National Aeronautics and Space Administration

Technology, Innovation, & Engineering Committee of the NASA Advisory Council

Hybrid Meeting
September 5, 2024

Meeting Minutes

G. Michael Green, Executive Secretary **Michael Johns, Chair**

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NASA Advisory Council Technology, Innovation, and Engineering Committee

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Overview of Agenda and Opening Remarks

Mr. G. Michael Green, Executive Secretary of the NASA Advisory Council (NAC) Technology, Innovation, and Engineering (TI&E) Committee, welcomed the meeting participants. He noted that there have been changes to the committee since its most recent Federal Advisory Committee Act (FACA) meeting, including the naming of Mr. Clayton Turner as the new Acting Associate Administrator. He thanked the Glenn Research Center (GRC) for hosting the meeting, and welcomed Dr. Wanda Peters, the Acting Deputy Director for GRC on detail from the Science Mission Directorate (SMD), where she is the Deputy Associate Administrator for Programs in the Science Mission Directorate (SMD).

Welcome to NASA's Glenn Research Center

Dr. Peters thanked Mr. Green, introduced herself, and noted that Dr. Jimmy Kenyon would have liked to have been at the meeting. She said the changes that brought her to GRC included Mr. Turner becoming Acting Associate Administrator for the Space Technology Mission Directorate (STMD) at NASA headquarters, and Dawn Schaible, Deputy Associate Administrator at GRC, becoming the Acting Center Director at Langley. She spoke of the pleasure of coming to and having an opportunity to learn about GRC. She thanked the committee for their time, guidance, and commitment to helping NASA and expressed appreciation for the senior leaders from the NASA team and all the employees who support the center's efforts.

The meeting participants introduced themselves.

- **Andrew Rush**, cofounder and CEO of Star Catcher, a company focused on space and space power beaming. He was formerly the President and CEO of both Made In Space and Redwire.
- **Mitchell Walker**, Professor and Chair of Aerospace Engineering, with a research specialty in electric propulsion, at the Georgia Institute of Technology.
- **Heshmat Aglan**, Dean of the College of Engineering at Tuskegee University.
- **Lindsay Kaldon**, Fission Surface Power Project Manager at GRC.
- **Clayton Turner**, Acting Associate Administrator of STMD.
- **Michael Johns**, Senior Vice President at Kratos SRE in Birmingham and Chair of TI&E.
- **Mike Green**, Deputy Associate Administrator for Management in STMD at NASA and Executive Secretary of TI&E.
- **Anthony Calomino**, current lead for Space Nuclear Systems at STMD at NASA.
- **Lauren Ameen**, Cryogenic Fluid Management Deputy Project Manager at GRC.
- **Alesyn Lowry**, Director of Strategic Planning and Integration at NASA.
- **Anyah Dembling**, member of the STMD Communications Team.
- **Mike Gazarik**, Faculty Director of the Engineering Manager Program at the University of Colorado, Boulder.
- **Rebecca Kramer-Bottiglio**, Assistant Professor at Yale University with a focus on robotics.
- **Mike Barrett**, Director of the Space Flight Systems Directorate (SFSD) at GRC.

Dr. Peters reviewed Glenn's mission and said the center touches all five mission directorates (MDs). She talked about the history of GRC, which dates back 80 years and is the third oldest NASA center, behind Langley and Armstrong. The location for GRC was chosen in part due to its close proximity to the airport. The original lab was unique for its expertise in propulsion and work at the lab played a significant role in engine performance for aircraft in WWII. In 1999, the lab was renamed for John Glenn, the first astronaut to orbit the Earth.

Dr. Peters reviewed the NASA Center locations and core competencies under the tagline "*power propulsion communication*." Several factors set Glenn apart: a decades-long experience in propulsion, including thrusters (one being developed for Gateway); test facilities to support testing of spacecraft and aircraft (every aircraft flying in the United States has some technology originating from GRC); wind and icing research; a drop tower, which simulates the weightlessness of space; the world's largest vacuum chamber, where Orion was tested for its first successful, crewed flight; and thermal modeling of integrated spacecraft.

GRC has two campuses, with approximately 3,200 employees in total: Lewis Field in Cleveland, and the Armstrong Test Facility in Sandusky. The workforce is highly educated and skilled: 75% of employees have advanced degrees and 25% hold PhDs. Support teams include business management, general counsel, procurements, technicians, and more.

GRC has a significant economic impact and wants to ensure a strong partnership with the community in Ohio, working closely with business, state government, congressional representatives and senators to ensure NASA is contributing to the economy in the state and around the nation. GRC's overall economic impact has exceeded $2B, and 9,000+ jobs have been created and supported.

Mr. Johns noted that other centers have seen loss of workforce to commercial space, and asked whether GRC is experiencing the same challenge. Mr. Green said that GRC does not see that as much as other centers; it is not the biggest impact on the mid-career workforce. Dr. Mike Gazarik asked whether the onsite versus remote work structure is working and whether there is a plan to get people onsite. Mr. Johns said about 60% of the total workforce is onsite on any given day. GRC leadership did not adopt a mandatory onsite policy; instead, it delegated directors to work with engineering and SMA, with project managers deciding who is onsite. On a project lifecycle, some programs are not in 5 days a week, but the large programs staff is onsite almost every day. Office chiefs are advised to pick certain days to try to get cross-offices to critical mass. GRC leadership has been monitoring the performance criteria and, if there's any drop-off on milestone achievement, will reassess. Dr. Peters added that the staff in GRC test facilities are onsite 5 days a week, including a summer maintenance program. A strong employee engagement program and the sense of family and community encourages people to be onsite, too.

Dr. Peters next talked about changes and challenges at GRC. With a nearly 85-year-old center, there are infrastructure challenges with a variety of solutions: 1) new, modern facilities and upgraded office spaces, including relocation of center leadership to increase engagement with employees; 2) a proactive maintenance plan with maintenance and repairs on an annual basis; and 3) the development of areas, including newer facilities, with a focus on attracting employees. A new Level 2 Program Office for Technology Transfer allows technology invented at Glenn to be patented and licensed to private industry for commercial use. Also, budget uncertainty remains a challenge. When it comes to infrastructure, funding has depleted or flatlined over the years, which requires creativity to keep facilities updated and forces some descoping of work. Dr. Peters said clear, consistent communication about these challenges to the agency, MDs, and partners is necessary, as is working with partners who may contribute.

GRC is experiencing a campus transformation. There is a plan to create a "Downtown Glenn" space for community and group think. Building 15, currently without employees, is being used for training and drills (e.g., law enforcement training) until its demolition, when it will be transformed into a park area for employee use. For older buildings, GRC is considering Enhanced Use Lease (EUL) agreements with individuals in the community, corporations, or industry partners to use the hangar and upgrade the facility as part of the agreement. For historical purposes, there is an effort to preserve the NASA meatball and the GRC sign.

Dr. Peters thanked everyone for being at GRC, said everyone's role is crucial, and invited feedback and questions.

Space Technology Mission Directorate (STMD) Update

Mr. Turner echoed Dr. Peters' appreciation for the meeting participants' time and clear outside views. He spoke to STMD's purpose as technology base for civil space and said STMD enables that work by looking beyond today's mission and putting in place that which enables future missions to venture further into the solar system and warp drive deeper into the galaxy: "deliver today and create tomorrow."

STMD's recent technology highlights include a solar sail demonstration deployment in August 2024, for which multiple centers worked together. Mr. Turner also mentioned solar electric propulsion, work with nuclear electric propulsion (NEP) and nuclear thermal propulsion (NTP), cryogenic fluid management (CFM). He spoke about the Flight Opportunities program investment in a Blue Origin New Shepard test flight, wherein for the first time, a research professor from University of Florida flew with their payload and conducted their experiment on the commercial suborbital rocket in real time. It is an example of bringing space to more people and more people to space.

The Space Technology portfolio is set up from a technology readiness level (TRL) structure from low, mid, to high. He said, as STMD transitions to a new organizational structure, areas in Early-Stage Innovation & Partnerships, Small Business Innovation Research/Small Business Technology Transfer (SBIR/STTR), Technology Maturation, and Technology Demonstration Missions (TDM) will be transferred to a domain structure to more smoothly move technologies from concept to demonstration and eventually implementation. There is approval to move forward with the structure and workforce, but no particular date in place for delivery. Mr. Turner stressed that delivery of something enduring requires deliberate work and flexibility, and expectations need to be communicated to centers and partners. This work will continue through Fiscal Year 2025 (FY25), but established milestones and deadlines will not artificially drive the process.

