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Space Life Sciences Lab
505 Odyssey Way
Exploration Park
Merritt Island, FL

December 9, 2022

Dr. Craig Kundrot, Director
Biological and Physical Sciences
National Aeronautics and Space Administration
Washington, DC 20546

Dear Dr. Kundrot:

The Biological and Physical Sciences Advisory Committee (BPAC), an advisory committee to the Biological and Physical Sciences (BPS) Division of the Science Mission Directorate (SMD) of the National Aeronautics and Space Administration (NASA), convened on November 15-16, 2022, using a hybrid platform of both in person and virtual attendees. The undersigned served as Chair for the meeting with the support of Dr. Michael Robinson, BPAC Designated Federal Officer (DFO), of NASA-BPS. The members of BPAC that participated in the meeting are listed below:

- Kenneth Davidian, International Space University
- William Davis, NASA Johnson Space Center
- Jamie Foster, University of Florida
- Simon Gilroy, University of Wisconsin-Madison
- Meredith "Mary" Guenther, Commercial Spaceflight Federation
- Nathan Lundblad, Bates College
- Maren Mossman, University of San Diego (virtual attendee)
- James Pawelczyk, Pennsylvania State University
- Aleksandra Radlinska, Pennsylvania State University (virtual attendee)
- Ali Rangwala, Worcester Polytechnic Institute
- Kathleen Rubins, NASA Johnson Space center
- Danilo Tagle, National Center for Advancing Translational Sciences
- Mark Weislogel, IRPI, LLC

The BPAC committee was briefed on FACA ethics, the 2022 GPRAMA process, and BPS research portfolio in Space Biology, Physical Sciences, and Fundamental Physics. Additionally, the committee received briefings on how BPS is engaging in areas of Inclusion, Diversity, Equity (IDEA), and Accessibility, Commercial Lunar Payload Services (CLPS), Artemis, Open Science, Commercial Low Earth Orbit Destinations (CLD), and Commercially Enabled Rapid Space Science (CERISS) programs. BPAC was tasked to lead the review of its one SMD performance goal listed below, as well as provide findings and recommendations for the BPS program.

P.G. 1.2.8: NASA shall demonstrate progress in understanding the properties of physical and biological systems in spaceflight environments to advance scientific knowledge, enable space exploration, and benefit life on Earth.

Findings of the BPAC committee: The BPAC committee made several observations based on the BPS presentations and annual report.

- The committee felt that BPS was optimizing its current funding by leveraging collaborations with programs from other divisions and directorates to increase the reach of the BPS division portfolio. Specifically, early BPS involvement in programs, such as Artemis, Orion, Gateway, Commercial Crew, CLD, HRP, and CLPS, has positioned BPS to identify optimal opportunities for affordable and timely science experiments.
- The variety of BPS-funded ground-based research in both the biological and physical sciences was viewed as a strength and is indicative of a healthy research program that will likely serve as an important knowledge foundation for future flight experiments.
- The committee was enthusiastic about efforts to integrate artificial intelligence and machine learning research in Open Science Programs.
- Members of the committee thought that the efforts of BPS to increase access to free-fall/microgravity environments were to be commended, especially regarding commercial suborbital capabilities and how they can be used to expand BPS research platforms.
- The BPAC committee thought that BPS efforts to improve workforce retention through meaningful and engaging professional development were commendable. The BPS efforts and initiatives have the potential to increase the diversity of space scientists and outreach to communities underrepresented in science.
- The committee was supportive of the focus on quantum science (e.g., entanglement, quantum communication, atom interferometry) given the rapidly growing role in the global research ecosystem. By engaging in quantum research and developing the first types of experiments of this type (i.e., Cold Atom Lab) BPS is providing an important platform for this important area that will impact our understanding of the universe.
- It appears to the committee that the ISS and CCP Program Offices need to prioritize enabling BPS' CERISS activity and implement logistic efficiencies that can be achieved to work through the backlog of BPS experiments and increase research throughput; this is not something BPS can solve, however, it significantly impacts BPS research capacity and could increase commercial interest in BPS' portfolio.

