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# ACCELERATOR WORKFORCE DEVELOPMENT*

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*Abstract*

Accelerator science has been hugely influential, contributing to physics Nobel Prize-winning research every three years. The U.S. Department of Energy (DOE) Office of Science invests in accelerator science to sustain America's excellence, and constructs and operates large-scale scientific user facilities to be vital tools of discovery.

Developing the next breakthroughs in accelerator science, and designing, building, and operating user facilities, requires a large, highly skilled workforce of accelerator scientists, engineers, and technical (AS&E) staff. Some portions of the AS&E workforce are best planned with a long-term, national perspective in mind.

A round table meeting, involving nine DOE National Laboratories and one Office of Science Nuclear Physics User Facility, assessed their current accelerator workforce projected workforce needs. Critical and endangered skill sets were identified and best practices for workforce development were shared. Future expansion of participation to universities and industry is planned for future round table meetings.

## ACCELERATOR SCIENCE AND ENGINEERING WORKFORCE CENSUS AND 10-YEAR PROJECTION

A January 2025 census surveyed over 4,100 individuals in accelerator-specific occupations across ten laboratories, comprising nine Department of Energy (DOE) National Laboratories and the Office of Science Nuclear Physics User Facility Facility for Rare Isotope Beams (FRIB), at Michigan State University (MSU). This workforce operates 14 National User Facilities based on accelerators, is involved in the construction or upgrade of eight large accelerators, and performs accelerator technology research and development. It also includes some workforce required for the upgrade to and operations of the primary fusion experiment at Princeton Plasma Physics Laboratory (PPPL), recognizing that the accelerator workforce is increasingly involved in providing magnet and RF expertise to the growing fusion sector.

To support the census, the round table participants developed a taxonomy, based on the Common Occupational Classification System [1]. This defined unique accelerator occupations and specialisms in a hierarchal structure under broad categories such as engineer, scientist, and manager [2].

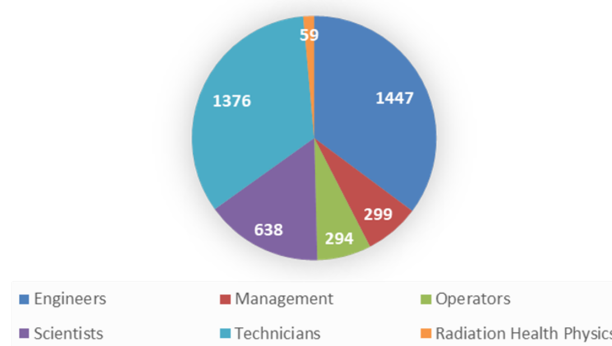


Figure 1: The breakdown of the accelerator workforce between the occupation classes.

The census shows that the accelerator workforce comprises approximately one-third engineers, one-third technicians, and one-sixth scientists, with the remainder in management, operations and health physics (Fig. 1). Electrical engineers (14% of the total accelerator workforce) and mechanical engineers (9%) engineers were prominent with key engineering specialisms including RF and pulsed power, instruments and controls, cryogenics, superconducting RF, safety credited controls engineering, vacuum engineering and accelerator systems integration. Scientists were predominantly physicists (11% of the total accelerator workforce) mainly specializing in accelerator and beam physics. Technicians were predominantly engineering technicians (17%)

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Table 1: Critical and Endangered Skill Sets Identified

| Short-term (< 2 years) | Mid-term (2-5 years) | Long-term (5-10 years) |
|---|---|---|
| Cryogenics (engineers, technicians and operators)<br>Radiation protection/health physicists for nuclear facilities<br>High power target and remote handling engineers<br>Technicians (engineering, vacuum, laser)<br>Controls engineering (including FPGAs and LLRF)<br>Applied mathematics | System engineering and value engineering<br>Lattice optics<br>(DOE specific) Project/program management<br>Technicians (with deep knowledge of customized vacuum, high power pulsed supplies, klystrons and RF components) | Collider physics<br>Superconducting RF<br>Superconducting magnets<br>Physicists to lead the next disruptive accelerator advancement |

working in the field with mechanical, vacuum and superconducting RF competencies.

