Perspectives from DOE Nuclear Physics

July 19, 2021

Dr. Timothy J. Hallman
Associate Director of the Office of Science for Nuclear Physics
Nuclear Physics
Discovering, exploring, and understanding all forms of nuclear matter

Understanding why matter takes on the specific forms observed in nature and how that knowledge can benefit energy, commerce, medicine, and national security, by discovering:

- How mass is created from energy in the interior of the proton using the future Electron-Ion Collider?
- What are the properties of the novel quark-gluon plasma discovered at RHIC?
- What is the mechanism underlying the confinement of quarks and gluons via CEBAF and RHIC?
- The search for new exotic particles and anomalous violations of nature’s symmetries at CEBAF
- The limits of nuclear existence? How are heavy elements made in the cosmos via FRIB and ATLAS?
- Is the neutrino its own anti-particle? Do the neutron’s precise properties point to new physics?
- The nature of the strong force in many-body systems via SciDAC?
- Advanced Nuclear Data for Space, Energy, and Research.
Budget Matters
Nuclear Physics – FY 2022 Highlights
Discovering, exploring, and understanding all forms of nuclear matter

Operations
- The Request supports operations of the NP scientific user facilities to enable world-class science:
  - **RHIC operates at 90 percent optimal utilization** and installs sPHENIX to study the Quark-Gluon Plasma.
  - **CEBAF operates at 90 percent of optimal utilization**, enabling highest priority 12 GeV experiments and critical maintenance activities and cryomodule refurbishments.
  - **ATLAS operates at 93 percent of optimal utilization** to enable the most compelling experiments in nuclear structure and astrophysics and invests in multi-user capabilities to increase utilization of the facility.
  - **FRIB** transitions from a construction project to a scientific user facility and **operates at 100% of optimal utilization** to support research, beam studies and commissioning.

Projects
- The Request also supports compelling major scientific investments:
  - Completion of the **super Pioneering High Energy Nuclear Interaction eXperiment (sPHENIX) MIE**, to further RHIC’s scientific mission by studying high-rate jet production
  - Continuation of the **Gamma-Ray Energy Tracking Array (GRETA) MIE**, to enable provision of advanced, high resolution gamma ray detection capabilities for FRIB.
Discovering, exploring, and understanding all forms of nuclear matter

Projects (cont.)

- Continuation of the **Measurement of a Lepton-Lepton Electroweak Reaction (MOLLER) MIE** to measure the parity-violating asymmetry in polarized electron-electron scattering with the 12 GeV CEBAF.

- Continuation of the **Ton-scale Neutrinoless Double Beta Decay MIE** to determine whether the neutrino is its own antiparticle.

- Continuation of the **High Rigidity Spectrometer (HRS)** research project at FRIB to maximize the rate of rare neutron-rich nuclei of central importance for understanding the synthesis of heavy elements in cosmic events.

- The DOE Isotope Program is embedded in the Nuclear Physics budget in FY 2021 Enacted but is broken out as a Program separate from NP in the FY 2022 Request.

- The **Electron Ion Collider (EIC)**, of critical importance to maintain world-leadership in nuclear physics and accelerator science, receives its third year of OPC and TEC funding. OPC funding supports conceptual design efforts and R&D, while the TEC funding supports design efforts, long lead procurements and Project Engineering Design (PED) activities.
Nuclear Physics – FY 2022 Highlights (cont.)
Discovering, exploring, and understanding all forms of nuclear matter

Research

▪ Funding is strengthened at national labs and universities conducting research in relativistic nuclear collisions, hadron physics, nuclear structure and nuclear astrophysics, fundamental symmetries and nuclear theory.

