

**NUCLEAR SCIENCE ADVISORY COMMITTEE
to the
U.S. DEPARTMENT OF ENERGY and NATIONAL SCIENCE FOUNDATION**

PUBLIC MEETING MINUTES

**Crystal City Marriott at Reagan National Airport
1999 Jefferson Davis Highway, Arlington, VA 22202**

November 2, 2018

**NUCLEAR SCIENCE ADVISORY COMMITTEE
SUMMARY OF MEETING**

The U.S. Department of Energy (DOE) and National Science Foundation (NSF) Nuclear Science Advisory Committee (NSAC) was convened at 8:30 a.m. EST on Friday, November 2, 2018, at the Crystal City Marriott at Reagan National Airport in Arlington, VA, by **Committee Chair David Hertzog**. The meeting was open to the public and conducted in accordance with Federal Advisory Committee Act (FACA) requirements. This meeting was also attended remotely through webcasting. Attendees can visit <http://science.energy.gov> for more information about NSAC.

Committee Members Present

David Hertzog (Chair)	Geoffrey Greene	Jeffrey Nico
Mei Bai	Kate Jones	Sofia Quaglioni
Jozef Dudek	Cynthia Keppel	Krishna Rajagopal
Olga Evdokimov	Yury Kolomensky	Artemis Spyrou
Lynn Francesconi	Suzanne Lapi	
George Fuller	Zein-Eddine Meziani	

Committee members unable to attend:

Helen Caines
David Dean
Silvia Jurisson
Daniel Phillips

NSAC Designated Federal Officer:

Timothy Hallman, U.S. Department of Energy, Office of Science (SC), Office of Nuclear Physics (NP), Associate Director

Others present or used remote access for all or part of the meeting:

David Asner, Brookhaven National Laboratory (BNL)	T. Reneau Conner, Oak Ridge Institute for Science and Energy (ORISE)
Ethan Balkin, DOE	Matthew Coon, University of Chicago, Illinois
Claire Ballweg, DOE	Thomas L. Cabbage, DOE
Elizabeth Bartosz, DOE	Paul Dabbar, DOE
Jay Benesch, Jefferson Lab (JLab)	James Decker, Yale University
Steve Binkley, DOE SC, Deputy Director	Abhay Deshpande, BNL
David Bossie, DOE	Karen Dow, Massachusetts Institute of Technology (MIT)
Cortney Bougher, APS	Kristen Ellis, DOE
Ashton Brown, APS	Rolf Ent, JLab
Samantha Cadet, University of Georgia	George Fai, DOE
Joseph Carlson, Los Alamos National Laboratory (LANL)	Michael Forbes, Washington State University
Leland Cogliani, Lewis-Burke	
Stephen Colovas	

Glenn Fox, Lawrence Livermore National
Laboratory (LLNL)
Alexandra Gade, Michigan State University
Jehanne Gillo, DOE
Chris Gould, North Carolina State
University
Oleg Grachov, Yale University
Fanqing Guo, Yale University
Stuart Henderson, JLab
Tanja Horn, The Catholic University of
America
Barbara Jacak, LBNL
Ben Jones, University of Texas at Arlington
Ben Kallen, Lewis-Burke
Natalie Klco, University of Washington
David Krofcheck, University of Auckland
Krishna Kumar, Stony Brook University
Kristina Launey, Louisiana State University
Ted Lavine, DOE
Sonia Letant, LLNL
Alec Lindman, Johannes Gutenberg
University Mainz
Deborah Lockhart, NSF
Brenda May, DOE
Robert McKeown, JLab
Russell Moy, JLab

Richard Milner, MIT
Berndt Mueller, BNL
Paul Mueller, Oak Ridge National
Laboratory (ORNL)
Kristian Myhre, ORNL
Allena Opper, NSF
Erich Ormand, LLNL
Gertrude Patello, PNNL
Robert Pattie, East Tennessee State
University (ETSU)
Alan Poon, LBNL
David Radford, ORNL
Gulshan Rai, DOE
Martin Savage, University of Washington
Linda Severs, ORISE
Michelle Shinn, DOE
Michelle Sneed, DOE
Melanie Snyder, Western Energy Board
Alan Stone, DOE
James Symons, LBNL
James Thomas, NSF
John Weiland, DOE
Philip Wild, DOE
Sherry Yennello, Texas A&M University
Wu Zhang, BNL

Friday, November 2, 2018
Morning Session

WELCOME AND INTRODUCTIONS

NSAC Committee Chair **David Hertzog** welcomed everyone and asked the NSAC members to introduce themselves.

