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Forecasting the Economic Need for Personnel with Higher Scientific Qualifications

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Abstract—This paper has presented methodology for assessing the economic need for personnel with higher scientific qualifications and the mechanisms for regulating the process of its reproduction. Approaches to forecasting the dynamics of personnel of higher scientific qualifications that take into account the provision of additional annual need for Candidates and Doctors of Sciences in scientific, educational, and knowledge-intensive sectors of the economy, as well as the experience of countries with effective market economies, have been considered. Based on the developed methodology, quantitative indicators of the annual additional need for Candidates and Doctors of Sciences for different sectors of the economy have been calculated.

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Under the conditions of Russia's transition to the fourth technological order, economic growth is possible only due to the development of new high-tech knowledge-intensive labor markets. The innovative economy (the knowledge economy) is beginning to be dominated by a qualitatively new generation of employees, i.e., knowledge workers [1]. The core of this generation is personnel of higher scientific qualifications (HSQs), including Candidates and Doctors of Sciences, who are creators of new knowledge and technologies that are in demand in high technology knowledge-intensive sectors of the economy and public administration [2].

According to the 2010 census, Russia had 596000 Candidates of Sciences (0.5% of the population) and 124000 Doctors of Sciences (0.1% of the population). Having a scientific degree at the level of Candidate or Doctor of Sciences is an indicator of having reached the highest level of scientific and professional competence in one's subject area for 460 scientific specialties, as well as signifies a high level of general cultural and universal competence.

The training process of HSQ personnel is long and requires significant financial resources and intellectual efforts from both the society and student for the degree. The reproduction of HSQ personnel focused on ensuring the current and prospective staffing needs of the economy is the most important task in the system of training and certifying HSQ personnel (some issues related to this problem were considered in [3–9]). The postgraduate system is the main institute for preparing Candidates of Sciences; more than 75% of applicants for the degree of Candidate of Sciences defended their theses after postgraduate training [10]. At the same time, the lack of a developed methodology and, as a consequence, a system for forecasting the demand for HSQ personnel focused on developing high-technology sectors of the economy, sciences, and higher education, is hindering the transition of the Russian economy to the fourth technological order. In connection with this, the development of a methodology to assess the need for HSQ personnel is of considerable scientific and practical interest.

Personnel with higher scientific qualifications: sectoral distribution. The training system and the system of HSQ personnel certification are complementary. In the institutes of postgraduate and doctoral studies, competitors for the degree of candidate or Doctor of Sciences prepare dissertations, which are then defended in dissertational councils. In 2015, 1616 doctoral and 12524 candidate dissertations were defended in 2647 dissertational councils established at 989 organizations [10].

The main places of work (study) during the postgraduate training of degree aspirants are higher education institutions and research institutes. In the last six years (2010–2015), 69% of defended Candidates of Sciences worked in universities; 20% at research institutes; and 11% in health organizations, scientific and industrial associations, or other organizations, while for Doctors of Sciences, these figures are 62%, 25%, and 14%, respectively.

The main places of work for Candidates and Doctors of Sciences are organizations of higher education (42400 Doctors of Sciences and 160000 Candidates of Sciences), state research organizations (18300 Doctors of Sciences and 45700 Candidates of Sciences), and scientific business sectors (3600 and 18200, respectively). Unfortunately, there is no information on the structure and size of HSQ personnel in terms of scientific specialties, public administration, healthcare, and high-tech sectors of the economy, ministries, and departments (with the exception of the Russian Ministry of Education and Science and the Federal Agency of Scientific Organizations). This greatly complicates the task of forecasting the demand for HSQ personnel in the real sectors of the economy and the public administration and healthcare sectors and requires the development of a special toolkit.