▪ NP participates in six crosscutting scientific initiatives:
  ▪ **Accelerator Science and Technology Initiative** – strengthening U.S. supply chain robustness to steward key technologies such as electron ion source developments and advanced approaches in SRF technology
  ▪ **Artificial Intelligence and Machine Learning** – R&D for automated optimization of accelerator performance and operation as well as algorithm development for data-analytics-driven discovery.
  ▪ **Integrated Computational & Data Infrastructure** – Cross-cutting cloud solutions to Big Data storage challenges in Nuclear Physics
  ▪ **Microelectronics** – R&D on detector materials, devices, advances in front-end electronics, and integrated sensor/processor architectures
  ▪ **Quantum Information Science** – leveraging discovery opportunities in sensing, simulation, and computing at the intersections of nuclear physics and QIS
  ▪ **Reaching a New Energy Sciences Workforce (RENEW)** - advancing a diverse, equitable, and inclusive research community
## Summary of 2022 President’s Request Changes Relative to FY 2021 Enacted

<table>
<thead>
<tr>
<th>FY 2021 Enacted</th>
<th>FY 2022 President’s Request</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Core Research</strong> reduced 3.75% from FY20 Enacted (including COL, this is a 5.6% cut from constant effort in FY20). New ECA awards are made.</td>
<td>Core research in Medium Energy, Heavy Ions, and Theory is increased by 12% from FY21 Enacted. (After accounting for COL, this represents a ~10% increase over FY21 Enacted,.)</td>
</tr>
<tr>
<td><strong>LHC M&amp;O</strong> commitments are met.</td>
<td>LHC M&amp;O commitments are met.</td>
</tr>
<tr>
<td><strong>FRIB Research</strong> flat with FY2020 and below the planned level.</td>
<td>FRIB Research is increased, but still below the planned level.</td>
</tr>
<tr>
<td><strong>nEDM</strong> supported below planned profile.</td>
<td>nEDM supported significantly below planned profile, possibly impacting schedule.</td>
</tr>
<tr>
<td><strong>SciDAC</strong> commitment are met.</td>
<td>SciDAC funding is increased to support SciDAC-5 (+$600k).</td>
</tr>
<tr>
<td><strong>Nuclear Data</strong> slightly increased over FY20 Enacted.</td>
<td><strong>Nuclear Data</strong> increased $3.5M from FY21 Enacted to support the expansion of experimental efforts.</td>
</tr>
<tr>
<td><strong>Accelerator R&amp;D</strong> subject to the 3.75% research reduction.</td>
<td><strong>Accelerator R&amp;D</strong> increased ~$1M over FY21 Enacted level.</td>
</tr>
<tr>
<td><strong>QIS</strong> at $9.5M.</td>
<td><strong>QIS</strong> increased to $10.5M.</td>
</tr>
<tr>
<td><strong>NP ML/AI Initiative begins</strong> with $4M.</td>
<td><strong>AI/ML Initiative support flat</strong> with FY21 Enacted ($4M).</td>
</tr>
</tbody>
</table>
## Summary of 2022 President’s Request Changes Relative to FY 2021 Enacted

<table>
<thead>
<tr>
<th>FY 2021 Enacted</th>
<th>FY 2022 President’s Request</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Four new initiatives are supported:</strong></td>
<td><strong>Facilities operations supported at &gt;90% of optimal.</strong></td>
</tr>
<tr>
<td>- Reaching a New Energy Sciences Workforce (RENEW) - $3M</td>
<td>- RHIC operates 18 weeks (90 % maximum)</td>
</tr>
<tr>
<td>- Accelerator Science and Technology - $2M</td>
<td>- CEBAF operates 31 weeks (90 % optimal)</td>
</tr>
<tr>
<td>- Integrated Computational &amp; Data Infrastructure - $1M</td>
<td>- ATLAS operates 39 weeks (93 % optimal)</td>
</tr>
<tr>
<td>- Microelectronics - $500k</td>
<td>- FRIB operates 12 weeks (100% of optimal)</td>
</tr>
</tbody>
</table>

### Facility operations funding reduced by 3.75%.
- RHIC operates 24 weeks (100 % maximum)
- CEBAF operates 7 weeks (41 % maximum)
- ATLAS operates 39 weeks (93 % optimal)

### FRIB operations supported at $50M.

### FRIB construction at baselined $5.3M in final funding year.

### EIC construction at TEC of $5M and OPC of $24.65M

### Major Items of Equipment:
- GRETA reduced below planned levels ($6.6M)
- sPHENIX at planned baseline level ($5.53M)
- MOLLER at $5M TEC
- TSNLDBD at $1.4M TEC
- HRS at $3M TEC

