dr. Mark Froggatt Chief Technology Officer	Mark Froggatt has been our Chief Technology Officer since September 2005. Prior to joining Luna, he co-founded Luna Technologies in the Fall of 2000 to develop instrumentation for fiber optic devices and served as Chief Technology Officer until Luna Technologies was acquired by Luna Innovations in September 2005. Before joining Luna Technologies, he worked at NASA Langley developing ultrasonic and optical instrumentation. Mark received a bachelor's and master's degree in Electrical Engineering from Virginia Tech and a doctoral degree from the Institute of Optics, University of Rochester. He has 15 issued patents in ultrasound and optics.
Dr. Ken Walker, Executive Vice President of Technology Development Division	Dr. Walker has served as Executive Vice President of Luna's since May 2005. He is a founder and former President of Specialty Photonic Devices, a business unit of OFS Fitel which focused on the development of proprietary materials and which was purchased from Lucent Technologies, Inc. He is also a former head of optical fiber research at Bell Laboratories. Dr. Walker received a bachelor's degree from the California Institute of Technology and a doctorate from Stanford University. He is a member of the National Academy of Engineering and holds more than 50 patents.
Mr. Scott Graeff, Chief Commercialization Officer	Scott has served as our Chief Commercialization Officer since August 2006. His responsibilities include operations along with oversight of all commercialization efforts, strategic initiatives and business development activities. Scott has also served as our Chief Financial Officer and Executive Vice President, Corporate Development, and was a member of Luna's Board of Directors from August 2005 until March 2006. He has financial management, strategic planning and

	capital markets experience in both privately and publicly held companies. During his career, has has been the Managing Director of a venture capital fund, the CFO of a software technology company that was sold to a Fortune 500 Company, and has held senior-level positions at various investment banking firms. In these various roles, Scott has completed a public offering and has been involved with mergers and acquisitions with a notional value of more than $8 billion. He is experienced in a broad range of capital market transactions, strategic planning, and financial management.

Schedule of quantitative commercialization results

Phase I

The development commercialization strategy will be an ongoing effort during Phase I. Luna will establish close contact with commercial and OEM partners to specify design goals. A major thrust of this objective will be the design of the system to be installed into the facilities being built for the FRIB. Allowing the end users to specify performance parameters will lead to the rapid commercialization of the proposed system. Another major thrust is to design the system for reasonable cost, reasonable-volume manufacturing.

During Phase II

Early in the Phase II project, Luna will thoroughly survey the market to determine the most relevant areas where we can leverage the current development to meet a near-term opportunity. Key customers and relevant specifications/target performance metrics will be identified. Luna will leverage the research to meet the broadest market possible while still meeting all of the project requirements.

At completion of Phase II

By the end of the Phase II, Luna expects to have a prototype system as well as test data available to demonstrate to potential customers to solicit prototype sales. It is anticipated that a limited number of beta prototypes will be produced and sold in the year after the Phase II is complete while customers evaluate the technology. Internal investments will be made to secure the necessary intellectual property. Based on previous history, and market surveys, Luna anticipates selling approximately several systems valued at ~ $150,000 each. The probes will also be sold with the systems, each probe would cost ~$2000. Multiple probes could be sold to a single customer increasing their monitoring capabilities.

After completion of Phase II

Following limited beta prototype sales, Luna anticipates receiving larger orders for production units from early-adopter customers. It is anticipated that system production would be transitioned to Luna's Product Division and internal investments used to finalize product development. Sales Revenues during this Phase are expected to ramp from $0.5M/year to $3M/year over five years.

Summary:
1st year sales: **$0.5M**
5th year sales: **$3M**
Sales over 5years after Phase II completion: **$8M**

5 Intellectual Property

The mission of Luna Innovations is effectively summed up in our business slogan: *Ideas Taking Flight*. Thus, protection of intellectual property is a company priority at Luna. Identification and protection of IP is the responsibility of the Vice President of Operations at Luna. Luna understands that high technology business success is built on a foundation of well-protected IP, whether developed internally at Luna or licensed from outside the company.

Management of IP at Luna is performed via a number of established processes and procedures that guarantee early identification and protection of internally developed inventions. These processes are summarized below.

Invention disclosure program: Laboratory notebooks are logged, and the individual pages are signed, dated and witnessed. Standard invention disclosure forms are provided on our intranet, and are logged into the system as they are filed by the inventors. Once logged in, the disclosures are reviewed for further protective action by an IP review committee.

