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

PUBLIC MEETING MINUTES

Virtual Meeting
November 16, 2021

NUCLEAR SCIENCE ADVISORY COMMITTEE
SUMMARY OF MEETING

The U.S. Department of Energy (DOE) and National Science Foundation (NSF) Nuclear Science Advisory Committee (NSAC) virtual meeting was convened at 10:00 a.m. ET on Tuesday, November 16, 2021, via Zoom®, by **Committee Chair Gail Dodge**. The meeting was open to the public and conducted in accordance with Federal Advisory Committee Act (FACA) requirements. Visit http://science.energy.gov for more information about NSAC.

NSAC Members Present

Thomas Albrecht-Schoenzart
Sonia Bacca
Lee Bernstein
Joseph Carlson
Gail Dodge (Chair)
Evangeline Downie
Renee Fatemi
Bonnie Fleming
Vicki Greene
Tanja Horn
Oliver Kester
Joshua Klein
Thomas Schaefer
Rebecca Surman
Fred Wietfeldt
Boleslaw Wyslouch
Sherry Yennello

NSAC Members Absent

None

NSAC Designated Federal Officer

Timothy Hallman, DOE, Office of Science (SC), Office of Nuclear Physics (NP), Associate Director

Presenters

Steve Binkley, DOE SC, Acting Director
Donald Geesaman, Argonne National Laboratory (ANL)
Timothy Hallman, DOE SC, NP, Associate Director
Michael Heffner, Lawrence Livermore National Laboratory (LLNL), Nuclear and Chemical Sciences Division
Sean L. Jones, NSF, Mathematical and Physical Sciences Directorate (MPS), Assistant Director
Kelsie Krafton, DOE SC, NP, American Association for the Advancement of Science (AAAS)
Allena Opper, NSF, Nuclear Physics, Program Director
David Radford, Oak Ridge National Laboratory (ORNL), Physics Division
Paul Sorensen, DOE SC, NP, Program Manager
Sharon Stephenson, DOE SC, NP, Program Manager
Lindley Winslow, Massachusetts Institute of Technology (MIT), Department of Physics
John Wilkerson, University of North Carolina (UNC), Department of Physics

Tuesday, November 16, 2021

Welcome and Introduction

Gail Dodge, NSAC Chair, welcomed attendees and asked committee members to introduce themselves.

Perspectives from the Department of Energy, Steve Binkley, Acting Director of the Office of Science

Dr. Binkley noted the DOE priority activities. Secretary Jennifer Granholm is actively articulating the vision of the Biden-Harris Administration, which emphasizes clean energy, climate, and diversity, equity and inclusion (DEI). Deputy Secretary David Turk is interested in SC operations and the national laboratories. Dr. Binkley reviewed the status of political appointees and SC staff. Asmeret Berhe, the SC Director nominee, awaits a final confirmation vote before the full Senate. Geri Richmond was sworn in last week as the Under Secretary for Science and has met with SC leadership. Adam Kinney is serving as interim Chief of Staff. Mailinh McNicholas is a new Special Assistant.

Under the Biden-Harris Administration, the DOE applied energy programs were returned to the purview of the Under Secretary for Science and Energy, as organized during the second term of the Obama Administration. This provides opportunities for closer work between the SC and applied energy programs.

The fiscal year 2022 (FY22) President's Budget Request (PBR) seeks $7.44B for the SC, which is a ~5.9% (~$414M) increase over the enacted FY21 budget level. The House Energy and Water Development Subcommittee issued a lower markup of $7.32B. The Senate markup is higher at $7.49B. Any increase to the overall budget will not necessarily be reflected in the budget for individual SC programs.

President Biden signed the Bipartisan Infrastructure Bill into law on November 15, 2021. The bill allocates significant funds for the DOE, but SC activities are not targeted. There are several Reconciliation Bill versions, offering the possibility of SC uplift. The DOE is operating under a continuing resolution (CR) in effect until December 3, 2021. A second, short CR is anticipated.

Discussion

Bernstein asked about DOE applied energy programs. **Binkley** said the SC has collaborated with the applied energy programs, which include the Office of Energy Efficiency Renewable Energy (EERE), the Office of Fossil Energy and Carbon Management (FECM) and the Office of Nuclear Energy (NE). The SC has allocated ~$2.7B for clean energy research, primarily through the Offices of Basic Energy Sciences (BES) and Biological and Environmental Research (BER), which strongly link to the applied programs. There is ongoing work to create data inroads between the NE and NP programs.

Perspectives from the National Science Foundation, Sean Jones, Deputy Assistant Director for the Mathematical and Physical Sciences Directorate

Dr. Jones reviewed leadership and staff changes in the MPS Directorate. In FY20, MPS awarded >$1.5B to ~2.5K competitive awards, supporting >29K individuals, ranging from

undergraduate students to senior professors and other professionals at many of MPS's facilities and centers.

All NSF facilities are operational under COVID-19 protocols. NSF is monitoring the impacts of the vaccination mandate on staff. COVID-19 impacts to the Daniel K. Inouye Solar Telescope (DKIST) were minimized, and the transition to operations is scheduled in late November 2021. COVID-19, however, delayed Rubin Observatory progress by ~22 months. The project is ~91% complete with a re-baseline underway. The High-Luminosity Large Hadron Collider (HL-LHC) is ~20% complete, with university contributions most impacted by the pandemic. Cleanup of the Arecibo Observatory is projected to be completed by the end of 2021. A recent workshop explored future ideas for site instrumentation and Science, Technology, Engineering and Math (STEM) roles. Minor damage from Hurricane Ida to the Laser Interferometer Gravitational-Wave Observatory (LIGO) installation in Livingston, Louisiana has been addressed. Given growing concerns about satellite constellations, NSF is working with other federal agencies and the scientific community to raise awareness and explore mitigations.