Discussion

Hertzog reviewed the agenda, noted Long Range Plan (LRP) topics that were shared at previous NSAC meetings, and reminded NSAC their role is to respond to requests for advice from NSF and DOE. Hertzog mentioned the International Union of Pure and Applied Physics (IUPAP) meeting and the tasks of the Working Group 9 (WG9) in nuclear physics. WG9 looks at the long range plan reports from around the world. The U.S. program is a world class, world leading program to be proud of.

Hallman noted that all charges to NSAC are developed and approved jointly with NSF.

NEWS FROM THE OFFICE OF THE UNDER SECRETARY FOR SCIENCE

Paul Dabbar, Under Secretary for Science, DOE, thanked NSAC for the invitation to speak and expressed appreciation for the input NSAC provides, Hallman's leadership, and the nuclear science community. Dabbar said the nuclear science community shows exceptional execution of user facilities, construction projects, and has pre-established user groups ready to utilize facilities. Dabbar mentioned the significantly higher budgets across DOE, NSF, and the National Institutes of Health (NIH). He noted six areas of science and research that DOE touches: quantum information science (QIS), artificial intelligence (AI) and machine learning (ML), advanced and sustainable energy, mobility, space exploration, and genomics.

Congress demonstrated interest in QIS with a \$1.25B National Quantum Initiative (NQI). DOE recently announced \$218M in funding opportunities for QIS. He touched on the national isotope strategy and stated members of Congress are interested in helping with the application of isotopes for the life sciences and broader applications. He mentioned physical science cross-cutting technologies such as next generation accelerator technologies as well as DOE's continued support for the Large Synoptic Survey Telescope (LSST).

Dabbar indicated the National Labs will soon have the authority to conduct facilitated reviews for smaller Strategic Partnership Projects (SPP) and Cooperative Research and Development Agreements (CRADA) below \$1M; this involves ~50% of all CRADAs and SPPs.

PERSPECTIVES FROM THE DEPARTMENT OF ENERGY

Steve Binkley, Deputy Director for Science Programs, DOE SC, thanked NSAC for the opportunity to speak and for their input and guidance on scientific investments; he focused on budget, political appointees, and AI and ML. DOE's FY19 budget is \$6.585B and the Nuclear Physics program's budget is \$690M.

Dr. Christopher Fall was nominated for the Director of the Office of Science in May 2018. The Senate hearing for Dr. Fall was held June 26, 2018 and SC is awaiting Senate confirmation. Dr. Fall is currently the Principal Deputy Director of Advanced Research Project Agency-Energy (ARPA-E); he served with the Office of Naval Research and the White House Office of Science and Technology Policy (OSTP).

FY19 priorities include continuing operations of the national laboratories, continue exascale computing research, expand quantum computing (QC) and QIS efforts, focus on robust cybersecurity program, cutting-edge, early-stage research and development (R&D), and maintaining interagency and international partnerships.

There has been considerable interest in exploiting AI and ML capabilities in SC's scientific programs. Summit, at ORNL, is being commissioned for operation; it is the most powerful supercomputer in the world, and will be the most powerful AI machine. AI has considerable potential for advancing the handling of data and increasing the rate of discovery in a number of areas. The budget guidance document from OSTP and Office of Management and Budget (OMB) last July stressed four aspects of AI (direct applications, science applications, computer science applications, and staff recruiting). DOE is looking at opportunities for further research in areas related to using AI for government services, removing barriers to AI innovation, and supporting R&D.

Discussion

Fuller asked for a working definition of early state science. **Binkley** defined early state science in terms of technology readiness levels (TRL), noting that early stage research is

typically TRL level 0 and 1. SC is focused on basic or foundational research while the applied programs in DOE have pushed out into commercialization and demonstration.

Rajagopal asked about the focus of funding opportunities in AI for nuclear physicists.

Binkley indicated the focus is using AI to answer challenges in nuclear physics.