### Ongoing Major Item of Equipment:
- GRETA below planned levels ($6.6M)
- sPHENIX at baseline level ($0.2M)
- MOLLER at $7M TEC
- TSNLDBD at $1.44M TEC
- HRS at $3M TEC

### Isotope Program embedded within NP budget

### Isotope Program no longer embedded within NP budget
## NP - FY 2022 President’s Request
*(Dollars in thousands)*

<table>
<thead>
<tr>
<th>Section</th>
<th>FY 2019</th>
<th>FY 2020</th>
<th>FY 2021</th>
<th>FY 2022 Request</th>
<th>FY 2022 Request vs FY 2021</th>
<th>FY 2022 Request vs FY 2020</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Total, NP FY21 – FY20</strong></td>
<td>651,500</td>
<td>635,000</td>
<td></td>
<td>-16,500</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>FY21 NP Appropriation</strong></td>
<td>713,000</td>
<td>713,000</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

FY 22 House Mark $665
General Outlook

• The budget uncertainty continues.

• We need to stay focused and continue to deliver important outcomes for the nation.

• Delivering exciting discoveries, important scientific knowledge, technological advances, and workforce training is what we do.

• We need to keep up the good work!
Recommendations:

1. Capitalize on investments made to maintain U.S. leadership in nuclear science.

2. Develop and deploy a U.S.-led ton-scale neutrino-less double beta decay experiment.

3. Construct a high-energy high-luminosity polarized electron-ion collider (EIC) as the highest priority for new construction following the completion of FRIB.

4. Increase investment in small-scale and mid-scale projects and initiatives that enable forefront research at universities and laboratories.

NP continues to execute on the 2015 LRP Vision
Upcoming Decisions

Three Front-Runner Technologies

- Scintillating bolometry (*CUPID*, $^{100}$Mo enriched Li$_2$Mo$_4$ crystals)
- Enriched $^{76}$Ge crystals (*LEGEND-1000*, drifted charge, point contact detectors)
- Liquid Xenon TPC (*nEXO*, light via APD, drifted ionization)

Background constraints are exceptionally challenging < 1 count/ton of material/year

Also, there are three possible sites

- SURF (SD)
- SnoLab (Canada)
- Gran Sasso (Italy)
0νββ Progression

- Ongoing interactions with potential international collaborators to introduce U.S. perspectives, hear European perspectives, and suggest a global approach to investment in DBD science.

- DBD Portfolio Review was held July 13-16, 2021 to inform U.S. investment strategy. Instructions published by April 15, 2021.

- North American – European Summit will be held September 29 to October 1, 2021 to see if common ground exists for an international approach to DBD investment.

- Funding for ton-scale 0νββ is going to be challenging.
The Fourth, Newest Microscope: Facility for Rare Isotope Beams (FRIB)

- FRIB issued a call for proposals to its 1500 member user group.
- 82 proposals received from 130 institutions in 30 countries requesting 9,784 hours of beam time
- FRIB Program Advisory Committee Meeting held in May 2021.
- First science in spring of 2022

World Leadership in Nuclear Structure & Nuclear Astrophysics Research
ATLAS Continues as a Premier Stable Beam Facility
NEUTRON GENERATOR UPGRADE

- Replace $^{252}$Cf source by neutron-induced fission on actinide foils
  - More reliable source of fission products
  - Operationally easier to maintain and operate
  - Higher fission yield feeding in the $^{132}$Sn region
Consistently high facility availability (~85%)

No other facility worldwide, existing or planned, rivals RHIC in science reach and versatility as a heavy ion collider. It is the only polarized proton collider in the world.

The continued focus at RHIC: search for a critical point between the phases of nuclear matter

Cooling of low energy, bunched heavy ion beams (3.85–5.75 GeV/n) to increase luminosity

Project on track for use in low-energy RHIC runs

- Consistently high facility availability (~85%)
- No other facility worldwide, existing or planned, rivals RHIC in science reach and versatility as a heavy ion collider. It is the only polarized proton collider in the world.
The sPHENIX Upgrade is Continued

- mapping the character of the hadronic matter under extreme conditions by varying the temperature of the medium, the virtuality of the probe, and the length scale within the medium.
- understanding the parton–medium interactions by studying heavy-flavor jets.
- probing the effect of the quark–gluon plasma on the Upsilon states by comparing the p-p (proton-proton), p-A (proton-nucleus), and A-A (nucleus-nucleus) collisions.

