Prof. J.P. Allain
Professor and Head of the Ken and Mary Alice Lindquist Department of Nuclear Engineering
Pennsylvania State University

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**Introductory remarks**

I would like to first thank the National Academy of Sciences Committee on Key Goals and Innovations Needed for a U.S. Fusion Pilot Plant study for this invitation and their effort to understand how we can achieve the challenging feat of a fusion pilot plant. I am Professor and Department Head of the Ken and Mary Alice Lindquist Department of Nuclear Engineering at Penn State University. I've served on numerous panels for the Department of Energy examining research priorities and strategic plan directions and more recently examining Transformational Enabling Capabilities that could provide innovation in one of humanity's grandest challenge to harness fusion energy in our planet.

- What are the roles of the manufacturers, developers, universities, and the national labs in developing a pilot plan in your opinion? How would we proceed from here to the actual construction of a pilot plant?

Development of a fusion pilot plant that can harness thermonuclear fusion and enable power generation on the grid requires several key roles for manufacturers, developers, universities and national labs. The first is the establishment of a supply side sector that has a strong and robust R&D fusion technology ecosystem supported by university centers and institutes as well as strategic national lab partnerships. In addition, to workforce development, universities serve the role of supporting the translation of R&D intellectual property (IP) to the private sector by linking expertise in areas of fusion technology to manufacturers and developers. Any viable commercialization pathway must understand the role of positioning IP in making the US competitive worldwide. The focus must not only be a fusion pilot plant, but also establishing a robust, free-market driven value chain that enables energy generation from fusion, economically viable. Pre-competitive partnerships working closely together towards a fusion pilot plant is a strategy with strong precedent, for example, in the semiconductor industry. Technology development must be informed not only from a research perspective but also from a policy, regulatory and business perspective; all which can dictate pilot plant design. For example, tritium management and its impact on the size, operation and energy conversion technologies necessary to make the pilot plant safe, reliable, and within a reasonable cost.

- What innovations are needed prior to the design and construction of a pilot plant? What do you recommend to decrease the cost of the pilot plant?

Innovations in materials technology include: internal materials components, structural materials, blanket materials, energy conversion technology, and magnet technology are some of the outstanding technology development gaps that currently exist and impact the cost of a pilot plant. Advanced manufacturing has demonstrated opportunities for cost reduction by integrating novel additive manufacturing approaches to the fabrication of complex components of relevance to fusion technology development. For example, joining of internal materials components that must withstand significant extreme environments of temperature, radiation and mechanical loads. Further, the convergence of advanced computing and nuclear fusion technology will be significant in providing for reliable and robust operation of a fusion pilot plant. Advances in new materials including radiation tolerant steels, refractory metal alloys and composites, high-temperature alloys, and liquid-metal technology must be accelerated and standards established to help qualify these materials for their use not only in a fusion pilot plant but to help develop a robust supply-side ecosystem of manufacturers and developers. By establishing an experienced, reliable supply-side sector that works closely with academia and national labs you are able to de-risk the technology, which in turn helps lower the cost of a pilot plant and further development needed for commercial-ready fusion power plants.

- What is the role of your institution (and more generally, U.S. Universities) in supporting the design, construction and operations phases of a pilot plant?

US universities play a critical role in technology development as innovation is critical for a viable and sustainable competitive advantage to US fusion commercialization strategies. It is not sufficient for us to ask US universities to engage and participate. Given the ambitious timeline to a Fusion Pilot Plant of about two decades and the constrained funding in fusion technology there is a significant gap in fusion technology infrastructure that must be addressed in order to provide the necessary support to a needed fusion technology ecosystem that will drive university-industry-national lab partnerships. Penn State University, for example, has a significant advanced manufacturing infrastructure in high-temperature materials and a strong advanced materials science ecosystem. However, to pivot these type of resources towards support of a fusion pilot plant will require significant investment in multiple top university programs across the country.

- How do you anticipate public-private partnerships affecting the development of fusion?

Given the ambitious timeline proposed for a fusion pilot plant, accelerated development will require close interaction with technology experts in academia and essential to address multi-disciplinary problems that can become technology showstoppers. In addition, manufacturers will also require support from academia in very focused activities that result in accelerated development of key technology attributes. Innovation is seeded by both basic and applied science but these need to be nurtured by a coordinated relationship between a fusion technology ecosystem of industry stakeholders, academia and national lab infrastructure. National labs play a pivotal role in providing for specialized infrastructure that is at a scale where universities cannot provide. In many of the daunting challenges for nuclear fusion development, a strong partnership with a focused vision of translational R&D must be forged.

- What are your perspectives on workforce development needed to support the design, development, construction and operation of a pilot plant?

Establishing a fusion technology ecosystem of supply-side manufacturers working closely with university researchers through targeted capstone design activities is one way to provide support in design and development of a fusion pilot plant while making an impact in workforce development. With respect to fusion technology, there is limited participation from outside your traditional groups supported by DOE funding. We will need to expand participation of programs beyond physics and nuclear engineering. The challenge in the case of fusion materials research is that many traditional materials science programs have transformed in the past two decades and critical programs in metallurgical engineering has dwindled significantly. Moreover, fusion technology efforts will be competing for talent (i.e. faculty, students, postdocs, etc...) and only significant investment and impactful incentives to junior level scientists would enable attracting young talent to these activities.

- What ideas or best practices have you seen that could lead to increased diversity and inclusion within that workforce?

The workforce in physics and nuclear engineering has seen some of its greatest challenges in its diversity and inclusivity over the past decades. It's a tremendous challenge that is entrenched both in its industry and also in academia. The first step to diversifying its workforce is diversifying its leadership as well as those that train our future workforce. At universities this means providing a pathway for mentorship and advocacy that begins with graduate education and those that aspire to become faculty. Therefore, diversifying our faculty population at all levels in academia is one first step. To make this happen, the second step must integrate training and education in nuclear technology from middle school through high school via outreach programs that incentivize faculty and university students in participating. Engaging college freshmen to not only pursue UG research but also provide a multi-disciplinary training and capstone experience in engineering design for all four college years that link engineering students with students from other disciplines including: science, economics, business, policy and social sciences. Furthermore, providing for fusion technology 2-year certificate programs to educate and train a workforce to support future nuclear fusion technology as an alternative to 4-year BS programs is also key to support a robust value chain.