Methodology for forecasting the economic need for HSQ personnel. The key element in the development of methodology for forecasting the economic needs for HSQ personnel is the selection of principles for forecasting the dynamics of personnel and the methods for implementing them. The following principles can be used:

1. ensuring the reproduction of the amount of HSQ personnel and its structure within the Nomenclature of Scientific Specialties (*the principle is "based on progress"*);

2. ensuring the production of the number of HSQ personnel and its structure in accordance with the standards within the Nomenclature of Scientific Specialties (*the principle is "based on the standards"*);

3. meeting the needs of knowledge-intensive sectors of the economy (healthcare, public administration, and high-tech sectors of the real economy, such as information and communication technologies, nuclear and defense industries, etc.) for HSQ personnel based on strategic programs for economic development (*the principle is "according to need"*);

4. providing the HSQ personnel to the sectors of the Russian economy in amounts similar to those in countries with an effective market economy (*principle "by analogy"*).

At the existing level of knowledge, these four principles exhaust the whole range of possible approaches to forecasting the needs for HSQ personnel. These principles, to some extent used in forecasting the needs of the economy for personnel with professional education [11, 12] proved to be adequate for their adaptation to the methodology of forecasting the needs of the economy for HSQ personnel taking into account both a detailed study of the existing information about HSQ personnel and the development of methods and tools for the indirect quantification of missing indicators.

The annual additional need for HSQ personnel, which is defined as the number of workers with academic degrees needed to provide the planned volume of production of goods or services, is used as quantitative indicators of forecasting [13]. Let us consider the forecasting techniques based on each of these principles to form the scope of their application.

The principle "based on progress": scientific sector. One of the main working spheres of HSQ personnel is the state and entrepreneurial scientific sectors. The approximately stable distribution of the number of Candidates and Doctors of Sciences in each field of science (scientific specialty) has been formed at the State Academies of Sciences over time. For example, for 2010–2014, the number of researchers with academic degrees in the public and entrepreneurial sectors of science changed by no more than 0.8%. On average, these numbers were as follows: 21800 Doctors of Sciences and 62300 Candidates of Sciences [14].

The forecasting method based on the principle "based on progress" is intended for the field of activity where the priority is the need to maintain the current number of scientific employees with a scientific degree by replenishing natural age-related withdrawals. To forecast the annual additional need, it is necessary to know the number of Candidates and Doctors of Sciences and the rotation ratio in each field of science (or scientific specialty for forecasting at a more detailed level). Rotation ratios show the share of annually withdrawing HSQ staff, Candidates of Sciences R_{cs}, and Doctors of Sciences R_{ds} in relation to their total number in the current year and are equal to the inverse ratio of the average time of service of this personnel.

If we take the average age at which the service of Doctors of Sciences is completed to be 70 years and that of Candidates of Sciences to be 65 years, then, using the average age of the applicant for a scientific degree as the date of the candidate's or doctoral dissertation defense, we can calculate the average number of years of service of Candidates and Doctors of Sciences, followed by the corresponding rotation rate. With an average duration of service of a Doctor of Sciences of 22 years and Candidate of Sciences of 29 years, the corresponding rotation rates will be R_{ds} = 0.046 and R_{cs} = 0.035. These indicators are slightly different for different fields of science, ministries, and departments.

The annual additional need for Candidates of Sciences (ΔL_{cs}) as part of the researchers of the state and business sectors of science will be determined by the value of the natural age-related withdrawal of Candidates of Sciences and the transfer of Candidates of Sciences to the category of Doctors of Sciences and calculated using the ratio

$$\Delta L_{cs} = \Delta L_{cs}^{withd} + \Delta L_{cs}^{ds} = L_{cs} R_{cs} + \Delta L_{cs}^{ds}, \quad (1)$$

where ΔL_{cs} is the annual additional requirement for Candidates of Sciences, ΔL_{cs}^{withd} is their natural age-related withdrawal, L_{cs} is the number of Candidates of Sciences working in the industry, R_{cs} is the coefficient of rotation of Candidates of Sciences, and ΔL_{cs}^{ds} is the number of doctoral dissertations defended by Candidates of Sciences employed full time. Similarly, the annual additional need for Doctors of Sciences is calculated without taking into account the last term.