NSF flagship activities in quantum information science (QIS) include foundries, research centers and the Quantum Leap Challenge Institutes (QCLIs). NSF will continue to support these initiatives in FY22, including through Research Experiences for Undergraduates (REUs), NSF Research Traineeships (NRTs) and other targeted activities for students and professors, especially those from underrepresented institutions. The second NSF QLCI competition issued two awards in FY21, conferring a total of $25M each over five years to the QCLI for Quantum Sensing in Biophysics and Engineering and the QCLI for Robust Quantum Simulation. The Quantum Interconnect Challenges for Transformational Advances in Quantum Systems (TAQS) program issued ten awards totaling ~$25M to FY21. NSF and DOE have formed a joint oversight group in quantum science and engineering.

The MPS community will also contribute to Artificial Intelligence- (AI-) enabled research in the physical sciences, including modeling and simulation; data and model analytics; concept discovery; and physical systems and experiments. In anticipation of a possible reissuing of the National AI Research Institutes solicitation, MPS published a Dear Colleague Letter (DCL) for Advancing Discovery with AI-powered Tools (ADAPT) in May 2021. Awards have focused on EArly-concept Grants for Exploratory Research (EAGERs), Research Advanced by Interdisciplinary Science and Engineering (RAISEs) and supplements to existing awards. ADAPT prioritizes collaboration among MPS domains; collaboration between MPS and AI researchers; broadening participation; and collaborations between industry and academia.

NSF's COVID-19 response prioritized individuals from the most strongly affected groups and those at vulnerable transition points, including those at Minority Serving Institutions (MSIs) or less affluent institutions; women researchers; underrepresented groups (URGs); undergraduate students; graduate students; postdocs, trainees or fellows; and early and midcareer faculty. Resources were distributed through existing and new initiatives. In FY21, MPS issued 33 and 45 Ascending Postdoctoral Research Fellowships (ASCEND) and Launching Early-Career Academic Pathways (LEAPS) awards, respectively. Awardees from both programs will broaden participation of URGS in MPS and STEM fields in the U.S. MPS anticipates 40-50 ASCEND and 20-40 LEAPS awards in FY22. Partnerships for Research and Education in Physics (PREP) and Partnerships for Research and Education in Chemistry (PREC) are new MPS programs to increase the recruitment, retention and degree attainment by URGs while strengthening ties with MSIs. PREP and PREC build on the Division of Materials Research (DMR) Partnerships for Research and Education Materials (PREM) model.

The FY22 PBRs of ~$10.2B and ~$1.7B, respectively, for NSF and MPS are ~$1.7B and $0.1B higher than enacted FY21 levels. The PBR allocates ~$865M for the new Technology Innovation and Partnerships (TIP) Directorate. TIP will cut across existing NSF directorates to accelerate innovation and partnerships at speed and scale through three subdivisions. The Technology Translation subdivision will encompass the existing Partnerships for Innovation (PFI) and Small Business Innovation Research and Small Business Technology Transfer (SBIR/STTR) programs and generate the new Innovate Pathways program. The Technology & Innovation Ecosystem subdivision will comprise the existing Convergence Accelerator and Innovation-Corps (I-Corps) programs and the new Regional Innovation, Industries of Tomorrow Co-investment and Entrepreneurial Fellows programs. The Partnerships as a Foundation subdivision will manage the new Accelerate Partnerships program. TIP legislation envisions new Regional Innovation Accelerators or Regional Innovation Engines (RIAs/ RIEs) at scales much larger than typical NSF centers. RIAs/ RIEs will address major scientific and technological goals while serving as research hubs in NSF's broader portfolio to incentivize partnerships and balance geographic activities bringing about broad societal benefits.

Discussion

Yennello inquired about the federal vaccine mandate. **Jones** said the NSF is still determining the mandate's impact for those funded through cooperative agreements. Cooperative agreements make some awardees federal employers. Additionally, some NSF facilities have been affected by state mandates. NSF and employees are evaluating legal ramifications and flexibilities afforded by the mandate. **Dodge** remarked that the mandate does not apply to many principal investigators (PIs) who are not working under cooperative agreements.

Klein requested more information about TIP. **Jones** explained the NSF is determining how TIP will measure success. TIP may set return on investment milestones of three- to five-year periods with associated reporting requirements. Such metrics will be set in partnership with the community. The rest of the NSF will remain curiosity driven with the aims of advancing scientific knowledge and broader impacts and TIP will work synergistically with these directorates within the curiosity-driven-to-use-inspired cycle of innovation

Dodge asked if TIP is likely to survive budget finalization. **Jones** stated TIP is high priority for the NSF Director and reflects the Biden-Harris Administration's priorities.

DOE Office of Nuclear Physics Overview, Timothy Hallman, Associate Director

Hallman reviewed NP vacancies and staff changes.

The FY22 PBR for NP requests $720M. The House and Senate marks are $665M and $744M, respectively. Though budget uncertainty continues, it is imperative that NP stay united and focused on delivering discoveries, scientific knowledge, technological advances and workforce training. Compared to the enacted FY21 budget levels, the FY22 PBR increases Core Research in Medium Energy, Heavy Ions and Theory by ~12% and the Fundamental Symmetries, Nuclear Structure and Nuclear Astrophysics portfolios by 15%. The FY22 PBR increases aim to reverse the downward trend in research funding over recent years. Commitments for the Large Hadron Collider (LHC) management and operations are met. Research for the Facility for Rare Isotope Beams (FRIB) is increased, but below the planned level. Support for the neutron electric dipole moment (nEDM) experiment is significantly below the planned profile, possibly impacting schedule. Relative to FY21 levels, Scientific Discovery

through Advanced Computing (SciDAC) is increased by $600K to support SciDAC-5, while Nuclear Data, Accelerator Research and Development (R&D) and QIS initiative are increased by $3.5M, ~$1M and ~$1M, respectively. Funding for the Artificial Intelligence and Machine Learning (AI/ML) initiative is flat at ~$4M. NP will participate in four additional, cross-cutting initiatives in FY22: Reaching a New Energy Sciences Workforce (RENEW) at $3M, Accelerator Science and Technology Accelerator (S&T) at $2M, Integrated Computational and Data Infrastructure at $1M and Microelectronics at $500K.