PERSPECTIVES FROM THE NATIONAL SCIENCE FOUNDATION

Deborah F. Lockhart, Deputy Assistant Director for Mathematical & Physical Sciences (MPS), NSF, mentioned staffing changes in MPS, shared awards won by MPS Principal Investigators, discussed the FY19 budget, underscored the NSF Big Ideas, and emphasized the NSF policy on harassment.

NSF is awaiting its FY19 appropriation from Congress and is operating on a continuing resolution until December 7, 2018. MPS's FY19 budget request is 1.3% below FY17.

NSF announced 10 Big Ideas in which to focus targeted investments. Lockhart focused on three of the six research-related Big Ideas: Harnessing the Data Revolution, Windows on the Universe, and Quantum Leap. Funding for each of the research Big Ideas for FY19 is ~\$30M and \$60M for Mid-scale projects. Windows on the Universe is a collaboration of MPS Physics and Astronomy with Polar programs. Harnessing the Data Revolution supports fundamental research in data science and engineering. MPS is the lead steward of Quantum Leap which will support fundamental research on observing, manipulating, and controlling the behavior of particles and energy at atomic and subatomic scales and hopes to develop next generation technologies for sensing, computing, modeling, and communicating.

To fill a gap between two funding streams, \$6M for Major Research Instrumentation (MRI) and \$70M for Large Facilities, a number of NSF Directorates formed Mid-scale programs. The National Science Board (NSB) issued a report that contains community-generated ideas for potential Mid-scale projects. NSB recommended supporting Mid-scale with a long-term agency commitment, investigating the feasibility of using the facilities construction account as a funding mechanism, reviewing oversight and management structures to ensure compatibility with Mid-scale range investments, and developing an assessment and evaluation program to look at the full scope of demand. Two Mid-scale solicitations are anticipated this fall, one to address projects between \$6M – \$20M, and the other between \$20M – \$70M.

NSF has developed a new set of policies to address harassment. Awardee organizations, such as universities and nonprofits, must notify NSF if they have a finding or a determination that an NSF-funded Principal Investigator (PI) or co-PI committed harassment. Possible actions by NSF include removing the PI from the award, reducing the funding for the award, or suspending or terminating the award. NSF will work with the institutions to determine what level is appropriate. The policy was effective on October 22nd. People can also report any allegations directly to the NSF Office of Diversity and Inclusion.

Discussion

Fuller asked about Windows on the Universe and theory directed at interpretation of data. **Lockhart** recommended contacting the program officers to discuss proposal ideas because the Big Idea allocation is a particular designation of funding.

Spyrou asked how the Big Idea's funding will be used. **Lockhart** said all of the Big Ideas will have funding opportunities by early spring 2019. Windows on the Universe will encourage proposal submission through a set of existing programs.

Kolomensky sought information about interagency coordination and collaboration between DOE and NSF. **Lockhart** noted there is a committee at the White House level on QIS,

on which a number of agencies sit. **Binkley** explained two primary mechanisms of high-level coordination are the Interagency Working Group and quarterly coordination meetings between DOE and NSF that cut across all of the programs. Regular dialogue also occurs between the SC Associate Directors and their counterparts in NSF.

Meziani questioned the appropriateness of a Mid-scale proposal for construction of an instrument residing in a DOE laboratory. **Opper** explained that the MRI program is open to all scientists and allows funding for instrument construction at DOE laboratories and that the Mid-scale programs might be structured in a similar way. **Lockhart** said the only restriction is that the research must fit under the rubric of NSF support areas.

Hertzog asked if the new NSF-wide Mid-scale program adds new funds. **Lockhart** said there is a \$60M request for Mid-scale in NSF's FY19 budget request; the hope is it will be largely new money. **Opper** explained that existing Mid-scale programs at NSF are funded from Division monies, usually no higher than \$20M. The new NSF-wide Mid-scale has a higher range of funding opportunity.

Bai asked if DOE scientists are eligible to apply for Mid-scale projects. **Lockhart** replied that DOE-funded PIs are eligible to submit proposals for MRIs but she could not discuss the Mid-scale solicitations until they are public.

Hertzog adjourned NSAC for a break at 11:00 a.m. The meeting was reconvened at 11:20 a.m.

DOE OFFICE OF NUCLEAR PHYSICS OVERVIEW

Timothy J. Hallman, Associate Director, NP, DOE discussed the budget, new insights, progress on facilities, QIS, isotope program, workforce, and harassment. The FY19 budget for NP is \$690M which allows NP to address the second, third, and fourth recommendations in the 2015 LRP.