Elsewhere in Heavy Ion:
CMS MTD Science Review Ongoing
ALICE Forward Upgrade Review Anticipated

implemented from within RHIC base by limiting operations to one detector and periodically not operating facility.
New results from GlueX illuminate the mechanism of threshold J/ψ production and the upper limit on the pentaquark. The latter provides constraints on the structure of the LHCb pentaquark, favoring a molecular description.


(Based on ~25% of collected data.)
New P-REX Results Unblinded!

- The weak radius can be combined with the well-known charge density to obtain the baryon density of $^{208}\text{Pb}$
- This is the first clean determination of the central baryon density of a heavy nucleus and is accurate to 2%
- Provides an important benchmark to chiral EFT calculations that is closely related to nuclear saturation density
- Result has direct relevance for bounding the radius of neutron stars in concert with neutron star merger data from LIGO
MOLLER: a “Must Do” Experiment To Point the Way to New Science

The scientific world rather desperately needs additional markers due to the consistency thus far of LHC data with Standard Model Predictions. Due to the technical challenge of constructing a next generation accelerator with very high accelerating gradients, those markers will have to come from “indirect” discovery experiments like MOLLER.

In MOLLER, polarized electrons are scattered of unpolarized electrons. The amount of parity violation due to interference of the two possible exchange mechanisms (γ or Z) is precisely predictable in QED. (No messy quarks or color charge, or QCD to worry about, only quantum electrodynamics). The theory is so “clean” that like the g-2 approach, If the level of parity violation is greater than expected, a new particle must be the source of the discrepancy.

Project at CD-1, FY 2021 Enacted: $5M

Solid Science Review Report in Preparation
National Academy of Science Report: AN ASSESSMENT OF U.S.-BASED ELECTRON-ION COLLIDER SCIENCE

“An EIC can uniquely address three profound questions about nucleons—neutrons and protons—and how they are assembled to form the nuclei of atoms:

• How does the mass of the nucleon arise?
• How does the spin of the nucleon arise?
• What are the emergent properties of dense systems of gluons?”

The EIC would be a unique facility & maintain leadership in nuclear science

The EIC would maintain leadership in the accelerator science and technology of colliders
The EIC will be located at BNL and with TJNAF as a major partner. The realization of the EIC will be accomplished over the next decade at an estimated cost between $1.7 and $2.8 billion.

Utilize existing operational hadron collider; add electron storage ring, cooling in existing RHIC tunnel and electron injector.

EIC scope includes the machine upgrade to RHIC asset and two interactions regions with one of the interaction regions outfitted with a major detector. Working towards CD-1 in Q3 FY 2021

The EIC will be a game-changing resource for the international nuclear physics community. DOE looks forward to engaging with the international community and the international funding agencies about potential collaborations and contributions to the EIC effort, in nuclear, accelerator and computer science.
EIC User Community

EIC Users Group Formed in 2016
EICUG.ORG

Status February 2021:
- Collaborators 1259
- Institutions 252
- Countries 34

Annual EICUG meeting
2016 UC Berkeley, CA
2016 Argonne, IL
2017 Trieste, Italy
2018 Washington, DC
2019 Paris, France
2020 Miami, FL
2021 Warsaw, Poland
Office of Science
ESAAB Equivalent Board
Critical Decision Approval

Kurt W. Fisher, Director
Office of Project Assessment, SC-23
Office of Science, U.S. Department of Energy

https://science.osti.gov/opa

June 25, 2021

EIC CD-1 is Approved
Many types of nuclear data are “crosscutting” to numerous applications

NP Leads a Nuclear Data Interagency Working Group (NDIAWG) that has published 4 FOAs
Active Participants in WANDA and/or NDIAWG
In Support of Clean Energy Goals

Next generation reactors use faster neutrons, different fuels, and coolants to achieve greater safety and modularity

\[ k = \eta fp e P_{FNL} P_{TNL} \]

- Neutron multiplication factor
- Thermal fission factor
- Thermal utilization factor
- Resonance escape factor
- Fast fission factor
- Fast Non-leakage factor
- Thermal Non-leakage factor