Recommendations of the committee: Based on the presentations and discussions of the BPAC committee, there are a few recommendations for BPS to consider.

- The BPAC committee recommends revising the language of the GPRAMA performance goal to either clarify or remove "*the properties*," to simplify the sentence. For example, "*the properties*" could be replaced with "*mechanisms*" or "*processes*" or simply be removed. Additionally, BPS may want to consider a change to "*physical and biological*

systems [utilizing] spaceflight environments" to clarify the importance of high-impact fundamental research requiring an ongoing microgravity environment or other spaceflight-native property.

- The Cold Atom Lab (CAL) has been highly successful with BPS providing most, if not all, of the funding. It is recommended that BPS explore whether the CAL platform could be benefited and expanded by receiving investment from other federal agencies (e.g., NSF), which could enable further development of scope and possibilities for post-ISS (and post-Bose-Einstein Condensate and Cold Atom Lab (BECCAL)). Additionally, it is recommended to determine whether the CAL could be transferred to a future CLD.
- Due to BPS's unique role in collaborating with many different divisions and directorates, it is recommended to increase opportunities for BPS scientists to rotate within and outside of NASA (e.g., commercial providers).
- One recommendation to potentially increase efficiency aboard the ISS is to work towards conducting more frozen science experiments rather than live/fresh science to enable more experimental flexibility.
- The varied number of IDEA programs was exciting but there was little information on the number of students reached or metrics to assess the efficacy of these engagement programs. It is recommended to include assessments of the various IDEA programs to help define and understand their impact on helping to build a robust community and sustainable workforce.
- There was extensive discussion of efforts for Open Science and IDEA engagement in the biological sciences, the committee would like to recommend seeing more (or hearing more) about similar efforts in the Physical Sciences and Fundamental Physics.
- The committee recommends BPS explore taking a leadership role in the development of a high throughput drop tower facility capable of partial gravity that could support fundamental and applied research within BPS. In addition to supporting BPS research, such a unique nation-level facility could be exploited by NASA, DoD, and commercial aerospace communities to buy down risks, and thus costs, for fundamental and applied partial-gravity research and development.

Areas to be discussed at future BPAC meetings: The BPAC committee did have some additional questions derived from the discussions that could serve as potential talking points or presentations for the next committee meeting.

- As utilization of the ISS is near maximum, BPS is doing well to maximize available resources (e.g., up/down mass, stowage, crew time); however, how will BPS work to increase that efficiency to increase scientific experimental throughput?
- The breadth and depth of various programs both in biology and physics were impressive; however, there was less clarity in terms of continuity of these activities on CLDs, and if there are plans for increased research capacity given the potential increase in the number of destinations.

- Additionally, perhaps a discussion regarding how BPS fits into NASA's larger plans to avoid gaps between the ISS to CLDs transition especially if timelines slip for the construction of the CLDs. As BPS productivity is sensitive to dependencies (i.e., linkages) to the activities and operations of other organizations and programs, including, but not limited to, research infrastructure, station operations, launch capacity, return capacity. In other words, how does BPS plan to avoid research delays during the transition and how will the plan for Open Science access continue on CLDs?
- Furthermore, as the ISS funding subsidy will disappear when the ISS program ends (currently 2030), there is a significant financial threat to BPS capacity to continue its work. How will BPS address the potential budget gaps to maintain research capacity and momentum?
- Although the amount of outreach and open science opportunities that the BPS is offering to the younger generation of investigators and K12/University students is commendable, there was concern that the current scope of BPS IDEA efforts ignores community colleges where there are many students from underserved populations. We would like BPS to potentially address their efforts to engage this important segment of the educational pipeline and involve all tiers of community colleges/universities not just top-tier research institutions and HBCUs, HSIs, and TCUs.
- Provide additional budget breakdown within the BPS program so that the committee can understand the distribution of funds within the BPS program.
- As stated earlier, BPS is leveraging their position and portfolio to expand their capabilities, however, what new relationships with other agencies or divisions within NASA could be developed to generate new customers for BPS knowledge products that might support exploration on both the physical and biological sides?
- We note that there are certain cross-cutting contributions of the fundamental research pursued by BPS that are enabling to technological advances for space exploration, but that this objective does not appear a 'high' priority. Should a level of expectation along these lines be formally established? (i.e., ~ % research with near-term exploration applications potential?)

