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Factors Influencing the Nuclear Knowledge Loss Risk in Republic of Bulgaria: External Factors Overview

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Abstract. In the recent years, personnel ageing, loss of critical knowledge and gaps in education and training are observed worldwide. Nuclear knowledge preservation, transfer, and expansion are critical for sustaining viable nuclear power sector and increasing nuclear applications' usage in non-energy fields. Moreover, efficient knowledge management is paramount for ensuring safe, reliable, and effective operation of nuclear facilities. Bulgaria possesses substantial experience and knowledge in the nuclear power domain. Nuclear knowledge management approaches, however, are only partially applied. The current paper analyses the external factors – demographics, workforce, education, and nuclear industry development – that influence the risk of nuclear knowledge loss on a national level. The results of the current analysis would serve in further risk analyses and would be useful for nuclear knowledge strategy development and implementation.

Keywords: nuclear education, nuclear knowledge, nuclear workforce.

1 Nuclear Knowledge

Knowledge is generally defined as the facts and principles accumulated by humankind through the course of its history and development. It is also the ability to acquire, understand, and interpret information. In that context, knowledge management is an integrated systematic approach that is applied in order to identify, acquire, transform, develop, disseminate, use, and preserve the knowledge, relevant to achieving given objectives [1]. In particular, nuclear knowledge incorporates facts, opinions, approaches, theories, models, *etc.*, which are related to comprehending nuclear-related issues and encompasses numerous domains of human knowledge such as physics, chemistry, medicine, and environmental sciences. The domains related to nuclear knowledge are shown in Figure 1 [2].

The main risks in nuclear knowledge management arise from the long life-cycle of a nuclear facility that, accounting for design, operation, life-time extension, and decommissioning, could span well over 100 years. That leads to the necessity of preserving knowledge, skills, and competencies, and ensuring their transfer between the generations in nuclear workforce, for several decades. New knowledge and skills should be developed and acquired in order to carry out upgrades and decommissioning procedures [3]. Furthermore, personnel ageing, loss of critical knowledge and gaps in education and training are

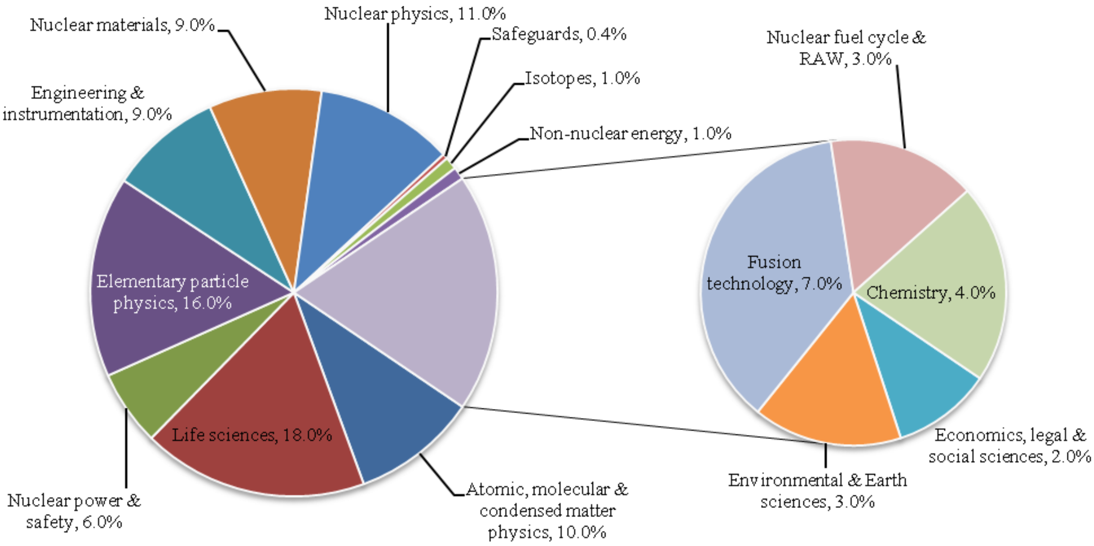

Figure 1. Nuclear knowledge subjects' scope [2].

observed worldwide [2]. In the field of radioactive waste management, knowledge gaps and knowledge loss could lead to risks of poor decision making and the unintended elimination of possible future waste management options [4].

The long timescales in nuclear facilities' operation suggest that if a nuclear knowledge loss risks are to be identified and analysed on a national level, it is necessary to outline the long-term tendencies in more general areas such as demographics, workforce, education, and nuclear industry development.

2 Objectives

The objectives of the current paper are to outline the major external factors influencing the nuclear knowledge loss risk, such as nuclear power's place and development perspectives; demographic dynamics –population number, growth projections, age structure; workforce availability; education's quality; amount of people obtaining major in science or technology related field – mathematics, physics, chemistry, engineering; quality of power engineering education. All these factors influence directly or indirectly either nuclear energy field's development or education and training of highly qualified and motivated staff for the nuclear industry (technicians, engineers, project managers, supervisors, researchers), or both.

The understanding of the trends in the development of these factors would allow identifying their impact on human resources education, training, and management, and on the overall nuclear knowledge accumulation, transfer, and application in Bulgaria.

In addition, Bulgaria has already experienced significant industrial knowledge loss on a national level. Due to a political decision, the uranium mining in the country was suspended in the early 1990s. That decision led to the full loss of the accumulated knowledge and experience which occasionally created difficulties in decommissioning and land reclamation, and has left some of the sector's issues unresolved [5,6]. This example shows that even if a whole industrial sector were to be totally removed from the country's economy and development plans, knowledge preservation and qualified personnel would be needed for executing safely and effectively the decommissioning and reclamation operations that may span decades. Consequently, even if worst-case scenario regarding nuclear power's development is considered, nuclear knowledge management and transfer remains a relevant issue.

3 Nuclear Power's Role in Bulgarian Energy Sector. Possible Developments

3.1 Historical development and status-quo

Bulgaria started early the development of its nuclear power sector. An agreement between Bulgaria and the Soviet Union, signed in 1956, arranged the terms of bilateral cooperation in the peaceful use of nuclear energy and set the basis for establishing a research centre in the Bulgarian academy of sciences. Further bilateral agreement, signed in 1966 between the two states, set the framework for constructing a nuclear power plant in Bulgaria. Unit 1 of Kozloduy NPP was connected to the national grid on 24 July 1974, thus making Bulgaria the first country in Southeastern Europe and the eleventh country in the world to operate a nuclear power station [7]. At the moment, the installed nuclear capacity is 2000 MW in two units with reactors WWER-1000/V-320 at the Kozloduy NPP site. Each reactor has nameplate thermal power of 3000 MW and nameplate electric power of 1000 MW [8].

Currently nuclear power is one of the pillars of Bulgarian power system, alongside lignite-fired thermal power stations. For the 2005–2014 period nuclear energy has contributed to between 33.5% and 43.1% of Bulgarian electricity generation [9]. In 2015 the net nuclear generated electricity is 14.3 TWh (approximately 32.2% of Bulgarian net generation) [10]. Moreover, nuclear power in Bulgaria is highly reliable – the average load factor of Kozloduy NPP for the period 2007–2015 is 86.35%; that value is substan-

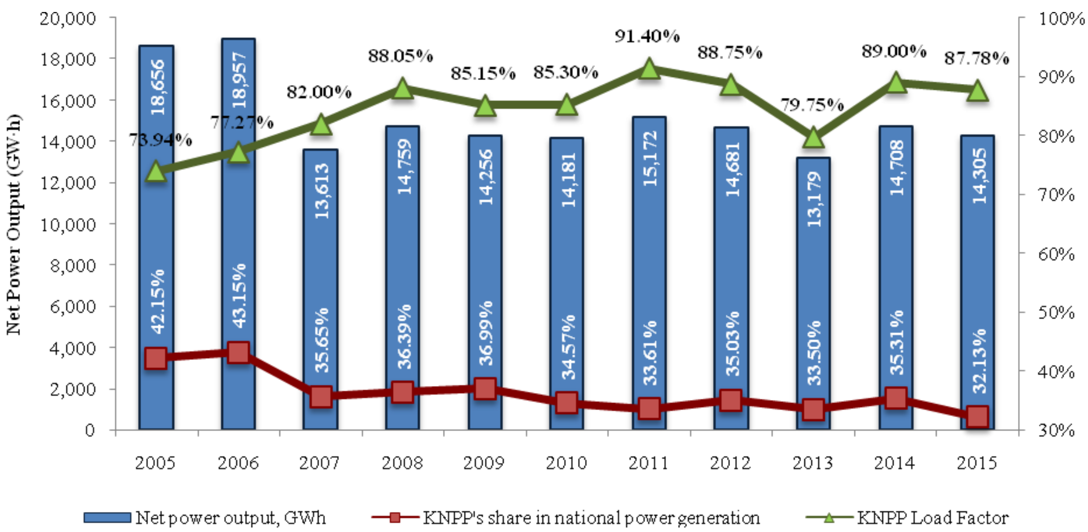

Figure 2. Nuclear energy's net power generation, load factor, and share in national generation [10,12-22].