IP review committee: The IP review committee consists of the VP of Operations, the technical Group Directors, the VP of R&D and the President. Monthly committee meetings are convened during which the invention disclosures are discussed individually with each inventor after prioritization by Group Directors. At the conclusion of these meetings, each disclosure is assigned a protection class and priority, and relevant further protective action is determined.

Protection Classes: Based on the discussion and explanation provided to the committee in the disclosure and orally by the inventor or Group Director, a protection class is assigned to each disclosure. These classes generally fall under the categories of “utility application” if the invention is fully formulated with adequate supporting data to warrant immediate filing of a patent application, “provisional application” if the invention is noteworthy but not developed enough for a full application, or “trade secret” if the invention appears to be unpatentable or if it makes business sense to prevent public disclosure altogether.

Review by legal counsel: Decisions made by the committee are submitted to Luna’s patent attorneys for review, especially when patentability issues are involved. Infringement is watched by recurring scheduled web searches and review of Delphion searches and notifications. Also, nondisclosure agreements are put in place when meetings/discussions are held with outside groups or individuals.

Owned and Licensed Patents: Luna owns several patents related to the proposed research as well as owns licenses for the OFDR technology. The patents that are related are listed below:

U.S. Patent No. 6,856,400
U.S. Patent No. 6,900,897
U.S. Patent No. 7,042,573
U.S. Patent No. 7,330,245
U.S. Patent No. 7,538,883

Luna is licensing the OFDR technology from NASA under the patents:

U.S. Patent No. 6,376,830
U.S. Patent No. 6,426,496

SBIR/STTR Commercialization History

Small Business Name: Luna Innovations Incorporated

					Sales and Revenue					Investment					
Agency	Grant / Contract#	Year of Award	Project Title	Award Amount	SP	SF	SO	LR	Total Award Sales	IS	IF	AI	VC	OI	Total Award Investment
NIH	1-R44-GM074373	2009	Sutureless Resorbable Anti-Adhesion Films	866,925	0	0	0	0	0	0	0	0	0	0	0
NIH	2 R44-DE018582	2010	Delipidated Adipose Grafts for Craniofacial Reconstruction	1,114,064	0	0	0	0	0	0	0	0	0	0	0
UDA	20053361016470	2005	Groundwater Flow Monitor 2	296,000	0	0	0	0	0	0	724,684	0	0	251,143	975,827
NIH	2-R44-AI066612	2008	Development of RSK Inhibitors as Novel Therapeutics for Yersinia Pestis	2,092,698	0	0	0	0	0	0	0	0	0	0	0
NIH	2-R44-AR053750	2008	Model Acute Compartment Syndrome Study	737,302	0	0	0	0	0	0	0	0	0	0	0
DOC	50-DKNB-9-90128	1999	Composite Process Monitor II	275,000	86,381	0	0	0	86,381	0	0	0		188,024	188,024
NIH	5R44EY013902-03	2005	Miniature Non-invasive IOP Measurement Device	824,829	0	0	0	0	0	0	0	0	0	0	0
EPA	68D-70059	1997	LPG/Pesticide Detection II	224,927	174,368	0	0	0	174,368	0	0	0	0	181,368	181,368
UDA	99-33610-7889	1999	LPG Refractometer II	220,000	219,115	0	0	0	219,115	0	0	0	0	348,200	348,200
Army	DAAB07-02-C-P612	2002	Bluetooth II	729,962	0	0	0	0	0	0	0	0	0	0	0
Army	DAAD13-01-C-0016	2001	Chem Detection II	727,762	0	303,037	0	0	303,037	0	0	0	0	0	0
Army	DAAD13-99-C-0026	1999	Microcantilever Biosensor II	749,947	235,569	0	0	0	235,569	0	0	0	0	512,756	512,756
Army	DAAD19-00-C-0116	2000	Molecular Microarrays II	499,950	157,041	0	0	0	157,041	0	0	0	0	341,827	341,827
Army	DAAD19-03-C-0114	2003	Fluorosomes II	447,358		52,002	0	0	52,002	0	0	0	0	0	0
Army	DAAD19-03-C-0115	2003	Cell Viability II	348,457	11,637	0	0	0	11,637	0	0	0	0	0	0
Army	DAAD19-03-C-0139	2003	Compartment Syndrome II	352,516	597,719	500,764	0	0	1,098,483	0	0	0	0	0	0
Army	DAAE30-03-C-1056	2003	Gun Barrel Ph. 2	675,655	57,019	130,387	0	0	187,406	0	0	0	0	0	0
Army	DAAH01-02-C-R084	2002	Tunable MicroDevices II	749,940	0	0	0	0	0	0	0	0	0	0	0
Army	DAAH01-94-C-R010	1994	Smart Structures	494,915	1,215,897	7,079	0	0	1,222,976	0	0	0	0	455,271	455,271
Army	DAAJ02-96-C-0034	1996	Cure Monitoring II	599,982	1,505,636	0	0	0	1,505,636	0	0	0	0	1,062,571	1,062,571
Army	DACA42-01-C-0010	2001	Blast Sensors II	364,975	915,893	222,238	0	0	1,138,131	0	0	0	0	646,372	646,372

