The National Academies of
SCIENCES · ENGINEERING · MEDICINE

Radioactive Sources: Applications and Alternative Technologies

Virtual Meeting

DRAFT PUBLIC AGENDA
SUBJECT TO CHANGE

December 16-17, 2020, Eastern Time (ET)

Day 1, Wednesday, December 16, 2020

Connection details:
Link: https://nas-sec.webex.com/nas-sec/j.php?MTID=md44e040d8f255dbae889fd301690a092
Meeting ID: 199 907 8477
Password: PJkgCWnp282 (75542967 from phones and video systems)
Telephone: +1-415-527-5035 or +1-929-251-9612
Access code: 199 907 8477

10:00 am – 10:05 am	**Call DAY 1 to Order and Welcome** Thomas Kroc, Session Chair
10:05 am – 10:20 am	**1.1 Nucleic Acid Targeted Pathogen Reduction Treatment of Blood Components for Prevention of Transfusion Associated Graft versus Host Disease** Laurence Corash, Chief Scientific Officer, Cerus Corporation and Professor, Laboratory Medicine, University of California, San Francisco
10:20 am – 10:30 am	**Q+A and Discussion**
10:30 am – 10:50 am	**1.2 Precision's X-Ray Irradiation Technology for Research and Insect Sterilization** Bill McLaughlin, President, Precision X-Ray Irradiation
10:50 am – 11:00 am	**Q+A and Discussion**
11:00 am – 11:20 am	**1.3 xStrahl's Irradiation Technology for Research and Brachytherapy** Adrian Treverton, Chief Executive Officer, Xstrahl Amanda Tulk, Chief Science Officer, Xstrahl

11:20 am – 11:30 am	**Q+A and Discussion**
11:30 am – 11:45 am	**1.4 IBA's Accelerator-Based Sterilization Solution** Cody Wilson, Product Manager and Director of Business Development, IBA
11:45 am – 11:55 am	**Q+A and Discussion**
11:55 am – 12:00 pm	**General Q+A and Discussion**
12:00 pm – 1:00 pm	**BREAK**
1:00 pm – 1:15 pm	**1.5 Mevex: A Review of X-ray Solutions for R&D and Industry** Philippe Dethier, Business Development, Mevex
1:15 pm – 1:25 pm	**Q+A and Discussion**
1:25 pm – 1:40 pm	**1.6 Steri-Tek's Industrial Sterilization Technologies** Larry Nichols, Chief Executive Officer, Steritek
1:40 pm – 1:50 pm	**Q+A and Discussion**
1:50 pm – 2:10 pm	**1.7 Varian's LINAC Radiotherapy Systems** Sasa Mutic, Senior Vice President, Radiation Treatment Solutions, Varian Andrew Whitman, Senior Vice President, Government Affairs, Varian
2:10 pm – 2:25 pm	**Q+A and Discussion**
2:25 pm – 2:45 pm	**1.8 BD's Industrial Sterilization Technologies** James McCoy, Program Manager, Sterilization R&D, BD
2:45 pm – 3:00 pm	**Q+A and Discussion**
3:00 pm – 3:15 pm	**1.9 DOE's Office of Science Support for Basic Research on Alternative Technologies** Eric R. Colby, Office of High Energy, Physics and Office of Accelerator R&D and Production, DOE-SC
3:15 pm – 3:25 pm	**Q+A and Discussion**
3:25 pm – 3:30 pm	**General Q+A and Discussion**

Day 2, Thursday, December 17, 2020

Connection details:
Link:https://nas-sec.webex.com/nas-sec/j.php?MTID=meb1d174d64b4d14825e6c0e88cbf22a2
Meeting ID: 199 897 1304
Password: wtBmxMsB643 (98269672 from phones and video systems)
Telephone: +1-415-527-5035 or +1-929-251-9612
Access code: 199 897 1304

10:00 am – 10:05 am	**Call DAY 2 to Order and Welcome** Thomas Kroc, Session Chair
10:05 am – 10:20 am	**2.1 Introducing NNSA's Alternative Technology Research and Development Projects** Lance Garrison, Office of Radiological Security, NNSA Donald Hornback, Office of Defense Nuclear Nonproliferation Research and Development, NNSA
10:20 am – 10:50 am	**2.2 Stellarray's Projects on Alternative Technologies for Medical, Research, and Insect Sterilization** • Self-Contained Blood Irradiator using Flat Panel X-ray Sources • Modular, Addressable Research Irradiators Using Flat Panel X-ray Sources • Sterile Insect X-Ray Irradiator Mark Eaton, President and CEO, Stellarray
10:50 am – 11:05 am	**Q+A and Discussion**
11:05 am – 11:25 am	**2.3 Team Nablo – Industry Collaboration To Fill Education and Data Gaps Involving E-beam and X-ray Sterilization** Mark Murphy, Pacific Northwest National Laboratory
11:25 am – 11:35 am	**Q+A and Discussion**
11:35 am – 11:45 am	**2.4 Starfire's AmBe Replacement With Tunable Neutron Spectra For Downhole Applications** Brian E. Jurczyk, President, Starfire Industries LLC
11:45 am – 11:50 am	**Q+A and Discussion**
11:50 am – 12:00 pm	**2.5 Euclid's Inexpensive Brazeless Medical Accelerator** Chunguang Jing, Senior Vice President and Chief Technology Officer, Euclid Techlabs LLC
12:00 pm – 12:05 pm	**Q+A and Discussion**
12:05 am – 12:25 am	**2.6 TibaRay's Projects on Alternative Technologies for Medical and Industrial Applications**