For the Identification Of Nuclide A (FIONA) at LBNL, the 88 Inch Cyclotron is in operation. Upgrades mentioned include the JN accelerator at the Laboratory for Experimental Nuclear Astrophysics (LENA) facility, the Argonne Gas-Filled Analyzer (AGFA), and An In-flight Radioactive Beam Separator (AIRIS) at the Argonne Tandem Linac System (ATLAS) Facility. The Facility for Rare Isotope Beams (FRIB) is more than 88% complete and is expected to be finished in FY21. The High Rigidity Spectrometer (HRS) is being proposed at FRIB, and the Gamma Ray Energy Tracking Array (GRETA) project is in progress to build premiere instrumentation for photon detection at FRIB. The 12GeV Continuous Electron Beam Accelerator Facility (CEBAF) program expects to operate for 32 weeks in 2019. The Relativistic Heavy Ion Collider (RHIC) continues to implement new capability for new discoveries, and is performing in an outstanding way, exceeding expectations.

Both the RHIC and JLab communities have been making the science case for an Electron Ion Collider (EIC). The 2018 National Academy of Sciences (NAS) study gave very strong support for a U.S.-based EIC and for the must-do nature of the physics it could enable: understanding how the mass of the nucleon arises, how the spin of the nucleon arises, and the emergent properties of dense systems of gluons. The EIC will maintain U.S. leadership in accelerator science and technology of colliders and could possibly be the only machine of its kind constructed for quite some time.

There are a number of demonstration projects towards the ton-scale experiment on Neutrino-less Double Beta Decay ($0\nu\beta\beta$) showing that necessary sensitivities are achievable. NP is well positioned to take next steps. NP made five awards for QIS, a growing area in science

and in nuclear physics. Construction for the Stable Isotope Production Facility (SIPF) is underway and university production sites will be included in the isotope production network to enable local production of short-lived isotopes. Harvesting isotopes at FRIB is firmly on the radar screen as an attractive opportunity.

Almost 50% of the NP-trained workforce went to non-academic, non-laboratory positions, marking a great value for the nation and contributing to national needs in a variety of areas. SC has an Office of Workforce Development for teachers and students offering internships and opportunities. NP continues to support the Early Career program having made six university awards and four laboratory awards.

While SC does not have the same type of guidance or policy on harassment as some other agencies, it takes harassment and diversity extremely seriously. SC is in the process of developing policies and guidance for issuance. In the interim, NP continues to emphasize it fully embraces the American Physical Society (APS) Code of Conduct.

Hallman mentioned other NP news items including Funding Opportunity Announcements, three new NSAC charges, progress on MIE's, staffing changes, neutron electric dipole moment (nEDM) progress, and a Workshop for Applied Nuclear Data Activities (WANDA) to be held at George Washington University on January 22-24, 2019.

Discussion

Kolomensky asked about fundamental symmetries and if NP has plans to move Measurement of a Lepton-Lepton Electroweak Reaction (MOLLER) forward. **Hallman** said fundamental symmetries refers to experiments like MOLLER where its electron-electron scattering was exceptionally clean, no hadrons were involved, and the theory is exceptionally well-known. MOLLER has CD-0 and progress should be seen this year.

Spyrou inquired about the long-term solution for the replacement for the Nuclear Data and Nuclear Theory Computing Program Manager. **Hallman** shared that NP has permission to make a permanent hire and a solicitation will come out soon. A community-based panel is helping to identify interested candidates.

Kolomensky asked about the SIPF capabilities for $0\nu\beta\beta$ isotopes. **Gillo** said the isotope program is making a lot of investments in R&D for efforts such as $0\nu\beta\beta$, building up capability to mitigate U.S. dependence on foreign supply of isotopes. Community input is collected biennially for their updated demand. Having both electromagnetic ion separation and centrifuge technology, the isotope program will reach out to the community again. There is an invitation-only workshop exploring alternate enrichment technologies for isotope program investment that may be of interest to the $0\nu\beta\beta$ community.

Bai mentioned the timeline for EIC. **Hallman** indicated EIC is a very large project and will require approval for CD-0 at the level of the Deputy Secretary of Energy.

