Strengthening and Optimizing Professional Talent Team Building to Enhance the Effectiveness of Major Science and Technology Infrastructure Postprint

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Abstract

Major scientific research infrastructure (hereinafter referred to as "large facilities") entails not only fundamental scientific research issues in its construction and operation, but also complex engineering and management challenges. Strengthening and optimizing the professional talent team construction constitutes a critical factor for comprehensively enhancing large facilities' effectiveness. Currently, insufficient attention to professional engineering, technical, and management talents in personnel funding support, talent assessment, and incentive system development for large facilities in China has seriously undermined the stability and motivation of professional talent teams, thereby directly constraining the scientific and social benefits of large facilities. Through investigations of multiple large facilities across China, this study systematically reviews the problems and difficulties in talent team construction. Building upon this foundation and incorporating advanced experiences from relevant international facilities, three policy recommendations are proposed to promote China' s efforts to build a world-leading science and technology power by leveraging large facilities.

Full Text

Strengthen and Optimize Professional Talent Team Building to Enhance the Effectiveness of Large-Scale Research Infrastructures

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Abstract

The construction and operation of large-scale research infrastructures (hereinafter referred to as "large facilities") involves not only fundamental scientific research issues but also complex engineering and management challenges. Strengthening and optimizing professional talent team building is therefore a critical factor for comprehensively enhancing large facility effectiveness. Currently, China's support systems for large facilities provide insufficient attention to professional engineering, technical, and management personnel in terms of funding, talent evaluation, and incentive mechanisms. This has seriously undermined the stability and motivation of professional talent teams, directly constraining the scientific and social benefits generated by these facilities. Through investigations of multiple domestic large facilities, this study identifies key problems and difficulties in talent team building. Building upon these findings and drawing on advanced international experiences, we propose three policy recommendations aimed at enabling China to better leverage large facilities in building a world-leading science and technology nation.

Keywords: large-scale research infrastructure, talent team building, funding management, talent performance evaluation

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Large-scale research infrastructures provide essential material foundations for exploring the unknown world, discovering natural laws, and achieving technological transformations by offering extreme research capabilities to address frontier scientific challenges and critical national needs. Since the 18th National Congress of the Communist Party of China, General Secretary Xi Jinping has repeatedly emphasized the need to accelerate the establishment of world-class large-scale research infrastructure clusters. On February 21, 2023, during the third collective study session of the Political Bureau of the CPC Central Committee, Xi Jinping specifically pointed out the need to "scientifically plan and layout forward-looking, strategic, and application-supporting large-scale research infrastructures, strengthen supervision during and after construction, improve whole-life-cycle management, and comprehensively enhance open sharing levels and operational efficiency"[1]. This sets higher requirements for the management and effectiveness of China's large facilities.

China's large facility construction can be traced back to the "Two Bombs, One Satellite" program, entering a rapid development phase after 2000. The National Development and Reform Commission, Ministry of Science and Technology, and

Ministry of Education launched 12 major facility projects in 2007, including the Spallation Neutron Source, High Magnetic Field Facility, and Large Astronomical Telescope. The State Council' s 2013 *Medium- and Long-Term Plan for National Large-Scale Research Infrastructure Construction (2012–2030)* aimed to gradually improve the national large-scale research infrastructure system by targeting scientific frontiers and major national strategic needs. The 2017 *13th Five-Year Plan for National Large-Scale Research Infrastructure Construction* further emphasized strengthening the supporting role of these facilities in economic and social development, national security, and scientific progress, with the goal that "by 2020, the overall technical level of large-scale research infrastructure construction and operation would enter the international advanced ranks, with overall operational and utilization efficiency reaching international advanced levels, and a batch of facilities achieving internationally leading technical indicators."

However, current large facility construction and operation in China have revealed several problems, with some facilities failing to achieve their full potential. A key reason is the inadequate development of professional talent teams. Influenced by the traditional fiscal approach of "emphasizing equipment over personnel," national funding for large facilities during the construction phase generally covers only equipment and infrastructure costs, not personnel expenses. Host institutions such as research institutes and universities are responsible for assembling dedicated teams for development, engineering, and management, and for covering most personnel costs [2]. Yet when host institutions lack sufficient permanent staff positions or additional funding, construction personnel often face excessive workloads or low compensation. The resulting talent attrition and instability directly impact facility construction and operation.