The ten laboratories projected their accelerator workforce demand by skill set according to the taxonomy for the next ten years. In general, accelerator activities can be divided into projects, operations, and research. Baselined projects have a resource-loaded schedule with well-defined workforce needs by type of worker with time. Operations have defined start and end dates. In this 2025 exercise, laboratories assumed that available research funds grew at 2%. The resulting projections for each laboratory were compiled into a single dataset and shared between the laboratories.

The benefit of sharing workforce projections across the laboratories was recognized by the round table participants and the practice will be continued. Future iterations will aim to improve the quality of the projections and distinguish between hiring and staffing projections by considering workforce attrition rates.

## CRITICAL AND ENDANGERED SKILLS

Particular accelerator-specific occupations and specialist skill sets are critical and endangered (Table 1).

In some occupations, concerns are due to low retention rates coupled with high demand. In other occupations, the skill set is not in high demand, but strategic investment is needed to cultivate and retain the skill set during fluctuations in funding. For example, the High-Luminosity Large Hadron Collider Accelerator Upgrade Project currently involves experts with specialisms in superconducting magnets, which is a skill set that may be needed for new accelerators (such as 10 TeV colliders or future light sources). Without research opportunities after the end of the current project, these skills may be lost.

Three themes were identified that apply more broadly: legacy systems, hands-on experience, and leadership.

*Legacy Systems* - The laboratories are hugely reliant on technologies that are decades old. Several specialized skills that are seen as aging fields are difficult to hire for:

- RF/pulsed/high-power electronics engineer
- Theorists at the interface between applied mathematics and physics
- Cryogenic engineers capable of maintaining legacy systems

*Hands-on Experience* - The round table noted that recently, newly hired early career scientists have less hands-on and hardware experience.

*Leadership* - The training of mid-career professionals in leadership is important in all occupations. A career path is needed, managed at the laboratory level, to hone their capabilities. Increased training of DOE processes is needed.

### *Methods for Laboratories to Address Critical and Endangered Skills*

*Laboratory interchange* – Laboratories with expertise in areas where other laboratories have a demand but do not have enough skilled staff may be able to provide expertise as a short-term reassignment or in a remote capacity, filling near-term needs. A formal exchange program to facilitate accelerator engineer, technician, and physicists moving between laboratories is recommended.

Examples: Projects with multiple laboratories have become common (e.g. Jefferson Lab, Fermilab, and Berkeley Lab collaborate with SLAC for the LCLS-II HE project). LaserNetUS [3] has a framework for skill exchange in its network of laser facilities.

*Traineeships* – Hosting students at the laboratories to engage in the research at the laboratory allows the student to gain hands-on experience and check their cultural fit to the laboratory. PhD traineeship programs are best focused on the long-term needs whereas master's programs address the mid-term. Examples: The DOE funds five accelerator traineeships for master's and early-year PhD students in topics aligned with DOE SC priorities (Fig. 2).

*Apprenticeships* - Apprenticeship programs provide a recognized credential with hands-on experience locally at the laboratory. An apprentice does not come with the critical skills but has an aptitude to learn. An effective program would be conducted on-site at laboratories through full-time employment for 3 or 4 years with rotations in different areas of the laboratories. Example: PPPL Apprenticeship scheme is an industry-driven, high quality career pathway for adults with a high-school diploma that places the apprentice at PPPL for four years with a portable, nationally recognized

