On personnel training for ITER in the Russian Federation

V Kurnaev and A Kurnaev
National Research Nuclear University MEPhI
(Moscow Engineering Physics Institute), Moscow, 115409, Russian Federation
vakurnaev@mephi.ru

Abstract. This paper describes the specifics of ITER, large-scale MegaScience-level international project, and analyzes the current personnel training challenges that Russia, as ITER participant, is facing. ITER needs a lot of specialists qualified in different fields of physics, engineering as well as in management and finance with practical experience in multicultural communication. The history of MEPhI involvement in training of undergraduate and PhD students in hot plasma physics and fusion technologies is briefly described. The features of training of students in English at lessons and international conferences and schools are also presented. The evaluation of the number of undergraduate and graduate students needed for training in Russia in fusion with magnetic confinement of plasma and personnel training for the ITER is given. Problems impeding the adequate personnel are enumerated as well as a set of measures that will help boost personnel training for this project.

1. Introduction: ITER project and its specifics
Evgeny Velikhov, President Emeritus of National Research Center «Kurchatov Institute», once said: “ITER is a gateway to thermonuclear energy that the world should go through”. Due to his initiative Mikhail Gorbachev during his visit to France in 1985 proposed to solve the grandest problem of controlled thermonuclear fusion (CTF) that different countries had been working on since the 50s and for this to build the International Thermonuclear Experimental Reactor (ITER). The fact that this proposal came from Russia is no accident as it was «Kurchatov Institute» where the first tokamak – the most effective magnetic trap for hot plasma confinement – was developed. The name ITER is wordplay as iter means “the way” in Latin. Thus, the name itself shows the world community how to respond to global challenges.

Currently, 7 official parties participate in ITER project: European Union, India, China, Korea, Russia, the USA and Japan. Europe, where the reactor is being constructed, contributes 45% to the construction process while other countries contribute around 9% each. The reactor’s engineering design was finished in 2001, the construction site was chosen in 2005 and the first plasma is expected in December 2025. Each participant supplies reactor parts and contributes financially to ITER International Organization (ITER IO) located in Cadarache near the construction site. The cost of reactor is evaluated to be $19 billion. The scale of ITER project is unparalleled: the number of people involved exceeds a half of the world population while the number of employed technologies and the amount of funding are tremendous.

Figure 1 gives an impression of the design of the international experimental thermonuclear reactor, which is currently being constructed in Cadarache, and its size.

ITER aims are:
1. to prove the scientific and technological feasibility of thermonuclear energy use for peaceful purposes on an industrial scale,
2. to achieve ignition of controlled thermonuclear reaction when the thermonuclear power is 10 times greater than the power consumed to generate and heat the plasma,
3. to demonstrate the steady state plasma burning regime,
4. to develop and test the systems and technologies necessary for power thermonuclear reactor.

A short description of thermonuclear fusion with magnetic confinement and associated technologies is presented in [1-4], while more detailed description of fusion technologies can be found in [5-8].

**Figure 1.** ITER reactor within the reactor building, its size ~30 x 30m. Circled in red is a man.

It is important to note that in order to make a controlled thermonuclear fusion (CTF) reactor, understanding of confinement process in magnetic fields of plasma heating is not enough and there is a number of problems connected with other areas of knowledge that need to be solved. Primarily, these problems include the development of: 1) construction and shielding materials compatible with a coolant and able to withstand high temperature loads and radiation damage caused by fast neutrons and demonstrating quick decrease of residual radioactivity, 2) superconducting systems for maintaining a strong magnetic field, 3) high-power injectors of neutral atoms and high-frequency sources for plasma heating and current drive, 4) optical, corpuscular, laser, electromagnetic and nuclear systems for plasma diagnostics.