	• Novel Low-Cost Medical Accelerator Designs for Use in Challenging Environments • Ultra-Portable X-Ray Source using Novel RF Technology Vinod Bharadwaj, President & Founder, TibaRay, Inc.
12:25 am – 12:35 pm	**Q+A and Discussion**
12:35 pm – 12:40 pm	**General Q+A and Discussion**
12:40 pm – 1:00 pm	**BREAK**
1:00 pm – 1:10 pm	**2.7 X-Wave's Novel Full Matrix Capture Ultrasonic Imaging System for Non-Radioisotopic Inspections** Arnab Gupta, Sr. R&D Engineer, X-wave Innovations, Inc.
1:10 pm – 1:15 pm	**Q+A and Discussion**
1:15 pm – 1:45 pm	**2.8 RadiaBeam's Projects on Alternative Technologies for Medical and Industrial Applications** • Safe, High-Throughput, Self-Contained Irradiator • Ultra Portable X-Ray Source for Field Radiography • Compact, Improved Betatron X-ray Source Salime Boucher, CEO, RadiaBeam Technologies, LLC
1:45 pm – 2:00 pm	**Q+A and Discussion**
2:00 pm – 2:15 pm	**General Q+A and Discussion**
2:15 pm – 2:30 pm	**Opportunity for Public Comments**

POINTERS TO PRESENTERS

Day 1 Industry Presenters

- Please provide an overview of your company and its market.
- Please provide an overview of your company's products that utilize radiation sources and/or alternative technologies and their applications.
- To the extent possible, please describe your company's market share both nationally and internationally.
- What are some pros and cons in performance of radioactive source versus alternative technologies for the different applications?
- What trends has your company observed over the past 10-15 years in terms of demand for radiation sources versus alternative technologies in developed and developing countries?
    - To the extent possible, please provide quantitative trends.
    - What are, in your view, the factors that led to those trends?
    - What are some challenges that currently exist with adoption of your technology in developing countries and what efforts are in place to help address them?
    - To the extent possible, please provide specific examples of developing countries, adoption trends challenges, and potential solutions.
- What are your views about the future of radiation sources and alternative technologies over the next 10 years both nationally and internationally (including developing countries).
- How does your company support implementation of your technologies in developing countries? Do you collaborate with international agencies such as the IAEA?
- Please provide any information on new/emerging non-source technologies that your company is developing and may be deployed over the next 10 years.
- Please provide any additional information that you think is relevant to this committee's work.

DOE Office of Science and NNSA Presenters

- Please introduce the ORS and DNN R&D programs, explain the process of how projects are prioritized and selected for funding, and how you coordinate with each other to identify R&D needs.
- Are there any examples of projects that received basic science support and then R&D support?
- Are there any examples of projects that received support from DOE/NNSA and now have a product in the market?

Day 2 Small Business Innovative Research Project PIs

- Please introduce your company and any existing products, if available.
- Please provide an overview of the technology you are developing, its capabilities, and potential applications.
- What specific problem(s) is your company's technology addressing with regards to alternative technology adoption for a specific application?
- What level of technology development readiness is this technology?

- What are the next steps for this technology development and how will could it be supported?

READING MATERIAL

1.1

Sim et al., Transfusion of pathogen-reduced platelet components without leukoreduction; Transfusion, Volume 59: 1953-1961; 2019:
https://onlinelibrary.wiley.com/doi/epdf/10.1111/trf.15269

Castro et al., Amotosalen/UVA treatment inactivates T cells more effectively than the recommended gamma dose for prevention of transfusion-associated graft-versus-host disease; Transfusion, 58(6):1506-1515; 2018:
https://onlinelibrary.wiley.com/doi/epdf/10.1111/trf.14589

1.2

Kamen et al., 2019, Successful Migration from Radioactive Irradiators to X-ray Irradiators in One of the Largest Medical Centers in the US:
https://journals.lww.com/health-physics/Fulltext/2019/11000/Successful_Migration_from_Radioactive_Irradiators.9.aspx

Belley et al., 2016, Regional Microdosimetric Variations in Bone Marrow for Photon Irradiation at Different Energies:
https://precisionxray.com/wp-content/uploads/2019/10/bone_marrow_microdosimetry.pdf

U. California, 2018, University of California Systemwide Radioactive Source Replacement Workgroup Recommendations:
https://media.nti.org/documents/Radioactive_Source_Replacement_Working_Group_Recommendations_05_02_18_FINAL.pdf

Andersen et al., 2020, Comparison of Multirad350 X-Ray Irradiation System and caesium (^{137}Cs) source for irradiation of NOG mice and subsequent transplantation of stem cells

1.7

Velarde et al., 2020, Taking Guatemala From Cobalt to IMRT: A Tale of US Agency Collaboration With Academic Institutions and Industry Int J Radiat Oncol Biol Phys. 2020 Aug 1;107(5):867-872: https://www.redjournal.org/action/showPdf?pii=S0360-3016%2820%2930986-X

2.2

Eaton et al., Alternative X-Ray Sources as Substitutes for Radioactive Isotopes in Irradiation Applications: American Nuclear Society Transactions; Volume 121, Number 1, Nov 2019: 1085-1088: https://ans.org/pubs/transactions/a_47764