Table 1. Expected additions of power generation capacity by fuel type [27]

		2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	Total
Kozloduy NPP	[MW]	100	100	-	-	-	-	-	-	-	-	**200**
Thermal PP	[MW]	10	37	34	20	-	-	50	-	46	-	**197**
Renewables	[MW]	180	240	91	83	217	107	150	151	146	55	**1,420**
Hydro	[MW]	*3*	*1*	*1*	*1*	*1*	*3*	*47*	*60*	*71*	*5*	*193*
Wind	[MW]	*120*	*50*	*40*	*70*	*120*	*80*	*70*	*50*	*30*	*20*	*650*
Solar	[MW]	*38*	*185*	*46*	*8*	*92*	*19*	*27*	*35*	*38*	*25*	*513*
Biomass	[MW]	*19*	*4*	*4*	*4*	*4*	*5*	*6*	*6*	*7*	*5*	*64*
Total	[MW]	**290**	**377**	**125**	**103**	**217**	**107**	**200**	**151**	**192**	**55**	**1,817**

tially higher than the world average for PWR units with installed capacity of over 600 MWe, which is 77% [11]. The complete data for nuclear power's net electric output, load factor, and share in Bulgaria's power mix are illustrated in Figure 2. The total operational experience of Bulgaria as of 31 December 2014 amounts to 157 reactor-years and 3 reactor-months [11]. The total power production of Kozloduy NPP for the period 24 July 1974 – 31 December 2015 is 570 TWh [22].

Other aspect of nuclear power is managing the radioactive waste and spent nuclear fuel. Currently, the amount of spent nuclear fuel is considerable – as of 31.12.2014 in spent fuel pools and wet and dry spent fuel storage facilities 4,208 WWER-440 and WWER-1000 fuel assemblies are stocked, which contain 803.664 tones of heavy metal [23].

3.2 Outlook

Currently the Bulgarian nuclear programme includes lifetime extension and power uprates of the existing units 5 and 6 at Kozloduy NPP [24], decommissioning of units 1-4 at Kozloduy NPP [23], and possible construction of unit 7 at Kozloduy NPP. The considered new unit should be equipped with pressurised water reactor (PWR), either Russian-designed WWER-1000 or Westinghouse's AP1000 [25]. Nuclear energy will be maintained and developed as a key power generating technology; this includes not only units 5 and 6's operational lifetime extension and constructing new units with installed capacity of up to 2000 MW, but also national low- and medium radioactive waste (RAW) storage facility, and final spent fuel repository [26]. The document that outlines an action plan for spent fuel and radioactive waste management in Bulgaria up to 2030 is the *Revised Strategy for Spent Nuclear Fuel and Radioactive Waste Management*, approved in 2015 by the Council of Ministers [23].

Considering the mid-term perspective for a new nuclear unit construction, the anticipated power demand should be taken into account. The national transmission system operator (ESO) in its scenarios for grid development expects that the annual power consumption would rise between 5.2% and 9.6% by 2025 on 2016 basis (Figure 3). According to their analyses, new nuclear unit wouldn't be needed prior 2035, while additional nuclear capacity would come from power uprates of the present units. ESO's forecast for the new installed capacity by 2025 is given in Table 1 [27]. On the other hand, others anticipate a more modest average load growth for the period 2015-2025 – only 0.8% compared to expected average growth for South-eastern Europe of 1.3% (excluding Turkey) [28]. The same study suggests Bulgaria might have an electric energy surplus of between 9.687 and 10.119 TWh in 2020 and

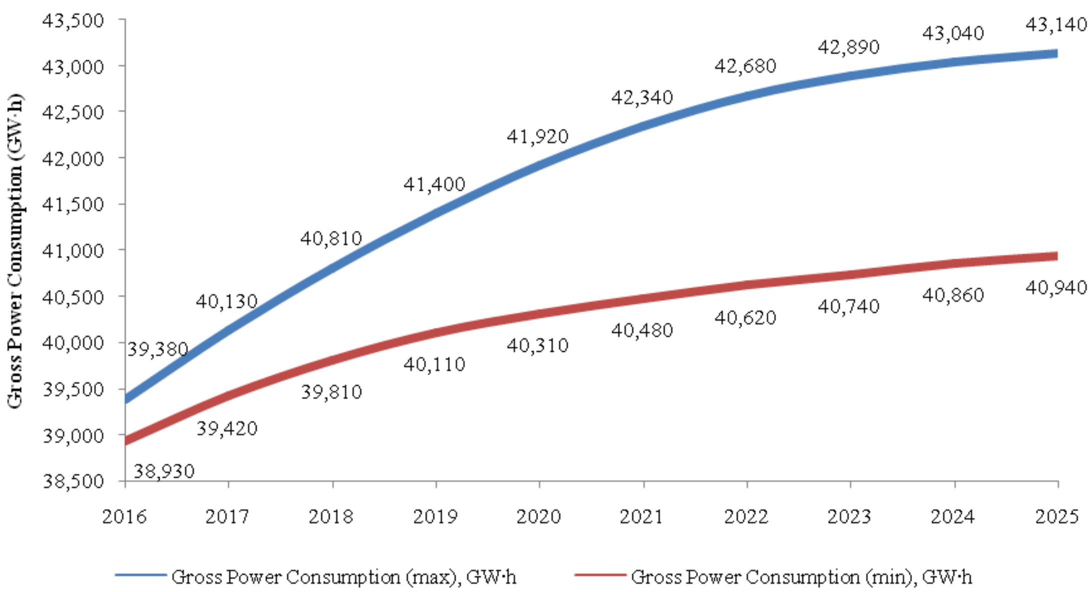

Figure 3. Power consumption in Bulgaria forecasts, maximal and minimal scenarios [27].

between 8.699 and 17.030 TWh in 2025. The presented results, however, do not clarify the structure of the power generating mix in the country. Nevertheless, because of the implementation of the policies concerning the Energy Union formation, 10% electricity connectivity should be achieved for the period 2015-2020, and 15% interconnection target should be reached by 2030 [29]. This value effectively means that 10% of the dispatchable installed power generating capacity should be always available in order to ensure the normal work of the fully integrated energy market and guarantee security of supply should a disruption occur. Bulgaria's connectivity in 2014 is 11% [30].

Since nuclear knowledge management, and personnel education and training are lengthy processes spanning decades, it is essential to have some insight about nuclear energy's long-term development perspectives. Climate change mitigation policies promoted by the European Union during the COP21 conference might increase the future role of nuclear energy in reducing greenhouse gases (GHG) emissions – the proposed EU binding target is a GHG emissions reduction by at least 40% by 2030 compared with 1990. This target is much more stringent than the current policies [31]. It is evaluated that in order to meet its decarbonisation goals, the EU member states need to add 731 GW of renewables and 64 GW of nuclear power to their generating capacity for the 2015-2040 period [32]. Based on these policies there are already several forecasts about nuclear power's share in the future Bulgarian electric system – Bulgarian Energy and Mining Forum's assessments are that it would be 40% in 2030 and 52% in 2050 [33], while Energy Management Institute's calculations with the PRIMES model show that nuclear power might generate 20,148 GWh (36.9% of total production) in 2050 [34,35], this figure representing a 40.85% increase compared with the 2015 value (14,305 GWh). Thus, nuclear power would have the largest share in Bulgaria's power generation (Figure 4).

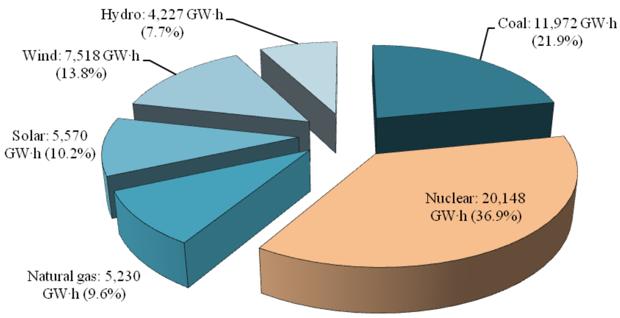

Figure 4. Anticipated Bulgarian power generation mix in 2050 [35].

Although it is hard to anticipate long-term developments, it seems that within the coming decades Bulgaria might be constructing new nuclear power unit(s). In addition, at some point of the future, units 5 and 6 of Kozloduy NPP would be decommissioned, and the historic and emerging radioactive wastes and spent nuclear fuel from current and future operations ought to be managed. An approximate evaluation of the expected amounts of generated spent fuel and radioactive waste for different technologies investigated for the considered 7th unit at the Kozloduy site could be found in Ref. [23].