The annual additional need for HSQ personnel of the state and business sectors of science, calculated by the ratio (1), will be 990 Doctors of Sciences and 2170 Candidates of Sciences. According to the reports of dissertational councils, in 2015, 364 doctoral and 1966 candidate dissertations were defended by full-time employees and post-graduate students of the state and business sectors of science.

An analysis of the values of the annual additional need of the scientific sector for HSQ personnel shows that defenses of candidate and doctoral dissertations by graduate students and scientific sector employees do not fulfill it.

The principle "based on the standards": University sector. In the sphere of higher education, a stable structure of the distribution of higher-education teaching personnel (HETP) by branches of science and scientific specialties has formed, while the number of HETP depends on two important factors.

The first factor is the requirement for the proportion of individuals with scientific degrees as part of the number of faculty members of the university, which are defined by federal state educational standards for higher education in each area of training. For different areas of training, these standards are somewhat different. Thus, the proportion of scientific and pedagogical workers (in terms of the integer values of faculty members) with scientific degrees and (or) academic titles in the total number of scientific and pedagogical workers implementing the educational program for the bachelor's program 11.03.04 Electronics and Nanoelectronics must be at least 50%; for 11.04.04 Electronics and Nanoelectronics, it must be at least 70% for the academic master's program and at least 55% for the applied master's program; for the specialty 31.05.01 General Medicine, it must be at least 65%; for the bachelor's program 45.03.01 Philology, it must be at least 60%; for the master's program 45.04.01 Philology, it must be at least 80% for the academic master's program and at least 70% for the applied master's program. The average value of the proportion of faculty members who have scientific degrees in all areas of training and at all levels of higher education is 65%.

The second factor is the number of students that determines the number of faculty members, that is, the amount of employed higher-education teaching personnel of the university.

Thus, based on the number of students, standard requirements for the qualification of HET personnel, and the standard number of students per HET personnel unit, it is possible to calculate the minimum number of teachers with academic degrees required to provide training for bachelor's, specialist's, and master's degrees at higher-education institutions.

Figure 1 shows the number of students of state and non-state educational organizations of higher education taking into account all forms of education, full-time, evening, and correspondence classes, for 2004–2015. The forecast calculations for 2016–2020 considered the dynamics of the movement of students based on years of study taking into account withdrawal [15].

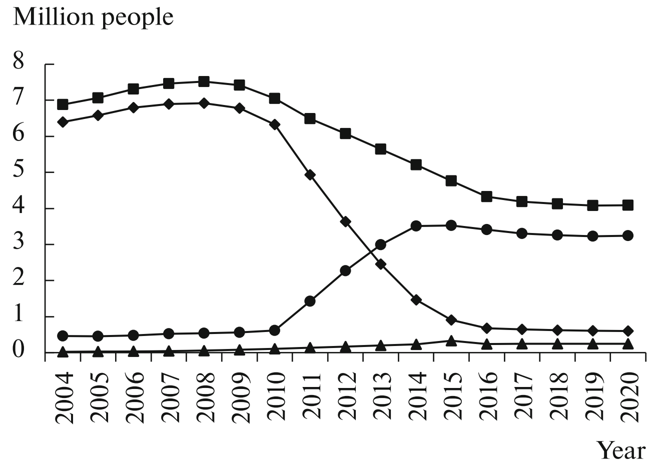


Fig. 1. Dynamics of the number of students of state and non-state higher education organizations: –◆– specialists; –●– bachelors; –▲– masters; –■– total. Actual values shown for 2004–2015; forecasted values shown for 2016–2020.

According to the standards, the staffing table for the higher education system is formed using the values of the adjusted number of students and the values of the number of faculty members adjusted to full-time employment. The values of the adjusted number of students L_{stud} are calculated by the ratio

$$L_{\text{stud}} = L_{\text{full-time}} + 0.25 L_{\text{part-time}} + 0.1 L_{\text{corresp}}, \tag{2}$$

where $L_{\text{full-time}}$, $L_{\text{part-time}}$, and L_{corresp} are the number of students enrolled in full-time , part-time (evening), and correspondence forms of training, respectively.