2. **List of specialties and requirements for candidates applying for ITER**

It is obvious from the above-mentioned features that ITER project requires not only plasma physicists but an entire range of other specialists qualified in such areas of knowledge as material science, thermal physics, nuclear physics, cryogenics, electrical physics, physics of strength, physics of safety, laser physics, vacuum technology, power supply, power electronics, mechanical integration, instrumentation and control, big data handling and many others including management and finance. The list of vacant positions, job details, level of diploma (master for engineers and PhD for scientists),
technical experience/knowledge, and general skills is published and is constantly updated on ITER website and open for candidates. It is very important to note that among the general skills there are the ability to collaborate with colleagues, communicate in multi-cultural environment, “ability to apply high standards of team mindset, trust, excellence, loyalty and integrity” and fluent English. As a rule, 6 - 10 years level of practical experience in the frame of main duties is necessary; moreover, participation in an international project is needed.

3. MEPPhI experience in training for fusion
The first institution of higher education to start training personnel for CTF was MEPPhI. In 1961 at the initiative of Kurchatov institute the Plasma Physics Department (PPD) was established in MEPPhI. Since then the major part of the faculty has been comprised of the leading CTF scientists from Kurchatov Institute and Troitsk Institute of Innovative and Thermonuclear Research (TRINITI, former subdivision of Kurchatov Institute). Over the years more than 800 professionals (engineer-physicists, masters and candidates of science) have graduated from PPD MEPPhI and considerable part of them in the field of magnetic fusion.

The curricula and the qualification level of Department graduates to a significant extent matches the current demands in CTF field as the students are trained by the leading specialists from Kurchatov Institute, TRINITI and MEPPhI. These institutions also provide employment for Department graduates specializing in CTF with magnetic plasma confinement.

In 2006 MEPPhI and EU coordinating institution Ghent University signed an Agreement on partnership with non-EU institutions within the framework of ERASMUS MUNDUS program for training specialists in physics and technology of fusion (the coordinator of this program Prof. Guido Van Oost contributed a lot to the launch of this program with MEPPhI as a non-EU partner). PPD of MEPPhI selected the best and the most motivated students to choose educational program in the field of Nuclear Fusion and Engineering, provide them special courses in hot plasma physics, plasma theory, engineering problems of nuclear fusion devices, fusion and hot plasma diagnostic, interaction of plasma with plasma facing components, special training in English, etc. Students selected for fusion research had practice in Kurchatov Centre, TRINITI carrying out individual educational and research projects with leading scientists of T-10, T-15, T-11M teams as well as with theorists. As for plasma-surface interactions selected students can have practice in PPD laboratories at MEPPhI. After 4,5 year of education the best can join EM Master program in Nuclear Fusion Science and Engineering Physics and after obtaining master’s degree can join Nuclear Fusion and Engineering Doctor program. This agreement allowed both parties to join their CTF personnel training efforts. Many students of the department have successfully finished masters and doctor’s (PhD) programs in Europe and are now working at international CTF laboratories. These laboratories and MEPPhI have long-term collaboration programs in which MEPPhI alumni are actively involved. A good example is the Agreement on strategic partnership between NRNU MEPPhI and Jülich Research Centre (FZJ) signed in 2013. Under this agreement a significant number of joint research projects have been completed and many joint papers have been published in top international journals.

In 2015 MEPPhI and ITER IO signed Memorandum of Understanding that regulates the relations between the two parties and also facilitates the internship process for MEPPhI students and collaboration between MEPPhI and ITER divisions and staff.

In 2017 MEPPhI became the first among Russian institutions of higher education to participate in ITER Project Associate (IPA) Scheme. Within the framework of this program a MEPPhI (Home institute) employee is to work for some period of time at ITER IO site with ITER subsequently compensating his average wage at Home institution, which continues paying salary to IPA. So, this scheme broadens the involvement of specialists from ITER Members in solving current ITER technical and scientific problems and contributes to integration between ITER IO Central Team and ITER Members. IPA scheme is beneficial also for domestic institutions as it allows them to keep national staff.
Throughout the years MEPhI has had many senior year students doing their internship at ITER. This internship was to a large extent paid for by the receiving party.