Dr. Mike Gazarik asked whether the plan is to continue with the organization described in the past year? Mr. Turner said, yes, STMD is moving forward with the domain structure with the change in pace for due diligence. Dr. Gazarik commented that it is amazing to see the University of Florida professor doing his experiment on the New Shepard vehicle after their was so much initial pushback on it.

Mr. Johns asked whether there any Catalysts in the process that are changing or going away, like the Space Technology Research Institutes (STRI) or the early-stage funding opportunities. Mr. Turner said it will all continue within the budget parameters, which will drive choices that align with the longer-term deliverable of a particular technology or capability.

Mr. Turner then reviewed a snapshot of the budget. The resource management team has been working hard for the transition and has to map the current budget structure to the new one while allowing for accounting of all resources and applications as a part of due diligence.

Dr. Walker asked whether entry, descent and landing (EDL) took a significant cut and what the impact would be. Dr. Michelle Munk, the EDL Systems Capability Leader and the Domain Formulation Leader for Land Domain, said that, under the current structure, the content attributed to EDL does go down in FY25, before the new structure is in place with dedicated budget allocations for each domain and capability area, but that large drop is not expected in the new structure. Dr. Walker followed up regarding On-orbit Servicing, Assembly, and Manufacturing (OSAM), which looks like it's coming to a stop. Mr. Turner said that is an ongoing discussion.

Mr. Andrew Rush asked about thoughts on how the SBIR money would be broken up among the five functional domains. Mr. Green said the SBIR money is split among the MDs at NASA, each of which has a certain number of activities funded through the SBIR program. STMD's portion of that money will stay in the Catalyst area as a separate line item, but new ideas and subjects will be put in the SBIR column by each domain. Each MD will still have an ability to put its technologies and problems within the SBIR program. Mr. Turner underscored that STMD has a portion to manage but it's in the budget for the agency. Mr. Rush asked whether there was an expectation for other MDs to adopt the Go, Land, Live, Explore, Enable paradigm for the SBIRs that they're directing. Mr. Turner said, while they may not have that structure, there will be alignment in the development to do something on the surface. Ms. Lowry added that the way the Catalyst awards are selected internally will be a bit more focused on the domains' demand for those awards and thus more aligned to fulfilling the needs of the roadmaps for all of the capabilities within the domains. Mr. Green said STMD will pick the subtopics and topics for SBIR, but he expects the other MDs will keep the same or similar topics as they've had in the past. Mr. Rush asked for clarification about connecting priorities between, for example, SMD and STMD if SMD proffers a set of topics and subtopics for SBIR that are relatively low-TRL maturation, how will those be mapped in and carried forward at STMD? Mr. Turner said where the investment is made, from the SBIR standpoint, would need to be coordinated beforehand.

Mr. Turner gave an FY25 snapshot of public language and various proposals from the House and Senate next to the President's Budget Request (PBR). He presented the list of congressional directions and noted that they are all in progress so there are no numbers available.

Mr. Turner spoke about the shortfall process and said the robustness of the process and ranking helps to inform the technology development roadmap; as STMD long-term roadmaps are developed, they will be the drivers of thinking and decisions. Mr. Turner said the shortfall information has been shared publicly and is available for public comment.

Mr. Turner reviewed upcoming space technology demonstrations on Intuitive Machines 2 (IM-2). The first effort had a couple of technologies and, while landing didn't go exactly as planned, demonstration of the Navigation Doppler Lidar (NDL) was possible; the data from that instrument tracked well with what was seen on the ground. The Stereo Cameras for Lunar Plume Surface Studies (SCALPSS) technology to investigate the plume interactions was in position and could have been used, though it was not turned on. He said the mission was a good model for how government and industry partners can work together and showed how STMD is pushing the envelope on things beyond the technology widgets and gadgets.

Dr. Mitchell Walker noted that the shortfalls chart showed EDL as a red item and looked to balance that against what was seen in the budget. Ms. Lowry said that this reflected the 2025 budget and was well-plotted before the shortfalls study, which will inform 2026 and beyond. It was noted that the number of green items shows the level of agreement within the community about what problems are important and should be tackled.

Dr. Gazarik asked whether there were any surprises or top-level observations in terms of the rankings? Mr. Green said it was a good mix between the top 30 goals/problems versus the short- and mid-term issues. Many of the items from stack reports from the past 40 years and all sorts of organizations are here, and there is consistency among study findings over the years: they are hard problems and, as an agency, the resources to address all of them have not been there. There are some things that are ranked lower than expected, perhaps because respondents came in with their own perspectives and directions to the community regarding mindset as they answered questions may not have been clear. It was noted that much of the response focus was "roads and commodes" – not just flashy items but things related to surviving the night. Dr. Gazarik said this confirms his thinking that they have the right problems to deal with.

2024 Shortfalls Ranking Process and Results Overview

Ms. Lowry, Director of Strategic Planning and Integration at NASA, introduced herself and Dr. Michelle Munk, Acting Chief Architect for the program. Ms. Lowry said the shortfalls process began with a feedback opportunity, released in spring 2024, to solicit feedback on 187 shortfalls to better understand the most pressing and pervasive problems. A migration to the term "shortfall" from the term "gap" was made to move towards technology needs and away from the suggestion of known endpoints with the term "gap." The methodology consisted of two surveys: one public with external agencies; one a NASA Spark campaign to get feedback from the NASA workforce. Submitters were asked to score the shortfalls (any but not necessarily all) on a scale from 0 to 9, plus N/A.

Ms. Lowry reminded people of the evolved strategic planning process to solicit input from all stakeholders and identify top problems. Currently, the analysis is focused on identifying how current projects align to the shortfalls and how well they contribute to the problem identified within the shortfalls. There is intention to create a methodology to rank projects quantitatively, so the return on investment of all projects can be evaluated. There will not be an arbitrary cutoff number on the list and, although rankings will be important input for investment, they will not be the only input. The process of developing roadmaps is underway and, under the new domain structure, each capability listed below the domain level has been asked to develop roadmaps, starting with identification and agreement of the goals within each capability area.

Ms. Lowry said the shortfall ranking process is meaningful because data drives conversations around relevant facts. The integrated and weighted ranked list will be one of several factors to guide the Planning, Programming, Budgeting, and Execution (PPBE) processes and is being used to inform the 2026 submission from the agency. The ranking results are published and the entire list is available online. STMD is excited about looking more deeply at what communities submitted and who may be engaged to reach solutions. Ms. Lowry said the ranked results are based on a quantitative numerical assessment on the scoring approach. The open comments, over 1,700, are still being processed.

There were 1,231 responses, a thrilling level of participation. The actual number of individual responses is higher, because about 20 submissions were considered consolidated. There was a good balance between external responses (462) and NASA badges (including civil servants, contractors) (769), good representation among various centers, industry, academia, other government agencies, and one input from each of the MDs at NASA for consolidated input. Representing industry, 185 companies of various sizes and from various sectors responded.

Ms. Lowry reviewed the ranking process and methodology. In brief, the 1,200+ responses were grouped according to stakeholder, consolidated by internal versus external response, and weighted. Experts are reviewing open comments to capture information and issues in their respective fields. Scores for consolidated responses were calculated by weight, by center, and by stakeholder group. The rankings for the final integrated ranked shortfall list were based on average scores, except for SMD and Exploration Systems Development Mission Directorate (ESDMD), which only had one submission each.

Ms. Lowry then reviewed the approach to weighting stakeholder groups: reflect primary customers' input with a recognition that all other stakeholders are critical in partnering to provide solutions and help develop the capabilities. She also reviewed the philosophical tenets that drove the weighting.

Overall observations included: the number one ranked shortfall, to survive and operate through the lunar night, was in the top 10 across all stakeholder groups; there was agreement about the top five ranked shortfalls and relatively broad consensus and support for top 30 shortfalls; there was diverse representation of capability areas in the top 20 shortfalls.

Ms. Lowry reviewed the Integrated Top 30 Shortfalls Compared to Stakeholder Group Rank chart. She noted that there are some short-term problems that need solutions for lunar needs but also a lot in the top 30 focused on longer-term needs on Mars. Many of the problems are big, long-term issues that need to be solved. She presented the full integrated shortfall rankings list and noted highlights for the group.