Since some full-time teachers work for a certain fraction of the K_i wage rate (K_i varies in the range of 0.1–1.0 in increments of 0.1), the given number of HETP (L_{HETP}) was calculated as the sum of the products of wage rate fractions (K_i) and the number of teachers working for this wage rate as follows ($L_{i,\text{HETP}}$):

$$L_{\text{HETP}} = \sum_{i=1}^{10} K_i L_{i,\text{HETP}}. \tag{3}$$

The analysis of the ratio of the adjusted number of students to the adjusted number of HETP in the higher education system over the last five years made it possible to justify the value of the $K_{\text{HETP/stud}}$ coefficient: the number of HETP per student equal to $^1/_{11}$.

The normative adjusted number of Candidates (L_{cs}) and Doctors of Sciences (L_{ds}) in the composition of HET personnel is determined by the following ratio (here and below, the term *adjusted* is omitted):

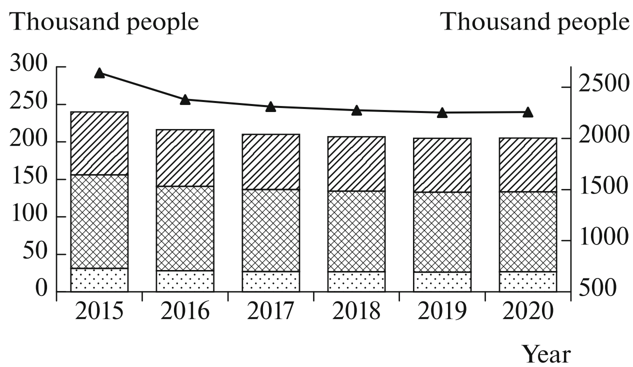


Fig. 2. Forecasted values of the standard number of HETP, taking into account values of the standard coefficients: ⬚ Doctors of Sciences; ▩ Candidates of Sciences; ▨ without degree; –▲– adjusted number of students (right scale).

$$L_{cs} = K_{cs} \cdot K_{deg\_tot} \cdot L_{HETR} = K_{cs} \cdot K_{deg\_tot} \cdot (K_{HETP/stud} \cdot L_{stud}), \quad (4)$$

where L_{cs} is the total number of Candidates of Sciences, K_{cs} is the proportion of Candidates of Sciences in HETP with a degree, K_{deg_tot} is the proportion of HET with a degree among the total number of HETP, $K_{HETP/stud}$ is the ratio of the number of HETP per student, and L_{stud} is the adjusted number of students.

Similarly, the standard number of Doctors of Sciences is calculated as follows:

$$L_{ds} = K_{ds} \cdot K_{deg\_tot} \cdot L_{HETP} = K_{ds} \cdot K_{deg\_tot} \cdot (K_{HETP/stud} \cdot L_{stud}). \quad (5)$$

Based on the data on the forecasted dynamics of the adjusted number of students, we calculated the forecasted values of the adjusted number of HETP and Candidates and Doctors of Sciences in the composition of HETP $K_{deg\_tot} = 0.65\%$, the ratio of doctors and Candidates of Sciences 4 : 1 ($K_{cs} = 0.8$, $K_{ds} = 0.2$), and the number of students per HETP unit ($K_{HETP/stud}$ = 1/11).

It follows from the calculation (Fig. 2) that, in the medium term, the forecasted minimum standard number of Candidates of Sciences (L_{cs}) and Doctors of Sciences (L_{ds}) in the Russian higher education sector will decrease annually by 2000–3000.

It should be noted that the number of Candidates of Sciences for the formation of the forecasted need for HSQ personnel should be calculated in the context of branches of science in accordance with the All-Russian Classification of HSQ Specialties 2013 (OKSVNK) (L^i_{cs}, where i is the index of the branch of science). Relations (4) and (5) conduct these calculations in the context of enlarged groups of training programs (UGNP) according to the All-Russian Classification of Education Specialties (OKSO) 2013 ([L^j_{cs}, where j is the index of the enlarged group of training programs). For the transition from UGNP to branches of science, it is necessary to multiply the value of L^j_{cs} by the transition matrix $M_{i,j}$, i.e., "enlarged groups of training programs in postgraduate studies/specialties in accordance with the Nomenclature of Specialties of Scientific Workers," which is formed based on the approved standard document.