2.4

Coventry and Krites, Measurement of D-7Li Neutron Production in Neutron Generators Using the Threshold Activation Foil Technique; Physics Procedia; Volume 90, 2017: 85-91:
https://www.sciencedirect.com/science/article/pii/S1875389217301876

Institute of Nuclear Materials Management, 57th Annual Meeting of the Institute of Nuclear Materials Management; Volume 1; 2016: http://toc.proceedings.com/32272webtoc.pdf

2.8

Kutsaev et al., Sub-Mev Ultra-Compact Linac for Radioactive Isotope Sources 1 Replacement, Non-Destructive Testing, Security and Medical 2 Applications; Nuclear Instruments and Methods in Physics Research; Volume 459: 179-187; 15 Nov 2019: https://reader.elsevier.com/reader/sd/pii/S0168583X19305890?token=27F889050E63B30526787110B350E21150B502C8CD4CF118B66E9AFE105EEFA142DDB84C003CFD9FF2226B9B116080F4

Kutsaev et al., AIP Conference Proceedings, X-ray sources for adaptive radiography and computed tomography; 2019: https://aip.scitation.org/doi/pdf/10.1063/1.5127706
Published Online: 02 October 2019

PRESENTER BIOGRAPHIES

1.1
Laurence Corash, M.D. is Senior Vice President and Chief Scientific Officer of Cerus Corporation, which he founded in 1992. He is Professor of Laboratory Medicine at the University of California, San Francisco, where he served for 15 years as Chief of the Clinical Laboratory Hematology Service. He has published 200 original research papers in peer reviewed journals in the field of hematology and transfusion medicine. Dr. Corash graduated from New York University School of Medicine and completed Internal Medicine training at Bellevue Hospital, New York, NY. He was a Research Associate at the National Institute of Child Health and Human Development (NICHD), Bethesda, MD (1971-73) and completed training in Hematology and Hematology-Pathology at the National Institutes of Health (NIH), Clinical Center. From 1977 to 1981 he served as Assistant Chief, Hematology Service at the NIH Clinical Center. He is Board Certified in Medicine, Hematology, and Hematology-Pathology. Dr. Corash has collaborated with scientists in academic institutions and government agencies throughout the US and abroad, as well as colleagues at Cerus on research in blood cell aging and technology for inactivation of infectious pathogens in blood components, and he has directed the development of technology for the inactivation of pathogens in labile blood components. Currently, he is the Principal Investigator of a contract from the US Department of Health and Human Services to complete development of the INTERCEPT Blood System for Red Blood Cells. He also leads the Convalescent Plasma for Emerging Pathogens Consortium to develop convalescent plasma for the COVID-19 pandemic. The INTERCEPT pathogen inactivation system for preparation of platelets and plasma he developed is in use by more than 200 blood centers around the world.

1.2
William McLaughlin is currently the President of Precision X-Ray Irradiation. Prior to this, he worked as a Research Associate developing radioimmunoassay blood tests at the Brigham and Woman's Hospital in Boston as well as 4 years at Eli Lilly where he developed and ran DNA and Protein Sequencing projects for the pharmaceutical company. He later went on to work as Product Manager at International Biotechnologies Incorporated which was purchased by Eastman Kodak Company in 1987. While at Kodak, he spent over 20 years as a Product Manager, Business Development Manager and then Director of R&D for the Molecular Imaging Systems group. He built the R&D and Commercial teams to develop and launch a wide array of Pre-Clinical Research products including the Kodak Scientific Imaging System's film business for radioisotope imaging and the first ever multimodal X-Ray, Bioluminescence and Fluorescence digital imaging systems for in-vivo small animal imaging. In 2013, Mr. McLaughlin accepted the position of President at Precision X-Ray where he has incorporated his expertise to help the team launch a number of image guided systems for pre-clinical cell and small animal

imaging and radiation therapy research. He graduated Bowdoin College with a BA in Biochemistry and is a graduate of Harvard Business School.

1.3

Adrian Treverton holds a Physics degree and Master of Science from Imperial College London. He followed his MSc in optics to take a technical sales role in a major optical components company; from there he went onto selling more advanced optical systems throughout the world. In 2003 he was recruited by a radiotherapy company to develop an optical system for external patient monitoring during treatment. Seeing a need for enhanced imaging, he then commercialized 3D ultrasound technology from Cambridge University, allowing the correlation of internal and external anatomy for radiotherapy planning. He joined Xstrahl in 2006 as Sales Director, leading the sales and marketing of their Orthovoltage x-ray therapy systems. In 2009 he was instrumental in commercialising the SARRP Image Guided Irradiator from Johns Hopkins University and then moved to the USA in 2011 to continue to expand their life science division, launching new products for non-ionizing X-ray irradiation and electronic Brachytherapy. In 2018 he led a management buy-out of Xstrahl and have since served as the global CEO.

Amanda Tulk is the Chief Science Officer at Xstrahl. Over the past 20 years at Xstrahl Amanda has worked across of medical and life science divisions, specialising the application of Xray technology for preclinical research for the past 10 years. Amanda holds a BSc Hons Degree in Clinical Radiotherapy which enables her to apply her clinical knowledge to preclinical research bridging the gap between radiation research and clinical implementation. She is involved with the preclinical dosimetry project in collaboration with the National Physics Laboratory in the UK.