Given that large facilities are large-scale complex systems engineering projects involving interdisciplinary issues across science, technology, engineering, and management [3], their construction and operation depend on high-quality professional technical and management talent in addition to research scientists. Professional technical talent includes facility engineering construction personnel, experimental scientists, and other specialized engineers. However, China' s current S&T talent evaluation system largely fails to account for the unique nature of professional technical work at large facilities. Evaluation and incentives for these professionals are not differentiated from general researchers, relying primarily on publications and research grants. This creates career development difficulties, severely reducing motivation and stability. Insufficient incentives for technical support personnel directly damage construction and operational efficiency, seriously constraining the scientific and social benefits of large facilities.

Innovation systems and innovation chain theory conceptualize innovation as encompassing a series of processes including basic research, applied research, technology development, production, and operation [4–6]. This complex process requires different types of innovative talents—researchers, technical professionals, and innovation managers—who interact continuously to generate new knowledge, technologies, and applications. For large facilities, this involves not only basic research but also complex engineering management issues and subsequent facility operation and technology transfer [7,8]. Maximizing facility effectiveness requires concerted efforts across engineering, science, technology, and translation. Yet China' s current S&T talent system focuses on cultivating and incentivizing basic researchers while neglecting professional engineering talent, technical specialists, and innovation managers. Therefore, strengthening and optimizing professional talent team building for large facilities and institutionally motivating all types of talent are crucial for enhancing facility effectiveness and national S&T competitiveness.

1. Diverse Talent System for Large-Scale Research Infrastructures

Large facilities are important platforms for scientists to conduct frontier experiments and achieve breakthroughs, but these experiments are accomplished through the joint efforts of various professionals including experimental operators, systems engineers, and facility managers. These professionals undertake critical tasks in process development, testing, data analysis, and user management, forming the key supporting force for facility effectiveness. Together with research scientists, they constitute the diverse talent system of large facilities.

Figure 1 [Figure 1: see original paper] presents the main activities and required personnel across different stages of the large facility lifecycle. At each stage—pre-research, construction, operation and maintenance, and modification or decommissioning—research talent, engineering construction talent, experimental talent, other technical personnel, and management talent all play vital roles, collectively determining the innovation effectiveness of large facilities.

Research scientists are the primary users of large facilities. They propose scientific questions, design experiments, analyze data, and draw scientific conclusions, collaborating deeply with engineering and management personnel during facility pre-research, construction, and modification phases. Engineering construction talent is responsible for designing, constructing, commissioning, and modifying facilities according to scientific requirements, ensuring experimental conditions and performance meet the needs of scientific exploration. Experimental talent serves as crucial technical support during scientific experiments, being the most familiar with equipment operation procedures, parameter adjustment, and technical problem identification and resolution. Their primary responsibilities include preparing materials for experiments, conducting most experimental operations, recording and analyzing data, and writing technical documentation. Due to their close connection with scientific experiments, experimental talent mainly participates during operation and modification phases.

In addition to experimental technical personnel, large facility operation requires other technical specialists such as facility systems engineers, radiological sample protection administrators, and data and system maintenance managers. Management talent oversees facility construction and operation, handling user management, science outreach, and professional academic conference organization, as well as traditional management functions like personnel, finance, and public services. Management talent is often interdisciplinary, requiring not only project management, team leadership, and communication coordination skills, but also solid scientific and engineering backgrounds to understand and grasp the technical principles and operational mechanisms of the infrastructure.

Although large facilities have gained widespread attention from government and scientific communities in recent years, China's overall facility level still falls short of goals for enhancing original innovation capacity and supporting major breakthroughs. Some facilities require improvement in S&T levels and utilization effectiveness, while management systems and mechanisms need optimization. Particularly due to inadequate compensation, unreasonable evaluation criteria, and unclear career prospects, many facilities suffer serious attrition of engineering construction talent, experimental scientists, professional engineers, and management backbone. These development constraints severely impact facility construction and operation, causing project instability or delays, limiting scientists' experimental work, reducing facility utilization efficiency, and even creating experimental safety hazards. Therefore, enhancing facility effectiveness through strengthened professional talent team building is urgent.

2. Outstanding Issues in Professional Talent Team Building for Domestic Large Facilities

From 2012 to 2023, our team conducted long-term tracking of five domestic large facilities in three cities at different stages: under construction, recently completed, and in stable long-term operation. We conducted eight site visits, 15 semi-structured interviews with project constructors, facility managers, experimental station engineers, and scientist users, and four expert symposiums. Based on these investigations, we identified three prominent issues regarding personnel funding and talent evaluation.