Based on the forecasted standard number of Candidates or Doctors of Sciences in the HETP composition, the annual additional need for them in the higher education system (ΔL^i_{cs}), as calculated based on the standards, will be determined by the ratio

$$\Delta L^i_{cs} = R^i_{cs} \cdot L^i_{cs} + \Delta L_{prod\_cs}. \quad (6)$$

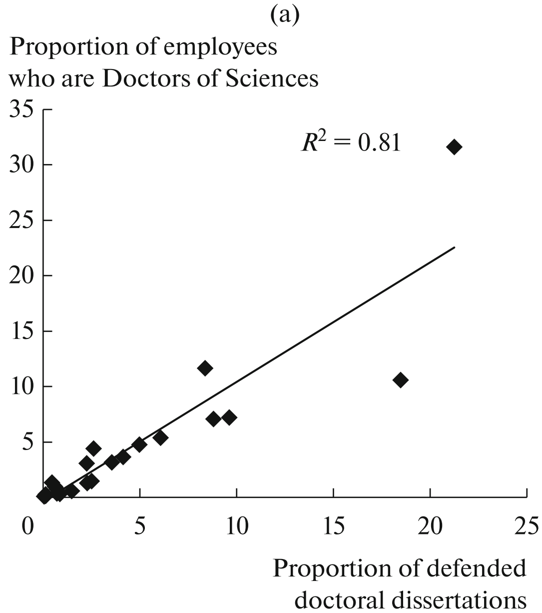
The value of ΔL_{prod_cs} (change in the number of Candidates of Sciences) can be either positive or negative depending on the dynamics of the student population. With reference to the methodology of forecasting the economic need for skilled personnel, this value corresponds to the component of the annual additional need associated with changes in the physical volume of output product [13]. As already noted, in the medium term, for the higher education system, the value of ΔL_{prod_cs} will be negative as the student population decreases.

The total values of the minimum standard number of the adjusted HETP population for the higher education system are 121 500 Candidates of Sciences and 30 400 Doctors of Sciences. In 2015, the adjusted HETP number in universities was 140 800 Candidates of Sciences and 36 500 Doctors of Sciences. This means that the actual number of HSQ personnel in higher education institutions exceeds the minimum allowable, i.e., the standard requirements of the Federal State Standards of Higher Education are met.

Taking into account the value of the rotation ratio of Doctors and Candidates of Sciences (0.046 and 0.035, respectively), the annual minimum additional need to replenish their natural age-related withdrawal from the university sector is 4250 Candidates of Sciences and 1060 Doctors of Sciences, along with taking into account a decrease in the number of students, 3830 Candidates of Sciences and 960 Doctors of Sciences (2016).

A comparison of the annual additional need for Candidates and Doctors of Sciences in the HETP composition and the number of defended candidate (6507) and doctoral (1055) dissertations by graduate students and full-time personnel working at universities has shown that, in 2015, the replenishment of the number of Candidates of Sciences satisfied the annual additional needs for HETP with academic degrees with a surplus and that of Doctors of Sciences at a minimum.

