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The Economics
of the Russian Nuclear Power Industry

Leonid Andreev

BELLONA

…Nuclear power generation is the only available alternative to oil and gas…
All other ideas are just for fun now.
Russian Prime Minister Vladimir Putin

Whatever is only almost true is quite false and among the most dangerous of errors.
Henry Ward Beecher (1813-1887),
American clergyman, social reformer, and abolitionist.

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Translator's notes:

Rules of etiquette established for official documents and literature sources require in Russian the use of initials standing for a person's given name and patronymic before or after the last name. Due to these peculiarities of usage, some of the sources cited in this report will be rendered in such way where the given name of the person in question is not available. A full name will be stated otherwise using standard transliteration rules.

For the reader's convenience, non-English titles of sources cited in this report are stated in their English translations followed by original titles rendered with standard transliteration rules (where the original is in Russian).

Letter and letter-numerical combinations used in original Russian designations – such as those of government documents, reactor models, and the like – are likewise rendered into English using simple Russian-to-English transliteration rules, unless common translated abbreviations exist as English equivalents.

Contents

Foreword

The economy of the Russian nuclear energy industry is the least known and most opaque of all the many facets that make up the vast dominion that is the Russian State Atomic Energy Corporation Rosatom. There is, today, plenty to learn about the environmental, technological, safety, and other aspects of Rosatom's operations – but economic information, if it is revealed at all, is only made available in relative figures and general data whose accuracy it is impossible to verify.

Still, many experts have made attempts lately to understand and estimate just how much exactly generating electricity from nuclear sources comes to, what it costs the Russian state budget – i.e. the Russian taxpayers – to build new nuclear power plants, including those built by Russia abroad, how big the spending is on managing spent nuclear fuel and radioactive waste, and, ultimately, if it is even worth it to invest billions of dollars into developing an industry that is hardly a cure-all for existing energy woes but instead carries with it an enormous potential threat of killing everything alive on the planet.

The economics of Rosatom's varied activities has become a topic of interest not just to the public – the ordinary taxpaying citizens, that is – but the Russian financial oversight agencies as well. For instance, one of the reasons that the newly minted draft law "On Management of Radioactive Waste" has not yet been passed, even as it remained on the legislators' tables all throughout 2010, is the ambiguities in the economic concept of the waste management system the new law was supposed to establish. The Ministry of Finance of the Russian Federation is yet to work out a definitive position with regard to what sort of expenses the state budget will bear in order to dispose of the radioactive legacy Russia has inherited from the Soviet Union and if the system suggested by the bill – the idea that the management of radioactive waste will be the responsibility of those who produce it – will prove economically effective.

Whichever provisions have been approved in those regulatory and legislative documents that have been adopted since the State Corporation Rosatom was established – starting with the Law "On the State Atomic Energy Corporation Rosatom" – and that have to do with the nuclear authority's economic activities have, as a rule, been such as to cater to the interests of Rosatom itself, rather than the public or even the Russian state. For instance, a passage in the Law "On the State Corporation Rosatom" stipulates that the Accounts Chamber of the Russian Federation – the federal body with a mandate to exercise oversight over fulfilment of the federal budget – can only perform external control over the corporation's activities. As for the audits of Rosatom's internal financial and economic operations, the efficiency of spending government-allocated financial resources or those held in special reserve funds, and other aspects – those are carried out by Rosatom's own Audit Committee. The public has a stake in knowing how much money has been accumulated on the accounts of special reserve funds that are maintained in order to finance decommissioning of old nuclear power plants and management of radioactive waste, but that, alas, is restricted information.

Rosatom and its daughter enterprises keep to a bare minimum what financial information they disclose in reports made available for public access or during events such as public discussions or so-called forum dialogues. If questions are asked during such events – for instance, how much does reprocessing of one tonne of spent nuclear fuel cost? – the answer, as a rule, is: This is commercial secret.

By adopting its financial reporting policy, Rosatom took upon itself the obligation to disclose, in annual reports made available for the public, the results and efficiency of spending funds disbursed from the state budget and other sources. But though they are posted on Rosatom's website, these reports say almost nothing on the industry's economy save for some general references or percentage figures which impart information of little practical use.

All of the above would indicate that everything is not as hunky-dory as the upper management's cheerful reports would have it – something that is furthermore confirmed by many expert studies both in Russia and abroad.

The present report offers some estimates of the levels of expenses the Russian nuclear industry bears in its operations and some arguments that explain why nuclear energy is a loss-making industry today. But the main purpose of this report is to initiate a broader discussion of nuclear energy economics in expert circles and the public domain alike in order to work out a better understanding of whether developing nuclear energy and committing enormous financial resources to this end is ultimately in the public's interest.

We are thankful to experts from Greenpeace and all the experts of the international environmental foundation Bellona for their generous contributions to this report. We will also appreciate feedback and comments with regard to the issues examined in this report and will welcome suggestions about how we could further improve and elaborate our study.

Introduction

The price that the public pays for its nuclear energy industry is fundamentally essential to a discussion of the industry's development prospects. The low cost of power and heat produced by the Russian nuclear power plants is the most important – and basically the only – argument used to justify the existence and development of this energy source. This is also what is disputed by experts who hold an unfavourable view of the atomic industry.

The situation in Russia resembles in many ways the debate that has formed in other countries with similar power industry structure and history – such as the United States, Germany, or France – and apparently, the same arguments are forwarded by both camps.

Russia's case, however, is rendered all the more specific by the problems that are particular to the Russian military complex and the economy that remains heavily influenced or supported by the state, as well as the peculiarities of economic relations within the Russian construction industry.

The purpose of this report is to make an assessment of the level of costs of the nuclear industry as expressed in the minimal electricity tariff that would enable it to effect profit.

To achieve this, we will analyse an assumed project of a new nuclear power plant of Model Project NPP-2006[1] with reactors of the type VVER-1200[2] and VVER-1000 that Rosatom continues to build in Russia and abroad. Capital and operating costs will be estimated as they apply to this project. Out of the possible range of realistic assumptions and estimates of calculation parameters, those that reflect the most optimistic economic scenario for the nuclear energy industry will be used; otherwise, data from official industry sources will be used where available.

This report will be based on a so-called full cost accounting concept – a method that will distinguish between the costs of the nuclear power industry and the costs (or expenses) borne by market participants. We have attempted to calculate all economically justified expenses – i.e. the price

[1] For more information about this project (dubbed AES-2006, in its Russian acronym), please see this page on the website of the Russian nuclear power plant operator company Concern Rosenergoatom: http://rosenergoatom.ru/wps/wcm/connect/rosenergoatom/site_en/about/development/npp_2006/. – Translator.

[2] VVER (from Russian, *vodo-vodyanoi energeticheskii reaktor*) is a pressurised water reactor (PWR) series developed in the USSR and Russia. VVERs come with power output capacities ranging between 440 megawatts and 1,200 megawatts. – Translator.

of everything that the nuclear power industry needs for its operations for reasons of either the technologies used or the legislation in force. The calculations thus include the expenses that the industry itself does not pay or does not pay in full – but that are in fact covered by someone else (society as a whole, the federal budget, etc.). At the same time, we exclude those expenses that the industry does pay but could very well avoid. For instance, we do not factor in the expenses incurred by reprocessing spent nuclear fuel, but we do include expenses associated with insuring nuclear risks. To the extent it has been possible, the issue of who pays for what is treated separately from that of how necessary and how big the expenses are.

The expenses incurred by maintaining the nuclear fuel cycle infrastructure have been calculated as regular deductions spaced out over the entire period of our model nuclear power plant's operation.

The report is structured as follows. We have compiled and examined data on various categories of expenses as well as on aspects that are not immediately connected to, but have a bearing on, the operation of the nuclear energy industry. The concluding section of the report offers a total expense calculation: Our tentative expense estimates were put together and discounted to the first period, and then net cash flows were calculated that would be sufficient to recoup these expenses, as well as the corresponding electricity price.

1. Capital costs

Nuclear energy is an extremely capital-intensive industry. Among all energy production sectors, it has the biggest share of construction costs in the total investment costs, and the issue of the industry's economic viability is essentially the issue of how much it costs to build a nuclear power plant.

The ability of a nuclear energy project to bring return on investments is very sensitive to the chosen parameters of the envisioned construction – the total cost, construction time frames, and the terms of financing. **Projects attempted in the nuclear energy sector require enormous investments and cannot be carried out today without some form of state support.**

That said, data on actual expenses are few and far between. Companies often decline to reveal such information, citing commercial secret, while what information is available in published sources is not always reliable. The costs of building a nuclear power plant are commonly estimated by way of expert assessments, and these estimates differ greatly from one another – something that can also be accounted for by the specificity of each individual project. Furthermore, the costs of building new power stations have been rising significantly over the past twenty years, and the real costs prove very frequently to be in excess of those projected at the start of construction.

For instance, a nuclear power economics study done by the Massachusetts Institute of Technology in 2003 cited a construction cost of $2,000 per kilowatt,[3] while the 2009 update to the initial 2003 report said that "since 2003 construction costs for all types of large-scale engineered projects have escalated dramatically. The estimated cost of constructing a nuclear power plant has increased at a rate of 15 percent per year…" The adjusted capital cost estimate, as per the 2009 update, was $4,000 per kilowatt[4], or $4 billion per gigawatt.

The increase in costs has to do with rising costs across the board in the construction industry, stricter regulatory requirements imposed on the nuclear industry, as well as a shrinking equipment

[3] The Future of Nuclear Power, an interdisciplinary MIT study. MIT, 2003. The full report is available at http://web.mit.edu/nuclearpower/pdf/nuclearpower-full.pdf.
[4] Update of the MIT 2003 Future of Nuclear Power Study. MIT, 2009. The update is available at http://web.mit.edu/nuclearpower/pdf/nuclearpower-update2009.pdf.

production market, where the volume of orders has fallen in the post-Chernobyl period, while prices have, on the contrary, gone up.

These considerations compel a measure of caution when viewing data on new power plant projects as well as those that have been built in the recent past. Shown below are some figures that help forecast costs of new nuclear power plant construction.

Second Line of Construction at Balakovo NPP[5], project developed in 2004[6]

As stated in the project documentation, the total cost of engineering works at the site is RUR 1,602,375,650 in early 1991 prices ($56,538,900). According to the Russian Federal State Statistics Service, consumer prices rose by 54,491.20 times[7] between December 1990 and December 2009, which gives us RUR 87,315,366,620 as of end 2009, or $2,925,226,110 – or $1.4 billion per gigawatt of installed capacity. There is no doubt that this figure is underestimated by the project designers and calculated with a downward shift, not to mention seriously outdated in light of increases in construction costs in recent years.

Firstly, the consumer price index is hardly the indicator to reflect correctly the actual price increases for those commodity groups that have a relevance to the construction industry. For instance, the average price of cement has risen in the past seven years by 7.48 times – from RUR 750.33 to RUR 5,615.02 for one tonne[8] – while the consumer price index has only risen by 2.31 times over the same period.

Secondly, not all the costs estimated in the project were calculated in 1991 prices. The initial operating funds of RUR 108.2 per one power unit were computed based on the 1989 price list released by the State Committee on Prices[9] of what was then the Soviet Union. Meanwhile, wholesale prices for fuel assemblies, control rods, fuel channels etc. have, of course, risen at a far greater pace than the consumer price index.

Baltic NPP,[10] a more recent project.

Baltic NPP's Reactor Unit 1 is slated to come online in 2016, with a second power unit commissioned in 2018. The plant, with a total installed capacity of 2,300 megawatts, will cost around EUR 5 billion (RUR 194 billion for two 1,150-megawatt power units) – or around $2.811 billion per gigawatt of installed capacity[11]. Furthermore, a number of power installations will have to be built in addition to the NPP proper, and the cost of that infrastructure may vary wildly between EUR 500 million and EUR 1.6 billion.[12]

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[5] Balakovo NPP is located in Saratov Region, South European Russia. For more information, please see Bellona's coverage at http://www.bellona.org/subjects/1140452665.16 and the plant's page on the operator company's website at http://www.balnpp.rosenergoatom.ru/wps/wcm/connect/rosenergoatom/balnpp_en/. – Translator.

[6] Balakovo NPP. Project of Second Line of Construction. Moscow, 2004. (Balakovskaya AES. Proyekt na stroitelstvo vtoroi ocheredi. M., 2004).

[7] In August 1997, the Russian rouble was denominated by a factor of 1,000: What was earlier 1,000 roubles became RUR 1. The resulting figures in this paragraph are correspondingly divided by 1,000.

[8] From publications in the St. Petersburg-based construction business weekly Stroika SPb (http://www.dp.stroit.ru/group/now/39/21235.html, in Russian).

[9] The committee, which regulated prices across all commodity groups of the Soviet state-planned economy, ceased to exist in 1991, when the USSR disintegrated and Russia became an independent state.