Non-existent or uncertain Nuclear Data needs to be redressed for new materials and fuels in order to correctly understand/model the neutronics in new designs at a high level of confidence

In Support of Clean Energy Goals

Kairos FHR

<table>
<thead>
<tr>
<th>Fuel</th>
<th>Coolant</th>
</tr>
</thead>
<tbody>
<tr>
<td>TRISO Pebble</td>
<td>Molten Salt</td>
</tr>
<tr>
<td>(U,C,Si)</td>
<td>(Flibe)</td>
</tr>
</tbody>
</table>

Terrapower

MCFR (Cl)

SMR (Na)
Nuclear Data & Space Nuclear Propulsion

Presented to: Workshop on Applied Nuclear Data Activities (WANDA) 2021

Space Technology Mission Directorate
Technology Demonstration Mission Program
Space Nuclear Propulsion Project
Kelsa Palomares, AMA Inc. | January 25, 2020
Naturally occurring radiation produced by environmental radioactive materials and cosmic rays is enough to limit the useful lifetime of superconducting qubit state to just a few milliseconds... Identifying ionizing radiation as a dominant source of excess quasiparticles... is a first step towards developing to mitigate its impact on superconducting circuits, including those used for quantum computation and quantum sensing.


New Scientist, Quantum computers may be destroyed by high-energy particles from space https://www.newscientist.com/article/2252933-quantum-computers-may-be-destroyed-by-high-energy-particles-from-space/
An FY 2021 NP/SC DEI Pilot Has Garnered Strong Interest

- NP received 36 proposals requesting funding to support over 200 traineeships across the country.

- The proposed collaborations involve 91 potential participating institutions including
  - 9 National Labs,
  - 44 MSIs of which 18 are HBCUs and 2 are PBIs,
  - 9 Community Colleges, and
  - 2 Women’s Colleges.

Congressional interest garnered as well
<table>
<thead>
<tr>
<th>FOA/Lab Call</th>
<th>Nuclear Data Interagency Working Group Research Program</th>
</tr>
</thead>
<tbody>
<tr>
<td>FOA/Lab Call</td>
<td>Quantum Horizons: QIS Research and Innovation for Nuclear Science</td>
</tr>
<tr>
<td>FOA/Lab Call</td>
<td>Pilot Program for Traineeships to Broaden and Diversify the NP Workforce</td>
</tr>
<tr>
<td>FOA/Lab Call</td>
<td>Data Analytic for Autonomous Optimization and Control of Accelerators and Detectors</td>
</tr>
</tbody>
</table>
### Other News Items

- **New Staff in DOE NP**
  - **Xiaofeng Guo**
    - Nuclear Physics Computing
  - **Ivan Graff**
    - Nuclear Physics Major Initiatives
  - **Kenneth Hicks (IPA)**
    - Heavy Ion
  - **Paul Mantica (IPA)**
    - Technical Advisory/Facilities & Project Management Division
  - **Melissa Emerson (CONTR)**
    - Administrative Specialist
  - **Saryna Cameron (CONTR)**
    - Program Support Specialist

- John Yates has joined as a DOE Intern
- Kiara Fenner has joined as a DOE Intern
- NP has solicitations out for Theory PM and Heavy Ion PM; Solicitation for International PM coming soon
Overall, Progress in Implementing the LRP Has Been Good

The vision to maintain U.S. leadership continues to be implemented: EIC construction; FRIB construction

World leading research supported at state-of-the-art NP National User Facilities

Pioneering experiments and research tools (MIEs) are created

Groundbreaking contributions to national cross-cutting priorities continue
There has been a long tradition in Nuclear Science of effective partnership between the community and the agencies in charting compelling scientific visions for the future of nuclear science.