The principle "based on need": example of SC Rosatom. The methodology for forecasting the HSQ personnel for other knowledge-intensive sectors of the



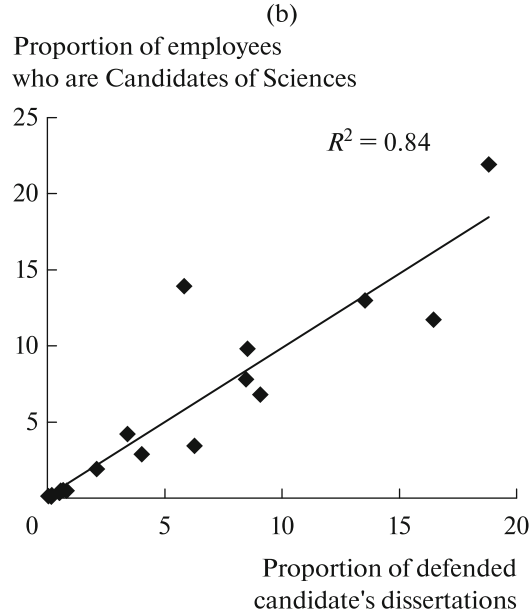


Fig. 3. Diagrams of distribution for universities subordinated to (a) the Ministry of Education and Science of Russia and (b) the Institutes of the State Academies of Sciences.

economy differs from the forecasting methodology in the higher education sector and the research and development sector in that it is necessary to take into account the structural personnel shifts in these sectors of the economy that occur in the fourth technological order and the knowledge economy.

In this case, the calculation of the annual additional need, as well as the natural age-related withdrawal of Candidates of Sciences ($\Delta L_{\text{cs}}^{\text{withd}}$) and changes in the number of jobs due to changes in physical volumes of production ($\Delta L_{\text{prod\_cs}}$), should take into account the qualitative changes in the structure of jobs in connection with the transition to a knowledge economy. Over the past ten years, the total number of employees with higher education has increased annually by 0.6%, while in manufacturing, it has increased by 1.0% [16]. Unfortunately, the state statistics provides no data about the number of employed in the economy with academic degrees of Candidate and Doctor of Sciences. By analogy with workers who received higher education, it can be assumed that the proportion of employed individuals with degrees in knowledge-intensive sectors of the economy should also increase by at least 1% annually as follows:

$$\Delta L_{\text{cs(struct)}}^{i} = L_{\text{cs}}^{i} \cdot K_{\text{struct}}^{i}. \qquad (7)$$

Consequently, for high-tech sectors of the economy, the annual additional need for personnel with academic degrees is calculated as follows:

$$\Delta L_{\text{cs}}^{i} = R_{\text{cs}}^{i} \cdot L_{\text{cs}}^{i} + \Delta L_{\text{prod\_cs}} + L_{\text{cs}}^{i} \cdot K_{\text{struct}}^{i}. \qquad (8)$$

Along with the lack of data about the number of individuals with academic degrees in terms of economic sectors, there are no data about the professional qualification structure (the number of employees with scientific degrees in terms of the fields of science and specialties). Since the data were missing, a hypothesis has been proposed that the professional and qualification structure of personnel with higher scientific qualifications in the economic sectors corresponds to the professional qualification structure of defended dissertations by graduate students and workers of these sectors. The hypothesis was tested based on the known data for institutions of higher education subordinate to the Ministry of Education and Science of Russia, as well as for the research-and-development sector. This hypothesis has been confirmed (Fig. 3), which allows it to be extended to other sectors of the economy [17].

Let us consider the definition of quantitative values of the need for HSQ personnel using the example of a knowledge intensive sector of the economy, i.e., enterprises and organizations subordinate to the State Corporation Rosatom. The number of HSQ personnel in the structure of state employees of the State Corporation Rosatom is 3670 individuals (1.4% of the total number of employees). Their composition includes Academicians and Corresponding members of the Russian Academy of Sciences (25 people), Doctors of Sciences (615 people), and Candidates of Sciences (3030 people) [18]. Based on the data on the number of candidate and doctoral dissertations that have been defended in terms of the scientific specializations for competitors with scientific degrees working at the State Corporation Rosatom [10], the proportions of