[10] The plant is being built in Russia's westernmost enclave of Kaliningrad Region. For more information, please see Bellona's coverage (http://www.bellona.org/site_search?query%3Austring%3Autf-8=baltic+nuclear+power+plant) or visit the plant's page on Rosenergoatom's website (old version) at http://old.baltnpp.rosenergoatom.ru/eng/index.wbp. – Translator.

[11] Baltic NPP: the Exclave Station, news article, AtomInfo.Ru, September 2, 2010. (Baltiiskaya AES – Eksklavnaya stantsiya, AtomInfo.Ru, 02.09.2010, http://www.atominfo.ru/news3/c0008.htm, in Russian).

[12] The necessity to build high-voltage power lines to export surplus energy produced by Baltic NPP is a consequence of the decision made to cover the increased energy needs of the region by building this nuclear

Real costs of nuclear power plants under construction today or completed recently.

These are almost always greater than estimates calculated at the start of construction. Furthermore, construction costs keep growing rapidly. For instance, in October 2006, the cost of building one standard power unit with a reactor of the VVER-1000 series was $2.3 billion, counting inflation calculated for the entire construction period.[13] However, according to the St. Petersburg-based news agency PRoAtom.Ru, Reactor Unit 3 of Kalinin NPP[14] and Reactor Unit 2 of Rostov (Volgodonsk) NPP[15] each cost over $4 billion.[16]

The estimated cost of remaining works at Reactor Unit 5 of Kursk NPP,[17] which had been completed to 70 percent when construction ground to a halt in the early 2000s, was over RUR 47 billion ($1.56 billion); that makes over $5 billion per kilowatt in total construction costs.

Total construction costs are impacted both by the rising costs of items on the expenditure list and delays in construction. For instance, the estimated costs of the second line of construction at Leningrad NPP[18] (Leningrad NPP II) doubled in 2009 alone, according to prices as per the renegotiated contracts. Likewise, the cost of completing Unit 4 of Kalinin NPP is almost double that of the initial estimates. Commissioning deadlines have been pushed back by three or four years at the least for the second units of both Leningrad NPP II and Novovoronezh NPP II.[19] These delays will increase the construction costs of both units by a minimum of 20 percent.[20]

Speaking with the news agency PRoAtom.Ru in 2010, Bulat Nigmatulin, former Minister of Atomic Energy and now first deputy director of the Moscow-based Institute of Natural Monopoly Problems, said: "With regard to completing Unit 2 of Rostov NPP – the "paired" one, which is 20 percent cheaper than a new odd-numbered one – the cost of one kilowatt of installed capacity [was] $4,000 in prices re-calculated for the resumed construction (construction works were resumed in 2005[21]; overall

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power plant. Thus, the cost of power line construction should probably be added to the capital cost of the plant itself.

[13] Federal Target Programme "Development of the Russian Nuclear Energy Industry in 2007 to 2010 and Development Prospects to 2015." (http://fcp.vpk.ru/cgi-bin/cis/fcp.cgi/Fcp/ViewFcp/View/2008/227/, in Russian).

[14] Kalinin NPP is located some 200 kilometres northwest of Moscow, in Tver Region in Central European Russia. For more information, please see Rosenergoatom's page at http://www.knpp.rosenergoatom.ru/wps/wcm/connect/rosenergoatom/knpp_en/ and Bellona's coverage at http://www.bellona.org/subjects/1140452716.22. – Translator.

[15] Rostov (Volgodonsk) NPP is located on the Don River in Rostov Region, Southern Russia. For more information, please see Rosenergoatom's page at http://www.vnpp.rosenergoatom.ru/wps/wcm/connect/rosenergoatom/vnpp_en/ and Bellona's coverage at http://www.bellona.org/subjects/1140452976.81. – Translator.

[16] "To distinguish defeat from victory," an open letter by Bulat Nigmatulin, first deputy director of the Institute of Natural Monopoly Problems, to Rosatom head Sergei Kiriyenko, March 29, 2010, PRoAtom.Ru (Otlichat porazheniye ot pobedy, 29.03.2010, PRoAtom.Ru, http://www.proatom.ru/modules.php?name=News&file=article&sid=2252, in Russian).

[17] Kursk NPP is in Kursk Region in Western Russia. Construction of Unit 5 of the plant was halted and resumed a number of times since it began in 1985. For more information, please see Rosenergoatom's page at http://www.kunpp.rosenergoatom.ru/wps/wcm/connect/rosenergoatom/kunpp_en/ and Bellona's coverage at http://www.bellona.org/subjects/1140452778.25. – Translator.

[18] Leningrad NPP is located in the town of Sosnovy Bor near St. Petersburg. For more information, please see Rosenergoatom's page at http://www.lennpp.rosenergoatom.ru/wps/wcm/connect/rosenergoatom/lennpp_en/ and Bellona's coverage at http://www.bellona.org/subjects/1140452784.53. – Translator.

[19] Novovoronezh NPP is in Voronezh Region, Central European Russia. A second line of construction is under way at the site, with the start of commercial operation planned for 2012. For more information, please see Bellona's coverage at http://www.bellona.org/subjects/1140452957.64 or Rosenergoatom's page at http://www.novnpp.rosenergoatom.ru/wps/wcm/connect/rosenergoatom/novnpp_en/. – Translator.

[20] See Footnote 16.

[21] Initial construction was started on Unit 2 of Rostov NPP in 1983. The unit was completed in 2009 and commissioned for commercial operation in December 2010. – Translator.

completion rate, including the equipment available in the storehouse, is no lower than 35 percent; the completion cost is around RUR 75 billion, plus 10 percent on account of it being an even-numbed unit). The costs of new construction at the sites of Novovoronezh NPP II and Leningrad NPP II are even higher. At that, construction time frames are only getting extended further, which is evidenced by the examples of these units."[22]

It is quite possible that nuclear construction is unjustifiably overpriced owing to ubiquitous corruption,[23] a problem prevalent in all Russian industries as well as bodies of government. According to Nigmatulin, corruption would account for no less than 40 percent of total costs. **Clearly, corruption results not just in growing project costs, but also in an inferior quality of construction materials used at the site and a less-than-desirable level of compliance with construction guidelines.** Nuclear construction is a field where very strict requirements must be imposed with regard to the qualifications and skills of the workforce engaged in the project, but in today's Russia, the majority of labourers building nuclear energy sites are unskilled migrant workers from Central Asia. From the economic point of view, this could well lead to an increase in future maintenance costs for the plant and a shorter service life on the whole.[24]

That actual construction costs exceed those projected at the outset is often called an extraordinary situation and assurances are heard that as construction experience accumulates and new nuclear construction sites become more uniform across the industry, costs will decrease accordingly. The reality, however, is yet to offer any evidence to support such claims.

Estimated costs of building NPPs for export.

The costs of nuclear construction projects implemented by Rosatom abroad are noticeably higher than in domestic projects – and thus may in fact be closer to the real expenses incurred. For instance, the price of the project Russia has negotiated to build in Turkey's Akkuyu was last year cited at over $5 billion per one 1.15-gigawatt power unit.[25]

In Belarus, Rosatom's export construction wing, Atomstroiexport, has landed a contract to build between 2011 and 2015 a nuclear power plant operating two VVER-type reactors in power units with a combined capacity of 2,400 megawatts.[26] According to a document entitled "Belarus's Strategy for

[22] Passing off ideas as facts, plans as results, and words as deeds, interview with Bulat Nigmatulin, November 22, 2010, PRoAtom.Ru. (Zamysel vydayotsya za fakt, plan za rezultat, slovo za delo. 22.11.2010, ProAtom.Ru, www.proatom.ru/modules.php?name=News&file=article&sid=2660, in Russian).

[23] Yegor Mityukhin. Corruption in Rosatom: Grand larceny at Novovoronezh NPP II construction site, news article, December 23, 2009, PRoAtom.Ru. (Mityukhin Ye. Korruptsiya v Rosatome: Masshtabniye khishcheniya pri stroitelstve Novovoronezhskoi AES-2, 23.12.2009, PRoAtom.Ru, www.proatom.ru/modules.php?name=News&file=article&sid=2106, in Russian).

[24] The US is currently implementing a programme by which the operational lifetimes of nuclear power plants that have been in operation for nearly 60 years will be extended by another 20 years. A sufficient level of reliability of the main structural components that are not subject to replacement must be shown as the necessary condition to obtain an extension on the existing operational license. Because the removable power production equipment is regularly upgraded in the course of operation, it is only the wear and tear – the fatigue – of the materials used to build the plant that does not allow an NPP to stay in operation forever. See, for instance: Nuclear power plants get to be 20 years older, news article. Aftenposten, November 11, 2010. (Atomkraftverk får bli 20 år eldre, Aftenposten, 22.11.2010, www.aftenposten.no/nyheter/uriks/article3914773.ece, in Norwegian).

[25] Energy Minister Shmatko: Russian Federation, Turkey agree on NPP construction terms, news article. RIA Novosti, May 8, 2010. (RF i Turtsiya soglasovali vse usloviya stroitelstva AES, RIA Novosti, 08.05.2010, http://www.rian.ru/economy/20100508/232023678.html, in Russian).

[26] The highly unpopular project to be carried out by Russia in Belarus's Ostrovets, Grodno Region, has faced both vigorous opposition from Russian and Belarusian environmentalists and official objections from neighbouring countries, such as Austria and Lithuania (the plant is to be built only some fifty kilometres away from the Lithuanian capital, Vilnius). A preliminary deal on the project in Ostrovets (where initial construction works at the site had already started) was reached between the Russian and Belarusian governments in early 2011, followed by

Energy Potential Development," adopted by Decree No. 1180 issued by the country's Council of Ministers, the new Belarusian NPP will cost $9.334 billion,[27] or $3.9 billion per gigawatt.

To sum up, if we take Russian NPP construction costs to be between $3 billion and $4 billion per gigawatt, this level would roughly correspond to the costs of building nuclear power plants in Western countries with developed nuclear energy – while being far greater than construction costs in, say, China.

Yet, for the purposes of further analysis in this report, we will assume the price of $5 billion for two reactor units of the type VVER-1200 to be the minimal construction cost, as the figure announced officially for the project of Baltic NPP in Kaliningrad.

2. Financing construction of new nuclear capacities

Building new energy-generating reactor units in Russia is done in accordance with the "Programme of State Corporation Rosatom's Long-Term Activities for the Period of 2009 to 2015," authorised by the Government of the Russian Federation in its Decree No. 705 of September 20, 2008, Energy Section, Focus Area 3, "Development of the Nuclear Energy Industry of Russia." Another document that governs domestic nuclear construction in Russia is the "General Layout Plan for Siting Power Generation Sites for the Period until 2020," approved by Decree No.215-r of February 2, 2008, by the Government of the Russian Federation.

Construction is paid for out of the State Atomic Energy Corporation Rosatom's own funds as well as funds allocated from the federal budget that are transferred onto the corporation's accounts as "asset contributions" to the development of the country's nuclear energy complex. The respective shares of these funds in Rosatom's annual construction budget are shown in Table 1.

Table 1. Funding sources used to finance construction of new nuclear power capacities in Russia (in million roubles).

Year	Funds from the state federal budget	Capital investments made with funds provided by Rosatom-affiliated entities	Total	Share of federal budget funds
2009	87,430.0	103,428.1	190,858.1	46 percent
2010	96,829.4	122,471.8	219,301.2	44 percent
2011	113,020.0	138,398.9	251,418.9	45 percent
2012	118,803.6	154,964.6	273,768.2	43 percent
2013	90,817.2	173,488.8	264,306.0	34 percent
2014	58,752.0	185,922.9	244,674.9	24 percent
2015	40,042.3	204,944.3	244,986.6	16 percent
Total	605,694.5	1,083,619.4	1,689,313.9	36 percent

The Federal Target Programme "Development of the Russian Nuclear Energy Industry in 2007 to 2010 and Development Prospects to 2015" envisions building in Russia ten new power units with VVER-

an intergovernmental cooperation agreement signed in March 2011 ((the first reactor is slated for launch in 2016). For more information, please see Bellona's extended coverage at http://bellona.org/bellona.org/site_search?query%3Austring%3Autf8=ostrovets. – Translator.

[27] Belarus pegs total NPP cost at $9.3 billion, news article. Newsland, August 24, 2010. (Belarus otsenivayet summarnuyu stoimost AES v $9.3 mlrd, Newsland, 24.08.2010, http://www.newsland.ru/news/detail/id/550017/cat/86, in Russian).

type reactors having a combined installed power-generating capacity of no less than 9.8 gigawatts. These are:

- Novovoronezh NPP II, Reactor Units 1 and 2
- Leningrad NPP II, Reactor Units 1, 2, 3, and 4
- Kursk NPP II, Reactor Units 1 and 2
- Rostov NPP, Reactor Units 3 and 4

However, at the end of 2010, Rosatom head Sergei Kiriyenko announced that the corporation's domestic construction programme would have to be revised owing to the additional construction contracts Rosatom had concluded with customers abroad. The new plans envisage building annually one reactor unit instead of two until 2015.