Quaglioni asked if funding for QIS will be entirely under the purview of nuclear theory. **Hallman** said the funding would be distributed in the various programs.

Meziani mentioned the list of DOE projects in the 2015 LRP, and asked if those projects will be used to maximize the science output. **Hallman** indicated a number of those projects are poised to make a next step and NP is identifying funding.

Kolomensky asked about funding lines for instrumentation development projects that do not necessarily fall into QIS. **Hallman** said NP has not yet started instrumentation R&D. NP is anticipating, with significant EIC progress, instrumentation R&D would begin reasonably soon.

Keppel posed a question about interaction with the particle physics community to support the EIC. **Hallman** noted there have been discussions but was unaware of any agreements. Italy has a low level ongoing effort and are looking forward to the EIC to become a fully canonized R&D program funded by Istituto Nazionale di Fisica Nucleare (INFN). There is also interest in EIC at Dark Energy Spectroscopic Instrument (DESI) and potentially at CERN. There are resources at CERN that could provide a test bed for a future detector R&D. Six SC labs have expressed interest in participating in the accelerator R&D aspects.

Bai asked about international partners involved in EIC. **Hallman** expressed his personal opinion, that a large international, intergovernmental effort, like CERN, could be a model for the future. The EIC is an experiment of its own. Hallman imagined that the pace of the EIC will likely mean it follows the traditional model where it is constructed by DOE. **Hertzog** mentioned the Deep Underground Neutrino Experiment (DUNE) as an example. **Hallman** said DUNE is proceeding with a hybrid model and has had some success.

NSF OFFICE OF NUCLEAR PHYSICS OVERVIEW

Allena Opper, Program Officer, Nuclear Physics, NSF, discussed personnel changes, the Physics (PHY) Division budget, and funding announcements. Jean Cottam Allen is the Acting Deputy Division Director; Jim Thomas is the Experimental Nuclear Physics Program Director.

NSF does not have a budget appropriation for FY19. The President's budget request is down 4% (~\$300M) but both the House and Senate Marks show 5% increase over FY18. PHY would manage the President's budget request for FY19 by flatly funding facilities, but Laser Interferometer Gravitational-Wave Observatory (LIGO) would get an increase. In PHY, Mid-scale funding comes from research dollars and supports projects in the \$4M – \$15M range. When a project is funded by the Major Research Equipment and Facilities Construction (MREFC) budget line, like the upgrades to the ATLAS and CMS detectors, the construction funds come from the MREFC line, but the funding for planning come from the programs. PHY has already invested \$5.7M in FY17 and FY18 with \$6.3M planned for FY19 for the planning and design work for the high-luminosity upgrades to ATLAS and CMS. Opper explained that since FY13 requested research funding is more than double the available funding. Since FY15 the proposal funding rate is 40% or lower. The funding rate of new PIs tracks with the funding rate of all PIs.

The MUon proton Scattering Experiment (MUSE), at Paul Scherrer Institut, will address the proton charge radius problem that exists in atomic spectroscopic measurements. The Proton Radius Experiment (PRad) at JLab measures elastic e-p scattering at low momentum transfer, which can also be used to extract the proton charge radius. PRad recently presented its preliminary result, which is consistent with the smaller charge radius extracted from muonic-hydrogen spectroscopic measurements and inconsistent with the hydrogen spectroscopic measurements and earlier ep-elastic scattering. PRad was a joint effort of DOE and NSF supported scientists.

Opper reminded NSAC that proposals to PHY need to be submitted through solicitation number NSF 18-564 and are due December 4, 2018. She asked the community to talk to PHY about any projects that fall in the PHY Division Mid-scale range of \$4M – \$20M. In FY18 PHY made four MRI awards in experimental nuclear physics totaling ~\$3.8M.

The Alliance for Graduate Education and the Professoriate (AGEP) are alliances of universities to increase the number of historically underrepresented minority faculty in STEM

disciplines. The funding supplements to support graduate students in underrepresented groups attending AGEP institutions are available.

Opper closed by mentioning the mentoring program that matches PIs to junior researchers to share proposal writing expertise. There are currently ~25 volunteers and ~3-4 junior faculty ask to see the list annually. She asked those interested in being a mentor to let PHY know; mentors are needed.

Discussion

Quagliani asked if mentors need to be NSF PIs. **Opper** said they do not have to be, but NSF PIs may be the best able to give feedback on the NSF review criterion of broader impacts.