					Sales and Revenue					Investment					
Agency	Grant / Contract#	Year of Award	Project Title	Award Amount	SP	SF	SO	LR	Total Award Sales	IS	IF	AI	VC	OI	Total Award Investment
Army	DAMD17-02-C-0098	2002	Yeast Based Biosensor for Organophosphate Detection	563,082	0	0	0	0	0	0	0	0	0	0	0
Army	DASG60-02-C-0043	2002	Fullerene Polymer Photovotaic	749,992	0	0	0	0	0	0	250,000		0	0	250,000
DOE	DE-FG02-02ER83485	2003	Power Turbine Sensors II	734,378	73,115	0	0	0	73,115	0	0	0	0	0	0
DOE	DE-FG02-04ER83991	2005	High Temperature Fiber Optic Sensors for Nuclear Applications	749,969	3,138,297	114,055	0	0	3,252,352	0	0	0	0	3,080,907	3,080,907
DOE	DE-FG02-05ER84389	2005	EXECS II	749,932	0	0	0	0	0	0	0	0	0	0	0
DOE	DE-FG02-06ER84628	2007	Neutron Spectrometer II	846,771	0	0	0	0	0	0	32,612	0	0	0	32,612
DOE	DE-FG02-07ER84686	2008	Low-Drift Ultra-High Temperature Thermal Sensors	826,515	0	2,900,000	0	0	2,900,000	0	3,182,596	0	0	0	3,182,596
DOE	DE-FG02-07ER84776	2008	High-Throughput In-line PV Manufacturing Diagnostic System	843,037	0	0	0	0	0	0	0	0	0	0	0
DOE	DE-FG02-07ER84806	2008	Carbon Nanosheets as Nanostructured Electrode in Organic Photovoltaic Devices	849,539	0	0	0	0	0	0	249,999	0	0	0	249,999
DOE	DE-FG02-08ER86348	2009	Low-Drift Temperature Sensor Gen-IV Simulation Test Planning and Hardware Development	749,740	0	0	0	0	0	0	32,611	0	0	0	32,611
DOE	DE-SC0003537	2010	Recovery Act - Advancement of Nanomaterial Production for OPV Acceptors	1,000,000	0	0	0	0	0	0	0	0	0	0	0
DOE	DE-SC0003542	2010	Recovery Act - Radiation Tolerant Ultra High Temperature Sensors for In-Core Use	1,000,000	0	0	0	0	0	0	0	0	0	0	0
NSF	DMI-0080372	2000	LPG Pathogen Detection II	449,464	348,435			0	348,435	0	0	0	0	711,380	711,380
NSF	DMI-0110370	2001	Flat Panel Displays II	499,913	0	0	0	0	0	0	0	0	0	0	0
NSF	DMI-0321630	2003	NMR Medical Phase	490,996	19,608	4,233,416	0	0	4,253,024	0	0	0	0	0	0
NSF	DMI-0349691	2003	Chem Separation II	499,958	0	2,159,895	0	0	2,159,895		7,106,640			7,350,000	14,456,640
NSF	DMI-0422010	2004	Lipids II	460,789	0	0	0	0	0	0	0	0	0	0	0