4 Demographic Dynamics

4.1 Population numbers

The Bulgarian population has been steadily declining since 1989 when the tendency of sustained growth abruptly reversed (Figure 5). From 1960 up until 1989 the population was steadily rising with an average annual growth of 0.48%, the total population growth being 14.78% for these 39 years. However, the growth rate has always been decelerating since 1960 (Figure 6). Then, within a very short time frame (1989-1993), the population decreased

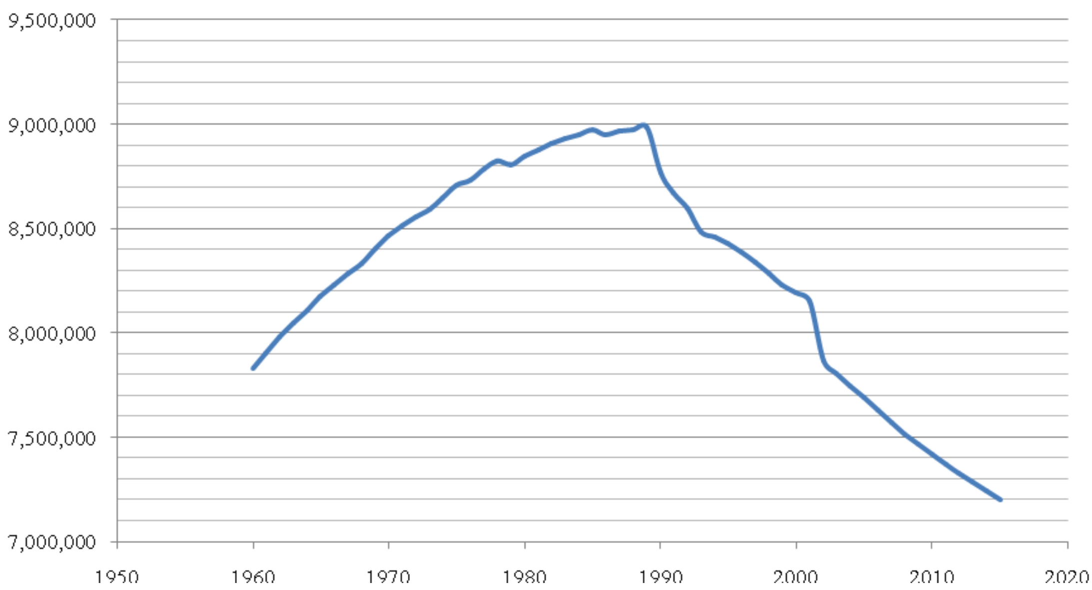

Figure 5. Total population dynamics (1960-2015) [38].

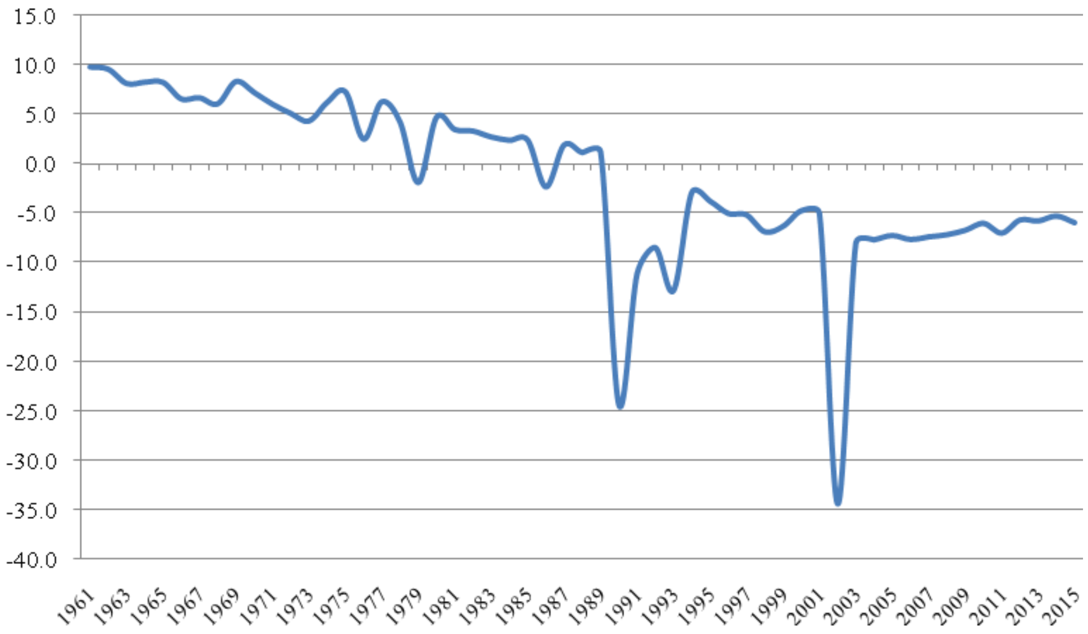

Figure 6. Population growth rate (1960-2015), ‰ [38].

by 5.58%, or Bulgaria lost half a million of its population within 5 years – a loss rate of 100,000 people per year. Following 1993 the decrease decelerated but still the growth rate remained negative (Figure 5, Figure 6). Between 2001 and 2002 alone Bulgarian population shrank by 3.44% (34.44‰) or almost 281,000 people. Since then a steady rate of decline averaging -0.68% (-6.8‰) has been observed. The population loss in the last 10 years (2006-2015) follows almost a linear law (Figure 5) – as of January 1, 2006 Bulgaria's population amounted at 7,629,371 while 10 years later Bulgarian population is 7,202,198[37]. In other words, the population has declined by 5.6% or almost 430,000 people. That averages as a loss of 43,000 people per annum.

The projections of both National Statistics Institute and Eurostat show that the trends described above would continue, the difference being the rate of decline (Figure 7). It is expected that in 2025 Bulgarian population would be between 6.72 and 6.84 million people; between 6.27 and 6.52 million people in 2035, and between 5.67 and 6.10 million in 2050 [36].

The aforementioned trends could be better understood by looking at the population growth rate which is determined

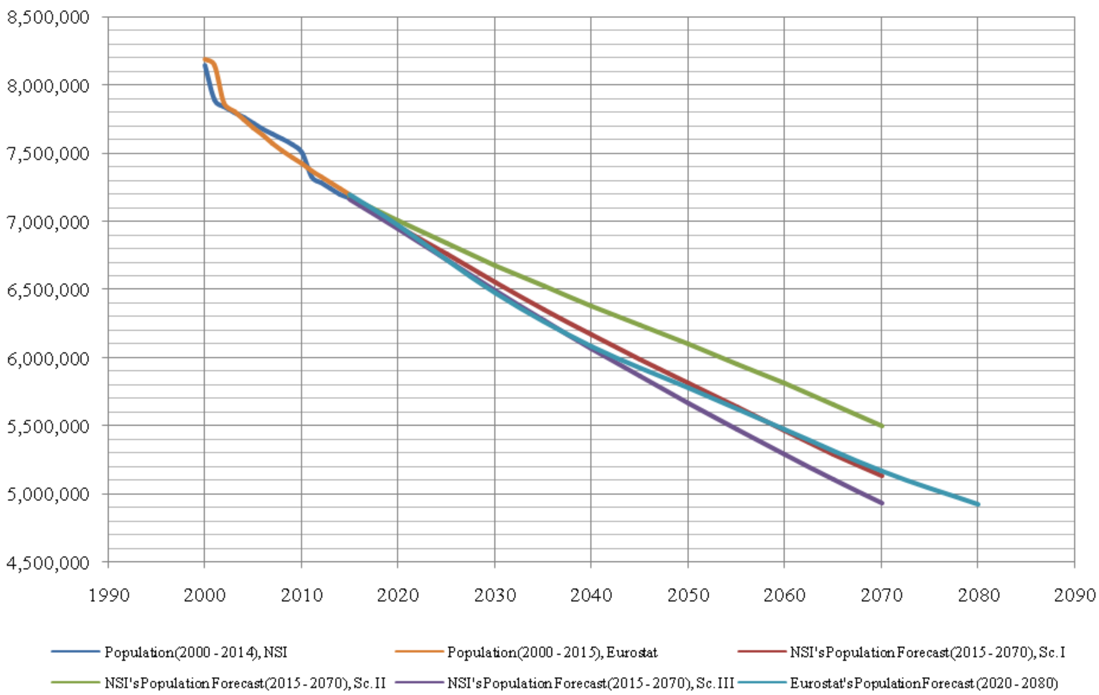

Figure 7. Population projections [36,37].