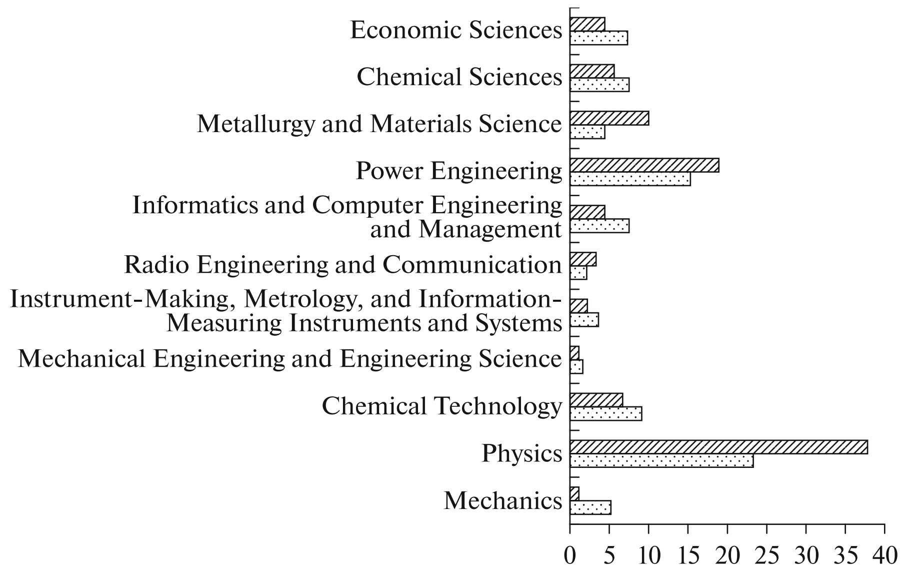


Fig. 4. Structure of defended dissertations for a scientific degree by the personnel of the SC Rosatom in terms of enlarged groups of scientific specialties (for the period from 2009 to 2014): Candidate of Sciences (▫) and Doctor of Sciences (▨).

the defenses of candidate dissertations in terms of scientific specialties were calculated.

Figure 4 shows the structure of the dissertation defenses for the scientific degrees of the Candidates and Doctors of Sciences given by employees of SC Rosatom in terms of the enlarged groups of scientific specializations with averaging for 2009–2014. The first 11 groups include the maximum number of defenses; the grouping is carried out according to the increase in the code of enlarged groups of scientific specialties.

The annual additional need of organizations (enterprises) of the SC Rosatom for HSQ personnel of all scientific specialties for the medium term, taking into account only the annual natural age-related withdrawal, was 80 Candidates of Sciences and 30 Doctors of Sciences. No changes in physical volumes of production by the SC Rosatom in the medium term are planned [18]; therefore, there is no corresponding component of the annual additional need. The contribution of structural shifts in the provision of the SC Rosatom with HSQ personnel to the annual additional need can be taken into account based on the available data only using the average growth rate of the proportion of individuals with degrees in knowledge-intensive sectors of the economy by 1% per year. In this case, $\Delta L_{(\text{struct.})}$ will be 30 Candidates of Sciences and 6 Doctors of Sciences.

Consequently, the annual additional need of the SC Rosatom for HSQ personnel for the medium term is 110 Candidates of Sciences and 36 Doctors of Sciences.

The principle "by analogy": total economy. The principle "by analogy" implies the formation of the structure and volumes of HSQ personnel in the sectors of the national economy in the same proportions as in other countries with an effective market economy, for example, in OECD countries. To compare the data when calculating the number of PhDs trained in the OECD countries and Candidates of Sciences in Russia in terms of fields of science, the International Standard Classification of Education (ISCE) codes provided in OKSVNK 2013 were used, which establish the correspondence between scientific specialties of the Nomenclature of Specialties and educational specialties of ISCE 2011.

For comparative analysis, the indicators of Germany and Japan as the countries-leaders of the economy of the 6th technological order were used. These countries are closest to Russia in terms of the population and the volume of training of HSQ personnel. In 2014, 28.1 thousand PhD theses were defended in Germany, 16000 in Japan [19], and 20000 in Russia in 2013 (in Russia, 2014 was a drop out year in terms of dissertation defenses (9900) due to the reorganization of the network of dissertational councils, so for the Russian Federation, the indicators for 2013 were used).