Facilities are supported at >90% of optimal, with the Relativistic Heavy Ion Collider (RHIC), Continuous Electron Beam Accelerator Facility (CEBAF), Argonne Tandem Linac Accelerator System (ATLAS) and FRIB operating at 18 weeks (90% of maximum), 31 weeks (90% of optimal), 39 weeks (93% of optimal) and 12 weeks (100% of optimal for its first run), respectively. FRIB operations are increased to $77M but are below the planned level of $82M. Construction for the Electron Ion Collider (EIC) includes $20M in Total Estimated Costs (TEC) and $10M in Other Project Costs (OPC).

Funding for ongoing Major Items of Equipment (MIEs) is below the planned level for the Gamma-Ray Energy Tracking Array (GRETA) at $6.6M; at the baseline level of $0.2M for the super Pioneering High Energy Nuclear Interaction eXperiment (sPHENIX); at a $7M TEC for Measurement of Lepton-Lepton Electroweak Reaction (MOLLER); at a $1.44M TEC for Ton-scale Neutrinoless Double Beta Decay (0vββ); and at a $3M TEC for the High Rigidity Spectrometer (HRS). The Isotope Program is no longer embedded within the NP budget.

Due to COVID-19, the SC is operating in maximum telework mode, with only mission-critical travel allowed.

Progress has been made on all top recommendations from the 2015 Long Range Plan (LRP) for Nuclear Science. Though a charge has not been delivered, a new LRP may be warranted based on FY22 appropriations.

Following on the portfolio review of ton-scale 0vββ technologies, a North American and European Summit was held this fall. One of the outcomes of the summit was that common ground exists for an international approach to 0vββ investment and the mounting of two ton-scale experiments in North America and Europe, respectively.

FRIB construction is concluding, and its science program will commence in February 2022. FRIB's 1500-member user group submitted 82 proposals from 130 institutions in 30 countries requesting ~9,800 hours of beam time. The EIC received Critical Decision 1 (CD-1) approval in June 2021. The DOE cost range is between $1.7B and $2.38B. New York State is planning to contribute a $100M grant to support EIC conventional construction. International stakeholders are anticipated to contribute ~$90M and ~$50M in-kind for the detector and accelerator, respectively. The estimated cost to reach CD-2 is ~$123M. Pending FY22 appropriations, the planned CD-2 date is the second quarter (Q2) of FY23. The SEparator for CApture Reactions (SECAR) was successfully completed. GRETA is preparing for re-baseline due to funding allocations falling below the funding profile established at CD-2. HRS and MOLLER implementations continue and both projects are making appropriate progress toward CD-2.

Addressing gaps in nuclear data is important for advancing cross-cutting work in medicine, astrophysics, nonproliferation, materials, energy and space exploration.

In addition to the open solicitation, FY22 Funding Opportunity Announcements (FOAs) are planned for Topical Theory Collaborations, Quantum Horizons, SciDAC-5, Interagency Nuclear Data, and R&D for Next Generation Nuclear Physics Accelerator Facilities. Additional

FOAs may be added. A new white paper titled *Accelerating Innovation in Medical Care through Discovery in the Physical Sciences (AIMDPS): A New Crosscutting Architecture for Leveraging DOE – National Institutes of Health (NIH) Collaboration* is available.

NP usage of the National Energy Research Scientific Computing Center (NERSC) will increase in FY22 and the Innovative and Novel Computational Impact on Theory and Experiment (INCITE) program requests are under consideration.

NP's RENEW efforts for FY21 and FY22 are primarily centered on traineeships for MSIs collaborating with research universities and national laboratories.

Community feedback from the American Physical Society Division of Nuclear Physics (APS DNP) indicates that gender DEI continues to be a serious issue. Reported complaints from the last six months range from dismissive behaviors based on gender to behaviors bordering on attempted sexual assault. Dr. Hallman emphasized that such behaviors must stop now. Bad behaviors can continue only if people of good conscience and integrity do nothing.

Discussion

Charles Hyde asked about the SC's role in the upcoming review of EIC detector proposals. **Hallman** said the NP will observe the panel convened by BNL and JLab.

Dodge raised the Research Director position. **Hallman** indicated NP has permission to fill the position and hopes to post an announcement in the coming months.

Dodge posed questions about COVID-19 protocols for DOE laboratories. **Hallman** remarked that each lab has its own SC-approved safety plan for restoring on-site activities. Some travel has been restored, though travel requests must be mission critical and receive approval from the Acting Office of the Director.

Fatemi (via chat) commented that COVID-19 has caused significant hardship at the Solenoid Tracker at RHIC (STAR) because LBNL colleagues are unable to take shifts. If the problem is severe, **Hallman** advised requesting an exception. He cannot make promises, but he will personally engage with issues he is made aware of. **Haiyan Gao** (BNL, chat) said LBNL recently approved travel to BNL for STAR shifts.

Bernstein called attention to the reorganization of the applied energy programs and asked about opportunities for collaboration between NP and NE. **Hallman** observed that the NP nuclear data program is working to provide accurate data to NE.

NSF Nuclear Physics Overview, Allena Opper, Program Director

Opper reviewed staff changes in the Division of Physics (PHY).

FY22 FOAs include the PHY Investigator Initiated Research; Major Research Instrumentation; and PHY Mid-Scale Instrumentation. PHY currently supports three Mid-scale projects in nuclear physics: nEDM, Large Enriched Germanium Experiment for Neutrino-less double beta Decay-200 (LEGEND-200) and MOLLER. PHY Graduate Research (PHY-GR) Supplements and REU Supplements emphasizing support for underrepresented minorities (URMs) in STEM fields are available through the PHY DCL titled *Growing a Strong, Diverse Workforce.* LEAPS and ASCEND proposals are due in early January 2022.

Several Broadening Participation programs in the Education and Human Resource Directorate are supported in the FY22 PBR: Organizational Change for Gender Equity in STEM Academic Professions (ADVANCE); Alliances for Graduate Education and The Professoriate (AGEP); Centers of Research Excellence in Science and Technology (CREST); Excellence Awards in Science and Engineering (EASE); Historically Black Colleges and Universities

Undergraduate Program (HBCU-UP); Improving Undergraduate STEM Education: Hispanic-Serving Institutions (IUSE: HSI); Inclusion across the Nation of Communities of Learners of Underrepresented Discoverers in Engineering and Science (NSF INCLUDES); Louis Stokes Alliance for Minority Participation (LSAMP); NSF Scholarships in STEM (S-STEM); and Tribal Colleges and Universities Program (TCUP).