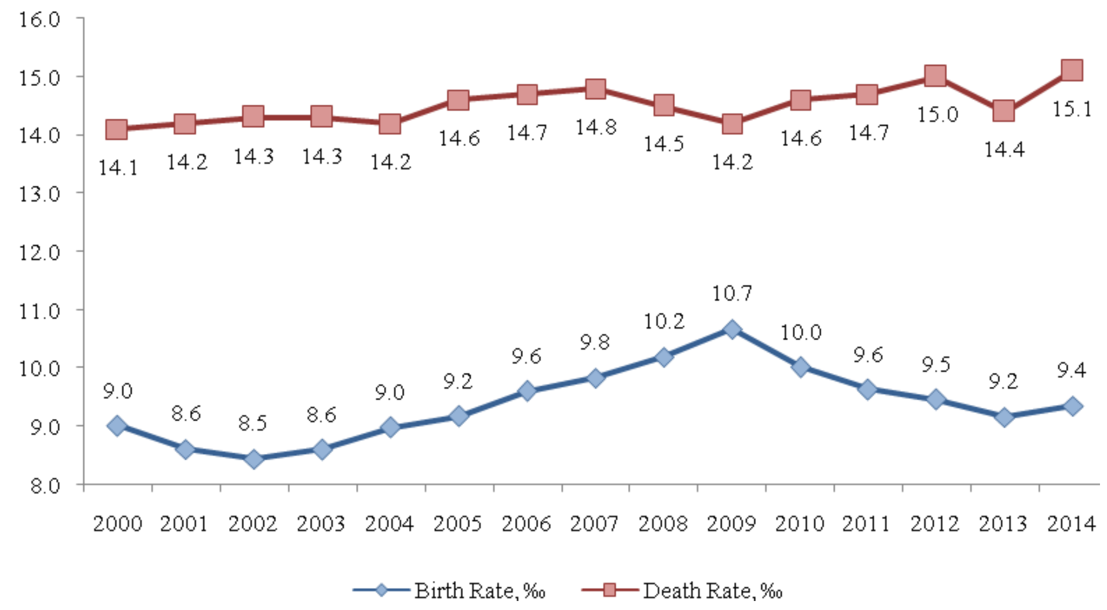

Figure 8. Birth and death rates [36].

by the natural growth rate (the difference between birth and mortality rates) and mechanical movement of the population (net migration). The growth rate has been negative since 1990; moreover, in two cases there are sharp drops. However, there is a tendency of stabilization after 2003–2004 – the growth rate remains negative but maintains similar levels (Figure 6).

Figures for birth and mortality rates for the past 15 years could be seen in Figure 8. Regarding the birth rate, four regions of the chart could be identified. The first is 2000–2002 when the birth rate was steadily declining until it reached its minimum for the considered period in 2002. From this moment until 2009 there was a substantial growth in the birth rate, reaching maximum in 2009. Afterwards the rate started decreasing again, returning to its 2005 level in 2013. At this point there was a slight rebound but the data is insufficient to outline a tendency and to find out whether there'd be a recovery or not. On the other hand, the mortality rate oscillates between 14 and 15‰ but tends to increase in the last 15 years. The data shown in Figure 9 illustrates the dynamics of birth, death, and natural growth rates since 1960.

In regards with the death rate, it becomes evident thatit has been increasing since 1960, the increment being almost linear until 1997. Afterwards there's decrease in mortality in 1998 but, nevertheless, it continues increasing although at slightly lower rate. The fact that the natural growth rate dynamics mirrors that of the birth rate change

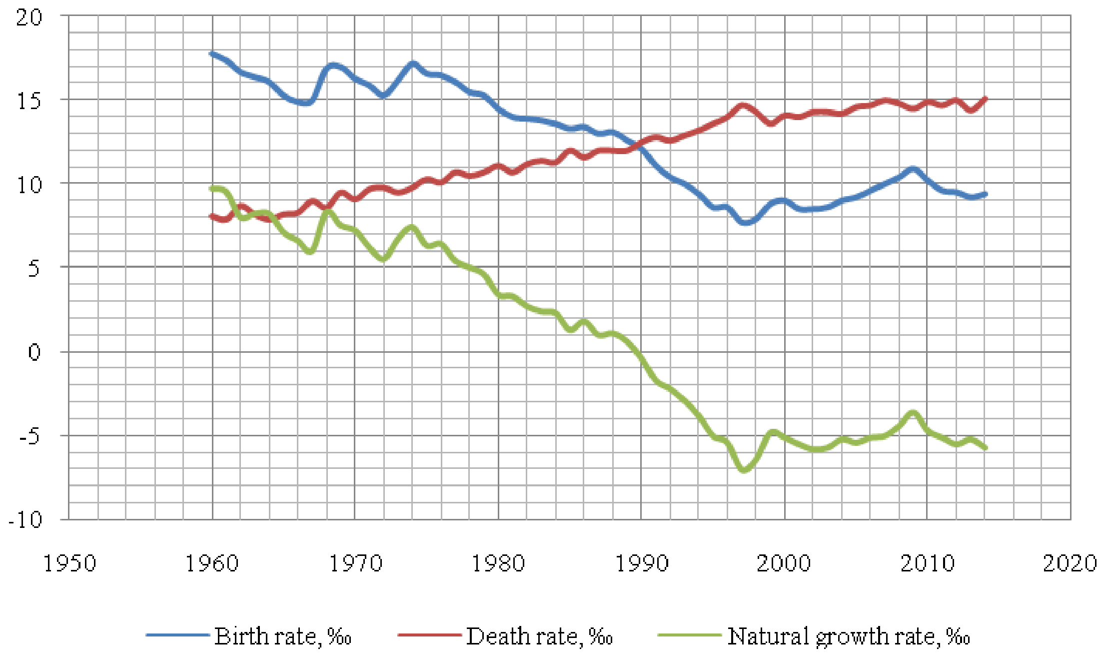

Figure 9. Birth, death, and natural growth rates (1960–2014) [38].

Table 2. Bulgaria's rankings according to mortality and natural growth rates for 2014 [38]

Birth rate			Mortality rate			Natural growth rate		
№	Country	[‰]	№	Country	[‰]	№	Country	[‰]
1	Portugal	7.90	**1**	**Bulgaria**	**15.10**	**1**	**Bulgaria**	**-5.70**
2	Japan	8.00	2	Lesotho	14.80	2	Serbia	-4.90
3	Italy	8.30	3	Ukraine	14.70	3	Ukraine	-3.90
4	Greece	8.50	4	CAR	14.53	4	Romania	-3.50
5	Germany	8.60	5	Swaziland	14.37	5	Latvia	-3.40
6	Hong Kong	8.60	6	Latvia	14.30	6	Hungary	-3.30
7	Rep. of Korea	8.60	7	Serbia	14.20	7	Lithuania	-3.30
8	Bosnia & Herzegovina	8.95	8	Chad	14.07	8	Croatia	-2.70
9	San Marino	9.10	9	Angola	13.72	9	Germany	-2.20
10	Spain	9.20	10	Lithuania	13.70	10	Portugal	-2.20

over time allows us to conclude that the mortality rate has grown almost linearly for the past 55 years.

As far as birth rate is considered, a slightly different dynamics can be observed. Between 1960 and 1973 there were oscillations within the range of 15 to 17‰. Afterwards a steady decline began, reaching an all-time minimum in 1997 with the rate of decrease accelerating after 1988. After 1998 a trend for slight recovery with a small peak in 2009 can be identified; after that year the trend inversed once again. However, at maximal mortality rate of 15.1‰ in 2014, the perspective for reversing quickly the negative growth rate is virtually absent.

Putting this data in international context gives worrisome results. Bulgaria has the highest mortality rate (15.1‰) and the lowest natural growth rate (-5.7‰) worldwide for 2014. At the same time Bulgaria has the fourteenth lowest birth rate (9.4‰) worldwide for the same year. Based on these data, summarised in Table 2, it is not very difficult to conclude that Bulgaria has a substantial demographic problem, if not a demographic crisis.

Natural phenomena, however, are only part of the processes that affect population dynamics. The other impact factor is migration. A net migration rate is obtained by subtracting the natural growth rate from total population change. The result is represented in Figure 10. The results from the last National Census show that 31.1% of the population decrease between 2001 and 2011 are due to emigration and the rest 68.9% are caused by the negative natural growth rate. The number of people that emigrated for that decade is estimated at 175,244 [39]. The net migration for the past four years is -8,676 for 2012, -11,354 (2013), -14,347 (2014), and -13,765 (2015) [36].