The distribution of graduates of PhD programs (ISCE level-8 programs) in these countries and in Russia by fields of science is shown in Fig. 5. The greatest difference in the structure of training personnel of higher scientific qualifications in Russia and selected OECD countries is observed in the fields of social sciences, business, and law. In Russia, its proportion is maximal and exceeds the values of Germany and Japan by twofold. In the field of science Healthcare and Social Security, for Russia, this proportion is minimal (three times less than in these countries).

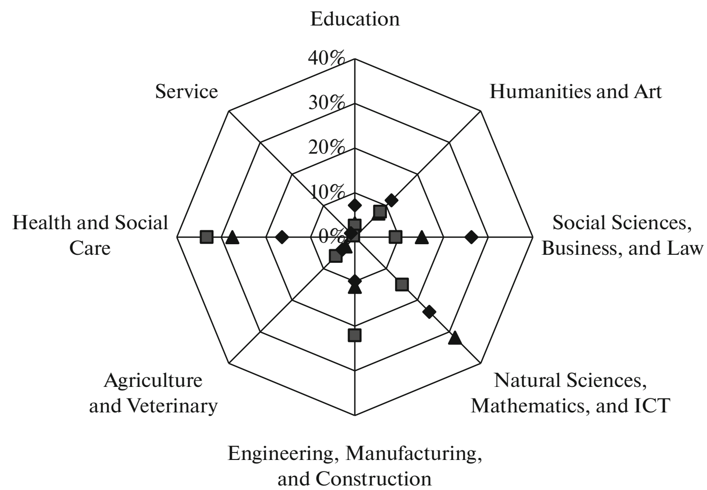


Fig. 5. Distribution of graduates of PhD programs in the fields of scientific activity, percent of total number of graduates of PhD programs: –◆– Russia; –▲– Germany; –■– Japan.

Proportions for other fields of scientific activity are not significantly different.

An analysis of the dynamics of these indicators over the past ten years (2005–2015) has shown that the above structural difference in the training of HSQ personnel in Russia and selected OECD countries persists. The HSQ personnel structure of Germany and Japan, which have high economic development indicators, can be adopted as a guideline for changing the structure of the formation of the annual additional need for HSQ personnel for these sectors of the Russian economy as Healthcare and Social Security.

Implementation of forecasting principles. The development of the forecasted Russian economic needs for HSQ personnel includes the calculation of the annual additional need for three main public institutions: education, science, and high-tech sectors of the economy. For education, the calculation is carried out in compliance with the principle "based on the standards"; for science, the principle "based on the progress" is used; and for high-tech sectors of the economy, the principle "according to need" is used. At the same time, all of the calculated formulas of the annual additional need include the replacements for natural age-related withdrawals; for the education and economic sectors, they additionally include changes in the physical production volumes; and, for the economy sector, they additionally include structural changes in the workplaces. These indicators are objective and require these needs to be satisfied by the state. It should be noted that the indicators of annual additional need do not take into account the intersectoral personnel movement associated with transfers of workers at their own initiative. The principle "by analogy" can be used to take into account structural changes in workplaces when comparing the volumes and specific weights of HSQ personnel for different scientific specialties in Russia and countries with efficient economies.

The total annual additional need for HSQ personnel in the country as a whole can be obtained by summing up the annual additional need for three main public institutions with specifications in terms of scientific fields or groups of scientific specialties.

CONCLUSIONS

The methodology of forecasting the needs for HSQ personnel presented in this paper makes it possible to carry out quantitative estimates of the annual additional need for Candidates and Doctors of Sciences for various knowledge intensive sectors of the economy. The implementation of forecast calculations for the sectors of science and higher education is not complicated. The calculation of the annual additional need for Candidates and Doctors of Sciences in the sectors of public administration, healthcare, and other knowledge intensive high-tech sectors of the economy is hampered by the lack of state and departmental statistics about the number and structure of HSQ personnel employed in these sectors. To fill the missing information for these sectors of the economy, the methodology for the formation of these indicators has been developed and tested based on the example of SC Rosatom.

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