New reactors are to be built at the expense of the Russian federal budget and reserve development funds held in accounts of the national NPP operator company, Concern Rosenergoatom.

It is presumed that new nuclear power plants are also financed out of both these sources. For instance, according to Rosenergoatom, construction works at Novovoronezh NPP II were financed in 2008 with RUR 17.956 billion out of the federal budget and RUR 680.9 million from Rosenergoatom's reserve development funds. Of these, RUR 13.0707 billion was spent on Unit 1 and RUR 5.5662 billion on Unit 2, respectively.

Because the domestic construction programme is already now barely moving along, the amounts allocated from the federal budget have shrunk accordingly. For instance, in 2010, the Russian state provided only RUR 53.2 billion for NPP construction.

Table 1 shows that the share of federal budget funds in the total NPP construction budget is decreasing gradually, and after 2015, as per the programme, the State Corporation Rosatom is expected to commission annually no fewer than two power units each with an installed power capacity of 1 gigawatt out of its own funds – but already today, these plans are being scaled down.

Rosatom should be able to start managing some of the construction on its own because, according to the recent concept of reforms on the power generation market,[28] the share of power and capacities sold on the open market is set to grow, and prices on the open market are currently

[28] The reform of the Russian electric power market and power production industry was initiated in July 2001 to change the state regulation system in the sector, introduce a competitive power market, and stimulate the creation of new, mostly private, companies on the market. A detailed description of the reform and the historical background behind it – the stagnation of the 1980s and the economic crisis of the 1990s, when the newly independent Russia was going through a painful transition period from a Soviet totalitarian state to a country with an incipient democracy and a free market economy – is available on the website of the former power supply monopoly Unified Energy System (RAO UES of Russia), an electric power holding company created in 1992 that owned the majority of Russia's installed electric capacity, high-voltage grid infrastructure, and transmission lines (with the exception of nuclear capacities). RAO UES also exported some of the electricity produced in Russia to other countries. In particular, this description says, the reorganisation of the 2000s was aimed at increasing the performance efficiency of power plants and creating a more favourable investment environment in the power production market. It envisioned changes in the market structure as well, where natural monopoly functions (power transmission and dispatching) were to be separated from potentially competitive ones (production and supply, repair works and services) and new structures responsible for separate activities were to replace former vertically integrated companies that used to carry out all these tasks. Generation, sales, and repair companies are now expected to become mainly private and enter into mutual competition. State control, on the other hand, is to tighten in natural monopoly sectors. The restructuring also implies that market prices will not be regulated by the state, but formed on a demand and supply basis, with market participants reducing their costs as a result of competition. The push for a privatisation of the power industry also led to the reorganisation or RAO UES of Russia, which ceased to exist as a state-owned monopoly and was transformed into several state-owned and private companies. For more information, please see http://www.rao-ees.ru/en/reforming/reason/show.cgi?background.htm#4 and http://www.rao-ees.ru/en/reorg/show.cgi?reorg.htm. – Translator.

noticeably higher than the regulated tariff – which may give the NPP operator company Rosenergoatom, which is wholly owned by Rosatom, additional earnings and more opportunities to develop without direct support from the state.

Besides that, Rosenergoatom has the following internal financing sources at its disposal that it could use to fund new construction:

A) Special targeted deductions that existing nuclear power plants pay as part of their expenses subject to reimbursement out of revenue derived based on the electricity tariff. In accordance with Government Directive No. 68, of January 30, 2002 – a document entitled “Rules of effecting by enterprises and organisations engaged in operation of especially radiation-hazardous and nuclear-hazardous production facilities and sites (nuclear power plants) of deductions paid to reserve funds maintained to ensure safety of nuclear plants at all stages of life cycle and development” – Rosenergoatom forms its reserves for the following purposes:

- to finance expenses on ensuring nuclear, radiation, technological, and fire safety (no more than 10 percent of sales revenue);
- to finance expenses on providing physical security and maintaining records of and control over nuclear materials (no more than 1 percent of sales revenue);
- to finance expenses on supporting the development of nuclear power plants (discretionary amounts set by annual appropriation decisions);
- to finance NPP decommissioning costs (1.3 percent of sales revenue).

Tables 2 and 3 show distribution of reserve funds that were available to Rosenergoatom in the year 2009.

Table 2. Reserve funds collected as per charter documents (reserves held for anticipated expenses established as part of the cost structure) (in thousand roubles).[29]

Reserve funds	Start of year balance	Amount received	Amount spent	End of year balance
For nuclear, technological, and fire safety	1,167,763	2,055,031	887,920	2,334,874
For physical security and tally of and control over nuclear materials	663,333	1,190,777	621,933	1,232,177
For development of nuclear power plants	20,596,931	60,899,835	5,350,749	76,146,017
For nuclear power plant decommissioning	708,905	1,379,968	120,726	1,968,147
TOTAL	**23,136,932**	**65,525,611**	**6,981,328**	**81,681,215**

Table 3. Reserve funds allocated as part of capital investments as per Government Directive No. 68, of January 30, 2002 (in thousand roubles).

Reserve funds	Start of year balance	Amount received	Amount spent	End of year balance
For nuclear, technological, and fire safety	2,308,008	3,118,761	2,283,213	3,143,556
For physical security and tally of and control over nuclear materials	32,791	234,389	105,617	161,563
For development of nuclear power plants	79	252,317	252,243	153
For nuclear power plant decommissioning	969,664	768,774	644,272	1,094,166
TOTAL	**3,310,542**	**4,374,241**	**3,285,345**	**4,399,438**

[29] Cited here and elsewhere are data from Concern Rosenergoatom’s Annual Report for 2009 (http://www.rosenergoatom.ru/rus/shareholders/raskr-inform/god-otchet, in Russian).

As follows from the tables above, the funds Rosenergoatom had at its disposal for the item "Development of nuclear power plants" alone came in 2009 to around $2 billion. If this value continues to remain at the same level in the future,[30] Rosenergoatom will be able to collect, on its own, enough money to build one new standardised nuclear power plant with two reactor units every two or three years.

B) In addition to the mentioned reserves, which are specific to the nuclear industry, the book value of Rosenergoatom's assets is depreciated in the regular way. The total amount of depreciation charges in Rosenergoatom's expense structure was RUR 10.9 billion in 2009 (an increase over the RUR 9.3 billion in 2008), or $365 million. The depreciation charges serve to accrue financial funds in order to subsequently restore and replace the fixed assets, but the concern's financial accounting information does not indicate that a depreciation reserve fund is accumulated. In this case, depreciation, same as profit, appears to be part of the net financial result.

C) With the liberalisation of the electric power market, Rosenergoatom was able to start bringing in significant profit. The electricity tariff, which is calculated based on the required gross revenue,[31] is essentially the bare minimum when selling on an unregulated market. As of 2009, volumes of electricity sold under regulated contracts totalled 95.8 billion kilowatt-hours (or 63 percent of total supply on the wholesale electricity market[32]); volumes sold on the day-ahead market[33] reached 54.7 billion kilowatt-hours (or 36 percent of total sales); and volumes sold on the balancing market[34]

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[30] According to Nigmatulin, the investment mark-up added to the price of electricity produced by Russian nuclear power plants in 2010 was estimated to yield that year a total of RUR 59 billion. See Footnote 16.

[31] The "required gross revenue" from sales of product generated as part of activities subject to state regulation is basically the volume of funding necessary to ensure optimal operation of Rosenergoatom enterprises. It is calculated as the sum of all recognised expenses borne by the concern, both those that are reported as deductions from the taxable base and the non-deductible ones, and its value is determined by the federal tariffs authority. Please see also Chapter 4. Operating costs as part of the prime cost of nuclear-produced energy, below, for a more detailed description. – Translator.

[32] Since September 1, 2006, new rules of the wholesale electricity (capacity) market have been introduced as part of the overall reform of the Russian power market, changing the entire system of relations between buyers and sellers of electric power and capacity. Liberalisation of the wholesale power supply market went hand in hand with that of the retail market. Wholesale suppliers are generation companies and importers of electric power, while buyers include consumers, reselling companies, and exporters. Under the new rules, the regulated sector and the free trade sector of the wholesale market were replaced by a system of regulated contracts – with prices regulated by the federal tariffs authority – to be concluded between buyers and sellers. Starting from 2007, wholesale buyers and sellers gained the right to enter into long-term regulated contracts, with more predictable prices ensuring a more attractive investment environment in the industry. Also since 2007, volumes of electric power (capacity) traded in the wholesale market at regulated prices were being reduced incrementally, a strategy implemented to allow for trading to start, as of January 1, 2011, to operate fully at free (competitive) prices. (From RAO UES of Russia's description of changes on the wholesale electricity (capacity) market, at http://www.rao-ees.ru/en/reforming/market/show.cgi?market.htm). – Translator.

[33] Following the enforcement of new rules on September 1, 2006, as the wholesale electricity (capacity) market was being reorganised, the free trade sector was liquidated and a spot market – or day-ahead market – was launched. The new market model implies two ways of electricity trading at free prices – free bilateral contracts and the day-ahead market. Under free bilateral contracts market participants have the right to choose contracting parties, prices, and supply volumes. The day-ahead market is based on competitive selection of bids submitted by suppliers and buyers a day before the electricity is actually supplied. (From RAO UES of Russia's description of changes on the wholesale electricity (capacity) market, at http://www.rao-ees.ru/en/reforming/market/show.cgi?market.htm). – Translator.

[34] As noted above, the day-ahead market is based on competitive selection of bids submitted by suppliers and buyers a day before the electricity is actually supplied. The competitive selection is held by the commercial operator (provider of services in the wholesale market). If there are deviations from the day-ahead forecasts, participants are obliged to sell excess amounts or buy missing ones in the balancing market. (From RAO UES of

came to 2.2 billion kilowatt-hours (or 1.5 percent of overall sales). Because, as of 2009, the weighted average annual price of nuclear-generated power sold on the day-ahead market was RUR 614 per megawatt-hour – with the electricity tariff set at RUR 165.09 per megawatt-hour – Rosenergoatom was able to generate RUR 25.608 billion ($854 million) in additional revenue, compared to the desired gross proceeds (or 15 percent).

Capacity will still be sold at regulated tariffs[35] and, according to a statement made by Sergei Novikov, head of the Federal Tariff Service of Russia,[36] in April 2010, this situation is not expected to change within at least two years.[37]

The domestic construction programme also contains a list of all sites designated for construction, so in that sense, the issue of a particular source of capital funding does not even matter that much since Rosatom has no leeway with regard to any new investment decisions be they supported by its own funding or not. The programme was anticipated to result, upon its implementation, in a combined overall capacity of Russia's nuclear power plants totalling 33 gigawatts by 2015 and a combined yearly electric power output produced by them reaching 234.4 billion kilowatt-hours, or 145 percent over the values of 2008. But it is clear already now that this task will not be carried out – something that has even been confirmed by Rosatom head Kiriyenko in his statements.

Foreign/private investments

The Baltic NPP project envisioned Rosenergoatom investing 51 percent into the construction, while the remaining 49 percent would be contributed by one or several private investors, including foreign funds. A project group within the Russian electricity export and import company Inter RAO UES[38] was charged with working out the funding model for the project and terms and conditions of attracting outside investors.[39]

Russia's description of changes on the wholesale electricity (capacity) market, at http://www.rao-ees.ru/en/reforming/market/show.cgi?market.htm). – Translator.

[35] As per the reform of the Russian power supply industry, the new wholesale market now also includes capacity trading, which is designed to ensure reliable and sustainable electricity supplies in conditions of growing electricity demand. Previously, suppliers received payment only for 85 percent of installed capacity of their generation equipment, and for buyers, payment for this capacity was included in the flat-rate tariff for electricity (capacity). Now there are separate payments for electricity and capacity. When selling capacity, suppliers are obliged to maintain their generation equipment in proper condition in order to always be ready to produce electric power. Capacity payments depend on the fulfilment of these obligations. (From RAO UES of Russia's description of changes on the wholesale electricity (capacity) market, at http://www.rao-ees.ru/en/reforming/market/show.cgi?market.htm). – Translator.

[36] The Federal Tariff Service (FTS) is the state tariff regulation authority. According to a description of its mandate on the service's website at http://www.fstrf.ru/eng, the FTS is an executive body authorised to exercise legal control in price and tariff regulation for goods and services in the Russian Federation. – Translator.

[37] An April 1, 2010 publication in *Rossiiskaya Gazeta* – the government daily newspaper of record, which publishes government decrees, directives and other documents, as well as newly adopted legislative acts – said the FTS would continue to regulate nuclear and hydroelectric capacity tariffs for at least two years.

[38] Inter RAO UES spun off from the Russian electricity holding Unified Energy System (RAO UES of Russia) in 2008, as the latter was being restructured following the start of large-scale reforms on the Russian power market in 2001. For more information, please see the company's website at http://www.interrao.ru/eng/ and a description of the reorganisation of RAO UES of Russia here: http://www.rao-ees.ru/en/reorg/show.cgi?reorg.htm. – Translator.