4. Language training
To apply for such an internship a student should not only be motivated and have extensive knowledge of physics and mathematics, but their English level should also be sufficient.

This is exactly why the curriculum of Department of Plasma Physics for 20 years has included English lessons and seminars for 3-5-year students aimed at additional training in English and developing public speaking skills.

Due to MEPhI participation in Russian Academic Excellence Project (5/100 program) aimed at increasing competitiveness of Russian universities among world leading scientific and educational centers, the attention paid to the language training has risen drastically. Currently, NRNU MEPhI has several educational programs executed in English and the number of such programs is increasing every year. Furthermore, MEPhI is in close collaboration with foreign research centers, institutes and universities. Foreign professors are often invited to MEPhI to give lectures in English. MEPhI’s Department of Foreign Languages actively employs communicative approach in the educational process making a major focus on developing speaking and writing skills. Students learn the English language for 3 or 4 years depending on the type of degree they are getting (bachelors or specialists). However, in order to raise the quality of language education there are certain challenges that need to be addressed, namely, the low English level of students entering MEPhI and the low number of English class hours. It’s worth noting though that MEPhI administration is aware of these challenges and takes measures to resolve them. E.g. this academic year the number of classroom hours at the second year has been raised from 4 to 5. But to have specialists with fluent English necessary for ITER it is essential to incorporate English in the most elements of master and PhD students training including lectures on basic subjects, seminars. Very important part of training is the real practice during international conferences organized by MEPhI. For example, the international conference on Ion Surface interactions (ISI) that MEPhI organizes every two years. The working language of the conference is English, so, all orals and posters are presented only in English. Many our students take part in this conference as reporters or volunteers helping in cultural program, accompanying foreign participants, etc. Other possibilities of practical training in English are the a) International Summer School on Physics of Plasma Surface Interactions that we hold every two years, b) be –annual conference on plasma diagnostics, c) annual conference of our LaPlas institution on plasma physics and fusion, etc. Additionally, many foreign parts employed professors deliver their lectures in English via internet or short courses during their staying at MEPhI.

This practice is good but insufficient. Very stimulating for students is the practice of participation of MEPhI students in International conferences and school abroad with their own scientific presentations. It is very important to send every master student for training to such conferences or to scientific centers we collaborate with. For PhD students such sort of practice should be not less than 2-3 times for 4 years long PhD courses.

Another possible solution is the systematic help to some selected students to pass TOEFL.

Specialized topical language publications such as explanatory English-Russian dictionary on plasma physics controlled nuclear fusion [9] also can be helpful (especially in replenished electronic form).

5. Estimation of possible control figures of enrollment (CFE) of undergraduate and graduate students needed for training in Russia the personnel for the ITER
Currently only 44 Russian specialists are working at ITER as professional and technical support staff comprising 4,5% of all ITER IO employees, which is half as much as the material contribution of the Russian Federation that equals to 9%. We can see the deficit of Russian personnel, so its training issue in Russia is far from being solved.
After the reactor’s launch in December 2025 ITER IO staffing should be equal to fifteen hundred while Russia’s contribution is expected to rise up to 10%. So, the number of Russian employees in principal can reach up to one hundred and fifty. Thus, up until 2026 starting with 2019 it is necessary to increase Russian part of ITER IO staff with ~110 members. So, the rough estimation of the number of people from our country employed per year equals to ~20 (taking into account that a part of employees is replaced and the limited duration of contract).

According to the rough estimation by Russian domestic ITER agency 1/3 of Russian quota for ITER should be occupied by specialists in fusion with magnetic confinement (hot plasma physics, physics of thermonuclear reactor sub-systems and specialists in different diagnostics). Thus, up until 2026 it is necessary to ensure recruitment of ~ 40-45 physicists. Due to the competitive nature of recruitment process the number of candidates must be higher.