4.2 Age dynamics

Alongside declining population, there's a tendency of ageing. For the past 10 years the number of people aged 65 and above has been constantly rising while the number of people aged 0-14 and 15-64 – decreasing. That phenomenon, in combination with declining overall population, leads to population's ageing. In fact, since 1999 the number of people aged 65 and above has been higher than the number of people aged 0-14 (Figure 11). The shares of different groups are shown in Figure 12. The size of each age group is listed in Table 3. The gradual ageing of the population

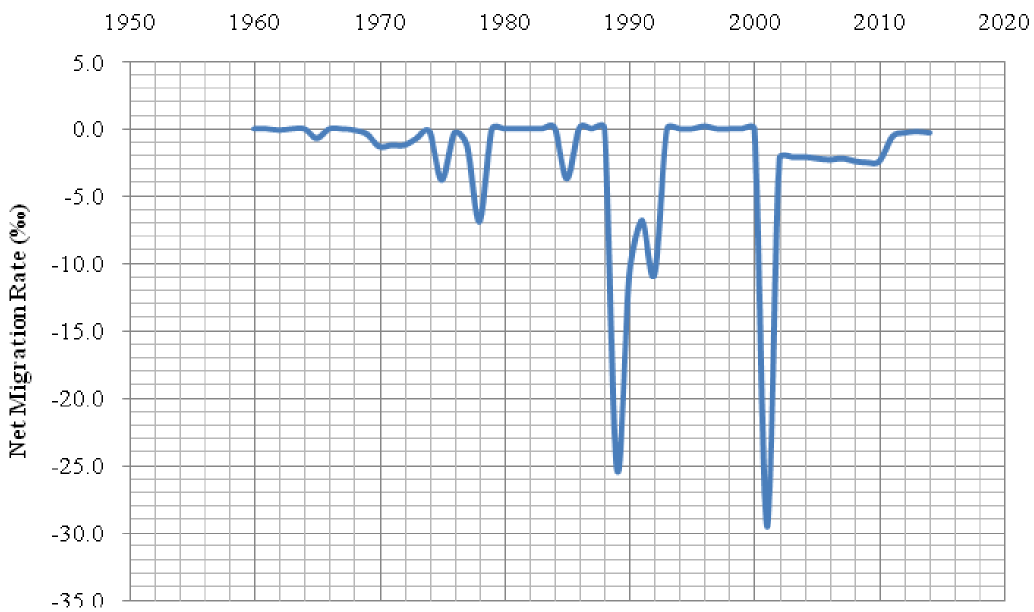

Figure 10. Net migration rate (1960-2014) [37].

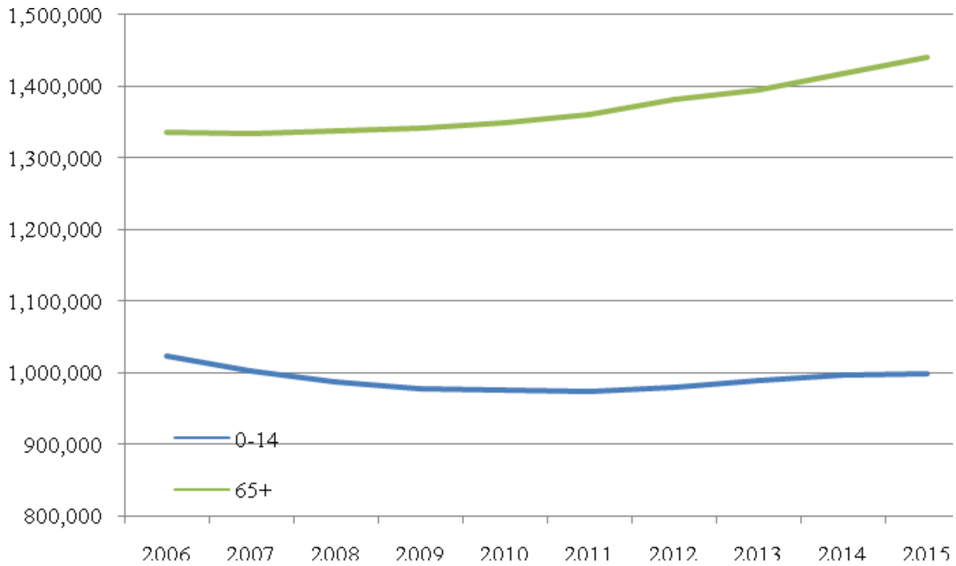

Figure 11. Dynamics of the age groups 0-14 and 65 and above (2006-2015) [38].

Table 3. Number of people by age group for 2006-2015 [38]

Year	0-14	Age group 15-64	65+
2006	1,023,523	5,270,029	1,335,819
2007	1,002,459	5,235,388	1,334,826
2008	986,900	5,193,519	1,337,583
2009	977,900	5,147,164	1,342,055
2010	976,188	5,097,115	1,348,463
2011	975,131	5,033,849	1,360,451
2012	979,956	4,966,189	1,381,079
2013	989,989	4,899,092	1,395,471
2014	996,144	4,831,866	1,417,667
2015	998,196	4,763,673	1,440,329

can be seen in the ratio of the number of people aged 65 or more to the number of people aged 0-14, and the ratio of the number of people aged 65 or more to the number of people aged 15-64 (Figure 13). As it can be seen, both ratios increase, and in 2015 the number of people aged 65 or more is almost 1.5 times greater than the number of people aged 0-14 and is nearing a third (30.24%) of the number of people aged 15-64, being a quarter of that figure 10 years ago.

The population ageing could lead to several negative consequences – reduced workforce, reduced number of people enrolling in universities, strain on country's finances – increased expenses for retirees and healthcare for elderly citizens may lead to reallocating public funds from other domains such as education and R&D support. Reduced workforce means that less people should provide economic growth needed to sustain growing expenditure for pensions and healthcare. Reduced number of freshmen could strip key economic sectors of highly qualified

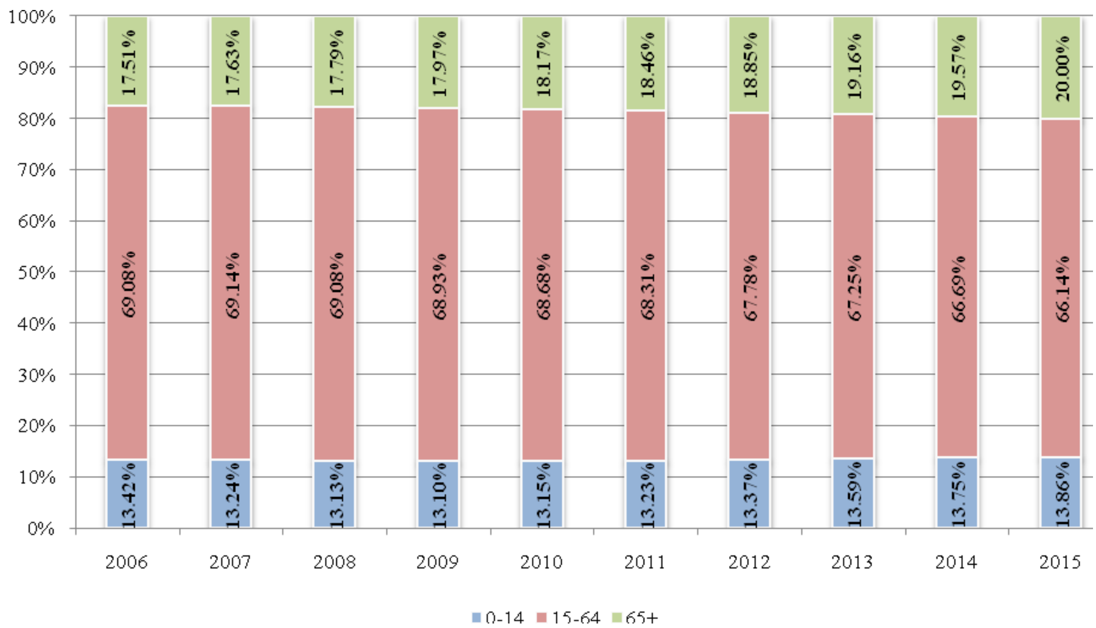

Figure 12. Age groups' shares in Bulgaria's population (2006-2015), calculations based on World Bank's data.

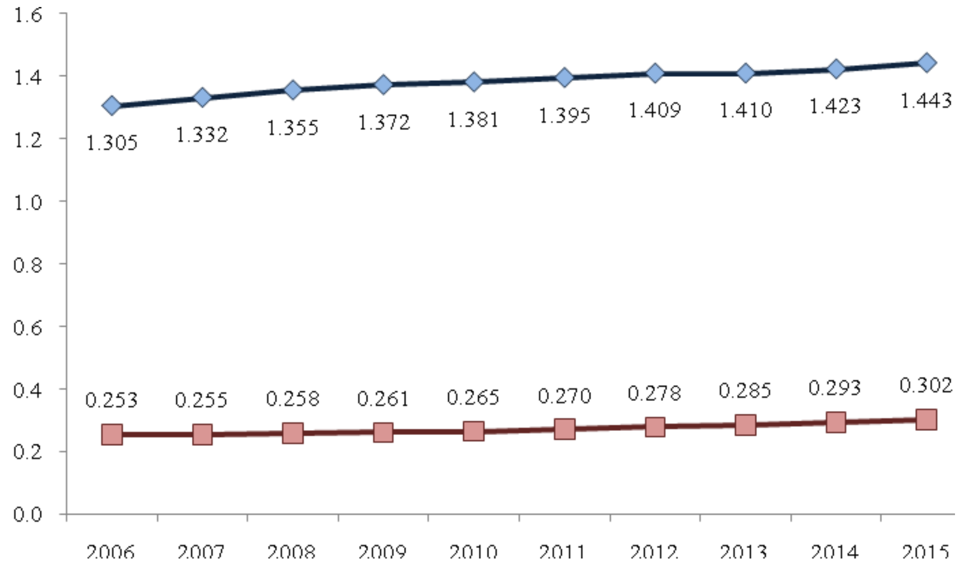

Figure 13. The age group 65 and above as a share of the age group 0-14 (blue) and 15-64 (red) (2006-2015), calculation based on World Bank's data.

specialists and would imperil the sustainable human resources management, needed to keep their role in the national economy. Some of the fields that might be affected are of strategic importance – power, mining and metallurgy, oil and gas, health care (see Section 5.4). As can be seen, ageing population could contribute to overall increase of the knowledge loss risk in critical for the national economy domains.