Contributing to next steps will be the lessons learned about how this effort was conducted and how the shortfalls were structured. There is room to consolidate and make changes, including adjustments to how the shortfalls were written and ensuring that shortfalls are informed by the roadmaps being developed. The ranked list will be used as one factor to help guide investments, but there will still be a balanced technology portfolio across all capability areas. There is a desire to solicit feedback annually, but the team wants to respect the time of respondents and be able to show progress against the list before the next survey. Ms. Lowry closed with an affirmation of the commitment to transparency in the process going forward.

Dr. Gazarik asked whether there would be roadmaps per domain. Ms. Lowry said the approach is shifting regarding ownership of the strategy to the domains. Domains will own the roadmaps, but there is a process to approval. Right now, there is ongoing work towards agreement regarding goals for each of the capability areas and the shortfalls should inform those goals. There will probably be multiple roadmaps per capability within the domains, but hopefully a few each on average. Dr. Munk said they are figuring out how all these things relate to each other and making sure there is a good flow down from shortfalls to capability goal statements to roadmaps to investment strategy. The end goal is to have a good hierarchy of needs and be able to trace those to shortfalls and map those to primary stakeholders' needs for ESDMD and SMD.

Mr. Johns asked about the process that leads to a prioritized list of investments: if "survive the lunar night" is the number one priority but there might be 30 different investment potential projects in there, how are those ranked and how is the cut off line in funding determined? Ms. Lowry said that's still being figured out. There is a rubric to score how well a project contributes to a shortfall; almost all projects will contribute to more than one shortfall. There is an effort to use a numerical approach but also take cost and TRL advancement into account. Mr. Turner said the biggest thing is to minimize the subjectivity of those choices, to identify the tallest pole and if that can't be done, move to the second pole and let a partner develop the tallest pole. Dr. Munk said the roadmaps will come in to play for the temporal sequence of activities for the best chance for success, as well as the degree of difficulty, perhaps starting development on one option and then doing a down select.

Ms. Lowry explained that items in red are the top three shortfalls within a priority area. Mr. Johns asked how it is handled when the item is low on the ranking but top three in the category. Ms. Lowry said it's an indicator that people didn't see it as a big problem, although some of the technologies are enabling for other solutions; so connections and considerations need to be taken into account. Mr. Green said NASA has invested a lot of money in manufacturing technologies over the last 10 years and the community may think all is well there and bigger problems need to be tackled. Mr. Rush suggested this might be a difference between strategic investments and tactical investments: "survive the lunar night" is an enabling but very tactical solution for Artemis, whereas advanced manufacturing is a strategic, transformational thing for all operations. Ms. Lowry said that, in the domain structure, there is a need to figure out the right investment approach for some of those capability areas. Mr. Green said "survive the lunar night" is tactical and specific and advanced manufacturing is very broad and, next time, the 187 shortfalls being at different levels of granularity needs to be considered. Ms. Lowry noted the speed within which the shortfalls process was done and, because comparison against different types of shortfalls is difficult, they would be written differently in the future. Mr. Rush said this is one of several factors that drive roadmapping and investments and projects, and that there is a balance between having something that fits Artemis today versus something that changes the way we do mission design over the next 15 years. He said MDs other than STMD are more Artemis-focused. Ms. Lowry said there needs to be a balance between push and pull; there can't be a unique focus on the specific big problems, but there needs to be an effort to continue to transform what we can do 30-40 years from now.

After a short break, Mr. Green read the OSAM statement that is posted publicly on the NASA website that announces the discontinuation of the OSAM-1 project. The statement includes information about reassessment of plans and reaffirmed the February 2024 decision to discontinue the project based on costs, schedule, and technical risks. Full details, including future plans that may be affected, can be found in the statement.

NASA Nuclear Systems Update

Dr. Anthony Calomino, the current lead for Space Nuclear Systems at STMD, gave a brief overview of the space nuclear technology front and mentioned that NASA is working with DOE in this area. The technology is enabling for the future of civil space and gives an edge on space leadership, feeds into the domestic economy, is synergistic with zero-emission green energy capabilities, and strengthens national posture and global competitiveness. In 2020, there was a pivot towards commercial grade enrichments on uranium, which opened an ability to engage industry in a broader way, including partners from the energy sector. Applications in near-Earth are being looked at, including potential to leverage advancements for a human Mars exploration mission in the late-2030s, early-2040s. From a power side, work is on track, technically and programmatically, to design, develop, build, and test a flight-qualifying 10kW/10skW fission power system by the mid-2030s.

The partnership with the Defense Advanced Research Projects Agency (DARPA) on Demonstration Rocket for Agile Cislunar Operations (DRACO) is on schedule and within costs and looking forward to a launch in the 2027 timeframe. That system, which is Gen Zero, is the first step to a Gen 1 capability, directly applicable as a near-Earth space hub or another fairing vehicle, able to take payloads from LEO to GEO. Industry is strongly interested in those applications. A Gen Zero NEP capability is a slow-powered 10s of kWs NEP that gives an experience on the integrated system, which offers some science mission benefits. That system is a stepping stone towards the multi-megawatt (MW) capability needed for a human exploration system. Moving towards that for NEP, some other high-powered complements come along: electric propulsion system, power management system, thermal radiator technology management for a low-weight optimized system. The benefits of combining NEP and NTP to get out of Earth's gravitational field and be able to have a long cruise time to an outer planet are also being considered.

In the last 4 years, NASA has changed the pulse on space nuclear systems, and other agencies are showing strong interest in the same capabilities. U.S. Space Force (USSF), with NASA personnel on the team, is looking at doing Joint Energy Technology Supplying On-Orbit Nuclear Power (JETSON), an NEP demonstration principle. NASA is partnering with DARPA on the DRACO to demonstrate a lower power, lower thrust, 5,000-pound kind of thrust vehicle and is on track for launch by 2027. There has been investment in the Fission Surface Power (FSP) project and an interagency partnership between NASA-DOE-DOD has been established to develop VALKRE, a small power system that could be used on the Moon or for an off-planet power system. NASA has interest from other organizations for powering small activities, such as disaster relief and supply chain work to remove oil dependencies.

Dr. Walker noted the enormous investment in fusion on the energy civil side and wondered whether that will be a topic that runs through here. Dr. Calomino said when there is an operational fusion power plant on Earth, it would be time for NASA to see whether it's a capability to offer advantages off-Earth.

Dr. Calomino said they are on cost and on schedule for the DRACO partnership. It's been a learning experience for NASA to adopt a DARPA hard process and come up to speed for demonstration. NASA teams have taken a risk posture on execution. There is reliance on primes and sub-primes to do the jobs; and embedded members of the team of prime working engineers gain understanding and insight live. As the costs of supporting the DRACO flight demonstration begin to wind down, the current funding profile has a ramping up on NEP to march towards the slow-power NEP flight demonstration.

Ms. Lindsay Kaldon, Fission Surface Power Project Manager at GRC, spoke about NASA's FSP Project, which is placing a small nuclear reactor on the Moon and, hopefully, Mars one day. The current 40kWe output is probably enough to power an Artemis base camp and maybe some rovers, targeting a mass of 6,000kg and having a 10-year life span. Nuclear is reliable, can go a long time, and is a great source of power in extreme environments. The plan is to use High-Assay Low-Enriched Uranium (HALEU) that is about 20% enriched.

The top goals and objectives for the project are to use the nuclear reactor to provide independent power for NASA missions, deliver a flight-qualified lunar demonstration system; and transition FSP technology to industry, which will build this reactor.

Ms. Kaldon reviewed the roadmap. Although 40KwE is not considered a high-power source, this is the first generation system. Future generation FSP systems will have to be higher power to help support a lunar economy to support in-situ resource utilization (ISRU). The FSP team is working with the Mars architecture team to gain understanding of their needs.

FSP is investing in technologies that address four of the five critical technology elements (CTEs) identified for NEP. There is momentum in the global nuclear industry toward small module reactors and microreactors for terrestrial use, and interest in NASA's investment in corrosion resistant materials that can operate in extreme temperatures.

FSP execution has two phases. Phase 1 for concept designs from industry, with only three requirements (power output 40kWe; launch and landing loads; and radiation protection), was completed about a year ago. Phase 2 will be an RFP to industry, pending budget received. The designs from Phase 1 are government-owned and include concepts, cost estimates, and schedules. Ms. Kaldon reviewed the Phase 1 concept designs and noted that the government side also took requirements and worked with DOE to come up with a Government Reference Design (GRD).