2.1. Insufficient Personnel Funding in Large Facility Construction Budgets

A major challenge in large facility talent team building is the lack of adequate personnel funding support during construction. According to the 2014 *National Large-Scale Research Infrastructure Management Measures*, large facilities are primarily state-invested, with local governments and other competent authorities responsible for developing and implementing supporting policies. However, state-allocated construction funding generally does not include personnel expenses. Using the Institute of High Energy Physics, Chinese Academy of Sciences (hereafter "IHEP") as an example, large facility construction requires additional personnel, but no dedicated funding supports this. Most personnel funding comes from IHEP' s own staffing budget. While fiscal funds can provide some additional support for rehired and externally hired personnel (e.g., temporary recruitment at 3,000 yuan/month), such compensation struggles to attract qualified talent [2]. Another facility in our investigation reported that construction funding jointly allocated by the National Development and Reform Commission and local governments contained no personnel expense category. Consequently, all types of professionals involved in construction—including engineering construction personnel, technical staff, and managers—must be affiliated with the host research institution. Their compensation, recruitment, and evaluation therefore follow host institution regulations, creating mismatches with the complexity and unique requirements of large facility construction tasks. When host institutions are research institutes or universities with high educational requirements for recruits, facilities struggle to hire suitable engineering and technical personnel.

The institutional reason for lacking personnel funding in construction budgets is that large facilities are classified as national capital construction projects. According to the Ministry of Finance' s 2016 *Basic Construction Financial Rules*, "construction costs refer to various expenditures arranged by project construction funds according to approved construction content, including building and installation engineering investment, equipment investment, deferred investment, and other investment expenditures." Personnel performance expenses thus fall outside the scope of construction costs. In recent years, the problem of insufficient personnel funding during construction has become increasingly prominent. In 2017, the 12th National Committee of the Chinese People' s Political Consultative Conference submitted a proposal to the NDRC recommending that personnel performance expenses be included in national large facility construction budgets. The NDRC responded by urging competent authorities and host institutions to establish and improve human resource management systems suited to national large facility characteristics, develop corresponding evaluation and incentive methods, and assemble and stabilize dedicated development, engineering, and management teams. However, current management measures provide only general descriptions of responsibilities for providing personnel funding. As China's large facility construction enters a high-speed development period, insufficient dedicated personnel funding during construction may severely constrain talent team building and facility development.

2.2. Mismatch Between Talent Evaluation Incentives and Tasks

Many large facilities also face mismatches between talent evaluation incentives and actual tasks. For a long time, basic research has been considered the driving force of scientific and technological progress and the original source of economic development [9,10]. Evaluation criteria for researchers have dominated China' s evaluation of innovative talent, particularly for professional engineering technicians and innovation managers. However, realizing the scientific benefits of large facilities requires a diverse innovation team encompassing basic researchers, experimental scientists, technical engineers, and facility management talent, necessitating institutional support to stimulate the innovation vitality and potential of all talent types.

A common problem identified in our investigations is that evaluation of experimental scientists and technical engineers must follow host institution regulations, with evaluation metrics focusing primarily on publications and research projects. This leads these professionals to avoid dedicating effort to instrument development, technical breakthroughs, and operational optimization, negatively impacting facility construction and operation. For example, one investigated facility has made improvements to personnel evaluation but still faces serious attrition of professional technical staff for two main reasons: First, facilities require highly skilled technical personnel, often needing doctoral degrees and relevant engineering experience, but such talent can find higher-paying positions in industry. Second, constrained by host institution regulations, professional engineering staff cannot supervise master' s or doctoral students, making team building difficult and increasing the challenges of conducting research and technical breakthroughs, thus making these professionals more likely to leave.

At another facility in our investigation, experimental scientists and beamline engineers reported that current compensation is not high, especially compared to research scientists. Moreover, their professional title evaluation "mainly depends on papers and projects, but the work content is more related to engineering and experiments, which is not conducive to publishing research papers." This causes these professionals to be unwilling to invest energy in facility construction and operation, affecting talent stability.

Many facilities also face difficulties in professional title evaluation, with associate professor or senior engineer often becoming a career "ceiling." Even the most outstanding technical talent struggles to obtain full professor-level titles.