SBIR/STTR Commercialization History

					Sales and Revenue					Investment					
Agency	Grant / Contract#	Year of Award	Project Title	Award Amount	SP	SF	SO	LR	Total Award Sales	IS	IF	AI	VC	OI	Total Award Investment
NSF	DMI-9322477	1996	Adaptive Vibration II	298,741	1,724,778	0	0	0	1,724,778	0	0	0	0	204,256	204,256
NSF	DMI-9901833	1999	LPG Bioremediation II	687,131	532,679	0	0	0	532,679	0	0	0	0	1,087,542	1,087,542
DTR	DTRA01-00-C-0075	2000	Fluorescent LPG II	749,987	581,407	0	0	0	581,407	0	0	0	0	1,187,026	1,187,026
DOT	DTRS57-01-C-10037	2001	Skid Warning II	199,979	501,841	0	0	0	501,841	0	0	0	0	354,164	354,164
EPA	EP-D-06-079	2006	Nano Remediation 2	224,963	0	0	0	0	0	0	0	0	0	0	0
Air Force	F08630-00-C-0009	2000	Neural Nets II	499,990	157,054	0	0	0	157,054	0	0	0	0	341,855	341,855
Air Force	F29601-03-C-0193	2003	Directed Energy Target II	658,078	28,293	43,491	0	0	71,784	0	0	0	0	0	0
Air Force	F29601-95-C-0208	1995	TRP II	749,020		0	0	0	0	0	0	0	0	689,021	689,021
Air Force	F29601-96-C-0156	1996	SMATTE II	482,642	151,605	0	0	0	151,605	0	0	0	0	536,557	536,557
Air Force	F33615-93-C-3616	1993	Structural Integration	494,711	0	0	0	0	0	0	0	0	0	455,083	455,083
Air Force	F33615-02-C-2293	2002	Sapphire Temperature Sensor II	749,984	0	235	0	0	235	0	0	0	0	0	0
Air Force	F33615-03-C-5600	2003	Aging DSS II	674,938	2,841,263	210,132	0	0	3,051,395	0	0	0	0	658,360	658,360
Air Force	F33615-96-C-3210	1996	Microphone II	749,970	180,947	412,384	0	0	593,331	0	0	0	0	0	0
Air Force	F33615-97-C-2713	1997	Skin Friction II	709,407	2,092,553	0	0	0	2,092,553	0	0	0	0	1,741,401	1,741,401
Air Force	F33615-98-C-2821	1998	LPG Fuel Contaminants II	792,921	614,690	0	0	0	614,690	0	0	0	0	639,366	639,366
Air Force	F33615-98-C-5410	1998	Smart Sensors II	745,516	269,769	0	0	0	269,769	0	0	0	0	509,727	509,727
Air Force	F33615-99-C-2908	1999	Silicon Carbide II	743,566	2,099,520	0	0	0	2,099,520	0	0	0	0	1,825,252	1,825,252
Air Force	F33615-99-C-5004	1999	Graded Structures II	746,404	234,456	0	0	0	234,456	0	0	0	0	510,334	510,334
Air Force	F33657-93-C-2300	1993	NASP	491,213	2,439,486	7,026	0	0	2,446,512	0	0	0	0	1,321,806	1,321,806
Air Force	F40600-00-C-0012	2000	Sting Balance II	597,796	0	0	0	0	0	0	0	0	0	0	0
Air Force	F40600-01-C-0012	2001	UWB Wireless Sensor II	629,549	1,687,926	0	0	0	1,687,926	0	0	0	0	1,467,426	1,467,426
Air Force	F41624-97-C-0021	1997	LPG/AFFF II	496,223	384,683	0	0	0	384,683	0	0	0	0	400,126	400,126
Air Force	F49620-03-C-0010	2003	High Temp Gas Turbine Systems II	493,041	57,270	0	0	0	57,270	0	0	0	0	0	0
Air Force	FA8501-08-C-0033	2008	Abrasion Resistant Hydrophobic Coatings for Corrosion Protection	749,901	0	0	0	0	0	0	0	0	0	3,830	3,830
Air Force	FA8650-04-C-2477	2004	Semiconductor Metal Joints II	499,935	500	0	0	0	500	0	0	0	0	0	0
Air Force	FA8650-04-C-8005	2004	Config Computing II	749,902	43,136	25,537	0	0	68,673	0	675,062	0	0	0	675,062
Air Force	FA8650-05-C-5043	2005	Impact Indicator Paints II	749,818	0	0	0	0	0	0	154,963	0	0	7,534	162,497
Air Force	FA8650-06-C-5013	2006	Aluminum Cleaning Methods	749,888	296,813	0	0	0	296,813	0	99,954	0	0	883,074	983,028
Air Force	FA8650-07-C-3709	2007	Fly-by-Light II	749,917	0	0	0	0	0	0	0	0	0	0	0