FSP works with all directorates across NASA to ensure their needs are met. For example, ESDMD is working with the Lunar Architecture Team (LAT) to meet an element initiation for Artemis. ESD will come with identified power needs and FSP will perform an Element Initiation Review and be able to say how they'll meet those gaps or shortfalls. Ms. Kaldon said FSP directly addresses or will be helpful to many of the integrated shortfalls (e.g., water extraction on the lunar surface).

Ms. Kaldon reviewed the FSP technology maturation investments being made. In addition to the reactor, power conversion, radiation tolerance, heat transfer, and power distribution (e.g. for a distance of one km from the user/astronaut) must be considered. Ms. Kaldon recently presented areas of investment at the DOD Nuclear Community of Interest Review to try to avoid duplication of efforts; she noted many opportunities for collaboration with other agencies.

The NEP benefits of FSP are the CTEs previously mentioned, including instrumentation and control. For FSP, everything green-checked is being invested in at this point, excepting Electric Propulsion Subsystem (EPS), which is being worked on under Solar Electric Propulsion (SEP) out of GRC.

Ms. Kaldon then reviewed the list of potential partnerships and collaborations. These include the VALKRE system, which is a collaborative effort with the Marine Corps as the DOD interest and the Operational Energy Office out of the Office of the Under Secretary of Defense (OUSD); an effort where NASA provides subject matter experts to help in reviews with Air Force Research Laboratory (AFRL) on JETSON; and other efforts with international space agencies, DOE, and more.

In response to a question about the evolution from 1MW to a 40kW small reactor, Ms. Kaldon said there is a desire to prove the concept, technology and limitations presented by the mass and efficiency of current systems. With the move to HALEU, the necessary redesigns make the system heavier. Dr. Calomino added that the strategy is to look for wins for real application in the near-term, 5 to 10 years. Also, in Phase 1 solicitations, industry was asked to design systems in modular fashion, so the core features of the design would work at 2MW and at 20MW or 40MW, too.

Mr. Aglan asked about a prototype in Phase 2. Ms. Kaldon said Phase 2 is expected to have an engineering demonstration unit (EDU)/prototype and also a flight unit, pending budget. The EDU/prototype could rely heavily on modeling and simulation. There are concerns about testing and whether there will be a vacuum chamber that can handle nuclear material, so a fully integrated system is to be determined and there may need to be tests of subsystems.

Next, Dr. Kurt Polzin, chief engineer for the SNP project at Marshall, spoke about efforts in NEP, specifically, although NTP and NEP are both in the portfolio. He said the DRACO demonstration helped hone in on gaps/shortfalls that need investment. With the many applications from crewed to science missions, there is great potential to support, enhance, and enable many missions. Dr. Polzin noted, however, that at the MW level, there are recognized challenges to developing a NEP system. Regarding those recognized challenges, including the five CTEs, Dr. Polzin said, as long as you control the interfaces on these systems well, you can make incremental progress and develop the technologies separately, including folding technologies from other programs in, as budgets become available.

Mr. Johns asked whether investments can be focused in all those CTEs or do you have to choose one and throw everything at it. Dr. Polzin said it is not necessary to throw everything into just one; all the desired work can be done in any single CTE, but there are long tent poles in each. There is an effort to attack the hardest parts in each technology element with the funding available. Responding to a question about budget, Dr. Polzin said they received $7M in 2024 and don't know the number for 2025.

Among the challenges are options other than FSP for low power: the SEP work done on Hall and Ion have given options. There is interest in the development for the Power and Propulsion Element (PPE), which will have multiple thrusters running as a cluster. In terms of high power application, some funding has gone into high-powered, lithium-fed MagnetoPlasmaDynamic (MPD) thrusters. Dr. Polzin discussed other challenging needs, including higher temperature operation, higher reliability, and a higher lifetime for science missions and human missions.

The development plan for NEP takes an evolutionary approach, starting at low power. With technology maturation comes the ability to do missions that are longer and higher power, to cargo and human Mars missions. As the FSP system is building its first flight system, a cadence of technology maturation and infusion develops where FSP and NEP are going back and forth on their technologies and improving the systems as they go along.

Regarding the terrestrial microreactor world, HALEU makes small modular reactors possible and allows technologies from terrestrial and space worlds to cross over. Dr. Polzin shared a comment made by a contractor: "Terrestrial nuclear makes space nuclear possible; space nuclear makes terrestrial nuclear better." To improve technology at both low and high-powered classes, testing with real hardware at size and scale is necessary. The TMP is to build the real test hardware and put it under duress to see how it works and fails.

Working with space science community members, SNP and FSP, participated in the Tempe Workshop to talk about what is being done in SNP and power and to learn about the space science community wants and needs, so something useful to end users can be built.

Dr. Walker asked about the available launch vehicle, considering the size and complexity of what might be built, and how that impacts the technology developed. Dr. Polzin said there is a dependence on the power level in the 5s; you'd like bigger is better, but there is a launch cadence of smaller vehicles: do you want to package it all into one launch vehicle or fairing; for a science mission the answer may be yes, whereas for a human mission it may be no. So SNP has started to explore how to structure the campaign, and consider – with big structures –whether the preference is to design a spacecraft optimized to fit into a fairing or actually accomplish the mission. An Early Career Initiative (ECI) has been supported and STMD-funded to look at assembly of larger structures for this purpose. Dr. Walker commented that Falcon 9 leaves the ground on average every 72 hours, and tempo can be very important.

Mr. Green said that investments in NEP are great and noted the interest at the NAC level on NEP versus NTP. Dr. Polzin said there are options and places where NTP or an NTP/NEP system hybrid looks good. There's a lot to be investigated and there are a lot of potentially complementary technologies, especially on the nuclear side. Because one is high thrust and one is high in-space propulsion (ISP), there might be advantages to having a system that has both, including better splitting of delta-Vs. Dr. Calomino made a comment about all the energy it takes to get a delta-V to go to an outer planet. For launch, staging is one of the greatest inventions of 20th century rocketry. He said NASA and DARPA are building real reactors on the DRACO right now and learning the difference between building a paper reactor and a real reactor. Some of the anticipated technology gaps on FSP and NEP are already being looked at. Mr. Johns said NEP has been talked about for the last couple years as the future thing and Airforce is looking at it and asked whether that was on the radar. Dr. Polzin said a lot of Ms. Kaldon's connections are on his radar. They've been plugged into JETSON. The investments in NTP from several years ago are what made DRACO possible in a lot of respects. Similarly, the investments that FSP and SNP make on NEP are going to make that possible not just for NASA but for the nation.

Cryogenic Fluid Management Portfolio Update

Ms. Lauren Ameen, the Deputy Project Manager of the Cryogenic Fluid Management Portfolio Project (CFMPP) office, said her presentation would serve as an update to the presentation to the NAC in 2022. In 2021, STMD reformulated a lot of how the CFM work was organized and consolidated it into the CFMPP with the intent to focus the CFM technology development on applications for in-space transportation and surface applications. Within the CFMPP there are 20 different "activities"/sub-projects and the portfolio project is a like a program. This presentation is an overview rather than a drill down into 20 activities. The CFMPP is a partnership between GRC and Marshall, with a project manager in each place.

CFMPP is aiming to close more in-space transportation gaps, focused on in-space stage development and surface applications. There is component-based development but also an attempt to focus more on integrated CFM system development. The majority of technologies range from TRL from 4-7 with a goal of 7 before leaving for industry or to another MD, for example. Most of the work reaches across the entire agency for expertise.

For transportation systems that will use cryogenic propellants, the pull is at an all-time high, across industry and within government. In order to push from the Moon to longer duration transportation, like Mars and beyond, capabilities in CFM will need to be pushed, requiring advancing integrated systems to a TRL of 6. CFM is agnostic to the in-space vehicle architecture selection. Whether you choose NTP or NEP-Chem stage, you're going to need advance CFM systems development.

Ms. Ameen said that as you increase mission duration, you need to increase both storage and transfer technologies, which increases complexity. The CFMPP office is organized into 4 sub-portfolios: technologies, subsystems, demonstrations, and modeling. The modeling portfolio takes data from different activities and infuses it into tools with the intent to have them be design tools for future mission designers.

Ms. Ameen sought to highlight activities from the CFMPP.

2020 Tipping Points: The United Launch Alliance (ULA) is a ride-share demonstration contract aiming to add a specific piece of demonstration hardware to a Vulcan Centaur to do a tank-to-tank liquid hydrogen transfer at the end of a future Centaur mission. The Critical Design Review (CDR) has recently completed and the flight is projected for 2025.