4.3 Workforce

The amount of workforce is directly influenced by the demographic processes – population decline, ageing, and migration. A good indicator for the workforce is the demographic replacement rate which is the ratio of the number of people entering working age (15-19) to the number of people leaving working age (60-64) [36]. The demographic replacement rate for the period 2001-2015 is shown in Figure 14 and the number of people in the respective groups is listed in Table 4. The last year the replacement rate was higher than 1 (*i.e.* the number of people entering working age exceeds the number of people exiting working age) was 2007 (the rate is 1.017). In 2008 the replacement rate was 0.949 while in 2015 its value was 0.619. These data suggest that there might be a workforce shortage in general and a negative impact on sustaining the needed amount of workforce to ensure knowledge transfer for guaranteeing safe, reliable, and economic operation of nuclear facilities in particular.

Figure 14. Demographic replacement rate (2001-2015), calculation based on World Bank's data.

Table 4. Number of people entering and exiting working age for the period 2001-2015 [38]

Year	Number of people entering working age (15-19)	Number of people exiting working age (60-64)
2001	553,925	443,070
2002	529,214	431,105
2003	522,354	434,146
2004	516,774	438,964
2005	511,408	442,618
2006	501,562	454,299
2007	483,805	475,550
2008	463,513	488,482
2009	437,999	504,452
2010	409,882	524,716
2011	380,036	540,149
2012	358,043	528,972
2013	335,811	524,797
2014	318,714	518,051
2015	313,313	506,367

5 Education

5.1 General figures

The last time the educational structure of the Bulgarian population was assessed was in 2011 during the National census; this structure is represented in Figure 15. According to the Census' results, 71.6% of urban and 40.3% of rural population have at least secondary education; 81,000 or 1.2% of the population aged 7 or more have never attended school; 112,778 people are illiterate[39]. In the recent years the net enrolment rate in universities has been increasing, the trend coinciding with the increased number of universities in Bulgaria (Figure 18).

5.2 Higher science and engineering education

The main education fields related to nuclear knowledge's acquisition, preservation, and transfer are science

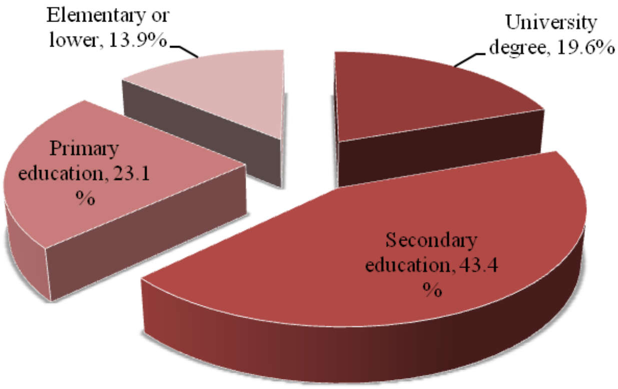

Figure 15. Bulgarian population's educational structure as of 2011 [39].

(physics, chemistry, mathematics) and engineering. With regards to the number of students enrolled in science and engineering programmes, an alarming trend is observed. Bulgarian higher education is divided in 9 broad domains that include a total of 52 professional fields. In 2105 45% of all enrolled students are pursuing a degree in a single domain – "Social, economic, and legal studies". Moreover, a third of all students are enrolled in programmes in only two professional fields – "Economics" and "Business administration and management" [40]. Furthermore, there is a clear downward tendency in the shares of undergraduates and master's in science and engineering of the total number of students (Figure 16, Figure 17). The downward trend could be observed in nominal terms as well, albeit less explicitly (Table 5). That is accompanied with increased number of universities and augmenting net enrolment rate (Figure 18), which means that fewer students choose to pursue a degree in science or engineering. The only upward trend is in the number of students enrolled in programmes in informatics. On the other hand, the increased number of universities and colleges, combined with high numbers of students enrolled in programmes outside science and engineering means that the majors in

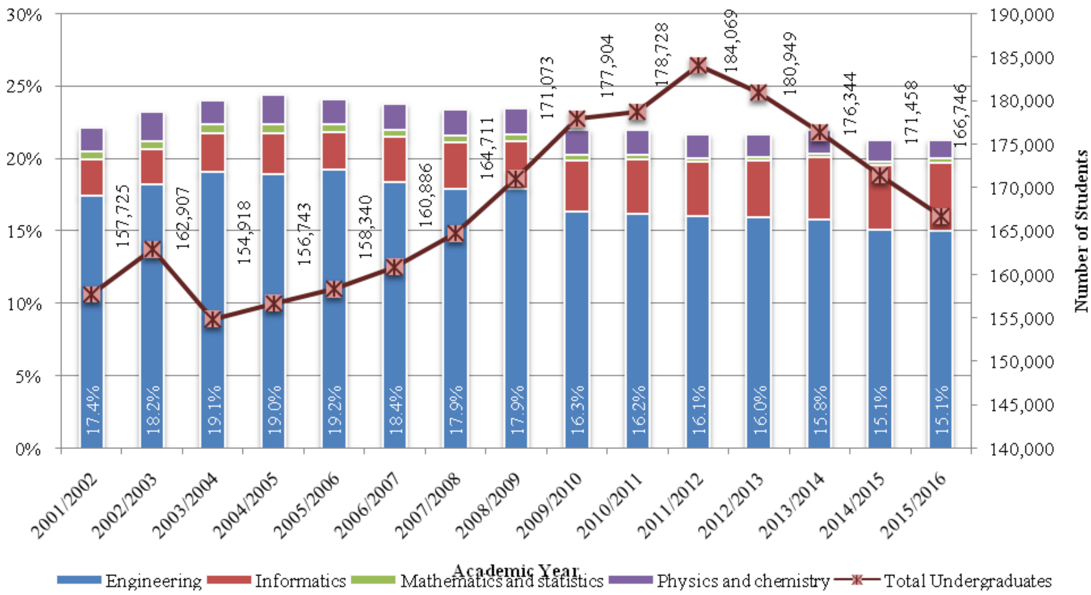

Figure 16. Total number of undergraduates and shares of the undergraduates enrolled in science and engineering programmes for the last 15 academic years [36].

Table 5. Number of enrolled students by scientific field and degree [36]

Academic year	Undergraduates: Physics and chemistry	Undergraduates: Mathematics and statistics	Undergraduates: Informatics	Undergraduates: Engineering	Master's: Physics and chemistry	Master's: Mathematics and statistics	Master's: Informatics	Master's: Engineering
2001/2002	2,640	909	3,966	27,460	726	187	685	8,984
2002/2003	3,297	895	4,037	29,639	302	55	656	6,073
2003/2004	2,563	909	4,225	29,521	494	120	678	5,704
2004/2005	3,148	950	4,418	29,725	626	85	892	5,624
2005/2006	2,652	877	4,168	30,422	675	111	1,032	5,665
2006/2007	2,782	760	5,026	29,636	730	128	1,308	6,305
2007/2008	2,859	779	5,294	29,540	615	125	1,187	6,740
2008/2009	3,025	767	5,632	30,697	622	105	1,167	6,619
2009/2010	3,115	667	6,325	29,039	580	132	1,283	6,840
2010/2011	3,043	578	6,747	28,879	704	127	1,429	6,838
2011/2012	2,990	492	6,864	29,565	789	98	1,515	7,231
2012/2013	2,841	443	7,067	28,932	754	93	1,677	7,142
2013/2014	2,914	405	7,556	27,852	850	78	1,661	7,511
2014/2015	2,621	399	7,591	25,939	839	84	1,693	7,403
2015/2016	2,179	417	7,822	25,098	677	71	1,659	6,651