1.4

Cody Wilson joined IBA as Product Manager and Director of Business Development in 2020. He is responsible for product development and market shaping to enable customer transition of sterilization modalities. He has extensive experience in system integration using electron beams and process development making use of sensors for feedback. He has published several journal articles and holds patents related to nuclear physics effects and novel techniques.

1.5

Philippe Dethier leads Global Business Development at Mevex, which develops electron beam and X-ray generators for medical device sterilization and food irradiation. He began his career with the irradiation processing industry in 2005 with IBA Industrial. He is based in the Belgian Mevex offices.

1.6

Larry Nichols is the CEO of Steri-Tek, located in Fremont, CA. He began working in the E-beam industry for Nutek Corp in 1996 as the business manager and soon assumed the position of Operations Manager, overseeing the shipping/receiving department as well as the machine operators. He was then promoted to VP of Business Development. In 2009, he assumed the position of CEO. In 2010, he became active on the committees ISO/AAMI 11137 and ASTM Dosimetry working group. When Nutek closed in 2016, he started Steri-Tek where he assumed the role of CEO. Mr. Nichols earned his BS degree in Business Management from Cal Poly in San Luis Obispo, CA.

1.7

Sasa Mutic joined Varian in June of 2020. Prior to this he was an Endowed Professor and Vice Chair of Radiation Oncology at Washington University School of Medicine in St. Louis, where he was for 24 years. After completing his medical physics residency at Washington University, Sasa joined the faculty there and over the years he led brachytherapy, imaging, and treatment planning services. In 2006 he was promoted to Chief of Clinical Medical Physics Services and became Division Director in 2014. In his clinical roles, Dr. Sasa led the clinical team which implemented the world's first large-bore CT simulator, developed the organization for one of the largest brachytherapy services in the world, and led numerous programs for standardization and automation of radiotherapy practices, including the clinical team which implemented the world's first MR-guided radiotherapy treatment machine. In 2010, Sasa co-founded Radialogica, LLC, a company dedicated to helping clinics, payers, and other stakeholders improve the quality and value of radiotherapy. Radialogica currently has 510(k) cleared clinical products, CE marking, ISO certification, and provides services to payer, academic, and government sectors. Also in 2010, he co-founded TreatSafely, a nonprofit 501(c)(3) group dedicated to improving the quality and safety of radiotherapy around the world. Dr. Sasa has participated in various activities of professional radiotherapy societies. He served as chair of the AAPM task group on CT simulation, a member of several additional AAPM task groups, and in various roles for ASTRO. In 2010, Sasa was named Fellow of the AAPM. He is certified by the American Board of Radiology and has been an examiner for the Board. He has published over 200 peer-reviewed manuscripts, 18 book chapters, over 300 abstracts, and has given almost 200 invited lectures around the world. Dr. Sasa has been a co-inventor on several patents and was named Innovator of the Year in Medicine by the St. Louis Business Journal in 2016.

Andrew Whitman joined Varian in 2008 as Vice President of Government Affairs and was promoted to Senior Vice President in 2016. He is responsible for global government affairs which includes advocating for Varian as the preferred partner to governments for increasing access to radiotherapy, proton therapy, and Varian's other oncology solutions for patients and health systems. Prior to joining Varian, Mr. Whitman served as the vice president for the Medical Imaging & Technology Alliance, a division of the National Electrical Manufacturers Association. In addition, he previously worked at the Carmen Group, Inc., a government relations firm in Washington, D.C., where he served as the senior associate for healthcare practice representing healthcare providers on Capitol Hill and the U.S. Department of Health and Human Services. He also previously worked as senior counsel for the U.S. Department of Health and Human Services in the Office of Counsel to the Inspector General, and served as senior corporate counsel for Integrated Health Services, Inc. Mr. Whitman has practiced healthcare law at several law firms, including Reed Smith, LLP and Grove, and Jaskiewicz and Cobert. He holds a BA from Hamilton College and a Juris Doctorate from American University.

1.8

1.9

Eric Colby is Senior Technical Advisor to the Department of Energy's Office of High Energy Physics, and Acting Director of the Office of Accelerator R&D and Production. These programs develop advanced accelerator technologies for the Office of Science and connect accelerator R&D with broader applications in medicine, security, industry, and energy & environmental uses of accelerator technology. Before joining the DOE in 2013, Eric was the Director of Accelerator Research at SLAC, having worked previously at FNAL, ANL, LANL, and LBNL.

2.1

Lance Garrison manages the Domestic Alternative Technologies portfolio in the NNSA Office of Radiological Security (ORS). In this role Lance supports the ORS mission to reduce the global reliance on high-activity radioactive sources by promoting the adoption and development of nonradioisotopic alternative technologies. Lance manages research, development, testing, and evaluation projects for novel alternative technologies; as well as the Cesium Irradiator Replacement Project, a voluntary program that helps users of high-activity source-based irradiators switch to source-free alternatives Lance previously served the NNSA Office of Defense Nuclear Nonproliferation Research and Development as a 2015 NNSA Graduate Fellow. In that role he supported Program Managers in a variety of missions including Radiological Source Replacement R&D. Lance holds a Ph.D. in nuclear physics from Indiana University and bachelor's degrees in physics and mathematics from the University of Missouri.