Greene mentioned potential increases in funding for proposals. **Opper** commented that although the community had been very effective it can be difficult to obtain blanket increases in budgets. Highlighting specific areas for increased support may be easier, e.g. support for mid-scale projects. If NSF funding in education goes up, those funds will be leveraged to create alliances with other programs within NSF.

Hertzog inquired about money for proposals on $0\nu\beta\beta$ from particle astrophysics. **Opper** indicated that \$1.3M was moved from particle astrophysics into nuclear physics in 2015.

Greene asked about systematically increasing the fraction of junior investigator awards. **Opper** noted that new faculty are funded close to or at the same rate as the more senior faculty. NSF does not provide guidance to reviewers to favor new investigators, but there is the Early Career program. **Hallman** cautioned against age discrimination in the allocation of funds.

Jones recommended sharing funding charts with senior administrators and expressed concern that the success rate to secure funding is decreasing. **Opper** indicated the PHY Division Director and MPS leadership know of these data. She pointed out that PHY has a much higher funding rate than other programs at NSF, most of which are 10% or lower. Opper agreed, however, that the trend is going down and that is problematic.

Rajagopal noted the perception that funding drops down once a researcher receives tenure and suggested gathering data to determine if there is a funding gap between pre-tenure and senior researchers. **Opper** agreed that data on success rate after the first award would be interesting information to have. **Hertzog** added it would be good to know if the community is providing continuity in the second phase of investigators' grant cycles.

NEW CHARGE: MOLYBDENUM-99

Hallman shared a recurring charge for NSAC to assess National Nuclear Security Administration's (NNSA) efforts to ensure an adequate domestic supply of Molybdenum-99 (Mo-99). The Secretary of Energy is directed by Congress to use NSAC to conduct annual reviews of the progress made in achieving the program goals and make recommendations to improve the program effectiveness. NSAC is requested to reconvene the subcommittee to provide a 5th annual assessment on the current status of implementation of the goals of the NNSA program and the progress made. The report is due by February 2019.

Discussion

Spyrou asked if past recommendations have spurred improvement to the Mo-99 program. **Hallman** thought there had been improvement. He explained that market forces drive a lot of the viability of an adequate domestic supply of Mo-99. NNSA has been fighting subsidization of Mo-99 production by foreign governments. There has been progress to produce

Mo-99 using low enriched uranium instead of highly enriched uranium. **Lapi** added there are many moving pieces including market forces and new players in the field.

Rajagopal asked about the process to end the activity since it was initiated as an act of Congress. **Hallman** said the answer is not entirely well defined. **Hertzog** added that a motivator was the cooperative agreement partners would turn into operating businesses once they achieved commercial production. **Lapi** explained other factors include determining what constitutes successful implementation of these new concepts.

COMMITTEE OF VISITORS

Timothy J. Hallman explained that every three years a Committee of Visitors (COV) charge is issued for the community to assess NP processes. The letter requests that NSAC assemble a COV to review and assess the management processes of the DOE NP, comment on observed strengths or deficiencies of the NP portfolio, and make suggestions for improvement. The results of the assessment should be documented in a report with findings and recommendations clearly articulated. The report should be submitted to NSAC by the summer of 2019.

Hertzog adjourned NSAC for lunch at 12:36 p.m.

Friday, November 2, 2018 Afternoon Session

The NSAC meeting was reconvened at 1:43 p.m.

NEW CHARGE: QUANTUM COMPUTING AND QUANTUM INFORMATION SCIENCE

Timothy J. Hallman described the joint charge between DOE and NSF and noted NSF's ongoing investment and interest; at SC QIS is a relatively new topic. The charge letter requests that the DOE, NSF, and NSAC conduct a study to identify unique opportunities for U.S. nuclear physics research to contribute to advances in QC and QIS. NSAC should provide information assessing the relative importance and potential benefits of QIS to nuclear physics and the potential contributions nuclear physics can make to QIS.

Discussion

Hertzog asked what type of report NP is seeking. **Hallman** explained NP is seeking a report that identifies categories, or areas, in nuclear science that are particularly connected to QIS research with examples for investment. Priorities would be useful to NP, but the end product is open for discussion. NP is looking for answers and some real insights. **Opper** added what is special about this charge is identifying the QIS connections with nuclear physics; where nuclear physics can contribute and how nuclear physics can gain something from QIS.