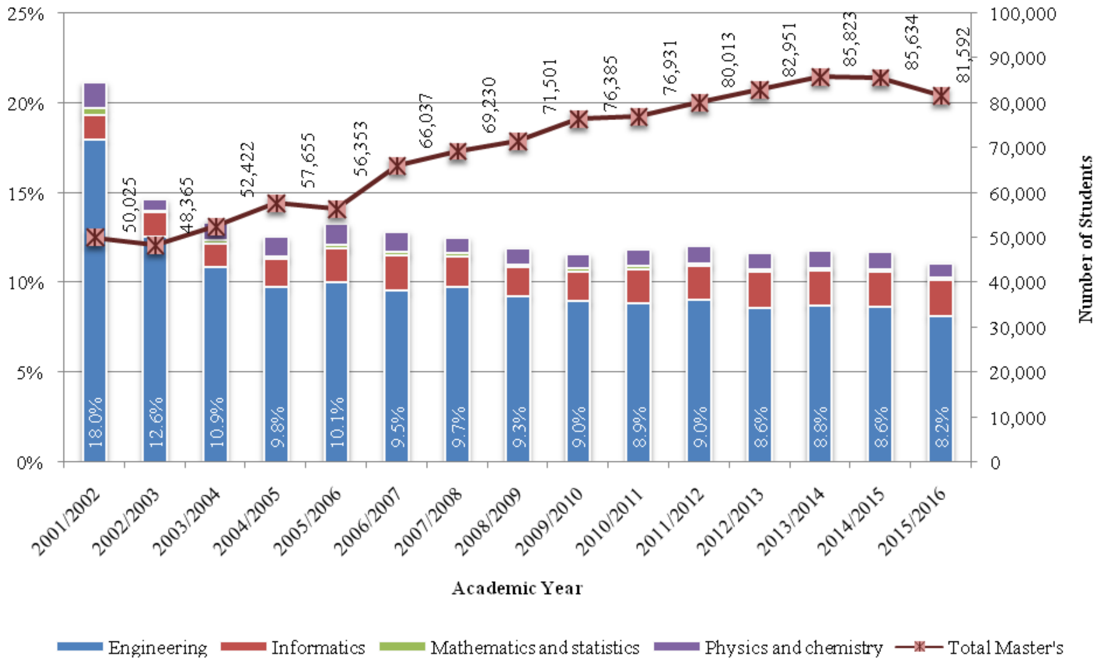

Figure 17. Total number of master's and shares of the students enrolled in master's programmes in science and engineering for the last 15 academic years [36].

those institutions are also outside science and engineering, most likely in economics and management, given the numbers presented by Rakovska [40]. The sharp decrease of the total number of undergraduates (Figure 16) and the plateau in the number of master's students (Figure 17) alongside increased enrolment rate implicitly shows the decrease in numbers of the younger population.

On the other hand, there's been a sustainable increase in the number of PhD students and PhDs awarded in science and engineering for the past few years (Figure 19, Figure 20). However, in the past two years the numbers plateaued and the future trend is unknown. On the other hand, the share of PhD students in science and engineering has been steadily decreasing since 2006/2007 academic year (Figure 21), this tendency being natural consequence caused by the trends in undergraduate and master's studies. The number of PhDs is important since this is the human resource base that is needed to support higher education and research and development activities in science and engineering, and in nuclear-related fields in this particular case. Decreasing share of these students implies risks for the future development of academia and R&D activities, and also suggests knowledge transfer and retention risks in universities and research facilities and institutions.

5.3 Qualitative assessment

Information about education's quality and relevancy could be extracted from the skills acquired by the students in

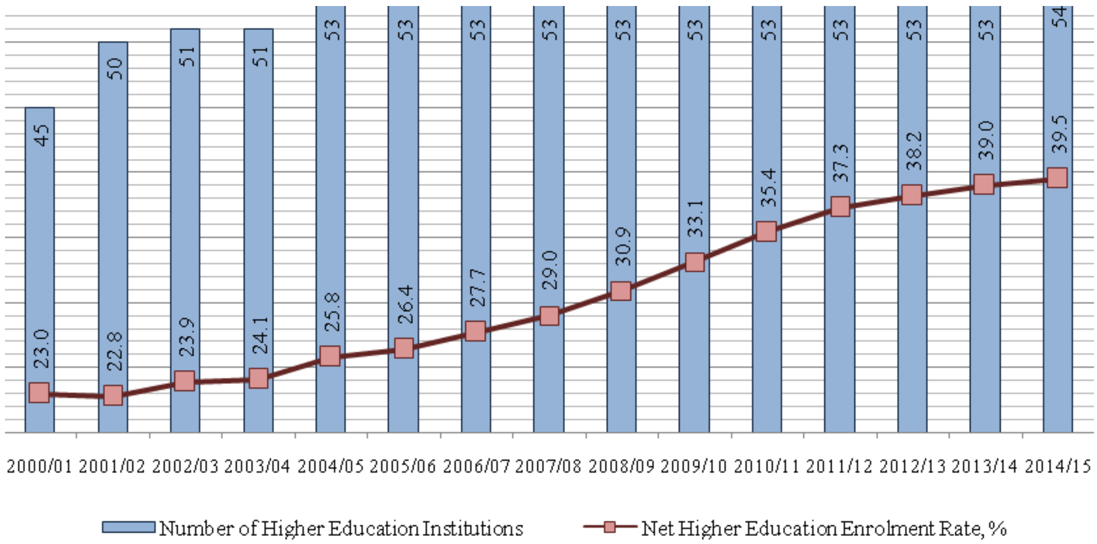

Figure 18. Net University Enrolment Rate and Number of Higher Education Institutions in Bulgaria [36].

each stage of their education and training and the ability of applying them. Such types of studies are undertaken by the OECD in its regular studies "Program for International Student Assessment" (PISA). During these studies the ability of 15-year olds to apply practically their skills in reading, mathematics, and sciences is assessed [41-45]. Bulgarian students' results and an OECD average are illustrated in Figure 22. There are no data for 2003 because then the survey wasn't able to gather enough statistically significant information about Bulgaria [45].

The presented results are indicatory – not only hasn't been there any progress for the period 2000-2012 but actually there was a drop in students' ability to interpret texts and apply what they've learnt in problem solving. The results of Bulgarian schoolchildren are considerably lower than OECD average results. There's a recovery tendency but the results show lower ability to understand and apply information, *i.e.* lower ability to gather, process, interpret, and apply data, turning it into knowledge and skills. The inability is particularly evident in reading; in other words Bulgarian schoolchildren are less able to acquire new knowledge in comparison with their OECD counterparts. A difference of 40 points shows a difference in skills' levels of one year of study. That means that in 2012 Bulgarian school children lagged 1.5 years in reading skills and almost 1.4 years in mathematics and science skills behind the average OECD schoolchild. It is worthwhile noting that these schoolchildren are the people that have been entering universities and the labour market since 2003. What is revealed by PISA studies is that Bulgarian educational

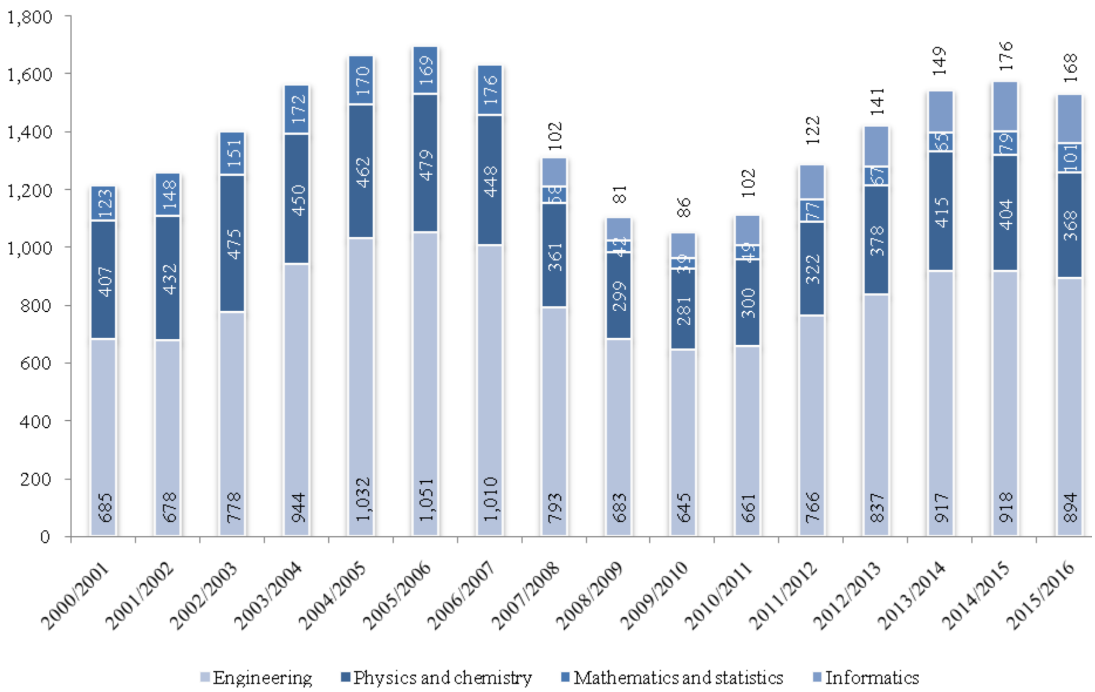

Figure 19. Number of PhD students by scientific domain [36].