Dr. **Donald Hornback** joined the DOE/NNSA Office of Defense Nuclear Nonproliferation Research and Development in October 2016 as a Senior Program Manager on the Enabling Capabilities Team. In this role he manages a diverse portfolio focused on early-phase development of nuclear detection and collection technologies with performers from academia, small businesses, and the DOE laboratories. From 2010-2016, Dr. Hornback served as a research staff scientist at Oak Ridge National Laboratory (ORNL) in the Nuclear Security Division. From 2008-2010, he was a postdoctoral researcher splitting time between the ORNL Physics and National Security divisions. Dr. Hornback holds a PhD in Experimental Nuclear Physics in 2008.

2.2

Mark Eaton is President and CEO of Stellarray, Inc., a company he founded in 2008. Stellarray develops novel radiation sources and systems using them to solve important problems in irradiation and imaging. Applications include self-contained irradiators (blood, research and sterile insect) using flat panel x-ray sources to replace dangerous isotopes and portable tomographic imaging systems using multi-spot x-ray sources. Previously, Mr. Eaton built Stellar Micro Devices, which developed new vacuum microelectronic technologies for microwave devices, displays and vacuum transistors. Before SMD he was Vice President for Strategy and Development at the Microelectronics and Computer Technology Corporation (MCC), a consortium of U.S. technology companies, where he built a foreign technology monitoring organization later spun-off as a successful company, increased consortium membership five-fold and led the creation of new consortia, including a seventy-member consortium for healthcare information systems. He worked for several MCC spin-offs in business development, technology licensing and strategic alliances. Earlier, Mr. Eaton was Vice Consul for Economic and Technology Affairs at the U.S. Consulate in Osaka-Kobe, Japan, with responsibilities for the control of sensitive technologies. Mr. Eaton was educated at the Johns Hopkins University (B.A., with general and departmental honors, 1977), the Johns Hopkins School of Advanced International Studies (M.A., with distinction, 1980) and Harvard Business School (Program for Management Development, 1990). He is the lead inventor on five issued U.S. patents and has others pending.

2.3

Mark Murphy has worked as a research scientist and manager at Pacific Northwest National Laboratory for over 30 years. He has expertise in a broad range of radiation dosimetry, radiation field metrology, and experimental design for irradiation studies. This work includes characterization and use of passive dosimetry that involves a wide range of phosphor-based, radiachromic-based, and photofluorescent-based dosimetry; as well as active dosimetry that involves real-time detection utilizing ionization chambers. This dosimetry and radiation metrology work has covered a wide range of applications, including nuclear worker protection, radiation effects on materials and electronics, medical therapy, radiation biology, medical sterilization and radiation processing. He currently manages the Team Nablo collaboration.

2.4

Brian Jurczyk is co-founder and President/CEO of US-based *Starfire Industries LLC* specializing in the nGen® and Centurion® ultra-compact particle accelerators for nuclear applications in imaging, geophysics, security and non-destructive evaluation, and IMPULSE®

and RADION™ pulsed plasma sources for advanced thin-film deposition and etching for specialty nuclear coatings, semiconductor, and material science applications. He is co-inventor on 10+ patents related to these technologies with products on 6 continents. Brian holds a dual Ph.D./MBA degree in Nuclear, Plasma and Radiological Engineering with a focus on technology commercialization and creative win-win solutions with industrial partnerships. He currently serves as an Adjunct Engineering Research Professor at the University of Illinois providing mentorship for both undergraduate and graduate STEM students and serving on thesis committees. In 2009, Brian joined the industrial advisory board for the NSF Center for Lasers and Plasmas for Advanced Manufacturing serving as Board Secretary for three years. Brian received the Innovation Celebration "Entrepreneurial Excellence in Management Award," and was named to Central Illinois Business' "40-under-40". He was nominated for a Tibbetts Award for US small business technical innovation. In 2019, Brian received the distinguished ANS Advocate Award for promoting nuclear, plasma and radiological engineering. For six years Brian chaired the CEO Roundtable, a quarterly executive networking forum serving the Champaign-Urbana tech ecosystem, and he mentors startups and emerging small businesses through their formation and early-stage growth phases. Brian is a limited partner in two venture capital funds making strategic investments in the Midwestern US and is an active angel investor in several startups.

2.5
Dr. **Chunguang Jing** received his Ph.D. in 2005 from the Illinois Institute of Technology, and joined Euclid Techlabs after graduation. He has also been a consultant at Argonne National Laboratory since 2005. He is currently Senior VP and CTO of Euclid Techlabs. Dr. Jing is responsible for implementation of research projects and customized products, and oversees the setup and normal operation of the fabrication/lab facility. He has, as a Principal Investigator, received numerous research grants from a variety of funding agencies, mostly concentrating on advanced accelerator concepts, the development of high power RF components, and beam sources. He has authored and co-authored a book chapter, book article, over 60 papers in refereed scientific journals, and more than 150 additional papers published in conference proceedings. He holds seven US patents.

2.6
Vinod Bharadwaj is the Senior Vice President and a cofounder of TibaRay, Inc., a company with a mission to commercialize recent inventions made at Stanford University and the SLAC National Accelerator Laboratory primarily in developing the next generation of Radiation Therapy systems for the treatment of cancer. His background in in high energy physics and all aspects of accelerator physics having worked at both Fermilab and SLAC for over thirty years before helping found TibaRay in 2014. He has, as Principal Investigator, has been awarded multiple DOE and NIH SBIR grants while at TibaRay, Inc. These SBIRs fund R&D on electron linacs, RF power sources, RF components, beam instrumentation and radiation therapy. Vinod hold a D.Phil. in High Energy Physics from the University of Oxford, England.