[39] From "Baltic NPP Project: First opportunity for foreign investors' participation in a Russian nuclear power plant" (http://www.rosatom.ru/wps/wcm/connect/rosatom/rosatomsite/resources/bec1a4004372c2a2aab9bb82958bd8d4/9.4_Kozlov_INTER_RAO_EES_kruglyy_stol_09062010_Atomekspo_2010.pdf, in Russian), a presentation prepared by Inter RAO UES's Head of Project Group "Baltic NPP" Maxim Kozlov for Rosatom's round-table session entitled "Investments in Nuclear Power Development. Project Management. Financial Guarantees" and held during the International Forum ATOMEXPO-2010, June 9, 2010 (http://www.rosatom.ru/wps/wcm/connect/rosatom/rosatomsite.eng/investmentstrategy/events/05da068043b667288d9fbf3f0f78db46).

Apparently, foreign investments will be provided in exchange for power supplies at guaranteed prices. An assessment of the price of future energy produced at the plant can in principle be derived from the terms of such a deal.

Another conclusion to be made is that participation of foreign investors in this project will enable foreign commercial organisations to avail themselves of subsidies provided by the Russian state.

Construction time frames and cost of capital

When providing funds for construction of new industrial assets, investors set forth their requirements with regard to the expected cost of capital. In the case of loan funds, it is the interest rate that is negotiated, and where it concerns a company's own capital, it is the cash flow that the investment generates and the time horizon that are important. **It should be noted that the Russian state, as investor – and Rosenergoatom, as an organisation whose all costs are reimbursed in full – proceed on extremely generous terms, an indulgence impossible not only on the Russian but on the foreign capital markets as well.** For instance, the two-unit project of Balakovo NPP is based on a cost of capital set at zero. Taking the bank loan into account, calculations peg the interest rate on the credit at 7 percent, with a repayment period of ten years beginning after the start of commercial operation at the plant.

The construction time frame, too, has enormous importance because it determines the anticipated point in time when the project finally starts generating a positive cash flow. The time frame envisioned in the Balakovo NPP project is assumed to be five years, but a comparison with the construction schedules of the first power units at Novovoronezh NPP II and Leningrad NPP II gives us a time frame of seven to eight years, and the commissioning deadlines for the second reactor units at those sites have been pushed back by two or three years. Reactor Unit 2 of Rostov NPP was put into commercial operation at the end of 2010 – it took six years to complete a project that had been built to almost 40 percent. And according to the industry expert Nigmatulin, one year behind schedule results in a 10 percent increase in costs.[40]

The problem of construction delays or projects going over budget is not uncommon in the West and is well recognised there. For instance, delays are expected in the first nuclear power plant to be built in Great Britain after a break in nuclear construction, a project that France's EDF and Great Britain's own Centrica aim to finish by 2018. In December 2010, Alistair Philips-Davies, energy supply director at the British energy company Scottish and Southern Energy, said he doubted the construction would be completed in time. "Often these things are [a] little bit more expensive than you think and come in a little bit later than you think," he told a committee of MPs, according to a story in *The Telegraph*[41].

Problems with keeping on schedule and within budget have plagued an NPP project in Finland as well: Two years' worth of construction delays at the site of Olkiluoto NPP have already resulted in an estimated EUR 2.5 billion in over-budget costs.[42]

[40] See Footnote 22.

[41] UK taxpayers face unlimited nuclear waste bills if costs spiral, news story. The Telegraph, December 8, 2010. (http://www.telegraph.co.uk/finance/newsbysector/energy/8187222/UK-taxpayers-face-unlimited-nuclear-waste-bills-if-costs-spiral.html).

[42] Finland has ordered a third reactor, an EPR model, for its Olkiluoto Nuclear Power Plant on Olkiluoto Island in the Gulf of Bothnia in Western Finland. Construction has been implemented by France's Areva, but delays caused by violations of construction standards and issues of supervision, as well as those of overspending have drawn criticism to the project from all sides, including energy experts, environmentalists, and STUK, the Finnish nuclear safety regulator. The new reactor was projected to go online in May 2009, but after several postponements, the deadline was most recently set for 2013. For more information, please see Bellona's coverage, for instance, here: http://bellona.org/articles/articles_2010/finland_repository. – Translator.

3. Problems of nuclear power industry regulation

State regulation of tariffs. The 2001 reform in the Russian power generation industry divided the activities performed in the energy generation sector into three separate branches: production, transmission, and retail power sale. Concern Rosenergoatom on the whole operates as a generating company and sells power and heat produced by Russian nuclear power plants in what is called the Wholesale Power and Capacity Market. Retail prices are partially regulated by the Federal Tariff Service of Russia.[43]

The very fact that Russia is attempting to copy the Western system of tariff regulation and reproduce it at home indicates that all the problems that are known to have shaped the long history of this issue in the West and the Western experience of dealing with them are applicable in Russia as well. An extensive body of literature written on the economics of state regulation is dedicated to the issues of regulation of tariffs.

Before reforms of natural monopoly regulation were launched in the West – and, in a sense, this situation continues to this day – the so-called "costs plus" regulation[44] was in place. It has long been in evidence, however, that even without information asymmetry,[45] this model of regulation contributes to overproduction and increasing costs.

Even though the relationship between a regulatory body and a regulated company is supposed to be, and appears to be, that of an authority and an entity it is supervised by, in effect, the regulated companies tend to have quite a considerable ability to defend their own interests.

For one reason, state regulatory agencies maintain very close ties with the industry. The only available labour pool to supply the regulatory authority with qualified personnel who are well enough versed in the industry's inner workings to understand its problems is usually that same industry. It happens quite often that once they have a regulatory job on their resumes, specialists can count on a much more lucrative position in one of the companies they used to oversee. In such a situation, people start perceiving themselves as part of the industry – and their work as a way to provide necessary assistance in solving the industry's problems.[46]

Secondly, the structure of information about the economic situation of any given regulated company is asymmetric – that is, the company itself is much better informed about its own costs than the official in charge of regulating its operations. This concerns the real level of costs the company

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[43] Rosenergoatom's operations as a generating company are regulated by the Federal Laws "On state regulation of electric power and thermal energy tariffs in the Russian Federation" and "On the electric power industry." The full text of the latter can be found here: http://www.kodeks-luks.ru/ciws/site?tid=0&nd=901856089&prevDoc=901889584 (in Russian).

[44] Under cost-plus regulation (or rate-of-return regulation), the tariff is calculated to cover costs reported by companies plus a market-determined rate of return on capital. The regulator ensures a fair price charged by the regulated company. The risks of overwhelming costs are thus reduced to the company, while consumers are protected against unreasonable pricing. This approach has been criticised, however, for giving monopoly companies little incentive to cut costs. – Translator.

[45] In state regulation, information asymmetry is a phenomenon where the regulated company has the advantage of possessing more information about its financials than the regulator it reports to. – Translator.

[46] Consider, for instance, this fragment from an interview FTS head Sergei Novikov gave to the Russian news agency Interfax, shedding light on the motivation behind the agency's work: Q.: The FTS and other agencies have been given a task of analysing, by December [2006], the efficiency of Rosenergoatom's participation in trades on the wholesale market. Why was this task assigned? What sort of consequences will such an analysis have for Rosenergoatom? A.: The thing is that there are certain obvious peculiarities to the operation of nuclear power plants that have to do with ensuring safety. And there have been certain special decisions made with regard to Concern Rosenergoatom to prevent under-generation of desired revenue associated with expenses that fall under the expenditure items linked to safety. (Published on the FTS's website on October 6, 2006; the full text is available here: http://www.fstrf.ru/press/interview/23, in Russian).

bears, how well they are justified economically, what opportunities there exist to cut down on these costs or distribute them between its regulated and unregulated activities, or spread them over periods of time, etc.

Several approaches have been worked out in literature dedicated to the issues of state regulation to solve the problem of information asymmetry which have both been found useful in practical application of state regulation principles abroad and have also been introduced into the current Russian legislation. These are essentially assorted devices designed to obtain a more accurate idea of a company's true level of costs and expenses. For instance, it is suggested to compare the regulated company in question with similar ones – a so-called "yardstick regulation"[47] approach.

Theoretical knowledge that has been supported by empirical studies has shown that regulated companies enjoy considerable latitude in manipulating the costs they report to the authorities. In a majority of cases, a regulated firm has a stake in exaggerating its costs. In our case, we must assume a more intricate motivation at play.

In order that the industry continue to receive state support and develop further, it needs to assert its cost-effectiveness compared with alternative sources of energy. This is why the costs that the nuclear industry reports to the regulatory agencies may be at any one level but they will be lower than those incurred by using other energy sources.

The nuclear industry, in other words, is not interested in disclosing all of its costs since some of its expenses are covered by state subsidies, including hidden ones.[48]

Of course, generation of electric power is not a natural monopoly and does not, theoretically, need price regulation. **That regulation is maintained in its current form in the field of nuclear power generation does not so much reflect the desire to offset monopoly pricing as it reveals the underlying goal to ensure guaranteed profit for the nuclear industry, as well as preserve the interests of the bodies that regulate it.**

Leniency in setting spending limits. It is the public, the society at large, that bears the economic consequences for various investment decisions taken, paying the price if these decisions have proven unwise. A private investor risks their own money and, by definition, will act under rigorous budget

[47] When utility suppliers do not face direct competition, regulators can put pressure on those firms by basing their prices on the cost performance of comparable firms, a technique that provides companies with strong incentives to cut costs and dampens the effect of information asymmetries between companies and regulators. From the Glossary of Regulation Terms, the Body of Knowledge on Infrastructure Regulation, http://www.regulationbodyofknowledge.org/. – Translator.

[48] It is the funds that are allocated as part of the government target programme that ensure that new capacities are built, old nuclear power plants receive extensions on their engineered life spans, or uranium deposits are developed, etc. The historical practice of close entanglement of civil and military goals, policies, and means to achieve the given objectives that the nuclear industry relies on enables its sector of commercial nuclear energy to thrive in a highly propitious environment incomparable with the conditions that exist for other power generation sectors. For instance, as per the "Programme of Activities of the State Atomic Energy Corporation Rosatom," the corporation also performs the role of the state contracting agency and holds spending authority in administering federal budget funds in the following federal target programmes: "Development of the Nuclear Weapons Complex of the Russian Federation in 2007 to 2010 and for the Period until 2015," "Ensuring Nuclear and Radiation Safety in 2008 and for the Period through 2015," "Industrial Decommissioning of Weapons and Defence Equipment (2005 to 2010)," "National Technological Base in 2007 to 2011," "Studies and Research in Priority Fields of Development of the Russian Science and Technology Complex for 2007 through 2012," "Development of the Military Industrial Complex of the Russian Federation in 2007 to 2010 and for the Period until 2015," "Development of the Nanotechnology Industry Infrastructure in the Russian Federation in 2008 to 2010," and "Development of the Electronic Component Base and Radio Electronics in 2008 to 2015." None of these programmes have a direct relation to power generation, but they provide funding to pay for, among other items, Rosatom's administrative, educational, and research expenses, which would otherwise have to be covered by revenue derived from sales of electric power.

requirements: If a wrong decision has been made, bankruptcy follows. In situations where state financing is involved, such restrictions are always more flexible, but the responsibility for the consequences that this or that economic decision will have is deferred so far ahead into the future that, for all intents and purposes, it simply does not exist in any practical sense. In essence, the very organisation of making investment decisions in projects undertaken in the nuclear power industry makes it so that the responsibility for errors of judgment and the ensuing repercussions lies with no one in particular. For instance, the obvious economic fiasco of the idea of floating nuclear power plants,[49] the exponential growth in costs of new reactor construction, and construction delays at new sites do not seem to complicate the lives of those who were responsible for the initiation and implementation of these projects in the first place.

Where nuclear energy differs prominently from all other sources of energy is the absence of the inverse relationship between technological progress and production costs. As technologies develop and are better known and used more efficiently, production costs decrease, and this feedback effect holds for all other energy generation sectors – but not the nuclear energy industry, where the costs of producing power from nuclear reactors keep growing instead.

There is a considerable number of theories explaining this phenomenon, of which the first and foremost is the idea of perception of the industry as a dangerous and harmful one – something that results in ever stricter requirements and standards imposed with regard to its safety. The availability of technological improvements to enhance safety of nuclear power plants makes it impossible to avoid toughening safety regulations correspondingly, and it is very difficult to draw the line between the necessary safety enhancements and the price which must be paid to achieve them. Indeed, if there are measures to limit the risks of accidents that threaten environmental contamination and harm to population health and yet they are not installed for reasons of economic considerations, then in cases when such risks do erupt into real accidents, the industry is bound to be hard-pressed to explain to the public why these measures were not applied.