Results of the discussion and vote: The committee extensively discussed the information presented by BPS and, ***all present voted unanimously for a "green" rating of the performance goal.*** The specific GPRAMA summary text generated by the BPAC committee for the performance goal is attached below. We thank the staff for providing source material with highlights from the NASA-supported missions and research projects. We welcome any requests from NASA BPS Division for clarification or elaboration on our findings.

Sincerely,

Jamie S. Foster

GPRAMA Summary Statement for PG 1.2.8

P.G. 1.2.8: NASA shall demonstrate progress in understanding the properties of physical and biological systems in spaceflight environments to advance scientific knowledge, enable space exploration, and benefit life on Earth.

The Biological and Physical Sciences Advisory Committee determined in November 2022 that NASA has demonstrated significant progress in its annual performance towards understanding the biological and physical processes impacted by the spaceflight environment and advancing the scientific knowledge needed to enable space exploration. Below are selected examples from FY22 that the committee found to exemplify this progress.

One of the major areas of advancement derived from BPS funding has been the continued progress to optimize and grow plants under both ground and spaceflight conditions. Plants are an integral component to the future human exploration of space and the research supported by BPS provided important advances in those areas. For example, a significant area of progress in the ground-based research experiments was the demonstration that the small flowering plant, *Arabidopsis thaliana*, a member of the mustard family, could grow in Lunar regolith collected from the Apollo 11, 12 and 17 missions. Although the plants growing in the Lunar material exhibited stress responses compared to controls, the seeds were able to germinate and grow. Examination of the stress responses of the seedlings will enable a precise analysis of the interactions between the Lunar material and plants and help improve the growth of plants on the Moon and under spaceflight conditions.

Another advancement derived from the BPS portfolio included improving ways to store and care for seeds and plants. A recent study showed that hydrogels can serve as a low-cost medium for plant cultivation, thereby demonstrating new ways to cultivate plants under simulated microgravity conditions that minimize the need for watering by the crew. Additionally, the MISSE-Seed experiment, in which seeds from several edible crops (e.g., lettuce, radish, tomato) were exposed to the space environment outside of the ISS to examine how seed quality is affected by seed storage conditions. Analysis of this spaceflight experiment is ongoing, but the results will likely help optimize storage conditions to maximize growth of plants during future missions.

Several important BPS-funded discoveries were made in the physical sciences in 2022, including several derived from the BPS-funded Cold Atom Lab (CAL) aboard the ISS, which enables novel quantum physics experiments to be conducted. The CAL facility cools atoms to near zero temperature and allows them to be studied in the absence of gravity for longer durations than what's capable on Earth. By removing the effects of gravity new insights into novel quantum physics can be obtained. For example, a new study examined the behavior of ultracold atomic

bubbles, which are unable to be formed on Earth and are an intriguing application of placing so-called “fifth state of matter” Bose-Einstein Condensates (BEC), into new geometries and topologies. These efforts could lead to new insights into the nature of quantum matter and development of new technologies.

Physical sciences research advances in 2022 also included new methods on the ISS to develop larger colloidal crystals suitable for various signal processing applications. Additionally, there were breakthroughs regarding increasing the speeds of electric vehicle charging. Laboratory experiments using knowledge gained from the NASA Flow Boiling and Condensation Experiment, which helps cool the conductor within the charging cable, enabled a rapid delivery of electrical current to the vehicle and may have widespread applications on Earth.

*Based on these achievements and other advances in FY22, the committee voted unanimously for a **GREEN** rating.*