The FY22 NSF budget proposal reflects the Biden-Harris Administration's priorities. While the PBR and the House and Senate marks increase overall NSF funding relative to enacted FY21 levels, the proposed increases vary. In addition, some budget increases are linked to the new TIP Directorate.

PHY program highlights featured the Young Scholars Program at the University of Illinois Urbana-Champaign (UIUC) that was initiated by the UIUC Nuclear Physics Group and expanded to the entire College of Engineering. Science highlights included results from the final Gamma-Ray Energy Tracking In-beam Nuclear Array (GRETINA) Campaign at NSCL; progress from the ReA Stand-Alone program; characterization of the symmetry energy of the equation of state in neutron stars; and improved measurement of the free neutron lifetime.

Discussion

None.

Dodge dismissed the meeting for lunch at 12:15 p.m. and reconvened at 1:00 p.m.

DOE NP Diversity Pilot Program, Sharon Stephenson, Program Manager; Paul Sorensen, Program Manager; Kelsie Krafton, American Association for the Advancement of Science Fellow

Despite several activities aimed at broadening participation, lack of diversity in the NP community has persisted. To address this gap, NP gathered information from 1) mentor experiences and observations of the NP portfolio; 2) community reports; 3) community examples of effective efforts; and 4) conversations with PIs from MSIs, HBCUs, Carnegie Research 1 (R1) institutions and others. Synthesized results culminated in the NP Traineeship Award pilot program offering paid, long-term research traineeships for undergraduates with an emphasis on faculty-to-faculty engagement. The pilot program builds on existing infrastructure, enabling national laboratories and universities to work with MSIs to provide extended training and mentorship to undergraduates during the summer and academic year. Guided by the AIP National Task Force to Elevate African American Representation in Undergraduate Physics and Astronomy (TEAM-UP) Report recommendations, the pilot program seeks to remove URG barriers to graduate school, providing students with a sense of belonging and developing a physics identity while receiving financial support during academic advancement.

In FY21, NP received 36 proposals to create collaborations with >40 MSIs and to host >200 trainees. The requested ~$12M exceeded the ~$3M in planned funding, making award selection challenging. A diverse panel of reviewers selected a total of 21 awards involving five DOE laboratories, one SC user facility, two NP centers of excellence and 37 colleges and universities. HEP is partially funding eight of these awards while NP is partially funding three awards in the HEP portfolio related to DEI. Of the 37 colleges or universities, 73% are MSIs, including 14 HCUs, nine HSIs, one Black-Serving Institution, one Predominantly Black Institution (BPI), two Asian American and Native Pacific Islander Serving Institutions (AANAPISIs) and one Native American Serving Institution. Of note, 43% of the awardees

participating in the pilot program are Pell Grant recipients. Pell Grants are awarded to undergraduate students without prior degrees and who display exceptional financial need. The percent of Pell Grant awardees among the populations attending the HBCUs, HSIs and non-MSIs participating in the NP pilot is 60%, 43% and 22%, respectively. Data collected during the pilot program will be analyzed in partnership with Dr. Felicia Commodore of Old Dominion University to inform future program implementation.

Early highlights from the pilot program include activities coordinated through the Institute for Science to Inspire the next Generation of a Highly Trained Workforce (INSIGHT) Center at FRIB; BNL; Skyline College, a community college; and LANL. Congress and the DOE recognized the enthusiastic response of the NP community, and the FY22 PBR allocates resources for the RENEW initiative to expand activities across the SC.

To make connections and advertise funding opportunities, NP is attending conferences, including those where the DOE has not historically had a presence, such as the Society for Advancement of Chicanos/Hispanics and Native Americans in Science (SACNAS). The SC is also considering development of an online resource hub to facilitate discovery of funding opportunities. NP is utilizing the White House-released guide titled *Best Practices for Diversity and Inclusion in Stem Education and Research* to steer program expansion.

Discussion

Bernstein thanked the speakers and noted the strong correlation of need-based students and participating MSIs, as evidenced by the percent of Pell Grant recipients. Those from underprivileged backgrounds carry hidden insecurities; it is very important that the NP community make students feel welcome in the field and let them know there is a place for them.

Glen Crawford, the HEP Research Director, voiced strong support for the NP pilot program and appreciation for the chance to co-fund proposals. HEP is actively developing a similar program as part of the RENEW initiative and looks forward to future collaborations.

Downie praised the program's collaboration with HBCUs and MSIs but urged further outreach to and involvement of community colleges. Community colleges are a source of diverse and talented students. Many community college attendees may not realize physics is a viable career path. **Krafton** commented the Office of Workforce Development for Teachers and Scientists is holding listening sessions with community college representatives present at each meeting. Information gathered at these listening sessions will help guide future SC outreach to community colleges. **Sorenson** added the FOA intentionally offered PIs the flexibility to accommodate unique institutional needs, capabilities and connections. The program made awards that rely heavily on community college engagement.

Yennello (chat) remarked that the 2022 April APS meeting will hold a mini symposium to highlight pilot program efforts. Abstracts are encouraged.

LEGEND-1000 Technical Update, David Radford, Physics Division at Oak Ridge National Laboratory

The LEGEND Collaboration aspires to develop a phased, Ge-based ton-scale $0\nu\beta\beta$ experiment with a discovery potential at a half-life ($T_{1/2}$) beyond 10^{28} years using existing resources as appropriate to expedite results. Formed in 2016 through a merger of the MAJORANA Demonstrator (MJD) and GERmanium Detector Array (GERDA) efforts and several new institutions, the Collaboration currently comprises ~260 members, 48 institutions and 11 countries.

The experiment envisions 1,000 kg of enriched ^{76}Ge detectors suspended within four encapsulated modules made of ultra-pure materials with ~100 detectors per module. The modules will contain liquid argon (LAr) and a dual-fiber read-out curtain. These modules will be shielded within an underground LAr cryostat enclosed in a water tank. The baseline site is Sudbury Neutrino Observatory Laboratory's (SNOLab's) Cryopit in Canada, and the alternative site is at Gran Sasso National Laboratory (LNGS) in Italy.