Recruitment process at ITER IO is competitive, which means that 2-3 candidates vie for a single position at the organization at the same time from one ITER party. Thus, assuming the number of Russian candidates per one position is 2.5, the number of candidates with a PhD or a higher degree (having work experience in one of ITER fields) should amount in steady state regime to 20x 2.5 = 50 people per year (~17 physicists).

Practice shows, the ratio of PhDs to master’s degrees for the best physics universities amounts to 1/3. Thus, in order to ensure that Russia can compete for job positions at ITER IO it is essential to have in 2020-2021 no less than 300 master’s degree graduates in technologies related to fusion and ~70 masters in fusion physics.

The most sought-after specialists for the project will be rather young but experienced well-trained persons preferably with work experience in international teams. The high level experimenters and theoreticians with PhD degree, as a rule, graduate from top physical universities, and have practical experience at Kurchatov Institute, TRINITI, MPEI, Ioffe Institute, Prokhorov General Physics Institute, Budker institute in Novosibirsk, Institute of Applied Physics of the Russian Academy of Science and other leading research centers.

It is worth noting that presently the number of foreign students in Russian must comprise 10-20% of the total number of graduates. With this in mind fusion related departments must have 160-240 graduates per year. This figure can be considered as evaluation of possible control figures of enrollment for master courses for leading universities involved in students training in fusion with magnetic confinement of plasma.

The necessary level of training in the field of magnetic fusion is ensured by such universities as NRNU MPEI, Moscow Institute of Physics and Technology, Saint-Petersburg State Technical University, Novosibirsk State University and University of Nizhny Novgorod. Moscow State University and Saint-Petersburg State University along with Bauman Moscow State Technical University and Moscow Power Engineering Institute also participate. All of these institutions except for Novosibirsk State University and Moscow State University are members of Consortium of Rosatom’s core universities.

Ensuring necessary qualifications on master’s degree and PhD level does not seem to be possible without the laboratory facilities located at top institutions related to fusion (Kurchatov Institute, TRINITI, Institutions of the Russian Academy of Science: Ioffe Institute, Budker Institute of Nuclear Physics, Institute of Applied Physics, Prokhorov General Physics, as well as NIIEFA). So close collaboration and integration of universities with these scientific centers is the mandatory part of students training.

6. Problems impeding the adequate personnel training
1. Control figures of enrollment of students for master courses in abovementioned universities needed for training in Russia the personnel for the ITER are insufficient.
2. Young specialists at Russian scientific centers and universities do not receive enough funding now. The funds that the university “obtains” together with a student are not enough to train a potential specialist capable of participating in international projects. More internships, schools
and conferences must be organized to alleviate the problem. With post-graduate students the situation is even worse. For this reason, the idea expressed by the heads of Ministry of Science and Higher Education this year and in which the concept of target PhD positions with an average scholarship of 40 000 rubles per month was proposed is highly relevant.

3. The lack of regulatory framework for double master’s in and PhD diplomas limits the opportunities for foreign equipment use, scholarships and language practice. Now there is progress in double master’s programs implemented by top autonomous universities like MEPhi, financial solution of the problem related to training in fusion (with high cost of students staying and training in partner university) is to be found.

4. Up to now there is no complex target training program for ITER in Russia (there are known only few special cases when organization involved in ITER activity could find funds for 0.5 year training of young student or specialist in ITER site in Cadarache).

5. The financial capacities for ensuring academic mobility (participation in experiments, conferences and schools, organization of international schools in Russia with the involvement of top foreign CTF specialists) have very inadequate funding. Thus, the main obstacle for training of qualified personnel for ITER in Russia is lack of funding. Simple evaluation of necessary funding can be done from practice. According to statistics, the budget of companies that purposefully train personnel, on average, does not exceed one to three percent of the company’s budget. Considering the cost of ITER project ($19 billion) and expected Russian part in ITER personnel as 10% one can easily evaluate the cost of personnel training (taking into account the exceptional complexity of the project and spending for training not less than 3% of budget) at least in 4 billion of rubles in total before 2026 year.