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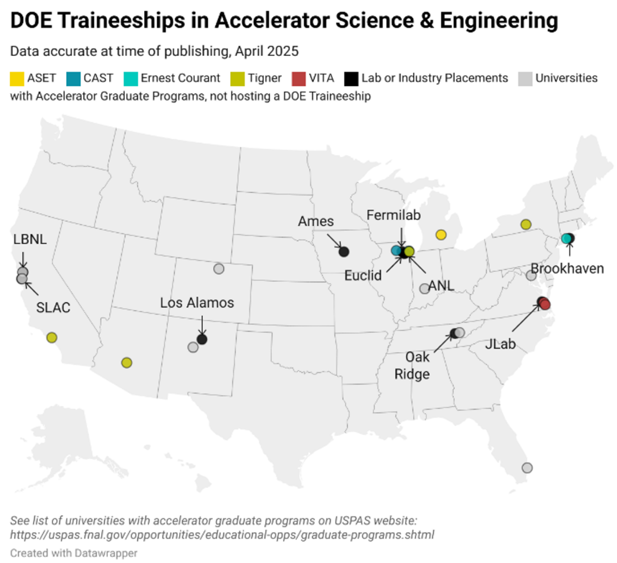


Figure 2: DOE currently sponsors five traineeships in Accelerator Science and Engineering. Students perform research under these traineeship programs, often involving a significant placement at a DOE National Laboratory with laboratory staff.

credential and possible career at the laboratory at the conclusion of the apprenticeship. Oak Ridge National Laboratory (ORNL) is joining PPPL under a DOE Office of Science initiative in 2025. This is a Department of Labor designated apprenticeship program.

*Intentional mentorship and succession planning* – Laboratories can address shortages by recruiting generalists and training them with the necessary skill sets, and on legacy hardware. Succession planning must be built into the existing workforce through ongoing mentorship; it can take six months or more to hire and there is limited time, if any, with the person they are replacing.

*Retraining opportunities* – Develop staff into areas of need (re-train) as projects or operations end. Programs such as the US Particle Accelerator School [4] (USPAS) are ideal for learning new fields. Subsequent small projects and research give staff opportunities to develop expertise in new areas.

*Laboratory long term R&D programs and test facilities* – Long-term R&D programs coupled with facilities for hands-on experience allows laboratories to maintain skills. Access to operating DOE National User Facilities for the development of skills is highly limited and does not provide a suitably error-tolerant space. Small-scale test facilities are often the most prolific in workforce training. Digital twins can be useful to some extent for training (as a “flight simulator” with no specific hands-on experience).

Example: The Argonne Wakefield Accelerator (AWA) test facility trains 75% of all the accelerator students that come through ANL even though 83% of ANL’s accelerator workforce are at the Advanced Photon Source, a User Facility, as it is a better match to workforce development and accelerator R&D. External access to AWA and other test facilities across the US to more external users is the aim of BeamNetUS [5].

### *University Programs*

University programs are essential to prevent skills from becoming endangered. Skill sets that are a match to university programs are in a better supply. University-scale facilities provide a huge draw for students into the field of accelerators. The facilities give students vital hands-on experience, developing highly trained members of the accelerator workforce. Continued support for current university programs and infrastructure is essential to preserve the pipeline of accelerator workforce talent.

Examples:

*Sources*: Cornell has a strong injector program with facilities including a state-of-the-art electron gun.

*Advanced Accelerator Concepts*: Laser Wakefield Acceleration and novel particle sources are studied at world-class laser facilities at universities, many of which are within the LaserNetUS [3] network.

*Cryogenics*: The MSU Cryogenic Initiative was established as a collaboration between FRIB and MSU College of Engineering to address critically needed skill sets by educating the next generation of cryogenic system innovators.