Eta Space: This start-up company is aiming to fly a small liquid oxygen payload being developed internally. There is a large set of CFM demonstration objectives, including zero boil-off (ZBO) and fluid transfer. They are planning to launch on Rocket Lab Photon, with a mission duration of no longer than 9 months. CDR was recently completed and launch is projected for 2025.

SpaceX: In March 2024, the Tipping Point Demonstration (TPD) flew on SpaceX Starship flight number 3, including tipping point-specific hardware that demonstrated capability to complete tank-to-tank transfer of liquid oxygen within Starship; although not ship-to-ship, this was a big milestone. SpaceX is working with NASA analysts to use data from the flight to validate design tools and SpaceX is using the data as a stepping stone as they continue Starship development. In response to a question, Ms. Ameen said they met the target objective to transfer 3 metric tons, the contract objective.

Radio Frequency Mass Gauge (RFMG) Demonstration: The Commercial Lunar Payload Services (CLPS) Intuitive Machines 1 (IM-1) successfully flew RFMG on a NOVA-C Odysseus Lander. All mission objectives were met on the IM-1 mission. CFMPP is working in line with the IM team during all phases of the mission. This demonstration was able to prove the technology and met all the performance objectives.

Low-Leakage Hydrogen Valves: NASA Marshall has been developing Low-Leakage Hydrogen Valves technology for a long time, focusing on reducing leakage rates of valves. CFMPP has been developing prototype valves based on a design patented this year and was able to demonstrate the ability to reduce the leakage rate to under one skin and achieve TRL 4 criteria. There is movement to infuse the design and information into industry. There will be a Request for Proposal (RFP) this summer with hope to award in October to procure a high fidelity prototype valve and push to TRL 6, right before fall with the intent to fly.

High-Efficiency Cryocoolers: There are two active SBIR Phase 3 contracts within CFMPP. The first is a 90K cryocooler contract nearing its end; it recently achieved TRL 5, has completed assembly, proof of performance, and vibration testing. It is scheduled for delivery to GRC at the end of September 2024. The second is a 20K cryocooler, more focused on a liquid hydrogen stage perspective and also a reversible rate cryocooler. Preliminary thermodynamic testing of the Brass Board Unit (BBU) is complete and there is now a push more toward an electron microscopy (EM) unit. It achieved TRL 5 and activity should complete in 2025.

Cryogenic Fluid Modeling: The agency has spent the last 20 years developing and validating multi-node and Computational Fluid Dynamics (CFD) tools to be used for future design applications. The modeling team uses experimental data from the ground and from flight. CFMPP is working with multiple stakeholders to understand what kind of design tools will be needed in the future to understand pre-predictive modeling needs and when might modeling be good enough and done. This area of the portfolio is continually being leveraged across the agency and CFMPP is doing the inline work and infusing the knowledge to industry.

Capability Shortfalls: There are five CFM-related capabilities in the list of 187. All CFMPP activities map to one of the five shortfalls within their office. CFMPP has been working on creative ways to close shortfalls without having to fly something new, including an assessment of all the funded cryogenic missions across the agency, and developing a government reference integrated system-level demo concept to help define requirements.

That development is being done through conversations with other agency stakeholders, including multiple conversations with DOD, USSF, AFRL, and others.

In response to a question about the three shortfalls without numbers and whether they map to a shortfall, Ms. Ameen said they do and explained how they align. She said the liquefaction one was in the middle; the predictive modeling was #39; and the cross-discipline CFM was near the bottom, because people might not have known what it was. And, from the CFMPP perspective, all the technology or hardware you would need to make a liquefaction system work on the surface you would already be doing for an in-space transportation; it's more on the operations side that you need to go demonstrate and close, but you don't need a flight demo to do that, you can do that on the ground. Mr. Johns was surprised that it only maps to five on the list: that they've heard a lot about CFM technologies as one of the enabling technologies. Ms. Ameen said her office did not connect to things on the list that did not explicitly say CFM and it is *the* enabler. She said some of the nuclear propulsion shortfalls mapped higher on the list but CFM is enabling to those shortfalls, although they're not called out specifically.

CFM Notional Near-Term Roadmap: There are three swim lanes to ensure a strategic path to meeting agency needs: 1) Ground Developments, focusing on storage and transfer and feeding into surface system applications, 2) Flight Demonstrations, to understand and define requirements, specifically for Mars mission development, 3) Advanced In-Space CFM Model Development, directly infusing system-level models into multiple funded NASA programs. CFMPP is working on an integrated strategy to meet the PBR date and determine an investment start date for a current Mars mission development system of 2039+.

CFMPP Approach for Integrated Flight Demonstration: This concept is for an integrated flight demonstration using a mission pull of 2039. CFMPP is working with the Mars Architecture team and Mars office. The team has baselined liquid hydrogen for the demo but that could change. The integrated demo is intended to buy down technical risk and increase the TRL and is still in pre-formulation with STMD. Assessment of funded agency contracts continues throughout FY25 while working with STMD on budget baselining.

Dr. Walker asked whether there were any users for the valves. Ms. Ameen said multiple companies are interested in infusing the technology into their product line, but there is still a lot of technology work to be done to be comfortable qualifying the valve for flight. The intent of the new contract is proving it works.

Mr. Johns asked about interest in high-efficiency cryocoolers. Ms. Ameen said there is direct interest but also a lot of development needed in that area. There is not a large industry base within the U.S., currently, doing high-efficiency, high-capacity, miniaturizing: making them small and maximizing mass, so CFMPP is trying to infuse industry with a contract let out in 2025 to try to have more designs that industry can use.

Commercial Lunar Payload Services Intuitive Machines-2 Technology Demonstrations Overview

Mr. Mark Thornblom, Deputy Program Manager for Technical Integration in the Game Changing Development Program office in STMD, gave a short overview of the NASA STMD investments for the NASA CLPS IM-2 mission, including information about the mission, challenges overcome, and some details and status of the funded payloads investigations onboard.

The IM-2 mission is planned to launch around December 2024. The NOVA-C lander will be launched on a SpaceX Falcon Heavy rocket and is targeted to land in the Shackleton connecting ridge area. It will have between 8 and 10 Earth days of mission time and is expecting acceptable illumination and communication for mission goals. This information is publicly available in the IM Payload Users Guide, and the majority, if not all, of the CLPS vendors are providing this information on their websites.

Mr. Thornblom gave an overview of the IM-2 NASA-funded payloads. Polar Resources Ice Mining Experiment 1 (PRIME-1) will demonstrate drilling into the lunar regolith using the mass spectrometer with the goal of identifying water and other volatiles. The IM Lunar Deployable Hopper was designed to demonstrate hopping ability with ability to explore harder to reach areas on the Moon like permanently shadowed craters. The Nokia 4G/LTE demonstration will demonstrate 4GLTE capabilities on the Moon, a crucial communications capability currently being infused to enable future Artemis missions. All three payload demonstrations are well aligned with STMD investment strategies.

Mr. Thornblom reviewed the task order for the IM-2 mission, signed in October 2020 with an original planned mission date of December 2022. The Nokia 4G/LTE and Lunar Deployable Hopper projects had been selected as part of the 2020 STMD Tipping Point call with the intention to fly. Those three payloads were manifested together to meet the STMD mass allotment for the CLPS mission and are taking advantage of some industry synergies.

A unique challenge for this mission was choosing a landing site that had acceptable illumination and communication opportunities, predicted ice flare deposits that the drill can access, and an area clear of major obstacles and steep slopes. The Lunar Surface Innovation Initiative (LSII) helped form a team of subject matter experts from government, industry, and academia that worked with the payloads to select the Shackleton connecting ridge location 2B landing site. This selection process, including subject matter experts, Now can be offered as a service in the future.

- *PRIME-1*: Objectives are to use the Honeybee Robotics-provided TRIDENT drill to bore up to a meter in depth in the lunar regolith and use the MSOLO mass spectrometer to detect and identify volatiles in the samples. *Project on time and in budget*.
- *Deployable Lunar Hopper*: Objectives are to demonstrate hopping ability on the lunar service. Hopping has advantages over traditional roving, including speed, the ability to bypass ground obstacles and rough terrain, and the ability to get out of low lying areas. IM is hoping to demonstrate the technology by making a series of hops within the mission. This technology may be provided in the future as a commercial capability to provide access to the extreme environments on the lunar surface. This project completes final environmental testing in September 2024 and will be delivered for final integration soon after. The Hopper is owned by IM and is in charge of its own destiny. *IM will meet their schedule and fly*.
- *Nokia 4G/LTE:* Objective are to adapt terrestrial 4G/LTE technology, ruggedize hardware, and adapt the system for a lunar environment. The technology was recently commercially infused and will be a capability in the next generation spacesuits for exploration of the lunar surface. Mr. Thornblom described the details of mounting, installation, and communication using the NOVA-C lander and MAPP rover. The data collected will provide critical updates to network lunar propagation models. *Project is ahead of schedule*.