Key factors:

1) Informed scientific knowledge as the basis for recommendations and next steps
2) Mutual respect among scientific sub-disciplines
3) Commitment to the greater good of nuclear science as a discipline
4) Meticulously level playing field leading to respect for process and outcomes
5) Deep appreciation for the wisdom of Ben Franklin

Staying united we can accomplish great things together

Division will setback the entire field and is the last thing needed right now
Additional Information
Science-Driven Project Requirements

Project Design Goals

• High Luminosity: \( L = 10^{33} - 10^{34} \text{cm}^{-2}\text{sec}^{-1}, 10 - 100 \text{ fb}^{-1}/\text{year} \)
• Highly Polarized Beams: 70%
• Large Center of Mass Energy Range: \( E_{\text{cm}} = 20 - 140 \text{ GeV} \)
• Large Ion Species Range: protons – Uranium
• Large Detector Acceptance and Good Background Conditions
• Accommodate a Second Interaction Region (IR)

Conceptual design scope and expected performance meets or exceed NSAC Long Range Plan (2015) and the EIC White Paper requirements endorsed by NAS (2018)

These challenging performance goals require a machine that is state-of-the-art
The Triangle Universities Nuclear Laboratory (TUNL) is Center of Excellence that focuses on low-energy nuclear physics research. TUNL is a consortium Duke University, North Carolina State University, and the University of North Carolina at Chapel Hill comprising about 30 faculty members, 20 postdocs and research scientists, and 50 graduate students.

The Texas A&M University Cyclotron Institute jointly supported by DOE and the State of Texas focuses on conducting basic research, educating students in accelerator-based science and technology, and providing technical capabilities for a wide variety of applications in space science, materials science, analytical procedures and nuclear medicine.

The 88 inch cyclotron also plays a crucial role in space radiation effects chip testing for the Air Force.
ARUNA - Association for Research at University Nuclear Accelerators

http://aruna.physics.fsu.edu

10 members
~200 users

John D. Fox Laboratory
U.Kentucky Accelerator
Ohio U Edwards Lab

Texas A&M U. Cyclotron Lab.
U Mass Rad Lab

Notre Dame Univ. ISNAP facilities

U of Washington CENPA
Hope Ion Beam Lab

Union College Ion Beam Lab

TUNL HIGS
TUNL LENA
TUNL Tandem Lab
Mo-99 Charge Letter

This letter is to request that, in accordance with direction given to the DOE in the National Defense Authorization Act (NDAA) for FY2013, the Nuclear Science Advisory Committee (NSAC) standing Subcommittee on Mo-99 conduct its annual assessment of the effectiveness of the National Nuclear Security Administration, Office of Material Management and Minimization (NNSA-MMM) Domestic Molybdenum-99 (Mo-99) Program (formerly known as the Global Threat Reduction Initiative).

The American Medical Isotopes Production Act of 2012 (Act), formerly known as S. 99 and H.R. 3276, was incorporated into the National Defense Authorization Act (NDAA) for FY2013. On January 2, 2013, President Obama signed the NDAA into law, enacting this legislation. A stipulation of the NDAA under section 3173 – IMPROVING THE RELIABILITY OF DOMESTIC MEDICAL ISOTOPE SUPPLY is that:

“...the Secretary [of Energy] shall...use the Nuclear Science Advisory Committee to conduct annual reviews of the progress made in achieving the [NNSA MMM] program goals and make recommendations to improve effectiveness.”

The Department of Energy (DOE) and National Science Foundation (NSF) very much appreciate NSAC’s six previous assessments as described in reports transmitted to the agencies on May 8, 2014, July 30, 2015, November 3, 2016, March 19, 2018, April 17, 2019, and March 16, 2020.
Mo-99 Charge Letter

We request that NSAC provide a seventh annual assessment addressing the following charge elements:

- What is the current status of implementing the goals of the NNSA-MMM Mo-99 Program? What progress has been made since the 6th NSAC assessment?
- Is the strategy for continuing to implement the NNSA goals complete and feasible, within an international context?
- Are the risks identified in implementing those goals being appropriately managed?
- Has the NNSA-MMM Program addressed concerns and/or recommendations articulated in the 2019/2020 NSAC assessment of the Mo-99 Program appropriately and adequately?
- What steps should be taken to further improve NNSA program effectiveness in establishing a domestic supply of Mo-99?

It is requested that this assessment be submitted spring of 2021.
We are aware that this charge represents an additional burden on your time. However, the involvement of NSAC is essential to inform the Agency regarding the effectiveness of efforts to steward Mo-99, and isotope essential for the health and well-being of the Nation.