2.7
Dr. **Arnab Gupta** is a Senior R&D Engineer at XII, with broad experience in developing diverse NDE technology, incorporating multiple inspection tools, signal processing, data and image analysis, algorithm development and computer programming. Dr. Gupta has been developing technology in several sensing and diagnosis applications, including volumetric imaging for high resolution feature detection using ultrasonic monitoring, additive manufacturing process monitoring using sensor fusion and artificial intelligence, and continuous physiologic monitoring of NASA space crew members using remote sensors for long term health evaluation. His expertise also includes developing flaw detection and damage evaluation technology using hyperspectral imaging and digital image correlation, real-time monitoring and qualification of

additive manufacturing parts using air coupled ultrasonic sensors, and detecting pipeline deterioration using magnetic field signature data.

2.8
Salime Boucher is the CEO and cofounder of RadiaBeam Technologies LLC, a company focused on the development of novel accelerator systems and components for both research and commercial applications. He has led or contributed to the development of several accelerator systems over the past 15 years, including X-band linacs and deflecting cavities, S-band linacs, S-band photoinjector guns, and betatrons. His background includes experience as an engineer with SureBeam, a manufacturer of industrial accelerator systems for food irradiation and product sterilization. His initial exposure to accelerator technology came from a four-year employment at the UCLA Particle Beam Physics Laboratory while he was an undergraduate and graduate student.

ABSTRACTS FOR SMALL BUSINESS INNOVATIVE RESEARCH PROJECTS

2.2 Stellarray's Projects on Alternative Technologies for Medical, Research, and Insect Sterilization

Phasing out certain radioactive isotopes, especially Cesium 137, in medical, research and industrial applications is an important priority for radiological security. Stellarray is developing irradiators for isotope replacement based on a new x-ray source architecture called the Flat Panel X-ray Source (FPXS). FPXS addresses the thermal, source-target coupling, reliability, uniformity and other problems that have inhibited the replacement of isotopes with electrical sources. In an FPXS, arrays of cathodes below a glass top exit window emit e-beam showers at high voltage across vacuum to a broad anode target. The anode has a top section with x-ray target material. The anode assembly, the top window and glass sidewalls form the vacuum enclosure of the source. X-rays are generated on the anode top surface to come back through the exit window and on to the irradiation subject. There is no "heel effect" in the FPXS anode, so power efficiency is higher than in an x-ray tube. The target surface is a broad piece of metal and e-beams are showered across its whole area, so there is minimal local power loading. For example, the anode for the blood irradiator panels has a top surface of 21,000 mm^2, dissipating less than 500 W. The outer side of the anode base plate is exposed to the external environment so it can be cooled directly over its broad area. Cooling can be by closed loop fluid circulation through heat exchangers or by potting materials with high thermal conductivity and high electrical insulation. The cathode array can be made of cold cathodes or filament cathodes. The self-contained blood irradiator (SCBI) and the digitally addressable research irradiator (DARI) are nearing commercialization next year. SBCI has been designed as a compact, benchtop cabinet in three models to suit the full range of user needs more reliably than x-ray tube models. DARI uses cold cathodes in a variant of the FPXS design to digitally irradiate the separate wells in the standard 96-well plate, which will accelerate several areas of radiobiology research, especially cell studies. The sterile insect x-ray irradiator (SIXI) is being developed as an industrial-scale system to provide a modular, robust solution that can help widen the use of the sterile insect technique without dangerous isotopes.

2.3 Team Nablo – Industry Collaboration To Fill Education and Data Gaps Involving E-beam and X-ray Sterilization

There are significant challenges for medical device manufacturers desiring to transition from cobalt-60 gamma-ray and ethylene-oxide sterilization modalities to electron-beam or X-ray. The

source of some of these challenges are the data and education gaps that exist in this process. In an effort to help fill these data and education gaps, in 2018 the National Nuclear Security Administration, within the United States Department of Energy, tasked Pacific Northwest National Laboratory to assemble a collaborative team. This “Team Nablo” currently has nine active member organizations that include leading medical product manufacturers, system integrators, contract sterilizers, accelerator manufacturers, and polymer testing labs.
The original goals of the team were to: 1) Identify specific polymer-based medical products currently sterilized with cobalt-60 that would have the greatest impact on the industry if electron-beam or X-ray irradiation were found to meet manufacturer and regulatory requirements for sterilization; 2) After irradiation of these products (and samples of their polymer constituents) to multiple integrated dose levels using these three irradiation modalities, perform *Functionality*, *Coloration* and *Mechanical* testing, as applicable; and 3) To collaborate on identifying and communicating to the industry the remaining data and education gaps that are impeding the transition to the e-beam and X-ray irradiation modalities. This public outreach would be in the form of multiple conference presentations, and publications in major scientific journals and via industry information outlets. Since late 2018 the team has tested five Becton-Dickinson and Stryker polymer medical devices (involving ~15 polymers) to cobalt-60, e-beam and X-ray fields to determine the dependence of *dose level* and *irradiation modality* on the polymer effects. The team is currently testing the Sartorius S71 polymer film to determine the dependence of dose level and irradiation modality, as well as performing a comprehensive study on the Becton-Dickinson products to elucidate the effects due to the *dose rate* of the radiation field. Goals for years three and four of the program are to assist industry with building an online polymer effects library, and help the Association for the Advancement of Medical Instrumentation (AAMI) create a guidance document that manufacturers of medical devices and biopharmaceutical systems can use in the future to efficiently navigate the transition to these alternative irradiation modalities.