SBIR/STTR Commercialization History

					Sales and Revenue					Investment					
Agency	Grant / Contract#	Year of Award	Project Title	Award Amount	SP	SF	SO	LR	Total Award Sales	IS	IF	AI	VC	OI	Total Award Investment
Air Force	FA8650-08-C-1361	2008	Co-Processor Secure Software Platform with Instruction-Set Emulation	749,892	0	25,537	0	0	25,537	0	675,062	0	0	0	675,062
Air Force	FA8650-08-C-5008	2008	Appliques for the Assessment of Damage on Composites	749,916	0	0	0	0	0	0	64,982	0	0	0	64,982
Air Force	FA8650-08-C-5009	2008	Nanocomposite for Electrically Conductive Structural Adhesives and Bolt Hole Fillers	749,961	0	0	0	0	0	0		0	0	1,000	1,000
Air Force	FA8650-08-C-5602	2008	Nanocomposite Inhibitors for Corrosion Resistant Conductive Coating	749,960	0	0	0	0	0	0	0	0	0	0	0
Air Force	FA8650-08-C-6852	2008	Web Interfaced Nanotechnology ESH Guidance System	748,432	0	0	0	0	0	0	0	0	0	0	0
Air Force	FA8650-09-C-2005	2009	Advanced Oil Filter Load Monitoring for Aircraft Engine Bearing Diagnostics	736,018	0	0	0	0	0	0	0	0	0	0	0
Air Force	FA8650-09-C-5903	2009	Remote Site Detection of Chemical Agents Using Functionalized Nanoparticles	750,000	0	0	0	0	0	0	0	0	0	0	0
Air Force	FA8650-10-C-5154	2010	Inhibited Electrically Conductive Adhesive for Rapid Aerospace Fastener Preparation	749,976	0	0	0	0	0	0	0	0	0	0	0
Air Force	FA8650-11-C-5113	2011	Quick Cure Sealant	750,000	0	0	0	0	0	0	0	0	0	0	0
Air Force	FA8651-06-C-0126	2006	FPGA Defrag II	749,921		25,537		0	25,537	0	7,778,103	0	0	300,000	8,078,103
Air Force	FA8651-07-C-0106	2007	Space Efficient Fuel Cell Fibers for Micro Air Vehicles	749,942	0	0	0	0	0	0	0	0	0	0	0
Air Force	FA9300-11-C-3008	2011	Quantitative Propellant Diagnostics with Ultrasonic Guided Waves	737,451	0	0	0	0	0	0	0	0	0	0	0
Air Force	FA9453-10-C-0050	2010	Space-Based Carbon Nanotube Ultracapacitor	749,995	0	0	0	0	0	0	0	0	0	0	0
Air Force	FA9550-04-C-0066	2004	Logic Gates II	499,938	0	0	0	0	0	0	0	0	0	0	0

					Sales and Revenue					Investment					
Agency	Grant / Contract#	Year of Award	Project Title	Award Amount	SP	SF	SO	LR	Total Award Sales	IS	IF	AI	VC	OI	Total Award Investment
Air Force	FA9550-06-C-0033	2006	Ultrahydrophobic Coatings II	749,935	0	0		0	0		239,874	0	0	46,830	286,704
Air Force	FA9550-09-C-0065	2009	Miniaturized Thermal Harvesting System	600,000	0	0	0	0	0	0	100,000	0	0	0	100,000
Air Force	FA9550-09-C-0088	2009	Photonic Nervebond System for Enhanced Nerve Repair	575,000	0	0	0	0	0	0	0	0	0	0	0
Air Force	FA9550-09-C-0150	2009	Novel Resin System for Low-VOC, Chromate Free, Highly Flexible Aircraft Primer	749,938	0	0	0	0	0	0	0	0	0	0	0
SOCOM	H92222-10-C-0046	2010	Distributed Sensing System for Health Monitoring of Deep Submergence Vehicles	1,446,553	0	0	0	0	0	0	0	0	0	0	0
NIH	HHSN268200900023C	2009	Small Diameter Platelet Resistant Cannulas for Usin in Pediatric Circulatory Assist Devices	721,684	0	0	0	0	0	0	0	0	0	0	0
MDA	HQ0006-07-C-7623	2007	SSP for Real-Time Software Anti-Tamper	999,835	0	25,537		0	25,537		924,897	0	0	0	924,897
MDA	HQ0006-07-C-7624	2007	Insensitive Munitions for BMD	899,933	0	0		0	0		249,933	0	0	0	249,933
MDA	HQ0006-07-C-7625	2007	Adaptive Sensor Electronics	1,000,000	0	0		0	0		250,000	0	0	0	250,000
MDA	HQ0147-09-C-7010	2009	Thermally Reversible Adhesives for Slow Cook Mitigation	999,960	0	0	0	0	0	0	0	0	0	0	0
NSF	IIP-0724380	2007	Immunological Tools for Trimetasphere Fullerenes	499,831	0	0	0	0	0	0	0	0	0	0	0
Navy	M67854-10-C-0011	2010	Polyurea Development and Modeling for Advanced Blast and Impact Mitigation	499,965	0	0	0	0	0	0	0	0	0	0	0
Navy	N00014-05-C-0030	2005	FR Packaging II	1,399,068	0	216,116	0	0	216,116	0	0	0	0	0	0
Navy	N00014-07-C-0731	2007	Hydrogen Embrittlement	449,956	0	0	0	0	0	0	0	0	0	0	0
Navy	N00014-10-C-0086	2010	Distributed Fiber Optic Twist Measurement in Shape Sensing Tethers	734,980	0	0	0	0	0	0	0	0	0	0	0