3. International Experience in Talent Team Building for Large Facilities

Compared with China, major scientific and technological powers such as the United States, United Kingdom, Germany, France, and Japan built and operate world-leading large facilities earlier and have valuable experiences in talent team building. To ensure relevance to domestic facilities, we selected X-ray Free Electron Laser (XFEL) facilities for analysis. XFEL technology, developed in the late 20th century, offers extremely high brightness and short pulse durations for studying material structures, dynamic processes, and chemical reactions, with broad applications in physics, chemistry, and biology [11]. Germany first built the FLASH facility at DESY in 2005, followed by the United States with LCLS at SLAC National Accelerator Laboratory in 2009, which opened to users in 2010. Major XFEL facilities worldwide also include Japan' s SCALA, Korea' s PAL-XFEL, and the European XFEL jointly built by multiple European countries.

Based on information from these facilities' official websites or their affiliated laboratories, we summarize their approaches to personnel funding, talent structure, compensation, and promotion.

3.1. Personnel Funding

International large facilities scientifically plan overall budget allocation according to facility lifecycle characteristics, attaching great importance to personnel costs during operation and gradually increasing personnel budgets as facilities mature. This adjustment aligns with lifecycle development—as facilities enter maturity and attract more scientists for experiments, more professional technical personnel are needed to support experimental work.

Among foreign XFEL facilities, the European XFEL provides the most comprehensive and representative budget information. The total construction budget is approximately €1.25 billion (2005 values), funded by EU member states and third-party sources like the EU Horizon 2020 program. In its first full year of operation in 2018, the total budget was €169.6 million, with €117.6 million (69.3%) related to operations. Operational budgets increased from €117.6 million in 2018 to €118.6 million in 2019, €132 million in 2020, and €137.3 million in 2021. Figure 2 [Figure 2: see original paper] shows the proportion of maintenance, personnel, and capital equipment costs in European XFEL' s annual budgets from 2016–2020. From 2020 onward, personnel costs became the largest expenditure category at €58.6 million, accounting for 44%—far exceeding the proportion at almost all domestic facilities.

3.2. Personnel Structure

International large facilities emphasize the collaborative development of scientists and other professional talents. A concrete manifestation is that as facilities begin operation, the number of research scientists gradually increases and stabilizes. To better support scientists, facilities also increase other personnel types, including professional technical staff and managers. Once facilities reach stable operation, the ratio of scientists to other talent essentially reaches 1:1.

For example, Figure 3a [Figure 3: see original paper] shows European XFEL' s personnel composition in the five years after opening (2016–2020): scientists increased from 156 to 225, engineers and technicians from 131 to 183, and managers from 50 to 65. Figure 3b [Figure 3: see original paper] shows PAL-XFEL' s personnel composition in the five years after opening (2017–2021): approximately half are research scientists, with a large proportion being technical personnel whose share rose from 37% in 2017 to 42% in 2021. PAL-XFEL' s management team is relatively stable at about 10% of total staff. Both facilities have nearly half their personnel as technical and management staff.

In contrast, at one domestic facility we investigated, researchers (including professor and researcher series) account for 71%, engineers 18%, and administrative managers 11%. The 29% share of engineers and managers is far lower than at comparable foreign facilities. Notably, domestic facility engineering technical staff can choose to become researcher-series personnel, so the 29% figure underestimates the actual proportion. However, this reflects the "talent hierarchy" dilemma [12] facing domestic professional engineering technical talent, where researchers often receive better compensation than technical personnel under equivalent conditions.

3.3. Talent Compensation and Promotion

At international large facilities, there are no significant salary differences between scientists and other professional talents. More importantly, these facilities establish position grade differences according to different talent career development characteristics, providing relatively clear career paths for all talent types.

At European XFEL, staff are divided into 15 grades (E1-E15), each with six sub-levels corresponding to different salary levels (Table 1). Positions at grades E5–E8 require vocational education, E9–E12 require bachelor' s degrees or degrees from universities of applied sciences focusing on applied science, engineering, or technological innovation, and E13+ require master' s or doctoral degrees. The highest sub-level (level 6) salary is approximately 1.2–1.5 times the lowest sub-level (level 1), reflecting Europe' s success in reducing socioeconomic gaps and providing equal employment and compensation opportunities. Grade salary gaps are more pronounced in the United States. According to LCLS recruitment information, the facility's lead engineers have five levels, with the highest annual salary reaching 3.1 times the lowest (Table 2).