2.4 Starfire’s AmBe Replacement With Tunable Neutron Spectra For Downhole Applications

^{241}Am-Be(α,n) radiochemical neutron sources are used for geophysical well logging serving groundwater, mining, geotechnical, environmental and research users—as well as the major Oil/Gas industries. There is an urgent need to prevent intentional or accidental diversion and/or use as a radiological dispersal device. It is difficult to track/safeguard these materials with ~9,000 active sources for domestic oil/gas and ~4,500 sources for non-oil/gas geophysical sectors. The primary obstacle cited for 241Am-Be replacement is a change to the source effects the neutron emission spectrum and properties—requiring recalibration, tooling redesign and data reinterpretation. Phase II research has shown that the 2.5MeV D-D neutron energy exhibits excellent sensitivity to formation porosity and tooling re-design that takes advantage of the end-generated neutrons can effectively replicate the Near/Far formation response for compensated neutron logging (CNL) in limestone, dolomite and sandstone with suitable counting statistics. Neutron emission is at the generator end allowing unrestricted placement of near and far detectors to tailor the geophysical formation response.

Starfire has partnered with Mt. Sopris Instruments to integrate our downhole neutron generator with an optimized set of near and far detectors to yield a compensated neutron logging tool that will mimic the Am-Be formation response. This is possible because neutrons in the 1-4MeV energy range are most responsible for the actual porosity measurement from the Am-Be reaction and the 2.5MeV D-D fusion emission is right in the sweet spot for optimization. Adjusting the near/far detector spacing, volume, pressurization, moderation and shielding results in an electronic CNL tool that is free from radiochemical sources with Phase IIB funding.

The tool can be extended to PGNAA and meet an urgent need for the underserved non-oil/gas market.

The technology has immediate application for radiochemical replacement in the underserved non-oil/gas geophysical water, mining and environmental well logging. Many customers cannot use Am-Be sources due to regulatory restrictions and threat of contamination. The Phase IIB technology would alleviate this gap and pain point for end uses. Partnering with Mt. Sopris for integration with industry-standard QL40 small-bore tooling and WellCAD software will be a boon for a wide customer base. Risk reduction for radiological terrorism can be accomplished by developing alternative technologies to replace radioactive materials used in open industrial use. Using an innovative accelerator, Am-Be material can be phased out improving safety for Americans and while meeting geophysical data needs

2.5 Euclid's Inexpensive Brazeless Medical Accelerator

The cost of the accelerating waveguide in modern medical accelerators and industrial linacs is substantial. This comes to no surprise, as the accelerating waveguide is a set of diamond – turned copper resonators brazed together. Such a multistep manufacturing process is not only expensive, but also prone to manufacturing errors, which decrease the production yield. In the big picture, the cost of the accelerating waveguide precludes the use of accelerators as a replacement option for radioactive sources. This is especially true for systems intended for operation in an environment with electricity, temperature, humidity, and water supply issues. Ultimately, an inexpensive and robust accelerator is needed. Euclid Techlabs LLC proposes a revolutionary brazeless accelerating structure made out of copper-plated stainless steel or tungsten cells, with copper irises serving as gaskets for vacuum and RF seals. Skipping the brazing step and using stainless steel components reduces the costs compared to copper. Because of a higher radiation screening efficiency for stainless steel or tungsten, the shielding weight is also reduced. Brazeless design allows the addition of cooling channels and embedded focusing magnets for performance optimization. Embedded focusing/steering elements allow for a small bore, lower current focusing coil for a significant weight and space reduction.

2.6 TibaRay's Projects on Alternative Technologies for Medical and Industrial Applications

TibaRay's primary mission is to use recent inventions made at Stanford University and the SLAC National Accelerator Laboratory to develop the next generation of Radiation Therapy (RT) systems for the treatment of cancer. Initially the concept was to solve the "motion management" problem – i.e., that all cancers move to some extent during conventional RT treatment – by increasing the rate of radiation delivery by a factor of 400 enabling sub-second treatment times and therefore making any effects due to tumor movement irrelevant. It has also been recently discovered that ultra-fast delivery of radiation, dubbed "FLASH RT", while maintaining effectiveness in cancer killing, quite unexpectedly, leads to far less damage to normal tissue. If implemented, FLASH RT can be a "game changer" and our RT concept, dubbed PHASER, is currently the only practical/economical path to treat all cancer indications.
The underlying and novel linear accelerator and high-power RF technology required to make PHASER possible also has many other uses and is relevant to this meeting. In our presentation we will describe the progress for two of TibaRay's SBIR projects – brief descriptions are provided below.