Mr. Turner asked whether Nokia is going to set up an account so it can do social media from the Moon. Mr. Thornblom said he isn’t sure what their capabilities are back to Earth networks but can ask. It would be great publicity during the Artemis campaigns.

Dr. Rebecca Kramer-Bottiglio was interested in Honeybee Robotics and the Hopper from IM, which seem like solutions that are likely translatable across missions. Mr. Thornblom agreed and said one big success story is working with instrument companies to make their existing lab equipment more rugged for a space environment. Teams are really pushing for future instruments that need to go to the Moon, particularly for environmental monitoring. They are hoping the trend continues and it is a good deal for NASA. Dr. Kramer-Bottiglio asked, within the drilling portfolio, does STMD have a large investment in burrowing and drilling outside this platform? Mr. Thornblom said no, this is it right now. Dr. Kramer-Bottiglio spoke about DARPA recent roll-out of a large program looking at ground and non-conventional technologies to lay cable based on bio-inspired animal burrowing solutions. She said the Office of Naval Research has robust burrowing programs, as well, and this could be an opportunity to leverage other investments for lunar and Mars missions in the future. Mr. Thornblom said their drilling work to date has been vertical drilling for ice and resource mining.

Dr. Gazarik asked whether the Nokia 4G/LTE fits in the architecture or concept of Lunar Net and a standard communications system by scan. Mr. Thornblom said he doesn't know, specifically. He offered to reach back out to ESDMD but said at the start, it was not a robust part of the Artemis strategy. The 4G/LTE network in spacesuits is a newer addition communications strategy for Artemis.

In response to a question, Mr. Thornblom said that one of the lessons learned on IM-1 that carries over to IM-2 is operational communication during the mission. Communications were very fast paced during IM-1, and being able to have a dedicated and ready communications strategy for making priority decisions as things change has been a topic of interest for IM-2. There will be a team in the program and a playbook to use as things change to make fast decisions during the mission, people at NASA's Johnson Space Center and Kennedy will work in shifts to meet those needs as they come up.

Niki Werkheiser, Director for Technology Maturation in STMD, spoke about the importance of using this kind of opportunity as a potential model for conscious action. The way these Tipping Point opportunities in 2020 combined with the CLPS call and PRIME-1 resulted in an entire lunar surface mission being inserted into the planning that utilizes the CLPS ecosystem but does not further stress their limited budget and constraints. So a whole technology mission was made possible by looking for ways to use acquisition mechanisms. The LSII ensures deliberate and conscious work with the external community and internally to use everything available to leverage limited budgets to the best of our ability.

Early Career Initiative presentation on Mitigating Arc Inception via Transformational Array Instrumentation (MAI TAI)

Ms. Meghan Bush, Principal Investigator for the Mitigating Arc Inception via Transformational Array Instrumentation (MAI TAI) project and research engineer at GRC, presented on MAI TAI.

Overall, through MAI TAI, this project is aiming to change the way solar arrays are designed and operated in variable charging environments to enable new solar cells and high voltage array operations. MAI TAI is a 2-year, $2M R&D effort funded by STMD. The team is primarily made up of early career personnel at GRC. She described the team, including her coinvestigator, Jeremiah Simms, and material and data scientists, electrical engineers, and programmatic and senior staff.

Ms. Bush gave an introduction to spacecraft charging, explaining hazards, including radiation, and the interactions between charged particles, plasma, and the Earth's magnetosphere that lead to unique charging regimes. She mentioned that solar arrays now mostly rely on more passive techniques, which are not necessarily best.

For solar cells in the presence of charged particles, the components of the cell will start to build up charge, which can induce a primary arc – an electrostatic discharge from the cover glass through the solar cell – which are not considered problematic, but they can induce a secondary arc, which is a current path created between two cells on adjoining strings. If the cells are actively in sunlight and generating power, that electricity will feed the secondary arc and it will not quench itself until the array is shadowed or the cell is destroyed. Unmitigated secondary arcing burns up cell components which destroys the cells and the bits of metal that are evaporated off can then deposit onto other areas of the array causing further problems.

The current state of practice for manufacturers is to have enough space between solar array strings and keep the differential voltage between those two strings below a certain threshold. Mr. Turner asked if lower is better why not drive the threshold very low. Ms. Bush said higher voltage operations get maximum power from the array, and keeping the operating voltages below a certain threshold would kneecap potential power for the sake of preventing damage. She said the passive mitigation techniques are not good for the lunar environment, where the charging environment is highly variable through the day and does not account for next-generation solar cells, which are getting larger and operating at higher voltages, so they’re bumping up on the limits of these best practices. She noted that this does not account for protecting thin-film solar cells.

MAI TAI is aiming to mature the way solar arrays are protected from arcing in three ways:

1. Passive mitigation for thin-film solar cells, which are susceptible to primary arcing and will degrade simply due to heat;
2. Active mitigation that is able to prevent these secondary arcs from happening without relying on passive techniques that will limit power generation;
3. Adaptive mitigation that is important to anything operating on the lunar surface; if you design for worst case scenario, you miss out on huge amounts of potential power generation at points in the lunar cycle where arrays are under illumination.

Mr. Johns asked whether they are not worried about primary arcing. Ms. Bush said for state-of-the-art solar cells, they don’t care about primary arcing; for thin-film cells it will be a major damage mechanism.

The benefits of this work include high-voltage operations for increased power output, and mass savings, which, from a launch standpoint, means cost savings; also, the work enables next-generation solar cells for further mass savings and compatibility with ISRU solar cell development that can survive the lunar surface charging environment. At the core of MAI TAI is changing the way we look at solar array operations: taking a more active monitoring standpoint as opposed to designing for worst case scenario. Ms. Bush added that this work falls neatly into the STMD shortfall #2, high power generation for M2M.

For active arc mitigation, MAI TAI is developing novel circuitry capable of detecting and quenching. Detecting primary arcs and notifying the system is important for active mitigations. Circuitry monitoring allows for customizing mitigation techniques using knowledge of the affected arcs and the environment.

The primary arc detector works by monitoring the current of the solar array without impacting power, detecting arcing events, and notifying the system/user that a primary arc has happened. A machine learning algorithm in development will work with the outputs of the PAD and adjust the array, using the array itself as an environmental sensor. The secondary arc detector detects and quenches arcs faster than a millisecond; the circuitry development and testing was the largest development of the past year.

Mr. Johns asked, on current solar arrays, are you measuring current at the cell level? Ms. Bush said a whole solar array is being measured at the same time, so not at the cell level, rather at the string level or a full test article level (multiple arrays). Mr. Johns followed up asking whether thin-film solar arrays currently being put in space are measuring voltage at the array level or the cell level? Ms. Bush said it's at the module level, the string level. Mr. Turner asked whether they are leveraging the imagery. Ms. Bush said they thought about trying to recycle what is being generated but, for now, are just dissipating it. For now these arcs can be quenched in the lab in 17 microseconds across a full data set (significantly faster than necessary); based on the fast response, the circuitry is starting to act within 4.6 microseconds of the secondary arc starting. Ms. Bush said they are fully shorting out the array to zero volts and quenching that arc pretty close to immediately. A major success of the project so far is this active circuitry and the continuous development and testing and figuring out exactly how we want these to work. She mentioned it's R&D right now, so the thinking is about where we want to go next. It's still a technology demonstration in the lab. Mr. Johns wondered, since basically the cell is being turned off, if you turn that cell back on will a secondary arc reinitiate? Ms. Bush said not immediately, although it can. Arcing events are random in nature and we're just trying to prevent a cell from being damaged to prevent critical damage. This will enable high-voltage operations, because you don't have to worry about the differential voltage threshold because you can prevent the arcs from damaging them in time.