Innovations have led to inverted-coaxial, point contact (ICPC) detectors with superb energy resolution and proven long-term stability in LAr. ICPCs are insensitive to alpha particles or n^+ outer contact. Their small p+ contact enables event topology discrimination while their large mass yields background levels four times lower than those of the Broad Energy Germanium detectors (BEGes) and P-type Point Contact germanium detectors (PPCs) used by GERDA and MJD, respectively.

The experiment aims to be quasi-background free, meaning less than one background count in a 4σ Region of Interest (ROI) with 10 tonne-years (t yr) of exposure. LEGEND-1000's background model builds on proven GERDA and MJD methods, and simulated experiments show a flat background in the area of a possible 0νββ signal. Simulations suggest a low-risk path to meeting background goals at 10^{-5} counts / (keV x kg x yr). LEGEND-1000 itself will measure background.

LEGEND-1000 has a technically driven funding profile at a total DOE cost-point estimate of $257M, including 56% contingency. The anticipated DOE project scope is 60% of the $442M total while international collaborators intend to contribute the remaining 40%. The project anticipates achieving CD-1 in Q4 of FY22 and CD-3 in Q3 of FY28.

The first phase of the LEGEND program, LEGEND-200, has a $T_{1/2}$ sensitivity goal of 10^{27} years and is located at LGNS. LEGEND-200 deploys an improved LAr system, ~135 kg of novel ICPC detectors plus 62 kg of PPCs and BEGes with low background materials while reusing the GERDA cryostat and infrastructure. LAr scintillation light will be detected through a low-background, wavelength-shifting curtain of fibers and Silicon Photomultipliers (SiPM) arrays surrounding detectors. LEGEND-200 is currently in commissioning.

Discussion

Dodge asked when LEGEND-200 will begin taking data. **Radford** said data taking will commence in early 2022. Information on background and other performance parameters will be available within a couple of years.

Wietfeldt inquired about the expected gamma ray energy threshold of the LAr veto. **Radford** replied the threshold is one photoelectron, corresponding to ~20 keV.

nEXO Technical Update, Michael Heffner, nEXO Project Director, Lawrence Livermore National Laboratory

The U.S.-led next Enriched Xenon Observatory (nEXO) experiment has well-defined project management roles and is supported by nine countries, 33 institutions and ~200 collaborators. The experiment proposes to encapsulate 5 tons of liquid ^{136}Xe (LXe) in a time projection chamber (TPC) with SiPM arrays to detect xenon scintillation. This configuration will be shielded by a copper vessel contained within a cryostat submerged in water. The entire apparatus is proposed to be located at SNOLab. A prototype, EXO-200, was completed seven years ago, demonstrating the deployable nature of this technology.

The nEXO TPC measures scintillation and produces a three-dimensional (3D) image of ionization. This enables particle identification, calculation of sufficient energy resolution and topological assessments that can locate where events originate in the TPC and help distinguish background from a signal. The LXe TPC offers favorable background scaling with mass indicating that background decreases with size and larger detectors are possible, including at the kiloton scale. ^{136}Xe can also be swapped for depleted or natural sources, permitting a possible null experiment to conclusively verify a discovery. A recent publication details an R&D path to obtaining kiloton of Xe.

Projections suggest nEXO will achieve a $T_{1/2}$ sensitivity of 1.35 x 10^{28} years at the 90% confidence level (CL) in ten years of data taking. nEXO backgrounds are also well-understood, including events resulting from ^{222}Rn and its daughter ^{214}Bi, experimental materials' intrinsic radioactivity, solar neutrinos and cosmic rays. In circulating LXe, ^{214}Bi decay is highly suppressed, and many decay events occur at peripheral TPC locations such as the cathode. Thus, the relevant radon background components do not have a signal-like spatial distribution. There is ongoing work to further reduce system Rn background. Additional R&D areas address readout electronics, SiPM development, radioassays, TPC prototyping and materials.

Discussion

Dodge asked about EXO-200 status. **Heffner** said the prototype experiment was completed. The detector is no longer running, and as much information as possible has been extracted.

CUPID Update, Lindley Winslow, CUPID Institutional Board Chair, Department of Physics at Massachusetts Institute of Technology

The Cryogenic Underground Observatory for Rare Events (**C**UORE) **U**pgrade with **P**article **I**D (CUPID) will replace the CUORE TeO_2 detector array with a new one based on Li_2MoO_4 to complement an international suite of experiments in 0νββ detection. Array replacement will confer new scintillating bolometer functionality enabling detection of light in addition to heat from decay events. Comparing light and heat signals facilitates discrimination of alpha events from β and gamma events. Additionally, the decay energy (Q-value) of ^{100}Mo is >3,000 keV, significantly reducing background. CUPID has the same mass scale as CUORE allowing cryostat reuse. Of note, CUORE is the largest 10 mK refrigerator in the world.

The CUPID scintillating bolometer technology is based on two prior demonstrator projects. The French-led CUPID-Mo Demonstrator at the Modane Underground Laboratory employed 20 $Li_2{}^{100}MoO_4$ crystals as scintillating bolometers. CUPID-Mo showed sufficient particle identification, low background level and satisfactory energy resolution to certify feasibility of a full-scale CUPID experiment. The Italian-led CUPID-0 Demonstrator at LNGS used 26 $Zn^{82}Se$ crystals as scintillating bolometers. Results allowed particle identification, but significant background was observed, primarily from crystal contaminants.