For instance, experts pointed out in numerous studies that have been done in the wake of the 1986 catastrophe at Ukraine's Chernobyl Nuclear Power Plant that Soviet designers had been putting too strong an emphasis on cutting costs – at the expense of safety at the plant and protection against accidents. It is obvious, in hindsight, that any measures that could have prevented that terrible disaster should have been used, no matter what the cost. But for Soviet nuclear specialists at the time, accident risks appeared too infinitesimal and safety standards too high. In any case, because nuclear projects are characterised with extremely long time horizons**, investors should be prepared to face tidal shifts in the prevailing attitudes to the industry – which, at the very least, may lead to changes in standards and regulations and corresponding cost increases.**[50]

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[49] Please see Appendix to this report, which details the economic deficiencies of the floating nuclear power plant (FNPP) project, a concept of non-self-propelled vessels with reactors on board devised to supply power in remote and poorly accessible regions. A first in a projected series of at least seven such plants is being completed at Baltiisky Zavod in St. Petersburg to be subsequently towed to the Kamchatka Peninsula in the Russian Far East. Rosatom admits that the project will not be economically viable unless at least several FNPPs are built in a commercial series and hopes to start serial production of these transportable nuclear power plants for export to other countries, primarily in Southeast Asia. An extensive report has been written by Alexander Nikitin and Leonid Andreev, with participation by experts at Bellona and other organisations, on the FNPP endeavour and the many risks – those of safety and security primarily, and expediency overall – that it entails. To read the report, entitled "Floating Nuclear Power Plants," Bellona Report 2011, please visit Bellona's website at www.bellona.org. – Translator.

[50] A more recent wave of revisions of safety standards swept across the global nuclear industry following the onset of the still ongoing, as of mid-April 2011, nuclear disaster at Japan's Fukushima Daiichi Nuclear Power Plant, where an 8.9-magnitude earthquake of March 11 and a devastating tsunami that hit in its wake destroyed the station's

4. Operating costs as part of the prime cost of nuclear-produced energy

The majority of costs in nuclear power generation that are incurred after a nuclear power plant is commissioned for commercial operation are semi-fixed costs, and the marginal costs[51] are insignificant. At the same time, decreasing power load is both expensive for a nuclear power plant and undesirable for reasons of safety. The engineering peculiarities of producing energy at a nuclear power plant dictate the only economically viable operating mode – constant operation at maximum capacity. If a nuclear power plant, on the other hand, is disconnected from the grid – for maintenance works, for example – the grid is forced to compensate for this loss of power supply by producing expensive energy using reserve capacities or by importing energy from other regions.

The Federal Tariff Service of Russia determines for Rosenergoatom what will be referred to in this report as "required gross revenue" (RGV) from sales of product generated as part of activities subject to state regulation – or the volume of funding necessary to ensure optimal operation of Rosenergoatom enterprises. The RGV is calculated as the sum of all recognised expenses borne by the concern, both those that are reported as deductions from the taxable base and the non-deductible ones.

Government Decree No. 459 of June 18, 2008 "On introducing changes to Decree No. 109 of the Government of Russian Federation, of February 26, 2004 'On the pricing of electric power and thermal energy in the Russian Federation'" defined operating expenses as expenses tied to the production and sale of product generated as part of regulated activities with the exception of depreciation of fixed assets, debt service expenses, expenses derived from lease of property used for the implementation of regulated activities, and expenses paid for services rendered by organisations carrying out regulated activities.

The following is, roughly, what qualifies for the industry's non-deductible operating costs, as per the law and relevant regulatory documents[52]:

- Material expenses, including all production-related works (services), purchases of raw materials and other materials, and all costs associated with the nuclear fuel cycle;
- Remuneration of labour;
- Depreciation of property;
- R&D;

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external power supply, resulting in multiple core meltdowns, containment breaches, exposure of spent fuel in the cooling ponds, and massive releases of radiation. Prompted by this nuclear disaster, which Japan now officially rated Level 7 on the International Nuclear Event Scale (the 1986 Chernobyl catastrophe being, before Fukushima, the only example of this highest degree of severity), nations with commercial nuclear capability have been reconsidering their stance on nuclear energy or considering instituting more rigorous safety standards. The European Union has called for mandatory stress-testing at some 150 NPPs operating on its territory, while Germany announced a temporary shutdown of several of its oldest stations pending safety review. For more information, please see Bellona's extended coverage of the Fukushima Daiichi disaster at http://www.bellona.org/subjects/nuclear-metldown-in-japan. – Translator.

[51] Marginal costs are costs incurred by producing one more unit of product and vary depending on how many more – or fewer – units (or units of volume) are produced. An increase in production volumes does not automatically mean rising marginal costs, however, and those can go down if more product is produced, since labour and infrastructure costs are part of the calculation and may not change with growing output. – Translator.

[52] See, for instance, "Instructional guidelines for planning and accounting of income and expenditure of Concern Rosenergoatom," approved by Rosenergoatom's general director Oleg Sarayev (Concern Rosenergoatom's Directive No. 265 of March 25, 2004) or "Temporary Instructional guidelines for calculating tariffs for electric capacity and electric power produced by Federal State Unitary Enterprise (FGUP) 'Russian State Concern for Generation of Electric and Thermal Power at Nuclear Power Plants' (Concern Rosenergoatom) on the Federal All-Russian Wholesale Electric Power and Capacity Market, "the Federal Energy Commission's Directive No. 80-e/4, of November 21, 2002.

- Property and liability insurance;
- Renovation of fixed assets;
- Other expenses related to production and sale of product (deductions to reserve funds, lease payments, expenses on security services, etc.).

In addition, the RGV includes proceeds from investment capital, which equals the product of the rate of return on investment times the regulatory asset base[53] reduced by the amount of capital returned, as well as investments provided for by the long-term investment programme approved in an established order, and the net operating capital set by the regulatory agency in accordance with the instructional guidelines in force. This is how income is formed, sufficient to pay income tax and all expenses paid out of net profit, and to derive, on top of these, net profit that is spent to cover the organisation's needs.

Expenses paid out of net profit are primarily all types of investments and deductions to reserve funds above the standard amounts required for Rosenergoatom enteprises.

Concern Rosenergoatom, on the whole, performs the functions of a generating company, and this situation contributes objectively to cross-subsidisation[54] – despite the legislatively established requirement to distinguish, in cost accounting, between costs related to different types of activities.

The value of RGV is distributed between the production of electric power (capacity) and thermal energy in order to determine the separate tariffs for electric power and heat.[55]

With regard to electricity, two tariffs are set separately – for electric power and for capacity.[56] It is believed that funds that generating companies receive from selling capacity are spent toward maintaining the generating capacities in working order, on the recovery of funds spent on upgrades and building new capacities. In reality, however, the tariffs are calculated in such a way that each of the tariffs would provide around a half of the required gross revenue.

When calculating the regulated capacity tariff for suppliers on the wholesale market, the RGV will include expenses on maintaining each of the suppliers' maximum available generating capacity as specified in the consolidated balance sheet for the regulated accounting period, including expenses on maintaining both the operating and the strategic technological capacity reserves.

As per Item 35.4 of Directive No. 109 of the Government of the Russian Federation, of February 26, 2004, tariffs are adjusted depending on the actual production volumes. If less electric power has been produced than it was planned, the required gross revenue will be divided by that lesser value of production volume, and the tariff will increase. Furthermore, the tariff is automatically adjusted for inflation and when interest rates grow in the financial market.

The FTS compiles a consolidated balance forecast for production and supplies of electric power (capacity) and determines, based on that, the projected yearly production volume. It is assumed that the consolidated balance forecast is prepared based on the principle of minimisation of the combined

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[53] Defined in law or by the regulator as the regulatory asset value on which the allowed rate of return can be earned. This may be calculated according to a variety of accounting methods: fair value, prudent investment, reproduction cost, or original cost. Depending on the jurisdiction, the rate base can include working capital and construction work in progress. It can be adjusted to take into account accumulated depreciation. From the Glossary of Regulation Terms, the Body of Knowledge on Infrastructure Regulation, http://www.regulationbodyofknowledge.org/. – Translator.

[54] The practice of using profits generated from one product or service to support another provided by the same operating entity (the European Commission's Trade Glossary, http://ec.europa.eu/trade/glossary/). – Translator.

[55] See Appendix to FTS Directive No. 485-e, of October 13, 2010, "Instructional guidelines for determining the volume of financial resources necessary to ensure safe operation of nuclear power plants and hydroelectric power plants."

[56] Government Decree No. 109, of February 26, 2004, "On price formation regarding electric power and thermal energy in the Russian Federation." See also Footnote 35.

cost of electric power (capacity) supplied to the consumers. If the nuclear energy industry reported detailed information specified for each of its power-generating plants, rather than averaged data, it could happen so that the power produced – and by extension, the costs borne – by the industry's least cost-effective nuclear power plants would be excluded from the balance forecast due to the high costs, which would, in turn, raise the needed tariff value.

The current fleet of Russia's nuclear power plants, in the forms and shapes they exist now, was not created for purely economic reasons only, and thus incurs rather high costs at all stages of service life. The plants differ quite noticeably relative to their baseline characteristics. In this situation, the generalised averaged data – the only available on Russian NPPs – do not give full information on the costs of a new power plant. On the other hand, cross-subsidisation is inevitable here since **Rosenergoatom covers all of its costs via the tariffs – so more cost-effective nuclear power plants are forced to pay for those that are less so.**

We will use two sources to assess the operating expenses of Russian nuclear power plants: estimated average annual costs of production of power projected for supply from Reactor Units 5 and 6 of Balakovo NPP as well as from the reactors of Novovoronezh NPP II. Table 4 lists these costs in 1991 prices, with the last two columns showing the same values calculated for prices as of end 2009 (at a ratio of 1:54.49[57]). Table 5 lists operating expenses across the entire Russian NPP fleet as per Rosenergoatom's annual financial statements.

Table 4. Operating costs as per the projects of second line of construction at Balakovo NPP and Novovoronezh NPP II (in thousand roubles).

Cost item	**Second line at Balakovo NPP (Reactor Units 5 and 6)**	**Novovoronezh NPP II**	**Second line at Balakovo NPP (Reactor Units 5 and 6), adjusted for inflation**	**Novovoronezh NPP II, adjusted for inflation**
Depreciation	40,005	44,449	2,179,920	2,422,079
Deductions for major overhaul and medium repairs	32,004	35,559	1,743,936	1,937,653
Payroll	6,654	6,654	362,584	362,584
Deductions for social benefits	2,382	2,382	129,798	129,798
Fresh nuclear fuel	102,385	102,385	5,579,082	5,579,082
Management of spent nuclear fuel and radioactive waste	24,163	24,163	1,316,671	1,316,671
Other expenses	19,451	21,370	1,059,908	1,164,477
Total annual average costs	**227,165**	**236,962**	**12,378,493**	**12,912,344**

Table 5. Concern Rosenergoatom's total costs in 2009 and 2008, in thousand roubles.

Cost item	**2009**	**2008**
Material expenses	40,861,427	40,830,085
Payroll and remuneration of labour	16,030,801	16,264,173
Deductions for social benefits	2,816,544	2,872,946

[57] See Footnote 7.

Depreciation	10,911,630	9,312,654
Other expenses	25,811,866	23,807,675
Total	**96,432,268**	**93,087,533**

The data shown in Table 4 are more detailed, but because this information is based on estimates calculated in 2004 on the basis of 1991 prices, they are still very approximate. The values shown in Table 5 are more precise, but, firstly, these are the combined expenses of Rosenergoatom as a whole – and thus, they can only give us ballpark figures with regard to the costs incurred by any one nuclear power plant in particular[58] – and secondly, all the meaningful cost items that are necessary for a detailed analysis are hidden under the titles “Material expenses” and “Other expenses” and are thus “diluted” among other expenses. **Basically, the major part of the “material expenses” is accounted for by costs associated with the nuclear fuel cycle, while “other expenses” include, among others, deductions to various reserve funds.**

Taking these data into account, and using the information available on the combined power output at all ten nuclear power plants operated by Rosenergoatom as of 2009 – 163.41606 billion kilowatt-hours – we can estimate the share of costs included in the prime cost of energy produced per one kilowatt-hour (see Table 6).

Table 6. Concern Rosenergoatom’s expenses in 2009, in US cents per one kilowatt-hour.

Material expenses	0.83
Payroll and remuneration of labour	0.33
Deductions for social benefits	0.06
Depreciation	0.22
Other expenses	0.53
Total	**1.97**

The above means that as part of the material expense item, the costs incurred by the nuclear fuel cycle may not exceed US 0. 83 cents per one kilowatt-hour. Because these figures apply generally to the industry as a whole, those power plants operating within the industry that are cost-effective should bear lesser expenses per one unit of generation.

There is no information available on expenses paid by one or another of Russia’s ten power plants, and we can only attempt to extrapolate the known costs across the industry’s individual plants depending on, say, an NPP’s installed capacity or volumes of electricity produced.