7. **Positive examples of personnel training for ITER**

At the same time there is some positive experience in dealing with above-mentioned issues which can be taken into account in the frame of the new Federal Target Program in fusion and plasma technologies that is under discussion now:

1. In 1997 the former Ministry of Science and Technologies (proposed vice-head of the Department of Basic Research by Anatoly Scherbak and supported by the Minister of Science Evgeny Fortov) announced a grant competition for young researchers under the sub-program "Controlled Fusion and plasma processes" of Federal Target Program (FTP) "Research and development in priority areas of development of science and technology for civil purposes". There were 22 winners (at 64 applicants) from a number of Russian universities and scientific centers, most of them were PhD students. This 3-year long grant was equal to 20 000 rub per year (more than the average annual income in Russia). The Competition Commission consisting of leading Russian scientists was headed by a well-known theorist in plasma physics Boris Kadomtsev. Technical implementation of the competition was entrusted to MEPhi. The funding was realized with money transfer to the involved institutions on the basis of the results of the annual reports approved by the Commission. The proceedings of scientific works of the winners of this grant competition were published in 1999. The vast majority of participants (mostly PhD students) defended their theses of candidate of science (PhD degree) and found employment in physical institutions. Many of winners now work successfully in fusion and plasma physics.

2. In 2012 Rosatom launched his own program of support of Rosatom personnel and young scientists from scientific centers and universities training at IO ITER site. Some participants of this program are now joint ITER permanent staff.

3. In 2012-2013 Rosatom funded R&D project at MEPhi aiming support of students and young researchers in fusion of different institutions all over Russia. The funds were used to support internship of possible candidates for ITER in foreign leading laboratories, participation of summer schools and international conferences.

4. Recently there was a new important issue for future ITER personnel training. Earlier in 2019 Rosatom has supported the MEPhi initiative in setting up at our University a small training and
demonstration tokamak. Construction of this machine should ensure the involvement of young people and increase the level of their practical training in the field of controlled fusion, with further improvement of competence at large devices in scientific centers of the Russian Federation. The major radius of this small tokamak is 25 cm ~ 250 smaller than that one of ITER ($R=6.2m$), so its cost (which is roughly proportional to the volume) should be ~15 000 cheaper than ITER reactor.

5. Implementation of 5/100 program which started in 2013 and which aims to “to maximize the competitive position of a group of leading Russian universities in the global research and education market” greatly expanded the opportunities for academic exchange and organization of international projects with involvement of undergraduate and post-graduate students. With the help of this program MEPhI has managed to organize three international schools on plasma-surface interactions (one of ITER fields) free of charge (no admission fees were required) with many foreign specialists actively participating. However, even considering the fact that most of the expenses are covered by ITER IO, the amount of funds received by ITER interns from the program (more than 300 000 rubles for accommodation) is still not enough since the program’s total budget covers a high number of other aspects aside from academic mobility.

8. Conclusions
1. MEPhI possesses great experience in training CTF personnel thanks to close collaboration with top Russian and foreign centers. MEPhI also has the necessary material and technical resources and seems to be convenient coordinator the ITER personnel training process in Russia.
2. Estimation of possible control figures of enrollment of master courses students needed for training ITER personnel in Russia shows that it is necessary ~ 50 -70 magnetic fusion oriented graduates of master’s degree per year.
3. Funds necessary for personal training evaluated in this paper may be considered during development of some Federal Program for CTF under personnel training section.
4. To coordinate the personnel training process and fund allocation in this field a special Coordination board must be established. The members of the board should include the representatives of Rosatom and universities involved in ITER personnel training.
5. Close collaboration with leading laboratories in fusion and academic exchange are mandatory.
6. The selection of joint PhD programs for different fusion topics can be the subject of agreed joint international programs for 2020-2024 yy.

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