The CUPID detector array will ultimately consist of 1596 $Li_2{}^{100}MoO_4$ scintillating bolometer crystals. The experiment adds an external muon veto and improved neutron shield to CUORE's setup. It is technically possible to scale to a 1-ton experiment (CUPID-1T), but time and cost are limiting factors. LNGS will continue to serve as the host lab where CUORE infrastructure can be leveraged and there is strong technical support. Since the CUORE system will be reused, CUPID will base its background on the existing, validated CUORE and Demonstrator background models. Ongoing efforts are addressing background from ^{100}Mo two-

neutron pileup ($2\nu\beta\beta$) to reach the background goal of $<0.5 \times 10^{-4}$ counts/ (keV x kg x yr). CUPID aims to cover the inverted hierarchy and a fraction of normal ordering with a target sensitivity of $T_{1/2} > 1.1 \times 10^{27}$ yr (3σ). Upgrading detectors or deploying CUPID-1T could augment discovery sensitivity to $T_{1/2} > 2 \times 10^{27}$ yr (3σ) or $T_{1/2} > 8 \times 10^{27}$ yr (3σ), respectively.

In addition to searching for $0\nu\beta\beta$, CUPID's science program has potential to investigate precision two-neutrino double beta decay; $2\nu\beta\beta$ and $0\nu\beta\beta$ decays to excited states; Majoron-emitting decays; tests of Lorentz invariance and charge, parity and time (CPT) violation; electric charge conservation; verification of the Pauli exclusion principles; tri-nucleon decay and bayron number conservation; light dark matter searches; supernova neutrino searches; solar axion searches; and millicharged particles.

CUPID builds on a multi-country and multi-institutional partnership led by the U.S. and Italy. The collaboration leverages a defined project structure and international funding. Isotope and crystal production are long-lead items currently driving the schedule. The timeline for deployment proposes completion of CUORE data taking in 2024; cryostat preparation and other system modifications in 2025; start of CUPID data taking in 2028 and new data and scientific results in 2030. The U.S. cost range is from $31.2 to $39.9, including scope contingency.

Discussion

Fatemi inquired about CUPID's crystals. **Winslow** explained that it is easy to grow clean lithium-molybdate crystals. The crystal grower that produced crystals for CUPID-Mo is located in Russia and is already growing test crystals to verify procedures. Radiation Monitoring Devices Inc. in Massachusetts has produced natural lithium-molybdate crystals through an SBIR; these crystals have been tested. Chinese collaborators have grown crystals that will be tested at LNGS this fall.

Dodge asked about CUPID's timeline, expansion to CUPID-1T and LNGS logistics. **Winslow** said when CUORE finishes taking data in 2024, the collaboration will perform cryostat maintenance and install system modifications. Crystal towers will subsequently be assembled and installed with close of the refrigerator in 2028. Data taking will begin in 2029. The CUPID baseline will fill the cryostat. To advance to CUPID-1T, multiple cryostats would be necessary. These could be installed at underground laboratories around the world as a cost-effective way to leverage expertise and funds. At present, LEGEND-200 and CUORE are both running at LNGS.

Dodge commented on the possibility of running two experiments at SNOLab. **Radford** remarked that experimental space in SNOLab's Cube Hall will be freed in five years. **Hallman** advised that at the North American-European Summit, SNOLab indicated it could accommodate two experiments if the community desired. However, further excavation would be necessary.

Dodge dismissed the meeting for a break at 3:00 p.m. and reconvened at 3:15 p.m.

Neutrinoless Double Beta Decay Progress and Perspectives, Timothy Hallman

The DOE NP Portfolio Review of LEGEND-1000, nEXO and CUPID found that each candidate ton-scale $0\nu\beta\beta$ decay experiment presented unique strengths. The total project costs (TPC), DOE-only TPC and project completion date range, respectively, are ~$442M, ~$257M and 2030-2023 forLEGEND-1000; ~$406M, ~$350M and 2028-2030 for nEXO; and ~$64M, ~$35M and 2028-2030 for CUPID. All three experiments were highly rated and judged worth pursuing. However, an international campaign would be necessary to realize all three experiments. The Portfolio Review also considered the Neutrino Experiment with Xenon Time

Projection Chamber (NEXT) as a potential option; however, technology is not sufficiently mature.

Prior experiments have investigated a portion of the possible 0νββ space. While a given ton-scale experiment would expand the explored space's boundaries, it would not be sufficient to address the entire possible space for 0νββ. Indeed, a single experiment might achieve a few tantalizing but inconclusive counts after ~10 years of construction and 10 years of operations. To provide definitive proof of 0νββ in nature, the community may need to prepare for a 0νββ campaign that engages more than one ton-scale experiment and different systematics, especially given uncertainty in nuclear matrix elements. Contemporaneous verification may be an important strategic component for the future 0νββ path.

The North American-European 0νββ Summit discussed the potential for an international campaign. DOE pointed to benefits of multiple experiments: 1) chances of a Nobel Prize are greatly increased; 2) a global investment strategy may strengthen international S&T ties; 3) collegial competition between experiments could accelerate progress; 4) a CERN-like international, intergovernmental alliance for 0νββ could result, facilitating near-term and possible future experiments like NEXT. The worldwide annual investment in accelerator-based research is ~$2B per year. Mounting two ton-scale experiments and CUPID would cost ~$1B over 10 years. Following the Summit, the National Institute for Nuclear Physics (INFN) reported that international stakeholders in 0νββ are interested in exploring whether a more formal structure for international collaboration would be beneficial. Follow-up discussions are ongoing internally within DOE and between DOE and international stakeholders. At present, the U.S.-led ton-scale experiments are pursuing CD-1 individually at a pace commensurate with available appropriations.

Discussion

Klein agreed with the physics argument for pursing more than one ton-scale experiment and asked about project costs. **Hallman** replied that CUPID's costs are modest enough that they could be contained in the base NP funding envelope. nEXO and LEGEND-1000 would be new line items that would require additional funding, at least in part, from Congress.

Dodge inquired if each experiment was pursuing CD-1 separately and about the role of long-range planning. **Hallman** clarified that each experiment is not at the same stage; DOE is proceeding in a direction where each experiment would hold its own CD-1 review. Presumably, the LRP will comment on the importance of this science and whether investment in more than one experiment is warranted. There is general agreement with the logic of multiple experiments, but individual experiments may have concerns about this strategy. This approach is not without risk, and the Portfolio Review's ranking method would come into play if it proves challenging to invest in more than one ton-scale experiment.