One particular aspect of all these calculations is that the resulting sum – which does not, strictly speaking, have much to do with production volumes – must be distributed over the existing output in order to determine the tariff per unit of production. In this sense, the installed capacity utilisation factor (ICUF) – in other words, the extent to which an installed productive capacity is used compared with the potential output using the same capacity – has an enormous importance.

[58] As of April 2011, when the English version of this report was being prepared, there were ten nuclear power plants in commercial operation, with 32 reactor units operating at these sites, under Rosenergoatom’s purview. – Translator.

To put this in perspective, according to Steve Thomas's 2005 study "Economics of Nuclear Power,"[59] "average [non-fuel operations and maintenance] costs for British Energy's eight plants, including fuel, varied between about [UK 1.65 pence and UK 1.9 pence per kilowatt-hour] from 1997 to 2004" (or US 2.7 cents to US 3.1 cents[60] per kilowatt-hour).

"However, in the first nine months of fiscal year 2004/05, operating costs including fuel were [UK 2.15 pence per kilowatt-hour] because of poor performance at some plants. The average over the period is about [UK 1.85 pence per kilowatt-hour]," Thomas writes. If the cost of fuel, including reprocessing, is assumed to be about UK 0.7 pence per kilowatt-hour (US 1.1 cents per kilowatt-hour),[61] "this leaves about [UK 1.15 pence per kilowatt-hour] as the non-fuel [operations and maintenance] cost, about 60 percent higher than the US average."

In the 1990s, operations and maintenance costs, without the fuel expenses taken into account, were on average in excess of US 2.2 cents per kilowatt-hour, while fuel expenses were over US 1.2 cents per kilowatt-hour, Thomas writes. "Strenuous efforts were made to reduce non-fuel nuclear [operations and maintenance] costs and by the mid-1990s, average non-fuel [operations and maintenance] costs had fallen" to about US 1.25 cents per kilowatt-hour and fuel costs to US 0.45 cents per kilowatt-hour, after which expenses started growing again because of increasing fresh fuel costs.

All the expenses that have been analysed in this chapter are included in the prime cost of energy produced by Rosenergoatom enterprises and are covered by revenue generated from the power and heat produced and sold by the concern. In the end, all of these costs are paid for by the consumer.

5. Fuel costs

5.1 Fresh fuel expenses

The uranium fuel cycle consists of the following stages: extraction of uranium ore; milling and production of uranium concentrate, or triuranium octoxide (U_3O_8) – also called yellowcake; uranium conversion into uranium hexafluoride, or hex (UF_6), for subsequent enrichment; enrichment and production of uranium fuel per se; the final stages include management of spent nuclear fuel (SNF), which implies, among other processes, storage and/or reprocessing of spent nuclear fuel.[62]

The price of unreprocessed uranium ore only constitutes about a half of the ultimate price of a uranium fuel assembly suitable for burning in a nuclear reactor, and the cost of producing electricity at a nuclear power plant is much less contingent on the price fluctuations on the raw materials market than is the case for power plants running on hydrocarbon fuels. This is sometimes used as an argument in favour of nuclear energy – even as it should rather be understood as the opposite, since it means that **nuclear power plants become quite vulnerable, economically, in periods of low market activity and**

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[59] Steve Thomas. The Economics of Nuclear Power. Nuclear Issues Paper No 5, Nuclear Power: Myth and Reality, a Heinrich Böll Foundation publication, December 2005. Please follow this link to view the publication in full: http://www.nirs.org/c20/atommythen_thomas.pdf.

[60] As per the pound-to-dollar rate current as of mid-April 2011, when the English version of this report was being prepared. – Translator .

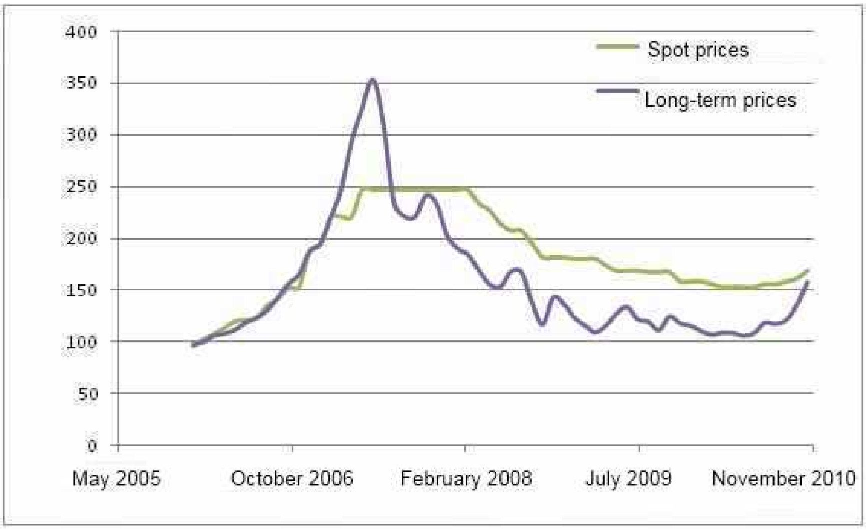
[61] Ibid. – Translator.

[62] Besides expenses incurred at these stages, there are other costs as well: For instance, future costs linked to the management of waste generated during fabrication of fresh fuel or reprocessing of waste produced during enrichment of natural uranium. Costs associated with re-enrichment of uranium tailings (depleted uranium hexafluoride), a by-product of uranium fuel production, range, according to a study done by Germany's Uranerzbergbau GmbH in 1995, between $0.31 and $105 per kilogram of uranium U_3O_8 produced. To an extent – and frequently, only very partially – these costs are recovered by sales of enriched uranium. In our analysis, we will disregard these expenses.

low prices, because a decrease in profit will not be balanced out by a decrease in costs. For instance, market liberalisation and a slump in prices in Great Britain caused many nuclear power plants to fail to recoup their operating costs and led to their bankruptcy.

There is a global market for natural uranium, but trading deals are done outside organised trading venues, being usually concluded privately via specialised companies acting as intermediaries on the market. In the past years, prices have been extremely volatile, and on the whole, price levels grew noticeably, triggered both by the depletion – in real estimates or otherwise based on hyped-up claims – of global uranium reserves and a growing demand for nuclear fuel. Uranium for nuclear power plants' needs is customarily bought on the global market under long-term contracts and, as a rule, at less volatile prices than quoted for spot settlements (or deals concluded for immediate delivery). **According to data from Canada's leading uranium mining and processing company Cameco, the long-term industry average price of U_3O_8 as of November 2010, was $65 per pound (or $169 per kilogram).**

Fig. 1. Global uranium market prices (in US dollars per kilogram of U_3O_8).[63]



So far, the Russian nuclear industry has satisfied its uranium demand by domestic production and has not been directly involved in the global uranium trading market – not, in any case, as a buyer.[64] The Russian uranium producer Priargunsky Mining and Chemical Works[65] supplies all of the uranium it mines to Rosatom's fuel production company TVEL[66] at fixed prices that are much lower than global market prices and, according to statements made by Priargunsky representatives, uranium mining has lately been yielding losses for the company.[67]

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[63] Cameco calculates industry average prices from the month-end prices published by the US-based Ux Consulting and TradeTech. For more information, such as current long-term and spot prices for uranium, as well as price history, please see http://www.cameco.com/investors/uranium_prices_and_spot_price/.

[64] By various estimates, Russia will start experiencing a shortage of uranium sometime between 2015 and 2017, and Rosatom has been actively pursuing deals seeing purchases of foreign uranium production assets. For more information, see, for instance, here: http://bellona.org/articles/articles_2011/slivyak_comment. – Translator.

[65] Priargunsky Mining and Chemical Works is a subsidiary of the Rosatom-owned uranium supplier Atomredmetzoloto (or ARMZ) Uranium Holding. For more information, please see http://www.priargunsky.armz.ru/eng/. – Translator.

[66] More information about TVEL Fuel Company is available at http://www.old.tvel.ru/en/. – Translator.

[67] "Russian Nuclear Fuel Producers," a research report by OLMA Investment Group, December 11, 2006 (Rossiisky yaderny sektor, OLMA Investment Group, 11.12.2006, http://www.olma.ru/files/analytic/tvel_061211_Rus.pdf, in Russian).

For instance, estimates done in 2006 by the Moscow-based investment company OLMA,[68] which based its analysis on a quarterly performance report issued by Priargunsky, pegged the average cost of uranium sold by the company in 2005 at $16.5 per pound of U_3O_8, or $36.5 per kilogram (though a different figure was named by Priargunsky's top management, namely, $14.5 per pound of uranium concentrate, or $32 per kilogram). On the global spot market, uranium concentrate was sold at the time for $28.5 per pound, or $63 per kilogram.

Because the entire nuclear fuel cycle in Russia is managed wholly within the vast corporate structure of Rosatom , it is suspected that transfer pricing[69] is at play in the Russian nuclear domain, a set of conditions and agreements on adjustment of charges for goods and services, established in order to mitigate the industry's tax burden and ensure cross-subsidisation. In addition, so-called toll-manufacturing schemes – where a company processes raw materials that remain the customer's property, so it is not the product that is the subject of a purchase-and-sale contract, but conversion, enrichment, and fuel production services – are in use. All of this complicates a reliable analysis of true levels of costs the industry bears when purchasing fresh nuclear fuel – even though in the view of analysts from the Bank of Moscow,[70] for instance, fuel fabrication prices in Russia approach those on the global market.

Judging by estimates compiled by the above-mentioned investment experts, the Russian nuclear fuel cycle, expressed in cost shares of services rendered in the fuel production chain, looks as follows (estimates here apply to the fuel used by reactors of the VVER-1000[71] design):

Table 7. Cost shares of services comprising the nuclear fuel cycle in Russia, in investment expert estimates (percentage shares of total fuel costs).

Expense category	**Bank of Moscow**	**OLMA Investment Group**
Uranium mining	50 percent	42 percent
Conversion	3 percent	6 percent
Enrichment	38 percent	36 percent
Fuel fabrication	9 percent	16 percent
TOTAL	**100 percent**	**100 percent**

In the West, separate markets exist to purchase and sell conversion, enrichment, and fuel fabrication services, and prices on these markets have in the past several years shown an upward trend, much like uranium prices examined above. See, for instance, the following charts from the US-based Ux Consulting Company illustrating global price fluctuations for uranium conversion and enrichment services (Fig. 2 and 3).

[68] Ibid.

[69] A practice of internal charges between branches of the same company adopted by multi-jurisdictional firms (including multinationals) so that their accounting practices result in reported high incomes and profits in those geographical areas with low tax rates. From the Glossary of Regulation Terms, the Body of Knowledge on Infrastructure Regulation, http://www.regulationbodyofknowledge.org/. – Translator.

[70] Yury Volov. Nuclear fuel cycle: From uranium to nuclear fuel, an analytical review. Bank of Moscow, May 6, 2008. (Volov Yu. Kompanii yadernogo tsikla. Ot urana k yadernomu toplivu, Bank of Moscow, 06.05.2008, http://www.bm.ru/common/img/uploaded/files/file_13985.pdf, in Russian).

[71] RBMK reactors, another Soviet-designed series, use cheaper fuel with a relatively lesser level of uranium-235 enrichment. (The Russian abbreviation RBMK stands for "high-power channel-type reactor" and represents a graphite-moderated reactor technology that was developed for commercial energy-producing operation in the 1960s. The first such commercial reactor, an RBMK-1000, was launched in Russia at Leningrad Nuclear Power Plant. It was also an RBMK-1000 reactor that exploded in 1986 at Chernobyl's Unit 4. RBMK-1000s are still operated at three nuclear power plants in Russia, namely, Leningrad and Kursk NPPs, and Smolensk NPP (in Smolensk Region, Central European Russia). – Translator).