Ms. Bush showed images of testing, which is done at GRC, and described the process of testing. Then, she reviewed the philosophy behind adaptive mitigation. It is crucial to lunar surface arrays to maximize power output throughout the lunar cycle, making sure arrays are operating at a low enough voltage to avoid things going haywire during the worst part of the lunar cycle and ramping up voltage when things have calmed down.

Regarding thin-film solar cells, there are many types with less mass and higher power density; they are cost saving and compatible with ISRU solar cell development on the lunar surface. Ms. Bush said passive mitigation is still part of the project because of uncertain time scale for damage, speed of the arcs, and easy of destruction of a thin-film solar cell. These cells are susceptible to primary arcing, so using testing to inform ideas for architecture and best practices to prevent them from failing is an important effort. MAI TAI is partnering with NREL and ASU to work on these challenges. Testing with perovskite solar cells from NREL has just finished. The testing allows the team to get a baseline of the damage and then see if it is reduced with mitigations.

Ms. Bush said ECI has been a good experience that allowed for working with early career people in a wide variety of fields. For example, she had an opportunity to work with Safety and Mission Assurance (SMA) at GRC to adapt elements of the way that flight programs are run and do a flight technology demonstration of the work on a solar array. So the ECI Program is working with SMA on agile project management. Working with the data science team has been instrumental for things like processing data into a machine learning algorithm. Adjusting to ticking boxes in a lot of areas as researchers has been a novel and impactful part of the project for the ECs.

Mr. Johns asked whether it takes longer to initiate a contract than they expected. Ms. Bush said, yes, we expected it to take about 3 months, but it took 6 or 7. We started in a continuing resolution and had to learn about the procurement process and interagency agreements. Mr. Johns asked what preparation there was for running a first big project. Ms. Bush said they relied a lot on mentors for preparation and leaned on people who have been through the ECI Program. She appreciated that the ECI Program listens when the team says something was tough (e.g., the procurement process) and has changed their timeline quickly as a program, so the next group can benefit from their suggestions. There was a discussion about preparation and the standing suggestion for a type of boot camp, which is in the works. Ms. Bush said they are working on a tailored APPEL program, required and optional courses for teams. Currently, she said, there is a lot of reliance on networks and tracking things down, and then you become a resource for people down the road.

Upcoming, the MAI TAI team will be focusing on thin-film solar cells, getting more samples from partners and figuring out passive architecture changes for the thin-film cells; adapting a vacuum chamber at GRC to investigate arcing behavior in a charged dust environment; validating the active arc mitigation circuitry; and developing and testing the machine learning algorithms.

In response to a question about forming the team, Ms. Bush said she brought along people she knew and people the center suggested; a material scientist recommended by the center technologist will be leading passive architecture development and testing, so also people from parts of the center we don't usually work with. The team is entirely at GRC except one mentor at NASA Johnson. Dr. Aglan asked whether the damage at the interface is between the cover damage and the cell. Ms. Bush said a lot of the damage is on the top/cover of the cell. Even if the cell doesn't take damage it may be contaminated by debris from damage to another cell. Dr. Walker asked if there is a modeling effort that goes with the experimental work. Ms. Bush said they do modeling and simulation for the circuit development but not necessarily the arcing, so they have an idea of response times and circuitry behavior all guided by simulations and the data science is machine learning. Dr. Aglan asked whether there can be mitigation against arcing all the time or is there allowance for some failure. Ms. Bush said, for the secondaries, the goal is to quench faster than damage, so we need to know the time scale of damage for a given solar cell and for a given solar array design. She said they don't care that they're happening, they just want to quench it before there's damage. For thin-film solar cells, she said they need to prevent the primaries from happening if it's going to cause damage so much more quickly.

There was group consensus that the presentation was excellent: energetic and clear. There was some discussion about having ECI members make a presentation at the upcoming full NAC meeting at Marshall and be on the tour, as well. It was suggested that there may also be value to having an ECI presentation at Headquarters.

Discussion, Findings, and Recommendations

Mr. Green noted that the NAC will meet October 1-2 at Marshall. The agenda has been set, with Mr. Johns is scheduled to present on the first day. The committee focused their discussion on things to include in that presentation.

Dr. Gazarik offered three main points for consideration. First, thinking ahead, there may be a story to tell about the terrific leverage of the flights, CLPS and Flight Opportunities, CFM demonstration on SpaceX. There are a number of technologies being flown and taking advantage of every opportunity to be in space. Second, technology shortfalls was a great presentation. Maybe add overall conclusions: what did that exercise tell us? The problems we've had since we did the roadmaps in 2011 or 2012 at the National Academies are largely the same problems we have and we need to figure out how to move the needle on high priorities and how that will impact investment strategy, even though it's still being formulated. Third, the ECI initiative is terrific.

Dr. Kramer-Bottiglio said the presentation on the shortfalls was interesting and thorough. It was good to hear about the big response and how they processed the data. She noted that some of the top-rated shortfalls had some huge discrepancies between the stakeholders. In particular, the 6th ranked shortfall was ranked high by large industry and very low by academia, at 176. She wanted to know how those big discrepancies between stakeholders were being handled. She thought the questions about enabling technologies versus tactical questions were insightful. And, she thought it was exciting that some of the committee's recommendations for the ECI Program are starting to be enacted. Everyone was anxious to see the boot camp acted upon, which was a full NAC recommendation.

Mr. Rush said the presentations were impressive. He said the shortfalls process creates an opportunity to go to a next level in communicating the STMD approach or strategy in a more quantitative way, and they give a quantitative framework for and approach to technology development. There's an opportunity to explain the thinking around how much of the portfolio should be focused on strategic cross-cutting technology development versus tactical technology development that supports Artemis, M2M, etc.; as well as clarifying the philosophy on technology push versus mission pull. He noted the number of successes that have happened or are about to happen that STMD has pushed forward: IM-2, the CFM Tipping Point and those should be celebrated and supported more as NASA and independent Space Technology successes. One other area for celebration is NASA leaning forward on working with commercial companies and with a pathway of TRL readiness and infusion; it's something the DOD is taking to a next level in directly engaging with the venture capital (VC) community in more active and investigative way (what are they looking for, what are catalysts and milestones that you get excited about at various stages and think is investable). On the DOD side they have programs where they explicitly say, a dollar from a civil program, a dollar from a customer, a dollar from a VC to create a whole program. STMD would be well suited to consider adopting the DOD approach, "a dollar from a civil program, a dollar from a customer, a dollar from a VC." An early step would be dedicated liaisons for the venture community. We don't have a term that people get excited about, like dual-use technology and defense technology. That's an area of funding that could augment the STMD budget. Mr. Green said they have looked a bit at that in the early stage area and the SBIR area and suggested bringing Jason Kessler, SBIR, and Jenn Gustetic into a future meeting for brainstorming. Mr. Rush said there is a need to get every budget authority for SBIR possible and thinks this is the right environment for it because now the VC community has funds completely dedicated to space technology and an appetite for it. NASA should be at conferences talking about how they're working with VC, in the same thoughtful and affirmative way that DOD does.

Mr. Johns suggested a finding about the shortfalls process and said the balance between strategic and tactical investments maybe sets it up better for success as far as evaluating and prioritizing programs. Mr. Rush said a risk from the shortfalls is using them as a lens to fund a series of programs that fill the exact gap – the ones at the top – versus the more cross-cutting things; something like advanced manufacturing is transformational in many ways but when stakeholders are responding to that they think lunar has solved that, making a better 3D printer, and think, "I don't know," so it goes lower. There was a suggestion for language about a balance for the recommendation.

Mr. Green reminded the committee that recommendations are very specific things to act on. There was a suggestion to work a finding on the shortfalls like this: It was a huge undertaking and was the first time we got this quantified data for the community to look at in this manner; it's a great way to add another datapoint for how and what we decide to ultimately invest in. Dr. Gazarik agreed that this would be a good finding. He said ranking adds a bit of a risk and it can lend itself to a list of things to do, i.e., 1-10, so it's important to have something along the lines of, "this is data to inform."