- Novel Low-Cost Medical Accelerator Designs for Use in Challenging Environments

The need for Radiation Therapy (RT) for cancer treatment is dramatically underserved in less developed parts both because of the high cost of RT systems and the fact that such systems need reliable utilities. A recent breakthrough in RF linac cell design and topologies has led to extremely efficient structures in terms of RF to beam efficiency. This topology results in a significant reduction in parts count and manufacturing cost. This structure technology will be combined with a low voltage electron gun, beam buncher and x-ray target to form the basis of the low-cost medical accelerator proposed in the SBIR. Intrinsically, because of low RF power and cooling requirements, the system is suitable for markets with unreliable utilities. In addition, our design can be easily adapted for use as replacements for radiological x-rays sources avoiding risk of the latter's potential misuse in a radiological dispersion device, often termed a 'dirty bomb'. Because of its efficiency and compactness, it can offer an attractive alternative for betatron-based mobile imaging systems.

- Ultra-Portable X-Ray Source using Novel RF Technology

There is a need for compact, portable systems that can non-destructively X-ray objects with unknown contents for security or contraband without disturbing the contents. In addition, such systems are needed to X-ray infrastructure such as bridges for internal faults that are not obvious from ordinary visual inspection. These systems are typically in the few MeV x-ray energy range. In our existing low-cost 6 MeV medical linac design – using our accelerator and RF component technology that allow for cost and size reductions for accelerator - the beam buncher that captures the electron beam coming from the gun is approximately 2.5 MeV. This combined with a bremsstrahlung target will provide up to 2.5 MeV X-rays. In addition, we will use a custom designed klystron and battery backed modulator to power the linac which will allow for portability and "un-plugged" operation for 5-10 minutes. We plan to use commercial X-ray detectors to image the X-rays to complete the commercial system.

2.7 X-wave's Novel Full Matrix Capture Ultrasonic Imaging System for Non-Radioisotopic Inspections

Radiographic techniques are widely used in NDE applications for inspections and flaw detection. However, the use of radio-isotopic materials poses a safety and security risk. To address the need for alternative, non-radiographic solutions to perform NDE, X-wave Innovations, Inc. (XII) is developing a novel full matrix capture ultrasonic imaging system. Our Volumetric Focusing Imaging (VFI) system is designed to perform ultrasonic inspections and acquire data in full matrix capture (FMC) mode. Signals from all ultrasonic sensors are retained and numerically combined to identify flaws and material inconsistencies. The VFI system improves upon currently available Total Focusing Method (TFM) by performing volumetric imaging of the specimen material instead of vertical planar analysis. Through numerical image reconstruction, custom internal views of the specimen material for any horizontal or vertical plane can be presented. Our goal is to build a prototype inspection system and transition the technology to address specific commercial applications.

2.8 RadiaBeam's Projects on Alternative Technologies for Medical and Industrial Applications

- Safe, High-Throughput, Self-Contained Irradiator

The Sterile Insect Technique (SIT) is an important pest management technique, however it relies on dangerous radioisotope-based gamma ray irradiators. In order to further the proliferation of the technique and reduce security concerns, non-radioisotope irradiators must be developed. While X-ray tube irradiators have been developed, they cannot produce energies above 1 MeV. A ~3 MeV irradiator is required to match the penetration of Co-60 and provide higher throughput. In response to this problem, RadiaBeam Systems is building an inexpensive, compact 3 MeV linac to act as the radiation source for a safe, self-contained irradiator for SIT and other applications. We use X-band RF power to reduce size, an innovative split-linac approach to reduce cost, a novel X-ray conversion target geometry to spread the beam out on the target, and an uninterruptible power supply to allow for operation in environments with unstable electrical power. The goal of the project is to build a prototype that can be smoothly transitioned to a commercial product. After Phase II, we plan to test the irradiator at the IAEA Insect Pest Control Laboratory.

- Ultra-portable X-ray source for field radiography

High-energy X-ray sources are used in many security, industrial and medical applications. Particle accelerators represent a safer and much more flexible X-ray sources than radioisotopes. However, in order to be considered as a suitable replacement for applications such as field radiography, the accelerator must have comparable weight, cost and dimensions. In this project, we will develop an ultra-compact Ku-band (15 GHz) linac system. The higher frequency makes the accelerating structure and RF power system smaller and more efficient. In order to reduce the fabrication cost of accelerating structures, and allow mass-production, instead of machining dozens of individual cells that must then be brazed together and tuned, we will develop an RF structure that consists of just two joined blocks of copper with a pattern micro-machined into the surface. This achieves greater precision at lower cost, reduces part count, avoids braze joints on sensitive RF features and potentially eliminates the need for tuning. In Phase I, we will carry out the conceptual design of the X-ray source, including the choice of optimal frequency, accelerating mode, and output parameters. We will perform beam dynamics, electromagnetic and multiphysics simulations, as well as conceptual engineering design. We will build a prototype of the split accelerating structure with tapered phase velocity and demonstrate the feasibility of such an approach using existing equipment on hand at RadiaBeam.

- Compact, improved betatron X-ray source

This project will develop and demonstrate a portable betatron gamma source that provides 1 - 6 MeV gamma rays with a variable duty cycle (1 - 200 Hz) and 5 cGy/min @ 1 m maximum dose rate. The system will be less than 100 lbs. and run on battery power. Modern design methods, improved magnetic materials and manufacturing processes will be applied to enable these goals. In addition, a modern control system will be implemented on the betatron to allow variability in both energy output and duty cycle.
In Phase I, the design and preliminary engineering of the betatron’s magnetic, vacuum, and electrical sub-systems will be completed. A prototype magnet demonstrating the feasibility of the approach to achieve the required parameters will be built and tested.