Wilkerson thanked Hallman for working with the NSF to move 0νββ forward. The presented strategy is consistent with the community's message of the last decade that multiple experiments using multiple isotopes are necessary. How will international participants balance the three experiments? **Hallman** explained that this is currently being explored. The vision is to create an organization like CERN where annually proposed budgets are assessed by the Research Review Board panel and final numbers are presented to CERN management. A similar process could assess needs for 0νββ experiments and report to international stakeholders, potentially the U.S., Canada, Germany, France and/ or Spain. Each country might have preferred activities but be willing to contribute to greater needs. In principle, the global community appears to agree

that a campaign is needed. There is a lot of supporting logic, but the community cannot wait a long time to know if the proposed strategic approach is viable.

Geesaman echoed Wilkerson's comments. The 2015 LRP called for one U.S.-led experiment with complementary efforts. The cumulative DOE TPCs for all three projects, however, are considerably more than the value projected in the 2015 LRP.

Hertzog asked if the budget will support seed efforts to develop the next generation of experiments. **Hallman** answered in the affirmative. DOE does not know at what level, but continued investment will be necessary to advance R&D, presuming the community is serious about attaining an answer. Nature may push exploration of the normal hierarchy, and the Summit discussed the possibility of countries jointly providing resources to create next generation technology. This has drawn interest from potential contributors like Spain.

Long Range Plan

In anticipation of a LRP charge from the DOE and NSF, **Dodge** said NSAC requested insights to the process from those directing the prior planning experience. At the time of the 2015 LRP, Donald Geesaman was NSAC Chair and John Wilkerson was head of the DNP.

The Nuclear Physics 2015 Long Range Plan Process, Donald Geesaman, Argonne National Laboratory

U.S. nuclear science has been guided by NSAC LRPs since 1979. Important facilities like FRIB have been driven by their standing in these plans. DOE, NSF, and Congress must act on LRP recommendations, and thus recommendation formulation is important.

Unlike the HEP Particle Physics Project Prioritization Panel (P5) charge, NSAC works in conjunction with DOE and NSF to optimize science delivery; trust between the community and agencies is paramount. Budget constraints are real, and thus low-ball estimates of project costs are dangerous. To be effective, the entire community must support the LRP, which should address the international context. Finishing started projects is a priority. Great care must be taken in selection of LRP Working Group to provide the best advice and avoid the perception of bias.

The 2015 LRP resulted from 18 months of effort beginning with charge delivery in April 2014. Other plans were produced in as few as 6 months. Following charge delivery, a ~60-member LRP Working Group was formed with observers from European and Asian nuclear physics associations. The DNP organized community Town Meetings, and one ad hoc meeting was assembled to address high-performance computing (HPC). A series of activities followed, including submission of white papers and a cost review of the Electron-Ion Collider (EIC). The final 2015 LRP was presented to NSAC and the public in October 2015.

Of note with regard to the LRP process, some topical areas are dominated by large facilities with significant resources, developed lab plans and user bases. Other communities are more diffuse, making consensus building a greater challenge. It can also be difficult for an open community to set priorities without a realistic budget. The importance of the science must be weighted against the community served to support the workforce. When formulating plan priorities, it is important to understand both the international context and the status of the prior plan's recommendations. Listing every project as a separate recommendation is not particularly useful; the LRP aims to prioritize science, not projects. The 2015 LRP recommendations were developed by consensus with the use of illustrative budget scenarios. Having sample budgets was important, and the LRP Working Group understood that hard choices had to be made. The

LRP Working Group focused on showing what would be lost by constraints and also generated the concept of a modestly increased budget. The LPR Working Group unanimously agreed on recommendations, and the community united behind the vision. Working groups for earlier LRPs have voted on the relative priorities of different initiatives.

Though NP research funding has increased since 2015, the total, non-isotope portion of the NP budget has fallen short of the 2015 modest growth scenario. Other considerations include the National Academies of Sciences (NAS) Decadal Plan; if the LRP and Decadal Survey offer different priorities, persuading Congress to act will be challenging.

The Role of the Division of Nuclear Physics in the NP Long Range Plan, John Wilkerson, University of North Carolina

The DNP facilitates community engagement in the LRP process. DNP is responsible for organizing community Town Meetings, including formulating topics; nominating topical conveners; providing guidance to conveners; offering modest financial support to each Town Meeting; and working closely with the NSAC Chair during the process. Town Meeting conveners are responsible for forming a representative organizing committee of ~10-20 people; communicating meeting details to the community through online and other platforms; and supervising submission of white papers to the LRP Working Group. Town Meetings may have multiple conveners to represent different topical areas within the field. Community-wide meetings are often organized as part of the DNP Fall and/ or April APS meetings but may be held as separate meetings. The DNP Chair serves on NSAC to represent the community. Depending on its length, the LRP process may span the term of two DNP Chairs.

For the 2015 LRP, the DNP Chair began organizing the planning efforts of its Executive Committee one month after the charge was delivered in May 2014. The Executive Committee selected Town Meeting topics and nominated conveners. In the intervening months, meetings were organized and held in August - September 2014. Plenary talks by the NSAC Chair, DNP Chair and conveners were held at the DNP fall meeting in October 2014. Each Town Meeting submitted white papers in January 2015. The following DNP Fall meeting in October 2015 hosted a plenary session devoted to the LRP.

From a DNP perspective, representation of all communities and their subfields is important. There is a need to strike a balance in the number of town meetings; communities with existing national user facilities and groups are well-positioned to have their views heard while there are challenges with representation of parts of the field that do not have a major home laboratory. Meetings have previously accommodated researchers with interests in multiple topics by collocating meetings. Hallway discussions have formerly been important to the process. The pandemic, however, requires consideration of the appropriate management and execution of hybrid in-person and virtual meetings. DNP may consider adopting communication software standards for town meetings.

Discussion

Bernstein asked about the importance of leveraging cross-disciplinary work that benefits from nuclear physics. **Geesaman** said it is very important that the LRP illustrate the benefit of nuclear physics to other communities. The LRP may also document how nuclear physics benefits from other sciences and technologies. Each prior LRP has a chapter devoted to this topic. Town Meeting conveners for the 2015 LRP were asked to consider cross-disciplinary impact. The Education and Innovation Town Meeting specifically addressed those issues.