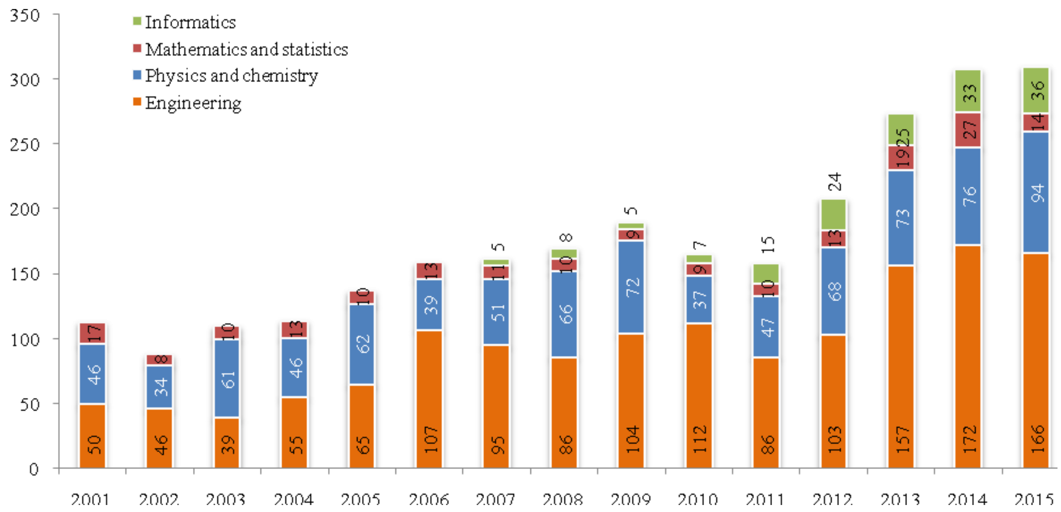

Figure 20. Number of awarded PhD degrees by scientific domain [36].

system struggles in giving the students in secondary education skills and abilities that would be necessary in obtaining a university degree and being employed as a skilled worker or employee.

Other indicator for education's quality is the match between labour market skills requirements and workforce's skills. An inadequacy of the workers' skills is suggested in Ref. [46]. This study reports that around a fifth of the workers in Bulgaria perceive they're overqualified for their job while almost half of the employers report skill shortage and difficulties in filling jobs. The worker-reported skill mismatch in Bulgaria is relatively low, while, on the opposite, the employer-reported skill shortage is high. The study suggests that a reason for this discrepancy might be that the education doesn't provide the level of skills and competencies that is sought by the labour market. These results also imply certain lack of adequate self-assessment among large share of country's workforce.

5.4 Domains at risk

Analyses, based on the indicators used by the National university ranking system, declare that the highest human resources demand increase would be in medicine, armed forces, computer science, resource exploration, electrical engineering, mechanical engineering, power engineering, chemical engineering, and materials science [40]. This study also states that the the most endangered by the demographic processes fields are education, medicine, natural sciences, engineering, mathematics, and informatics. All of these fields are related to nuclear knowledge preservation; some of them – education, engineering, natural sciences, and mathematics – contain core nuclear knowledge.

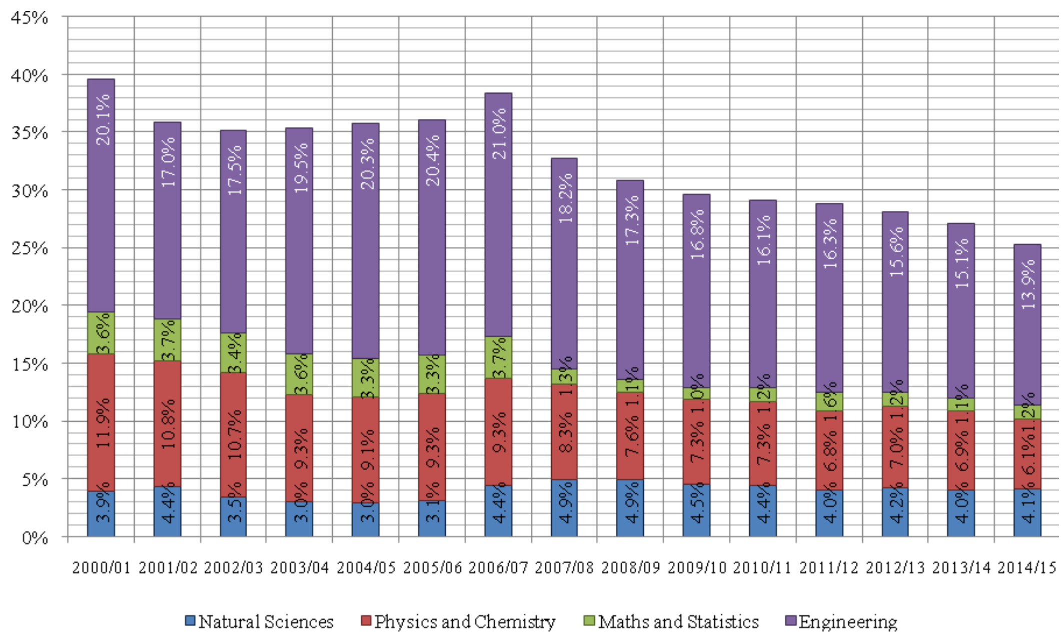

Figure 21. Percentage of PhD students in science and engineering of total PhD students, calculation based on NSI's data.

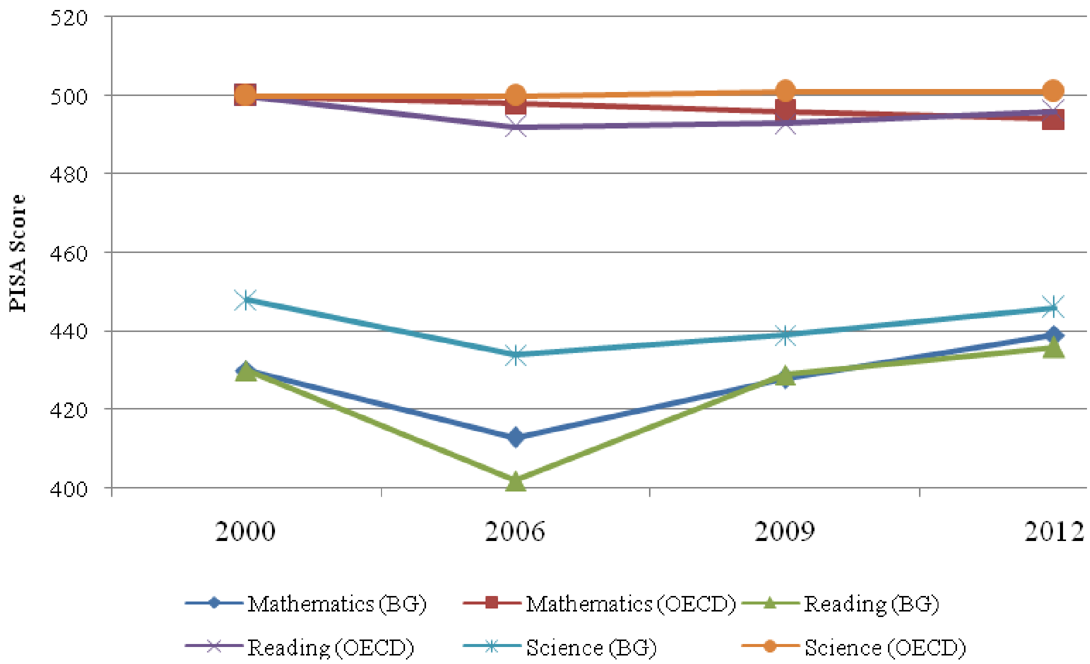

Figure 22. National scores in PISA assessments [41-44].

6 Conclusions

Based on the analysis and data presented in this paper, the following conclusions could be formulated:

- Bulgaria has significant scientific and operational knowledge, related to nuclear power plants operation and radioactive waste management;
- Nuclear knowledge retention, transfer, and expansion is crucial for the country for several reasons:
  - Nuclear power has the potential to play further role in Bulgarian power system;
  - There are significant amounts of radioactive waste and spent fuel that need to be managed;
  - New nuclear facilities in the back end of the fuel cycle must be designed, constructed, and operated;
  - The on-going decommissioning of units 1-4 at Kozloduy NPP site need to be supported and led to a successful end;
  - Even in worst-case scenario (no new nuclear build and future decommissioning of current capacity) significant human resources capacity and nuclear knowledge would be needed to manage the decommissioning process;
- A plethora of negative demographic trends exists; most importantly rapid diminishing and ageing of the population;
- Ariskof workforce shrinkage occurs;
- The amount of students in natural sciences and engineering decreases in both relative and nominal terms;
- Evidence for declining education quality is present.

The presented overview of external factors influencing nuclear knowledge loss risk identified several converging negative tendencies that threaten the preservation, transfer, and expansion of nuclear knowledge on national level. Therefore, the status quo in nuclear education and nuclear workforce in Bulgaria should be evaluated, nuclear knowledge risk assessment should be conducted, and strategies for knowledge retention and transfer need to be outlined. All of these investigations are within the scope of the current study and will be presented in future papers.

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