Rajagopal requested specifics about the phrase "relative importance" of QIS to nuclear physics, and nuclear physics to QIS. **Hallman** said the intent is for some judgment on concentration and tangential areas for investment, or establishing priorities among different possibilities. **Opper** stated identifying what would be most impactful.

Rajagopal asked how the investment in quantum research centers affects NP. **Hallman** mentioned a strategy to create quantum research centers in various places, for example the Chicago Quantum Exchange. A good portion of the \$1.2B NQI is targeted to fund those centers. Hallman expects separate programmatic funding for the research programs to pursue QIS; the programs may leverage capabilities at those centers.

Rajagopal revisited the work of the subcommittee clarifying that it is to provide advice to NP, NSF, and the nuclear physics community, as well as identify priorities where resources can be brought to nuclear physics. **Hallman** stated it would be a mistake to change the basic character of the NP program. However, if synergistic opportunities appear where NP can benefit from, and contribute to, QIS without changing the basic character of the research nuclear physics does, that would be a marvelous opportunity.

Kolomensky asked about funding lines to which investigators should apply for QIS-related ideas. **Opper** stated the deadline for proposals for the NSF nuclear physics program is December 4th and the deadline for the QIS program is two weeks earlier. Typically, if a proposal comes in to nuclear physics that has aspects outside of the nuclear physics scope, those Program Directors are contacted and a co-review takes place. She suggested aiming for the QIS deadline, and indicating that the proposal has relevance for two different programs.

Nico commented that QIS is quite broad, and there are a number of places to find involvement. Using quantum algorithms with various spin degrees of freedom is clearly QIS-related and important to those interested in detector technologies. There are discussions establishing the Standard Model, the foundations of which fall into nuclear physics. There are ways that nuclear physics can play an important role in QIS.

PHYSICS CASE FOR AN ELECTRON ION COLLIDER

Richard Milner provided an overview of the EIC, recent developments in accelerator R&D, and the NAS report on EIC. The EIC is focused on understanding the fundamental structure of matter. The present understanding of the subatomic world is summarized by the Standard Model of Physics, however, if the structure of nuclei and visible matter is fundamentally interesting, the Standard Model is not directly useful.

A central goal of quantum chromodynamics (QCD) exploration is to study the modification of gluons in the nuclear environment. EIC has become a central focus of the U.S. QCD community. A NAS committee assessed the scientific justification, and the merit and significance of the science, in the context of the capabilities of existing or planned facilities. The committee also assessed the unique scientific role to be played by U.S. EIC, the benefits to U.S. leadership in nuclear physics, and the benefits to science and society at large. The NAS committee expressed that the EIC can uniquely address three profound questions about nucleons and how they are assembled to form nuclei, how the mass and spin arises, and what the emergent properties of the dense systems of gluons are.

Accelerator R&D is a high priority and the expertise, scientific thrust, and scientific interest of current flagship facilities at BNL and JLab are well aligned with the EIC. EIC will lead the U.S. to the frontiers of collider technology. Substantial interest exists worldwide and international collaborations have yielded direct funding to colleagues in Europe.

Discussion

Kolomensky asked if the oversight group considered leveraging the expertise for linear colliders. **Milner** thought some level of that is occurring and agreed that every existing R&D

effort possible should be leveraged. **Rolf Ent** mentioned one example of overlap is the return coils for one of the solenoids. **Abhay Deshpande** noted that particular identification requirements are very different in the EIC than high energy physics; there are places where there is absolute need for new technologies. **Evdokimov** championed taking advantage of existing technological developments and involving the nuclear and high energy physics communities.

QUANTUM INFORMATION SCIENCE AND NUCLEAR PHYSICS

Martin Savage shared developments, advantages, and examples of QIS and QC worldwide. National laboratories are working with technology companies for access to quantum devices for scientists. Two quantum internet projects are occurring in Europe and in the U.S. QIS and QC show promise in nuclear physics in terms of quantum many-body systems, the Standard Model, and sensing and detection. QIS has demonstrated advantages in how quantum computations are performed and in quantum sensing.