Mr. Rush asked whether it would be good to make a recommendation about the frequency in which the shortfalls are revisited. Mr. Turner said that is an unknown at this point. They need to be gone through first, then there can be a decision whether it's every year or three years, but he agreed there should be some prescribed frequency. Ms. Lowry said she would like input from the critical external stakeholders, but it's important to balance survey fatigue. She would value the committee's input as to how and at what frequency they can get the best input from the communities. There is also an internal process to turn out. There was discussion about frequency and demonstration of change and progress. Mr. Rush suggested doing the first one relatively quickly. Mr. Johns suggested doing it a second time sooner, with lessons learned, to compare results. Mr. Rush said driving future participation would be mapping the shortfalls to budget priorities. Dr. Gazarik said you can use data to justify whatever you want it to and it can be used to justify investments on the Hill. He said, although they are in development, once you get those demand and capability roadmaps on the way, you can see where you're moving the needle, which might dictate the frequency of any gaps: are you making progress on a roadmap or not? Ms. Lowry said she was thinking of getting through the next fiscal year, focusing on the reorganization, getting all the pieces in place, developing roadmaps and then, next fall putting out another survey, but she is open to feedback. Mr. Johns suggested revisiting this at the next summer or fall meeting.

Dr. Aglan suggested that more attention be paid to the open-ended responses and wondered whether the data extracted from the responses can tilt the ranking, especially the bottom rankings. Ms. Lowry said the focus has been making sure the right people see the open-ended responses, although there could be a more formal disposition of them. Some people scored a certain way and wanted to tie their score to their comments. Dr. Aglan talked about designing the survey in the future, eliminating some of the questions or designing the next survey to be more robust than this one – especially aggregating the ranking. There was agreement that there is a need for less subjectivity in the scoring process for ranking, perhaps with changes to instructions.

Dr. Walker spoke about the recent history of nuclear discussions, but at this moment politically and socially and with time invested, he would like to see the nuclear program get another two or three years to get some more hardware underway. He wants to see the energy they've put into relationships with other organizations continue. Moving from paper studies to the real problems with the hardware is going in the right direction. Regarding a potential finding for CFM, are they getting good traction for more flight opportunities? Dr. Walker would like to support them so they can finish the technology development that clearly has to be done. Mr. Johns said he has a note about a finding for NEP technology, too, and asked Dr. Walker how he would craft a finding around nuclear. Dr. Walker suggested the following: The relationships that have been developed with other organizations, DOD, DOE, those have been gold for them because they don't have to do all this on their own and the other organizations may have been a little further along on the right systems and even the right power levels to use. Finding: They are starting to, from a space and surface reactor standpoint on the Moon, figure out what the big problems are, and they may not be what they thought they are. Mr. Turner said he heard, "We've spent this time, we've learned a lot, we have a better handle on what the challenge is now, we can be more specific on the problems." This was all good work, but now the finding is, "We've observed that good work, it's time to start letting them get into it." Mr. Green asked, related to CFM, is it simply identifying more flight opportunities to saturate technologies? Dr. Walker said, yes, they're going to need a lot of flight opportunities before someone really lets them fly to minimize risk.

Dr. Aglan liked the ECI project and wondered whether NASA is intending to increase these numbers to capitalize on the excitement. Mr. Turner agreed that increasing the ECI project numbers would be a good investment and is worth pursuing. More early career staff need a path and space to do it, but it needs to fit with everything else on the plate. Mr. Johns said a variety of ECI recommendations have boiled down to having more of them and to provide more preparation for them. With infinite budget, we'd do a lot of them and hopefully the boot camp will be implemented soon.

Mr. Johns said his notes echo the notes of others. He suggested a finding about building a program and funding around NEP. This has been mentioned in the last couple years and now there is a roadmap of strategic priorities and focused investments. It's small at $7M but hopefully grows in 2025 and keeps growing in 2026. A consensus opinion was that NEP was the more promising technology but had the highest number of hurdles, so NTP got a lot of investment because of Congressional direction. The NEP portfolio is getting more balanced over the coming years, so a finding related to that and encouraging that continued momentum on NEP technologies was suggested. Dr. Walker added that they've been good stewards of the small funding they were provided, working through the community and communicating broadly.

Dr. Gazarik liked the idea about the request for partnerships and how to leverage what's available. Mr. Rush thought the shortfalls exercise is a good additional tool in the box to frame the decision with respect to OSAM-1, that it does not align with the top 70 shortfalls. And private industry has caught up to the intention for OSAM-1, so it makes a lot of sense. He wondered if having a finding that echoes that would provide additional support for the decision that was made. Mr. Rush said it's a budget concern: in a limited budget environment, the return on investment on major programs is under a microscope. We've gone through this thoughtful process of identifying shortfalls that STMD is positioned well to address and OSAM is not a high priority, and it's very expensive relative to its initial baseline and those of one and two years ago. Compare that to the great things about to fly on IM-2 and the SpaceX Tipping Point success. It's an opportunity cost and the organization is extremely capable at effectively managing programs when given the room to do that. Mr. Johns said, depending on the year, it was somewhere between 10% and 20% of the budget on a nonstrategic program. Mr. Rush added that there could've been other successful OSAM projects if STMD had the room to spend that money in a more thoughtful way. Dr. Gazarik asked whether anyone could say more about the potential partnership with DARPA for their RSGS. Mr. Green said the agreement has been signed and subject matter experts are being selected to work with them on RSGS, it's moving forward. Dr. Prasun Desai affirmed that the interagency agreement with DARPA on RSGS is signed and we'll provide expertise to RSGS for the next three years for them to get the launch into orbit.

Mr. Johns asked whether there was a consensus to build a finding around OSAM-1. There was agreement to draft, circulate and gather quick feedback in preparation for the October 1-2 meeting.

Mr. Green thanked everyone for attending and brought up planning for the next committee meeting. Discussion ensued. It was noted that there might be a new STMD AA by the next meeting. Dr. Gazarik suggested trying to visit some industry partners, maybe AMES or JPL. There was agreement for December or January, with other details to be determined. The plan to circulate findings for approval was confirmed.

Adjournment
The meeting adjourned at 3:47 p.m.

Appendix A

Agenda

September 5 – FACA Public Meeting, Hybrid

8:30 a.m. EST	Overview of Agenda Mike Green, Executive Secretary
8:35 a.m.	Opening Remarks Michael Johns, Chair
8:40 a.m.	Welcome to NASA's Glenn Research Center Wanda Peters, Acting Deputy Director, NASA Glenn
9:10 a.m.	Space Technology Mission Directorate (STMD) Update Clayton Turner, Acting Associate Administrator, STMD
10:00 a.m.	2024 Shortfalls Ranking Process and Results Overview Alesyn Lowry, Director for Strategic Planning and Integration, STMD Michelle Munk, Acting Chief Architect, STMD
10:45 a.m.	NASA Nuclear Systems Update Anthony Calomino, Space Nuclear Technologies Lead, STMD Lindsay Kaldon, Fission Surface Power Project Manager, NASA Glenn Kurt Polzin, Chief Engineer for NASA's Space Nuclear Propulsion Project, NASA Marshall
12:00 p.m.	Lunch Break
12:30 p.m.	Cryogenic Fluid Management Portfolio Update Lauren Ameen, Deputy Manager, Cryogenic Fluid Management Portfolio Project, NASA Glenn
1:15 p.m.	Commercial Lunar Payload Services Intuitive Machines-2 Technology Demonstrations Overview Mark Thornblom, Deputy Program Manager, Technical Integration Game Changing Development (GCD) program, NASA Langley
2:00 p.m.	Break
2:15 p.m.	Early Career Initiative presentation on Mitigating Arc Inception via Transformational Array Instrumentation (MAI TAI) Meghan Bush, Principal Investigator, MAI TAI, NASA Glenn
3:00 p.m.	Discussion, Findings, and Recommendations
4:00 p.m.	Adjournment

APPENDIX B

Committee Membership

Mr. Michael Johns, Kratos SRE, *Chair*
Mr. G. Michael Green, NASA, *Executive Secretary*
Dr. Heshmat Aglan, Tuskegee University
Dr. Michael Gazarik, University of Colorado
Dr. Rebecca Kramer-Bottiglio, Yale University
Mr. Andrew Rush, Star Catcher
Dr. Mitchell Walker, Georgia Institute of Technology

APPENDIX C

Presentations

1) Welcome to NASA's Glenn Research Center [Peters]
2) Space Technology Mission Directorate (STMD) Update [Turner]
3) 2024 Shortfalls Ranking Process and Results Overview [Lowry, Munk]
4) NASA Nuclear Systems Update [Calomino, Kaldon, Polzin]
5) Cryogenic Fluid Management Portfolio Update [Ameen]
6) Commercial Lunar Payload Services Intuitive Machines-2 Technology Demonstrations Overview [Thornblom]
7) Early Career Initiative presentation on Mitigating Arc Inception via Transformational Array Instrumentation (MAI TAI) [Bush]