Sincerely,

J. Stephen Binkley
Acting Director
Office of Science

Sean Jones
Assistant Director
Directorate for Mathematical and Physical Sciences
National Science Foundation
Benefits of Training in Nuclear Science

- Highly Specialized Technical skills
- Creative problem analysis/solving ability
- Scientific communication skills
- Resilience despite frustration / perseverance
- Self confidence
- Time management ability
- Project planning skills
- Ability to team and working within a large collaboration
- Leadership development

The result is an essential national core competency useful not only for “things nuclear”, but for a variety of other challenge pursuits as well.
Safe nuclear energy is almost certainly part of a U.S. clean energy future. Accurate, reliable nuclear data is central to realizing that vision, terrestrially or “out of this world”.

1. HALEU Fuel Enrichment
   - Use of HALEU may drive the desire to thermalize the neutron spectrum compared to historic fast and epithermal designs

2. Unique Operating Regime – NTP operating temperatures vary from cryogenic to ultrahigh temperature (> 2750 K)
   - Cross section temperature dependence

3. High Temperature Moderators and Materials – space reactors may benefit from high temperature moderator candidates (metallic hydrides and beryllium compounds) and refractory metals / ceramics
   - Previous benchmarks and historic testing do exist for reference but spectrum may differ (possible need resolution of unresolved resonances over energy range)

4. Unique Working Fluids – Scattering in hydrogen can play a role in reactor control and reactivity
   - Scattering in hydrogen non-negligible contribution to overall reactivity

5. Prototypic Environment - The use of a nuclear reactor in space must consider background radiation and probabilities for interaction with the reactor
   - High energy photonuclear reactions and photon sources should be characterized to understand any impact to the reactor during idle, start up, or nominal operation
   - Different backgrounds expected for in-space or surface operation

6. Testing Infrastructure – Space reactor technologies could benefit from pre-existing or new infrastructure for experimental testing and evaluation of nuclear data

7. Uncertainty data – updated covariance data will allow for more accurate characterization of reactor uncertainty / sensitivities
In Support of Clean Energy Goals

Next generation reactors use faster neutrons, different fuels, and coolants to achieve greater safety and modularity

The harder neutron spectrum and different fuel introduce a dependence on types of nuclear data not explored

Neutron Spectra

Non-existent or sparse Nuclear Data needs to be redressed for new neutron energy regime to correctly understand/model the neutronics
nEXO Concept

Artist rendering of the nEXO TPC (left) and its installation at the SNOLAB cryopit (left). The cryostat is submerged in a water tank which acts as active shielding. SiPMs will be mounted between field shaping rings and detector wall.
The concept for LEGEND-1000 showing a number of the deployments Ge detectors. This cut-away view shows three of five 200-kg groupings of Ge.
CUORE: Towards Ton-scale NLDBD Search

Collected TeO$_2$ exposure: 1110 kg*year
Analyzeable exposure: 1031 kg*year (*as of Oct 26, 2020)

>1 ton*year analyzeable exposure
Largest dataset ever collected by a solid-state double-beta decay experiment
Continuous operations at 11mK since March 2019
Demonstrates readiness for a ton-scale bolometric double-beta decay experiment
CUPID proceeding to technical design
# Summary of 2021 Enacted Relative to FY 2020