Fig. 2. Spot prices for U_3O_8 conversion services (in US dollars per kilogram) on the European and American markets in 1995 through 2010.[72]

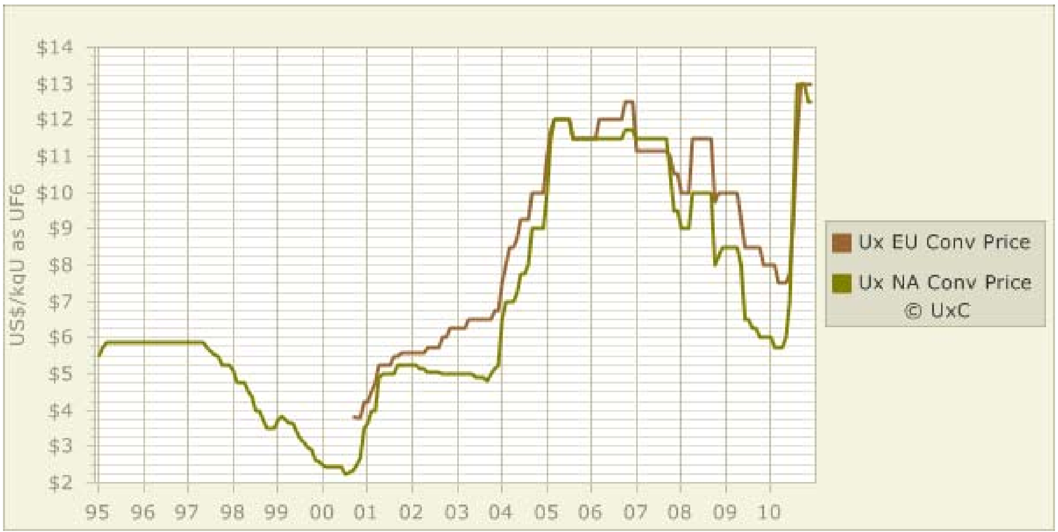
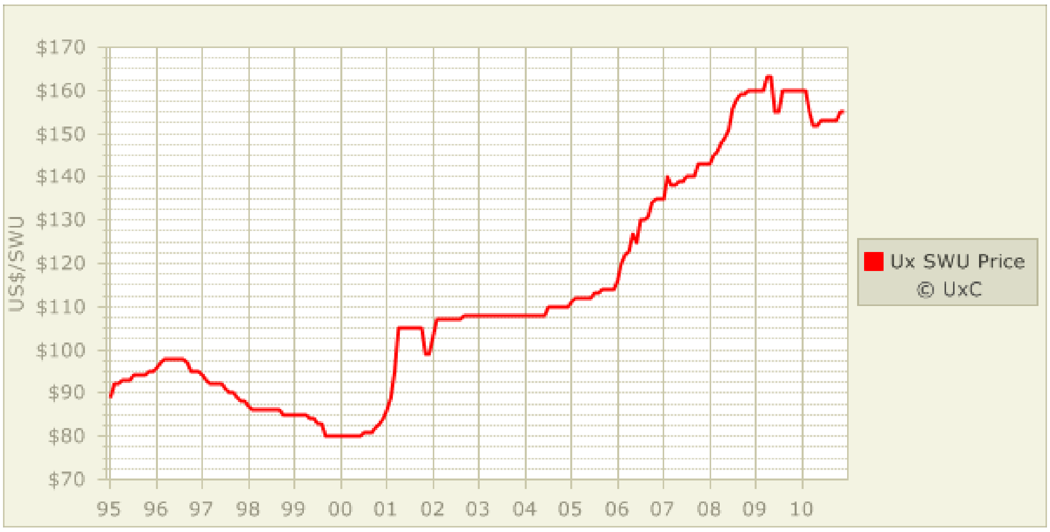


Fig. 3. Uranium enrichment spot prices in 1995 through 2010 (in US dollars per SWU[73]).



According to the same source, UxC, costs incurred by fabrication of fresh fuel range between $200 and $400 per kilogram of uranium.

Adding up the costs of the intermediate stages involved, we can conclude that fresh nuclear fuel costs around $650 [per kilogram), as shown in Table 8.

Table 8. Cost of fresh nuclear fuel (based on data from Ux Consulting Company).

Nuclear fuel cycle cost component	Cost (in US dollars per kilogram)
Cost of natural uranium	160
Conversion into uranium hexafluoride	13
Cost of separative work	160

[72] Source: Ux Consulting Company, LLC (UxC). For more information, please see http://www.uxc.com.

[73] For separative work unit, a complex unit that is a function of the amount of uranium processed and the degree to which it is enriched, that is, the extent of increase in the concentration of the isotope of uranium-235 relative to the remainder. For more information, see, for instance, here: http://www.uranium.info/index.cfm?go=c.page&id=44. – Translator.

Fuel manufacturing	300
TOTAL cost of nuclear fuel	**633**

A more accurate calculation of the total cost of nuclear fuel needed by light-water reactors such as the Western PWR or BWR[74] series to produce 1 gigawatt-hour of electric power per year – as based on the existing technological processes and market prices – can be done using the Uranium Project's online calculators, special online tools provided by the WISE Uranium Project, part of the World Information Service on Energy (WISE).[75]

We shall assume the following values for costs involved in the fuel production chain: Price for natural uranium at $65 per pound of U_3O_8; conversion cost at $12.5 per kilogram; enrichment cost at $155 per SWU, fuel fabrication at $460 per kilogram; management of waste generated during enrichment at $10 per kilogram of uranium "tailings"[76]; and spent nuclear fuel management costs at $600 per kilogram of SNF. The resulting values are shown in Table 9.

Table 9. Nuclear fuel cycle costs (in thousand US dollars).

Cost category	**Operating expenses**	**Future expenses on waste management**	**TOTAL**
Natural uranium	29,528.7		29,528.7
Conversion	2,184.2		2,184.2
Enrichment	17,201.7	1,445.7	18,647.4
Fuel fabrication	13,125.9		13,125.9
Total costs of fresh fuel	62,040.4	1,445.7	63,486.2
SNF management		17,120.7	17,120.7
TOTAL	**62,040.4**	**18,566.5**	**80,606.9**

The resulting fuel cost, computed with the help of the Uranium Project calculators from the parameters in the table above, will total US 0.92 cents per kilowatt-hour.

The actual price that Russian nuclear power plants pay for the fuel cycle is still noticeably lower than the price on the global market – which means, in essence, that nuclear power generation is subsidised in Russia by the nuclear fuel production sector.

But the domestic fuel price will, of course, increase in the future and tend to approach those on the global market. The major reason for this, despite the availability to Rosatom of old weapons-grade uranium reserves it inherited from the Soviet nuclear military industry, is the impending drop in uranium ore production volumes and profitability problems experienced at Priargunsky Mining and Chemical Works.[77] Because Russia's domestic production volumes alone will not be sufficient to cover its own

[74] For "pressurised water reactor" and "boiling water reactor," respectively, two most common light-water reactor series in use in at Western nuclear power plants. – Translator.

[75] For more information, please see the WISE Uranium Project Calculators page at http://www.wise-uranium.org/calc.html.

[76] Or depleted uranium hexafluoride, a by-product of uranium fuel production. See also Footnote 62.

[77] Under an agreement between Russia and the United States, known as "Megatons for Megawatts," or HEU-LEU (highly enriched uranium-low-enriched uranium), which expires in 2013, Russia mixes highly enriched uranium extracted from old nuclear weapons with uranium ore and, through Rosatom's daughter company, Tekhsnabexport, sells the down-blended material for commercial use in US nuclear power plants. The deal is aimed at keeping Russian nuclear materials off black markets. The US pays Russia for the weapons-grade uranium and, on top of that, compensates for the ore used during the conversion. Rosatom is not losing any uranium ore under this agreement, while Tekhsnabexport is free to use the profit it derives from the exports (over $8 billion). At the same time, this changes little in the fact that Russia's uranium production sites are operating at a loss, while using the ore they supply for the HEU-LEU trade creates an illusion of profitability: The US both makes up for the

uranium needs and the demand it has obligations to meet under Rosatom's international contracts, Rosatom will become more and more dependent on supplies from abroad[78] or on buying foreign uranium production assets – and the Russian nuclear corporation is currently making great strides in the latter endeavour.

Still, as pointed out in the analytical report by the Investment Group OLMA, "if, for instance, in 2007 Rosenergoatom [had] purchased uranium from [Priargunsky Mining and Chemical Works] at global spot market prices, then the concern would have incurred additional expenses to a total of $474 million – which exceeds the net profit generated by both Rosenergoatom and TVEL combined."[79]

5.2. Management of spent nuclear fuel and radioactive waste

Management of spent nuclear fuel is a fundamentally unsolvable problem of the global nuclear industry. SNF is either reprocessed or stored, depending on the chosen – open or closed – type of the nuclear fuel cycle in use. Russia is presumed to be aiming for a closed nuclear cycle, which implies SNF reprocessing and subsequent use of the resulting material as part of so-called MOX fuel – mixed oxide fuel that contains a blend of uranium and plutonium and is burned in fast-neutron reactors. But Russia's choice is largely an imaginary one, since the closed fuel cycle is an idea which has yet to be realised in practice, while prospects of its realisation remain unclear. But even if this goal is achieved, the closed fuel cycle is much more expensive than the existing open-cycle option, it is even less environmentally clean, and still cannot offer an acceptable alternative in terms of effective SNF disposal. The very reprocessing technology is extremely costly and energy-consuming, not to mention that it is environmentally dirty, carries potential contamination risks, and leads to the generation of mass quantities of radioactive waste of various kinds (exceeding by two orders of magnitude the original amount of reprocessed SNF). The resulting radioactive waste has to be disposed of, and the reactor-grade plutonium stored until the moment comes when it can be used as part of reactor fuel – which may not ever happen at all.

SNF reprocessing in Russia is done at the Production Enterprise Chemical Combine Mayak[80]. The scope of reprocessing is limited by relevant production capacities at Mayak and the technological properties of SNF of various types. In actuality, only the SNF from VVER-440 reactors is reprocessed, as well as that burnt in naval and research reactors. For technological reasons, SNF from RBMK reactors

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natural ore used in the process and pays for the enriched uranium and conversion, which only covers part of the ore extraction costs.

[78] Russia's annual consumption of natural uranium is at a level of around 7,000 tonnes; it also exports some 6,000 tonnes. The estimated reserves of natural uranium ore – a resource characterised with a low prime cost of production – available for extraction in Russia total 70,000 tonnes. (Vladimir Chuprov. What is the price of nuclear electricity and should we invest into building new reactors? Greenpeace report, April 1, 2004. (Chuprov V. Skolko stoit yadernoye elektrichestvo i stoit li investirovat v stroitelstvo novykh reaktorov? Greenpeace, 01.04.2004, http://www.greenpeace.org/russia/ru/press/reports/163305/, in Russian).

[79] See Footnote 67.

[80] Based in the closed town of Ozyorsk in Chelyabinsk Region, in the Urals, Mayak is a large industrial complex part of which is an SNF reprocessing facility. It also used to house plutonium production reactors, now shut down. In 1957, Mayak was the scene of one of the worst nuclear disasters in history, known as the Kyshtym disaster, when an explosion at the site caused a massive release of high-level radioactive waste. It also has an extensive history of dumping radioactive waste resulting from reprocessing spent nuclear fuel into nearby water bodies – the Techa Cascade, a relatively closed-loop system of four reservoirs, and Lake Karachai. Ozyorsk, a closed town formerly known under the designations Chelyabinsk-40 and Chelyabinsk-65, has been named the most contaminated place on the planet. For more information, see, for instance, http://www.bellona.org/articles/articles_2007/Musymovo_resettle. See also http://www.po-mayak.ru/ (in Russian). – Translator.

cannot be reprocessed and neither can spent nuclear fuel from AMB and EGP-6 reactors[81] or the uranium-zirconium or beryllium oxide fuels used in nuclear vehicle propulsion plants and some types of bench test and research models. In other words, the better part of SNF generated in VVER-1000 and RBMK-1000 reactors – the models that make the bulk of Russia's commercial power reactors – is not reprocessed and remains stored in on-site cooling ponds or temporary storage facilities at nuclear power plants, as well as the centralised storage facility of Building 1 at the Zheleznogorsk Mining and Chemical Combine in Krasnoyarsk Region in Central Siberia.[82] All of these facilities are nearly filled to capacity. As of early 2009, Russia had accumulated some 18,000 tonnes of spent nuclear fuel, half of which was in storage in reactor cooling pools at nuclear power plants. A 1999 report issued by the Russian industrial oversight authority, the Federal Service for Ecological, Technological, and Nuclear Oversight (Rostekhnadzor),[83] said the SNF storage facilities at Russian NPPs running RBMK reactors were already 80 to 90 percent full. Since then, the problem has only exacerbated.

Interim storage in cooling ponds – large pools filled with water that provides cooling to the spent nuclear assemblies burnt in nuclear reactors – is a necessary step in the SNF management process, needed to remove decay heat from the fuel until energy release and radioactivity levels subside. Experience shows, however, that long-term storage in cooling ponds is dangerous because of risks of leakage from the pools, generation of significant quantities of secondary radioactive waste, as well as corrosion of metallic components of the spent fuel assemblies. The depletion of existing natural uranium reserves and the corresponding spikes in uranium prices would have made the closed nuclear fuel cycle a relatively more attractive concept, economically, but this would also render the whole nuclear power industry unprofitable compared to other energy alternatives.