Overall, professional technical and management staff at foreign XFEL facilities receive relatively high compensation. Engineers with doctoral degrees at European XFEL and LCLS can earn over €60,000 or $100,000 annually. Notably, unlike in China, engineering technical talent at foreign facilities does not earn less than research scientists. For example, LCLS lead engineers at different levels can earn salaries comparable to median levels for university assistant, associate, or full professors.

In summary, international experience shows that large facilities should rationally plan personnel costs, structure, and professional technical staff evaluation and promotion according to facility lifecycle characteristics. Since foreign facility evaluations typically cover multiple dimensions—including achievement of scientific goals, operational status, management level, talent development, and funding effectiveness [13]—professional technical staff evaluation is not simply measured by patents or publications [14,15]. These aspects merit reference by relevant domestic authorities and decision-makers. However, we should note that international experience must be adapted to China' s national conditions. For example, local government financial support may face matching difficulties, and large grade salary gaps may exacerbate regional talent imbalances given China' s regional development and fiscal revenue disparities.

4. Conclusions and Recommendations

While many studies emphasize the importance of high-level talent for facility effectiveness, they focus primarily on research scientist teams [16,17], neglecting other supporting forces such as engineering construction talent, experimental talent, and facility operation management talent. Basic researchers are the productive force of S&T innovation, while technical and management personnel are the important production relations that realize this productivity. Therefore, while building systematic, high-level basic research talent cultivation platforms, we must also focus on improving the evaluation and long-cycle support mechanisms for technical and management personnel, adhering to a talent self-cultivation path based on large facility construction and development to maximize scientific and social benefits.

Based on domestic investigation results and international large facility experiences, we propose three recommendations for strengthening and optimizing professional talent team building:

(1) Ensure funding sources for supporting facility talent teams according to the facility lifecycle. We recommend learning from international peers by treating professional talent team building as an important component of large facility management. This requires competent authorities and host institutions to recognize the importance of all talent types for high-quality facility development and their critical roles at different development stages, with timely increases in personnel funding according to the facility lifecycle. Specifically, the state could consider separately budgeting personnel expenses during construction or clearly specifying in large facility management measures the supporting responsibilities of local governments and host institutions for personnel costs to ensure stable construction. During operation, besides seeking support from competent authorities and host institutions for staffing and funding, large facilities can also collaborate with the Ministry of Science and Technology, National Natural Science Foundation of China, local science and technology commissions, and other departments to develop diversified operational funding sources, including research project funds, talent program funds, and enterprise capital, to support stable team development and ensure scientific benefit delivery.

(2) Establish scientifically sound classified talent evaluation systems to improve stability and motivation. Large facility construction and operation involve substantial engineering management, technical breakthroughs, and experimental support, possessing dual characteristics of engineering and research. Evaluation systems should fully consider the characteristics and needs of facility construction and operation support personnel, developing management systems adapted to large facility development patterns. Specifically, we recommend that competent authorities and host institutions design flexible and diverse evaluation mechanisms to motivate different types of professionals to leverage their expertise. For technical specialists focused on R&D or experimental support who do not publish papers, evaluation systems should be developed based on task completion to maximize facility scientific and social benefits as the primary goal, unlocking the potential and enthusiasm of such personnel. For professional title evaluation, competent authorities and host institutions should eliminate career discrimination, providing more promotion opportunities for outstanding engineering and technical personnel to encourage continuous improvement. For professionals managing facility construction and operation, evaluation metrics should be developed based on the complexity and key challenges of large facility engineering management to enhance facility effectiveness from a management perspective.

(3) Develop effective talent incentive programs to promote high-quality development of professional teams. The long-term stable development of large facilities depends on high-level professional teams and, more importantly, institutional designs that ensure long-term competitiveness. We recommend that talent team building for facility support personnel should not only guarantee personnel funding during construction and operation but also provide sufficient incentives and returns for high-level talent. Competent authorities and host institutions should reasonably set salary and benefits. To attract and retain top experimental scientists, technical engineers, and facility managers, we recommend appropriately increasing the highest-level salaries and professional title benefits within position series. We should adhere to the principle of equal emphasis on engineering and research talent, providing clear career development paths for different categories of large facility professionals. Providing relatively equal student training opportunities and living facility support for non-research talent will attract more high-level technical and management personnel to actively participate in national large facility construction and development.

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