<table>
<thead>
<tr>
<th>FY 2020 Enacted</th>
<th>FY 2021 Enacted</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Facility operations</strong> at constant effort</td>
<td><strong>Facilities operations</strong> funding is reduced by 3.75%. Estimated run times are:</td>
</tr>
<tr>
<td>- RHIC operates 28 weeks (100 % optimal)</td>
<td>- RHIC operates 24 weeks (100 % maximum)</td>
</tr>
<tr>
<td>- CEBAF operates 22.5 weeks (100 % maximum)</td>
<td>- CEBAF operates 7 weeks (41 % maximum)</td>
</tr>
<tr>
<td>- ATLAS operates 41 weeks (90 % optimal)</td>
<td>- ATLAS operates 39 weeks (92.6 % optimal)</td>
</tr>
<tr>
<td><strong>FRIB operations</strong> supported at planned level $28.5M</td>
<td><strong>FRIB ops</strong> supported slightly below planned levels ($50M vs $59.8M)</td>
</tr>
<tr>
<td><strong>FRIB construction</strong> at baselined $40M</td>
<td><strong>FRIB construction</strong> at baselined $5.3M</td>
</tr>
<tr>
<td><strong>EIC construction</strong> at TEC of $1M and OPC of $10M</td>
<td><strong>EIC construction</strong> at TEC of $5M and OPC of $24.65M</td>
</tr>
<tr>
<td><strong>Ongoing Major Item of Equipment:</strong></td>
<td><strong>Ongoing Major Item of Equipment:</strong></td>
</tr>
<tr>
<td>- GRETA reduced below planned levels ($6.6M)</td>
<td>- GRETA flat with FY2020, below baselined level ($6.6M)</td>
</tr>
<tr>
<td>- sPHENIX at planned baseline level ($9.52M)</td>
<td>- sPHENIX at baseline level ($5.53M)</td>
</tr>
<tr>
<td>- SIPF at planned baseline level ($1.5M)</td>
<td></td>
</tr>
<tr>
<td><strong>New Major Items of Equipment initiated</strong></td>
<td><strong>Major Items of Equipment initiated in FY 2020</strong></td>
</tr>
<tr>
<td>- MOLLER at $2M TEC</td>
<td>- MOLLER increased to $5M, but below planned level</td>
</tr>
<tr>
<td>- TSNLDBD at $1M TEC</td>
<td>- TSNLDBD at $1.4M TEC</td>
</tr>
<tr>
<td>- HRS at $1M TEC</td>
<td>- HRS at $3M TEC</td>
</tr>
<tr>
<td><strong>Isotope Program</strong> at $60.5M</td>
<td><strong>Isotope Program</strong> at $78M</td>
</tr>
</tbody>
</table>
Summary of 2021 Enacted Relative to FY 2020

<table>
<thead>
<tr>
<th>FY 2020 Enacted</th>
<th>FY 2021 Enacted</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Total, NP</strong></td>
<td>651,500</td>
</tr>
<tr>
<td><strong>Total, NP Appropriation</strong></td>
<td>713,000</td>
</tr>
<tr>
<td><strong>Core Research</strong> reduced 5.5% from FY19 Enacted (including COL, this is a 7.4% cut from constant effort in FY19). New ECA awards were made.</td>
<td><strong>Core research</strong> reduced 3.75% from FY20 Enacted. This reduction also includes a reduced number of new ECA awards in FY21.</td>
</tr>
<tr>
<td><strong>LHC M&amp;O commitments were met.</strong></td>
<td><strong>LHC M&amp;O commitments met but subject to the research cut.</strong></td>
</tr>
<tr>
<td><strong>FRIB Research</strong> was supported as planned.</td>
<td><strong>FRIB Research</strong> is reduced by 3.75% from FY20; planned ramp-up is not supported.</td>
</tr>
<tr>
<td><strong>nEDM</strong> supported modestly below planned profile.</td>
<td><strong>nEDM</strong> supported below planned profile, possibly impacting schedule.</td>
</tr>
<tr>
<td><strong>SciDAC</strong> maintained relative to FY 2019</td>
<td><strong>SciDAC</strong> supported but subject to the research cut.</td>
</tr>
<tr>
<td><strong>Nuclear Data</strong> held flat with FY19 Enacted</td>
<td><strong>Nuclear Data</strong> research funds subject to the research cut. Experimental commitments met, but limited funding is available for new awards.</td>
</tr>
<tr>
<td><strong>NP QIS</strong> at $6.8M (NP QIS flat with FY2019)</td>
<td><strong>NP QIS</strong> at $9.5M, an increase of $2.7M from FY2020</td>
</tr>
<tr>
<td><strong>Accelerator R&amp;D</strong> was increased</td>
<td><strong>Accelerator R&amp;D</strong> is reduced by $1M beyond 3.75% cut.</td>
</tr>
<tr>
<td><strong>Machine Learning/Artificial Intelligence</strong> awards were initiated through the SC ML/AI FOA.</td>
<td><strong>The new ML/AI Initiative</strong> is supported with $4M of dedicated funds.</td>
</tr>
</tbody>
</table>