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Navy	N00014-98-C-0161	1998	ISAM Mtls & Devices II	300,000	94,234	0		0	94,234	0	0	0	0	205,117	205,117
Navy	N00024-00-C-4059	2000	Slip Ring II	1,217,511	382,437	0		0	382,437	0	0	0	0	832,441	832,441
Navy	N00024-02-C-4124	2002	Shipboard Applications II	588,791	396,767	0		0	396,767	0	0	0	0	883,074	883,074
Navy	N00024-03-C-4043	2003	Sub Comm II	599,995	319,875	25,537		0	345,412		994,937				994,937
Navy	N00024-05-C-4139	2005	Non-Skid Coating for Ships II	599,907	0	0	0	0	0	0	0	0	0	0	0
Navy	N00024-05-C-4144	2005	DCS Monitor II	599,236	152,800			0	152,800					1,093,000	1,093,000
Navy	N00024-05-C-4170	2005	Deck Blast Mitigation Coating	599,386	0	0	0	0	0	0	0	0	0	0	0
Navy	N00024-06-C-4101	2006	FRP Composite Ladders II	599,934	0	0	0	0	0	0	0	0	0	4,250	4,250
Navy	N00024-07-C-4121	2007	High Friction Nanocomposite Coating for Radar Absorption	599,949	0	0	0	0	0	0	0	0	0	0	0
Navy	N00024-08-C-4149	2008	Hydrophobic Non-fouling Periscope Head Windows	599,954	0	0	0	0	0	0	0	0	0	3,830	3,830
Navy	N00024-10-C-4145	2010	Development of Enhanced Conformal Jammer Antenna	300,000	0	0	0	0	0	0	0	0	0	0	0
Navy	N00024-10-C-4168	2010	Fiberoptic Temperature Sensors for Long Cryogenic Thermal Paths	375,000	0	0	0	0	0	0	0	0	0	0	0
Navy	N00024-11-C-4128	2011	Optical Array Shape Estimation (ASE)	299,984	0	0	0	0	0	0	0	0	0	0	0
Navy	N00163-96-C-0062	1996	Communication Link	720,000	133,308	0	0	0	133,308	0	0	0	0	86,393	86,393
Navy	N00164-05-C-6088	2005	RF Power Scavenging	592,195	0	0	0	0	0	0		0	0	0	0
Navy	N00421-96-C-1127	1996	Bypass Switch II	749,363	286,823	0	0	0	286,823	0	0	0	0	602,274	602,274
HSARPA	N10PC20218	2010	Evidence Preserving Hard Disk Unlocking System	750,000	0	0	0	0	0	0	0	0	0	0	0
Navy	N68335-02-C-0019	2002	Wireless Aircraft Health II	449,990	423,077	0	0	0	423,077	0	0	0	0	674,899	674,899
Navy	N68335-05-C-0005	2005	Radar Coating II	749,139	0	0	0	0	0	0	0	0	0	0	0
Navy	N68335-05-C-0122	2005	GHM II	746,501	0	0	0	0	0	0	0	0	0	0	0
Navy	N68335-07-C-0153	2007	Mini OFDR II	749,959	3,138,297	114,055		0	3,252,352					1,448,017	1,448,017
Navy	N68335-07-C-0155	2007	Cable Guardian II	749,939	0	0	0	0	0	0	0	0	0	0	0