QC and QIS are entering nuclear physics. There is significant potential to disruptively enhance the nuclear physics program and to address exponentially challenging problems. A limited fraction of the community is engaged in research and thinking about QIS. The nuclear physics community is organizing and movement will become more obvious in the next few months. Workforce training is critical. Nuclear physics has broad systemic knowledge of quantum many-body systems which are expected to be valuable to QIS, QC, and other scientific applications.

Discussion

Greene sought clarification on quantum sensors. He stated that measuring the separation between two states is critical for experiments, such as the determination of the nEDM. With the quantum system, coupling a number of qubits with entangled states, the phase sensitivity stays the same, but the splitting increases within. Essentially like magnifying the nEDM. **Savage** explained that no one has executed and demonstrated quantum advantage with a real device. In the Hamiltonian evolution everything is evolved in time with the unitary operations; the quantum device is actually doing that addition, but not stochastically. At the end of the computation one has to do measurements on the system to get distributions. The naive sign problem, is not present.

Kolomensky mentioned a workshop on QC will occur January 26-30, 2019.

Hertzog called for a break at 3:41 p.m. NSAC was reconvened at 3:55 p.m.

NSAC DISCUSSION

Rajagopal asked about the process for the QIS charge. **Hertzog** suggested two in-person meetings, phone meetings, and homework to educate the subcommittee.

Kolomensky inquired about the size of the subcommittee. **Hertzog** imagined 12-14 people to keep it manageable. **Rajagopal** asked if the subcommittee would include people outside the nuclear physics community. **Hertzog** indicated that two well-informed external people would be on the subcommittee and asked that recommendations along with a rationale for the suggestion be sent to him. **Hallman** suggested a QIS bibliography for the subcommittee.

Jones recommended visiting the outreach centers to learn more about QIS. **Hertzog** mentioned a high level understanding of the relative advantages to nuclear physics was necessary and wanted to select people already educated on the topic. **Nico** advocated for maintaining the

diversity of the field available because of the technical aspect of QIS in detector and sensor development, all of which is based on nuclear physics.

Quaglioni inquired about an international component on the subcommittee. **Hertzog** was open to the idea but noted flying to the U.S. for multiple meetings is burdensome.

Rajagopal asked about unique European or Chinese activities in their nuclear physics communities. **Savage** had no knowledge of activities in nuclear physics in China. Europe's activities are oriented in field theory and QCD and areas with substantial theoretical activity. **Hertzog** asked for Savage's input on the subcommittee. **Savage** preferred a diverse representation with experts from other fields, particularly condensed matter and high energy physics, and from Europe or Canada, but questioned the conflict that may exist with technology companies. **Kolomensky** offered to consult colleagues at LBNL for industry names.

Jones asked if there are experimentalists with expertise in QIS stating she had not thought of QIS being something for nuclear experimentalists. **Hallman** said there is at least one experimentalist with QIS expertise from MIT. **Savage** mentioned people conducting detection experiments in ultrasensitive measurements have expertise in QIS. He suggested the field complete a self-inventory to understand what the community has with regard to QIS. **Greene** said it is easier to imagine people trained in the art of quantum mechanics and doing calculations have a huge advantage because they already comprehend what a quantum calculation has to do.

Kawtar Hafidi mentioned a meeting at ANL and suggested beginning at the National Labs to learn about material science, condensed matter, and computing. A seeded project at Argonne is building the superconducting nanowire detectors. This technology was used to build nanocalorimetry around cryogenic targets in nuclear physics. The photonics group builds qubits and wants to add the photon detectors to their qubits to reduce waste when detecting light. The nuclear physics division also has atom trapping which allows activities with 3D lattices. Detection is similar to high-energy physics; if high-energy physics is strong in QIS, there is no reason for nuclear physics not to have the similar strength. **Kolomensky** asked if the Argonne meeting has proceedings available. **Hafidi** said the proceedings are not official, but she sent Hallman a copy of the white paper from the Argonne workshop.

Public Comment

None.

Hertzog adjourned the November 2018 NSAC meeting at 4:49 p.m.

The minutes of the U.S. Department of Energy and the National Science Foundation/Nuclear Science Advisory Committee meeting, held on November 2, 2018, at the Crystal City Marriott at Reagan National Airport, Arlington, Virginia, are certified to be an accurate representation of what occurred.



David Hertzog, Chair of the Nuclear Science Advisory Committee on February 7, 2019.