Though COVID-19 restrictions have eased and hallway discussions are invaluable, **Downie** cautioned that many institutions currently have constrained budgets. Costs should be minimized because many may not have access to travel support. Also, the NAS Decadal Survey, devotes a section to DEI. Perhaps the LRP should consider including DEI content, especially given concerns within the NP community. A minor investment from the national labs or other funding agencies could provide an ombudsman to help with issues in larger collaborations. Finally, APS is advocating for the use of the APS Engage communication platform. Slack may be viewed as unwelcome competition and selecting Slack will require payment for its use and to retain messages. **Geesaman** offered a personal opinion. Since high value is being centered on DEI, he hopes more emphasis will be placed on DEI issues in the next LRP than in the past. **Wilkerson** agreed. Since becoming Chair, the DNP has been actively pushing for DEI. This is an important issue that should be included.

Kester asked about gathering input on technology development, especially regarding accelerators in relation to the EIC and FRIB. **Geesaman** said Town Meeting conveners were instructed to collect this information. The LRP included a specific initiative addressing accelerator and detector R&D for both the EIC and 0νββ. The LRP Working Group included individuals with expertise in those areas, but the process could have been more thorough.

Horn inquired if AI for nuclear physics might merit a separate Town Meeting. **Wilkerson** called attention to AI in addition to quantum computing as strongly overlapping areas that may warrant other Town Meetings or mini meetings. Depending on the Town Meeting itself, participants may address areas where this rapid technological advancement has a large impact.

Dodge asked about the ad hoc Town Meeting for the 2015 LRP. **Wilkerson** replied that the meeting addressed HPC.

Returning to DEI, **Yennello** agreed with Downie. DEI is receiving more attention now than in the past and will be addressed by LRP workforce development. The LRP may also consider the importance of nuclear data and how it feeds into other applications as a way of demonstrating nuclear physics' importance to the world. The Isotope R&D and Production (IP) program is no longer in NP, but there is a relevant connection through nuclear data. Finally, the LRP is received by DOE and NSF, but there are some aspects of the NP field that are adjacent to and supported by the National Nuclear Security Administration (NNSA). Lines must be respected, but there should be some mutual awareness of what lies to either side of those lines. **Wilkerson** agreed. Differentiating nuclear physics from particle physics, especially in fundamental symmetries and neutrinos, is challenging. Agencies pay close attention to distinctions, and NP must honor how different agencies approach Congress and how money is allocated. Involving NNSA, IP and other communities as LRP observers offers a chance to gather feedback.

Bernstein concurred with Yennello. NP has successfully leveraged NP's connections to the application community to validate NP work. Of note, personal experience has demonstrated that the NP LRP can be an important tool for communicating with those working for the NNSA. Did the prior LRP intentionally direct content towards the NNSA? **Geesaman** said connections to national security were discussed in the LRP Applications section noting NNSA relies on NP work to move forward.

Dodge asked about LRP Working Group composition and consensus processes. **Geesaman** explained the 2015 Working Group comprised 60 individuals. Working groups traditionally include all NSAC members and the DNP chair line. A self-imposed rule stated that

no more than three individuals from any one institution could be members. This rule can be constraining if many individuals from the same institution are members of NSAC and/ or DNP Town Meeting conveners. However, not all Town Meeting conveners wanted to be Working Group members. Other considerations include geographic, gender and age diversity and ensuring there are approximately equal numbers of individuals representing each nuclear physics subarea. It is a delicate process. All 2015 LRP recommendations were made through consensus.

Wilkerson inquired whether Geesaman waited for convener designations before naming the LRP Working Group. **Geesaman** did not wait for conveners to be identified before issuing LRP Working Group invitations. Conveners were named by the time the last LRP Working Group members were selected. It was important to have the LRP Working Group solidified before any of the Town Meetings took place because then the LRP Working Group members understood their responsibility to actively participate in those meetings.

Hertzog asked when the LRP process will begin. **Geesaman** commented that if the FY22 budget is a disaster, it would be an inopportune time to start the LRP. If the budget is reasonable, it is up to the agencies to decide whether more guidance is needed and if new initiatives should be injected. **Hallman** replied that a charge is likely to come in a timeframe for this conversation to be relevant. FY22 appropriations will hopefully be made in in the spring of 2022.

Julieta Gruszko called attention to the ongoing HEP Snowmass process and noted that activities will potentially overlap with LRP processes. **Hallman** affirmed that joint activities could be considered. The two processes, however, have some different qualitative features and have always been carried out independently in the past. Since NSAC has successfully conducted its own LRP over many decades, it might be wiser not to change a successful model.

Bernstein asked if LRP processes should be modified to take the federal deficit into account. **Hallman** recommended that the LRP Working Group consider both optimistic and more sober funding scenarios. Documents resulting from blue sky scenarios are usually not helpful. Typically, DOE NP provides an envelope of budget possibilities. Last time, flat and modestly optimistic scenarios were provided. Budgets go up and down, and it is important not to get too wrapped up in the moment.

Dodge remarked that NSAC will wait for a charge from the agencies but should begin thinking about timing for the next meeting as these activities may be linked.

Yennello inquired if the DNP chair line should begin considering LRP activities. **Dodge** advised starting early if the chair line was willing.

Hallman and Dodge thanked Geesaman and Wilkerson for their insights and service.

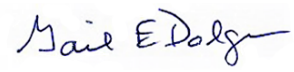
Dodge asked if either Geesaman or Wilkerson would have done anything differently in hindsight. **Geesaman** ignored some received advice but is not sure what could have been done differently in those instances. **Wilkerson** added that Geesaman dealt with a much harder problem than did the DNP. The LRP was well done. Budget scenarios provided by agencies were helpful. Ultimately, the science motivates and justifies funding.

Public Comment

None.

Meeting adjourned at 4:53 pm by Gail Dodge.

The minutes of the U.S. Department of Energy and the National Science Foundation/Nuclear Science Advisory Committee meeting, held on November 16, 2021, via virtual by zoom are certified to be an accurate representation of what occurred.



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Gail Dodge
NSAC Chair
Date: Feb. 20, 2022