## BEST PRACTICES FOR WORKFORCE RECRUITMENT AND RETENTION

Overarching trends have negatively impacted recent recruitment:

- Decrease in US school-age population
- Decrease in international scientists/engineers and increase in visa challenges
- Decrease in education funding and overall STEM preparation
- Limited number of universities offering accelerator preparation for scientists and engineers or formal technician training aligned with accelerators (e.g. undergraduate certificates at community colleges)

Factors that negatively impact retention include:

- High competition for technical workforce from industry
- Large investments overseas attractive to technical workforce
- Few career planning and development options and uneven mentoring
- Low compensation (covering salary, benefits, bonuses, compared to increased cost of living and housing)
- Lack of stability (e.g. gaps between facilities and projects, late decision making on funding, long-term decline in research funding for accelerators)
- Poor work-life balance, in particularly impacting those that engage in shift work who can suffer from burn-out more readily
- Workforce demographics (an aging population and not reflective of US population)
- Impediments to work and unnecessary bureaucracy
- Working with systems with obsolete components at accelerator with aging infrastructures

Specifically noted at the round table was the competition for workforce with emergent industry implementation of

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accelerators, fusion projects, the growing number of semiconductor manufacturers, and growing computing and electronic controls applications. In general, the people from the National Laboratories and the facilities were highly competitive in the job market. Retention issues are most acute for postdoctoral and early-career staff, though recently senior personnel have also been leaving.

### Best Practices for Recruitment

The recruitment of workforce to the field of accelerators needs a tailored approach depending on the skills and experience sought and the location and culture of the laboratory (e.g., Los Alamos National Laboratory (LANL) needs high-altitude desert dwellers that may be out-of-place in Silicon Valley or the mountains of Tennessee). However, many common elements were found.

*Create a positive hiring experience* – Use Human Resources experts and ensure hiring managers are available for exploratory conversations with sourced candidates. Use analytics and proactively approach talent. Give full disclosure on the manager for the open position.

*Hire according to potential* - Prioritize hiring someone with the will and capacity to learn and use on-the-job training opportunities and formal training programs to grow accelerator expertise.

*Provide and support a clear career-path* - Showcase professional growth prospects and career growth options as part of recruitment efforts. A unified approach across the DOE laboratory system would promote the diverse opportunities to learn across disciplines with long-term and meaningful careers with incredible opportunities.

*Use named fellowships and recognition awards* – Use prestigious named fellowships and awards strategically to hire promising talent with short-term appointments.

Examples: ANL has five fellowship programs and SLAC has the Alonzo W. Ashley Fellowship Program. ORNL uses prestigious Laboratory Directed R&D (LDRD) awards to attract senior engineers.

*Hire from a large pool* – Recruit from diverse backgrounds and non-traditional fields (e.g., chemistry, non-accelerator universities) by advertising at various career fairs and meetings.

*Recruit from navy and military* – Hire from the nuclear navy or military through relationships with the local bases or structured programs.

Examples: Fermilab uses the Veteran Applied Laboratory Occupational Retraining (VALOR) Program for technical career placement at the laboratory. DOD Skillbridge [6] allows transitioning service members of all ranks to enroll in an internship, apprenticeship or industry training in the last 180 days of their service and has been used at Brookhaven National Laboratory and ORNL. Jefferson Lab and LANL have historically recruited operators from the Navy.

*Make connections to university departments and community colleges* – Create a pipeline for workforce development starting at the undergraduate level.

Example: LANL seeds funds to undergraduate faculty at Texas Tech and University of New Mexico to encourage undergraduates to enter graduate programs that provide pipelines into LANL positions.

### Best Practices for Retention

Compensation and strategically applied bonuses are key parts to retention. Bonuses tied to agreements not to leave employment were raised as a best practice. However, given the highly competitive technology landscape, the National Laboratories and User Facilities need to leverage other techniques to retain workforce.

Best practices for retention include on-going mentorship, career development, the presentation of multiple opportunities, and reinforcing a strong sense of belonging to the community.

*Empower staff to take exciting opportunities in accelerator research* - Fund innovative ideas quickly and maintain access to research infrastructure. Intensifying R&D opportunities is seen as the best mitigation for start-up brain-drain.

Example: ANL has a "seed" LDRD specifically targeting early/mid-career staff and post-docs.

*Rotate staff* - Keep staff engaged and broaden their capabilities by offering rotations to multiple technical areas and programs.