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Navy	N68335-07-C-0161	2007	Stress Near Fastener Holes	699,952	0	0	0	0	0	0	0	0	0	59,996	59,996
Navy	N68335-08-C-0017	2008	Damage Indicating Paints for Composites	749,940	0	0	0	0	0	0	64,982	0	0		64,982
Navy	N68335-08-C-0119	2008	NDE based Accumulated Life Assessment of Turbine Disks	499,966	0	0	0	0	0	0	0	0	0	0	0
Navy	N68335-08-C-0125	2008	High Temperature Turbine Monitoring and Control System	749,997	0	0	0	0	0	0	0	0	0	0	0
Navy	N68335-09-C-0024	2009	Open Architecture Fiber Optic Engine Monitoring System	748,944	2,928,802	106,806			3,035,608	0	0	0	0	769,087	769,087
Navy	N68335-09-C-0099	2009	Smart Sensor Hub for Corrosion Monitoring	749,951	0	0	0	0	0	0	0	0	0	0	0
Navy	N68335-09-C-0107	2009	Smart Environmental Corrosivity Sensor Suite for Aircraft Applications	749,990	0	0	0	0	0	0	0	0	0	0	0
Navy	N68335-11-C-0225	2011	Innovative Approaches for Enhancing Interlaminar Shear Strength of Two-Dimensional (2D) Composite Reinforced Flexbeams and Yokes	374,993	0	0	0	0	0	0	0	0	0	0	0
Navy	N68335-98-C-0077	1998	LPG Corrosion Sensor II	741,055	574,483	0	0	0	574,483	0	0	0	0	1,172,889	1,172,889
NASA	NAS1-02063	2002	Nanotube Sensors II	599,990	0	0	0	0	0	0	64,982	0	0	1,497,112	1,562,094
NASA	NAS1-02099	2002	Flight DSS II	599,994	2,533,384	199,631		0	2,733,015	0	0	0	0	603,498	603,498
NASA	NAS1-20573	1996	Metal Coated II	575,347	1,624,539	17,280		0	1,641,819	0	0	0	0	1,412,320	1,412,320
NASA	NAS1-20581	1996	Polyimides II	591,000	1,668,737	0		0	1,668,737	0	0	0	0	1,450,744	1,450,744
NASA	NAS1-97013	1996	Thunder II	597,760	187,765	0		0	187,765	0	0	0	0	408,702	408,702
NASA	NAS3-02173	2002	DSS Space Reactors	599,998	2,313,158	147,252		0	2,460,410	0	0	0	0	603,497	603,497
NASA	NAS4-02019	2002	High Temp Sensor Suite II	599,959	1,607,309	35,861		0	1,643,170	0	0	0	0	1,062,530	1,062,530
NASA	NAS4-98028	1998	Accelerometers II	599,680	1,693,246	0	0	0	1,693,246	0	0	0	0	1,472,051	1,472,051
NASA	NAS4-99023	1999	Flight Test Skin Friction II	599,956	2,284,353	0	0	0	2,284,353	0	0	0	0	1,472,729	1,472,729
NASA	NAS8-02111	2002	Rotational Molding	596,943	0	0	0	0	0	0	0	0	0	0	0
NASA	NAS8-99077	1999	Space NDE II	499,975	1,411,720	0	0	0	1,411,720	0	0	0	0	1,227,302	1,227,302

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NASA	NNC07CA15C	2007	Real-time Micro-miniature Fiber Dosimeter	592,971	0	0	0	0	0	0	32,611	0	0		32,611
NASA	NNL07AA37C	2007	Space DSS	599,999	2,301,202	51,086		0	2,352,288	0	32,833	0	0	603,497	636,330
NASA	NNM04AA20C	2003	Microcantilever II	599,994	0	0	0	0	0	0	0	0	0		0
NASA	NNM05AB19C	2005	SAFE-100 II	592,467	2,301,202	83,856		0	2,385,058	0	2,169,239	0	0	8,603,497	10,772,736
NASA	NNM06AA07C	2006	Nano-Enhanced Hybrid MEMS	599,959	0	0	0	0	0	0	0	0	0	0	0
NASA	NNM08AA52C	2008	Post Process Characterization of Friction Stir Welded Components	599,982	0	0	0	0	0	0	0	0	0	0	0
NASA	NNS05AB01C	2005	LOX Pressure Sensors II	599,939	0	0	0	0	0	0	0	0	0	0	0
NASA	NNS06AB35C	2006	Cryo Temp Sensor Phase II	588,815	0	0	0	0	0	0	0	0	0	0	0
NASA	NNX09CB13C	2009	Self Healing Ultrahydrophobic Coatings for Corrosion Protection	599,914	0	0	0	0	0	0	0	0	0	4,830	4,830
NASA	NNX10CB38C	2010	Versatile Fiber Optic 6-Component Force Measurement System	599,995	0	0	0	0	0	0	0	0	0	0	0
NASA	NNX11CA80C	2011	High Speed Neutron and Gamma Flux Sensor for Monitoring Surface Nuclear Reactors	599,999	0	0	0	0	0	0	0	0	0	0	0
NIST	SB1341-05-C-0025	2005	Acoustic Pulsed Phase Locking Energy Sensor	286,828	378,000	50,000		0	428,000	0	0	0	0	3,815,000	3,815,000
Army	W15P7T-06-C-M608	2006	Network Intrusion Tolerance II	729,906	0	0	0	0	0	0	0	0	0	0	0
Army	W15P7T-11-C-H206	2011	Novel Materials and Designs for Low Cost, High Performance Printable UHF/VHF Antennas	729,991	0	0	0	0	0	0	0	0	0	0	0
Army	W31P4Q-05-C-R051	2005	Carbon Nanotube II	714,836	0	0	0	0	0	0	0	0	0	0	0
Army	W31P4Q-06-C-0498	2006	ASC Processor Hardware AT II	728,610	0	25,537	0	0	25,537	0	4,648,090	0	0	0	4,648,090
DARPA	W31P4Q-07-C-0010	2007	Technology for Trusted Circuits	746,498	0	25,537	0	0	25,537	0	4,762,978	0	0	0	4,762,978