*Encourage multidisciplinary research teams* – Use cross-disciplinary connections to develop accelerator scientists e.g. computer scientists engaging in accelerator artificial intelligence activities. This can be facilitated through joint seminars and networking opportunities across multiple groups within multidisciplinary laboratories. Teamwork additionally creates a sense of mutual purpose and appreciation of work.

*Provide vision* – Align day-to-day work to the laboratory mission. A sense of purpose is gained through involvement in meaningful work, especially large projects of national importance, and seeing the impact of the laboratories on the international stage. This is reinforced through opportunities to engage with the public via mechanisms such as colloquia and engaging with high schools. Giving staff a strong future prospective for accelerator-based facilities is essential, with exciting developments within a career-span.

*Foster a sense of community* - Early and mid-career workers need to have a strong sense of belonging within their workplace culture and to feel engaged to the broader accelerator community. Professional development and networking through attending conferences, workshops and schools (USPAS) is essential.

Examples: The Center for Bright Beams [7], funded through the NSF until 2026, has a professional development and community building program tailored to early-career scientists that increases enthusiasm and engagement in accelerator research across a network of geographically distributed institutions. The American Physical Society provides a professional network under the Division of Physics of Beams.

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*Provide stability* – Forward-planning to anticipate changes in workforce demand and ready the workforce for changes in roles is essential. It is critical for staff to be maintained through design, construction and operation phases of projects and during changes in funding profiles. Short-term increases in workforce demand at individual laboratories need to be addressed, potentially through coordination with other laboratories.

Example: Fermilab's Accelerator Controls Operations Research Network (ACORN) project has direct labor from three other national laboratories to supplement the Fermilab effort in part to prevent unsustainable staffing surges.

*Present advancement and leadership opportunities* – Promotion is important to retention. However, there is limited promotion authorization within an organization, and this incentivizes an individual to apply for higher level position in another internal or external organization. Individuals will feel stagnant if they are not given opportunities to lead and these may need to be found outside of the organizational structure through projects and community effort. This has particularly high impact in technician and administrative classifications. At all opportunities, job descriptions should be stretched and work delegated.

*Provide ongoing skill development opportunities* - Programs such as USPAS enable ongoing training and engagement and assist retention. It is important to have educational programs that specifically provide a pathway for advancement. The provision and encouragement of side-projects is also important.

Example: To address retention issues in operations staff (shift-workers), SLAC gives the operators projects that present opportunities to gain skills to support career progression to other parts of the laboratory, particularly in instrumentation and controls. LANL has a career path that goes through technician to technologist to engineer.

## SUMMARY AND FUTURE

The round table meeting in 2025 successfully established an accelerator workforce taxonomy, a snapshot of the current workforce, and a 10-year projection of future workforce needs at the laboratories. This effort to coordinate workforce and best practices between the laboratories will continue under laboratory leadership and be extended to include universities and industry that rely on and train the accelerator workforce.

Five high-priority questions were identified for future meetings.

Question 1: Coordination and sharing between laboratories are important including resource and tool sharing. What are the sustainable organizational structures and mechanisms that will enable and strengthen the sharing of resources and tools?

Question 2: Can ties be strengthened between university programs and National Laboratories/User Facilities to develop an accelerator workforce that is well-matched to laboratory hiring needs?

Question 3: National Laboratories/User Facilities are reliant on industry for accelerator components, often of uncommon designs that require unique expertise to fabricate (e.g. klystrons, superconducting RF cavities, high-power lasers). Are there opportunities to understand and help industry develop and retain capabilities for critical accelerator components?

Question 4: National Laboratories and User Facilities are a source of trained experts that industry benefits from hiring (e.g. vacuum, controls). How can laboratories better predict the workforce demands of industry to plan for this attrition?

Question 5: Some capabilities are so critical to National Laboratories and User Facilities that they should be stewarded within the laboratories. What expertise needs to be maintained in the laboratories and at which laboratories are they most effectively sited?

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