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DARPA	W31P4Q-08-C-0114	2008	Biosensor Assay for Avian Influenza Detection	749,990	0	0	0	0	0	0	0	0	0	0	0
DARPA	W31P4Q-08-C-0314	2008	Dynamic Hardware Development Methodology for FPGAs	749,842	0	25,537	0	0	25,537	0	675,062	0	0	0	675,062
Army	W31P4Q-09-C-0239	2009	Secure Software Platform for Tamper Detection and Response	729,986	0	25,537	0	0	25,537	0	675,062	0	0	0	675,062
DARPA	W31P4Q-09-C-0250	2009	Superlens for 193nm Lithography	749,987	0	0	0	0	0	0	0	0	0	0	0
Army	W56HZV-05-C-0651	2005	Mobile Parts Hospital 2	1,229,937	0	0	0	0	0	0	0	0	0	500,000	500,000
Army	W56HZV-09-C-0033	2009	Advanced Technologies to Improve Fire Resistant Fuels	727,617	0	0	0	0	0	0	0	0	0	0	0
Army	W81XWH-04-C-0049	2004	Isolation of Focal Adhesion Kinase-specific Modulators	849,885	0	0	0	0	0	0	0	0	0	0	0
Army	W81XWH-05-C-0027	2005	Bone Graft II	729,913	0	0	0	0	0	0	0	0	0	0	0
Army	W81XWH-06-C-0074	2006	Optically Clear Ballistic Resistant Nanocomposites	849,935	0	749,968		0	749,968	0	0	0	0	0	0
Army	W81XWH-09-C-0052	2009	Biodegradable Chitosan Gel Intracavitary Hemostatic Agent	729,996	0	0	0	0	0	0	0	0	0	0	0
Army	W911NF-04-C-0110	2004	Biocidal Textiles II	749,861	689,671	0	0	0	689,671	0	0	0	0	0	0
Army	W911NF-09-C-0039	2009	Thin Film Coatings for Antimicrobial Textiles	729,920	0	0	0	0	0	0	0	0	0	0	0
Army	W911QX-06-C-0076	2006	Low Cost Corrision Sensor II	749,861	0	0	0	0	0	0	0	0	0	0	0
Army	W911QY-06-C-0020	2006	Fluorescence Enhancement II	729,970	0	0	0	0	0	0	0	0	0	0	0
Army	W911QY-10-C-0071	2010	Superoleophobic Coatings for Easy Cleaning Textiles	729,997	0	0	0	0	0	0	0	0	0	3,830	3,830
Army	W911W6-07-C-0046	2007	Optical Weight and Center of Gravity Measurement System	729,948	0	0	0	0	0	0	0	0	0	0	0
MDA	W91260-09-C-0034	2009	Solid Freeform Fabrication of Anti-Tamper Containers	750,000	0	0	0	0	0	0	0	0	0	0	0

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Army	W912HZ-04-C-0006	2004	Small Scale Explosions II	366,185	173,560	0	0	0	173,560	0	0	0	0	0	0
Army	W9132T-06-C-0016	2006	Self-Healing Coatings	749,943	0	0	0	0	0	0	0	0	0	0	0
Army	W9132T-06-C-0017	2006	Piping Corrosion Sensor	749,918	0	0	0	0	0	0	0	0	0	0	0
					55,675,148	13,297,885	0	0	68,973,033	0	36,912,748	0	0	62,877,795	99,790,543