Because there are at present no economically or technologically expedient methods of disposing of spent nuclear fuel, the only option left is long-term monitored storage under controlled conditions until such time that solutions are found to this problem by future generations – which, in every practical sense, means forever. By extension, the concomitant expenses are of the open-ended kind as well: construction and maintenance of specialised temporary storage facilities, insurance of implied risks, etc. Safe accommodation of spent nuclear fuel in storage facilities is only possible for the duration of a limited period of time – around 50 years, as required by design characteristics – and some sort of a decision will have to be made after that as to what the next step will be. The storage facilities, too, have time limitations on how long they can safely remain in service – 100 years, as per the design – after which they will have to be taken out of operation in much the similar fashion as nuclear reactors. It

[81] AMBs (for Russian *atom mirny bolshoi*), were a Soviet series of light-water-cooled, graphite-moderated reactors (LWGRs); two such reactors (AMB-100 and AMB-200) were in operation at Beloyarsk NPP (near Yekaterinburg, in the Urals), launched in 1964 and 1969 and stopped in 1983 and 1990, respectively. EGPs (for Russian *energeticheskii geterogenny petlevoi*) are graphite-moderated boiling-water reactors for combined heat and power(GBWRs). Four EGP-6 reactors are in operation near Bilibino, in Chukotka in the Russian Far East, commissioned in the 1970s. (For more information, please see http://www.belnpp.rosenergoatom.ru/wps/wcm/connect/rosenergoatom/belnpp_en/ and http://www.bellona.org/subjects/1140452669.21 (for Beloyarsk NPP) and http://www.bilnpp.rosenergoatom.ru/wps/wcm/connect/rosenergoatom/bilnpp_en/ and http://www.bellona.org/subjects/1140452675.62 (for Bilibino NPP). – Translator.

[82] Officially, simply Mining and Chemical Combine or Krasnoyarsk Mining and Chemical Combine, a closed town formerly known as Krasnoyarsk-26. Prior to 1995, the enterprise specialized in weapons plutonium production. Main areas of operations include: storage and transportation of spent nuclear fuel, chemical reprocessing etc. For more information, see the enterprise's website at http://www.sibghk.ru (in Russian) or Bellona's coverage at http://www.bellona.org/subjects/1140454732.79. – Translator.

[83] Formerly, the Federal Service for Atomic Supervision (Gosatomnadzor, or GAN), merged in 2004 with the Federal Service for Technological Supervision to form Rostekhnadzor. – Translator.

remains unclear what can be done then with the SNF already in storage there. The spent fuel will possibly have to be moved into new storage sites with larger capacity – and so on ad aeternum.

Actual expenses on SNF management include capital costs of building and decommissioning spent nuclear fuel storage facilities, as well as current expenses incurred by preparing SNF for transportation and storage, transporting it, and ensuring required technological conditions at storage facilities, as well as payroll and remuneration expenses, insurance premiums, etc. The majority of these costs are semi-fixed ones – that is, they do not depend on the amounts of SNF placed into and remaining in storage.

Because all of the operations involved in the nuclear fuel cycle are carried out in Russia by Rosatom-owned enterprises, prices at which individual transactions take place between industry participants are of little significance. But the overall level of expenses involved in maintaining all of Rosatom entities engaged in the entire fuel cycle chain – from producing fresh nuclear fuel to managing spent fuel and disposing of radioactive waste – could be a source of information of much more representative value.

At present, a so-called "dry"[84] storage facility is being built in Zheleznogorsk; the first line of construction there, to accommodate 5,000 tonnes of spent fuel burnt in RBMK reactors, was commissioned in 2010.[85] The project cost around RUR 10 billion, but the total cost of the works is rather difficult to estimate since the storage facility is being retrofitted from an initially planned SNF reprocessing plant, a decades-long construction project that started as far back as the 1980s. In the early 2000s, the SNF storage facility project in Zheleznogorsk was assessed at RUR 15 billion. It is slated for completion and commissioning by 2015 and is expected to have a total storage capacity sufficient to accommodate 38,000 tonnes of spent fuel generated in RBMK and VVER reactors.

If we assume that no less than 10,000 tonnes of SNF is being stored today in on-site NPP storage facilities, and another 850 tonnes is generated yearly, simple calculations show that the Zheleznogorsk facility will be filled to capacity within 33 years – even if only Russian-produced SNF is accepted for storage. However, Russia, as a fresh fuel supplier, is also bound by international obligations to repatriate spent nuclear fuel generated in reactors built by the Soviet Union in other countries – primarily, the former USSR republics and satellite states; this totals almost 50 nuclear power reactors of the VVER type still in operation and RBMK reactors that have been shut down.

Obviously, the capital costs of building the Zheleznogorsk facility – as well as expenses tied to its subsequent decommissioning and building a new storage facility – should be clearly reflected in the deductions that nuclear power plants pay for management of spent nuclear fuel generated at their sites. These deductions should also at the very least be sufficient to cover current operating costs incurred by SNF transportation and storage, insurance, and maintenance of the entire SNF management infrastructure.

For the purposes of assessing capital construction deductions, which must at the very least provide enough funds to recoup the costs of building the SNF storage facility in Krasnoyarsk Region, we will make the following assumptions for the parameters involved (Table 10):

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[84] The practice of "wet" storage means placing spent nuclear fuel in on-site cooling ponds, where the fuel is accommodated in racks kept under water for several years until its radioactivity levels subside. The concept of "dry" storage, on the other hand, suggests loading spent fuel, after at least five years of "wet" storage, into "dry" casks (depending on the design, the casks can be used for both storage and transportation). These are typically sealed metal cylinders enclosed within a metal or concrete outer shell, either placed horizontally or set vertically on a concrete pad. (See the US Nuclear Regulatory Commission's Fact Sheet on Dry Cask Storage of Spent Nuclear Fuel at http://www.nrc.gov/reading-rm/doc-collections/fact-sheets/dry-cask-storage.html). – Translator.

[85] Vadim Ponomaryov. On the way to safer storage, news story. Ekspert Online, June 8, 2010. (Ponomaryov V. Khranit stanet bezopasnei. Ekspert Online, 08.06.2010, http://expert.ru/2010/06/8/hranit_bezopasno/, in Russian).

Table 10. Parameters for calculation of deductions related to SNF storage facility construction in Zheleznogorsk.

Construction costs	RUR 15 000 million
Annual SNF generation	850 tonnes
Decommissioning costs	25 percent of new construction costs
Duration of storage period	50 years
Storage facility service life	100 years
Discount rate	4.5 percent
Interest rate	3 percent

It can be presumed that after the Zheleznogorsk facility is filled to capacity, a new and identical one will be built. It remains to be seen what can be done about this fuel in fifty years. The idea is that it will have to be either reprocessed or kept in long-term storage – for a hundred or more years – in "dry" storage facilities. Either of these decisions will require building the necessary infrastructure and, by extension, new capital expenditure. If, for instance, the SNF is tucked away in dry storage using a method of permanent geological disposal – the concept of burying nuclear waste in a deep geological repository, namely, the so-called Nizhnekansky Granitoid Massif, a rock formation near Krasnoyarsk, is being actively discussed now in Russia[86] – the costs of building such a storage site (RUR 3 billion) will have to be added to the initial capital expenses.

In any case, after fifty years, the SNF of the first period of storage will have to be replaced with newly arriving batches, and this process will remain unchanged until the storage facilities exhaust their engineered life spans.

Estimates say a "wet"[87] storage facility must generate RUR 973 million per year in its active operation years to recover the initial investments, and reserve funds in the amount of RUR 9 million must be accrued to pay for decommissioning costs 100 years from the time of start of operations. In other words, the investment component of deductions for the 850 tonnes of SNF annually produced by the nuclear energy industry has to equal RUR 1,156, or $37 per kilogram.

Because there exists no solution that would once and for all put to rest the pressing issue of spent nuclear fuel and radioactive waste, the associated costs can potentially reach any scope imaginable, however high. This uncertainty is conceded to be the chief impediment to the nuclear industry's development as a commercially profitable energy sector.

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[86] Deep geological disposal of spent nuclear fuel is an idea that has been gaining attention in the West, as well, though experts are sceptical that this is an acceptable solution. One such idea has been proposed in Finland, where Olkiluoto – a site that houses Olkiluoto Nuclear Power Plant (see Footnote 42), in the Gulf of Bothnia in Western Finland – was also selected in 2000 to become the site of disposal of Finland's spent nuclear fuel. The project, however, has come under fire both from environmentalists and scientists, who say the waste will remain a significant environmental hazard for hundreds of thousands of years, while there are no guarantees that the bedrock in which it will be stored will remain geologically stable for that long. Risks of seismic activity and bedrock displacement are cited among the potential threats. In Russia, a controversial new bill, entitled "On Management of Radioactive Waste," has been proposed to govern the previously unregulated sphere of SNF management and disposal of radioactive waste in the country, including the selection of sites for future nuclear geological repositories. For more information, please see Bellona's coverage (http://bellona.org/articles/articles_2010/finland_repository, on Finland's repository project; http://www.bellona.org/articles/articles_2010/rao-law-russia and http://www.bellona.org/position_papers/new_bill_on_radwaste, on the bill on radioactive waste management in Russia). – Translator.

[87] See Footnote 84.

For instance, British energy companies have said already that they cannot build new power plants without the payments deducted for waste management capped at some particular level and have been lobbying for a bill that would place a ceiling on the SNF management expenses, at around £1 billion for waste generated by each new power plant commissioned for commercial operation. *The Telegraph* reported in December 2010 that the UK government insisted this amount was three times as much as Britain's anticipated waste disposal expenses and also included a risk premium. It also said the authorities would be able to spread the risks in such a way that no state subsidies would be required, even though there is an admission that the scope of future waste storage costs remains very uncertain. At the moment, the better part of the budget at the disposal of the British Department of Energy and Climate Change – or around £4 billion a year – is spent on decommissioning costs and storage of old spent nuclear fuel.[88]

A move to institute a cap on SNF management deductions places Great Britain among other nations with a commercial nuclear energy sector – such as the US, France, or Russia – where nuclear power-generating companies do not bear any costs of management of spent nuclear fuel other than the non-recurrent fixed fees after which the nuclear power plants can consider themselves free of any obligations or responsibility for the spent nuclear fuel or radioactive waste they produce.

The very issue of a just and economically well-founded amount of fee deducted for management of SNF and radioactive waste is one that rather lends itself to a debate. A scheme where a one-off fixed fee would serve to cover the very indeterminate storage costs for hundreds of years ahead is one out of insurance practice[89] where the state plays the role of the ultimate insurer – since the financial capabilities of enterprises rendering the services in the branch of SNF and radioactive waste management are apparently even more limited than those working in the nuclear energy production sector. **Such a mechanism of financing SNF and radioactive waste management costs is extremely propitious for the nuclear industry, but, from the point of view of organisation of funding, shares certain very familiar features with financial pyramid schemes**, in that the current activities of the infrastructure that deals with deliveries of nuclear fuel already removed from reactors is financed with fees paid for SNF and radioactive waste that is yet in the process of being generated. This means essentially that should a decision be made to phase out nuclear energy completely, the burden of taking care of the accumulated spent nuclear fuel and radioactive waste will fall on society as a whole.[90]

The exact amount of the SNF handling fee, in cases when spent nuclear fuel is repatriated from Rosatom's customer countries, is settled by negotiations – which often have a pronounced political subtext, such as it happens with Ukraine.[91] The current fee for Ukrainian NPPs is $423 per kilogram of SNF,[92] but it remains rather difficult to estimate whether this is a large amount. The Ukrainians might think that this is a rather steep price, since Russian nuclear power plants pay much less, but on the other

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[88] See Footnote 41.

[89] Or that of put options, if you will. (Investopedia at http://www.investopedia.com defines "put option" as an option contract giving the owner the right, but not the obligation, to sell an asset or a specified amount of underlying security at a preset price within a specified time in the future. – Translator).

[90] In an attempt to address this problem, certain countries have been creating specialised state-governed funds formed with deductions paid by nuclear power-generating companies. These assets are managed by investment companies.

[91] Ukraine is among the countries with the largest shares of nuclear energy in total energy production. Four nuclear power plants with 15 reactor units are in operation in Ukraine (all VVER reactors designed by Russia), with Zaporizhzhia Nuclear Power Plant being the largest in Europe. (http://www.world-nuclear.org/info/inf46.html). – Translator.

[92] Vladimir Chuprov, Oleg Bodrov, Igor Shkradyuk. A decreasing demand for natural gas in Belarus: A nuclear scenario and a path of innovation, monograph. Greenpeace, June 22, 2009. (Chuprov V., Bodrov O., Shkradyuk I. Snizheniye potrebleniya prirodnogo gaza v Belarusi: Yaderny i innovatsionny stsenarii. Greenpeace, 22.06.2009, http://www.greenpeace.org/russia/ru/press/reports/3519657, in Russian).

hand, the price is low enough to allow for an interpretation of this agreement as one by which Russia essentially subsidises the Ukrainian nuclear energy sector, for political or other reasons.

Foreign experience shows that the declared costs associated with the nuclear fuel cycle vary remarkably depending on the country and the technologies in use. For instance, a 2005 study based on a survey of market participants, compiled by the International Energy Agency (IEA)[93] and the Nuclear Energy Institute (NEI),[94] cited nuclear fuel cycle costs ranging between US 0.5 cents and US 2 cents per kilowatt-hour. As regards American nuclear power plants, their costs are relatively low (the IEA's American nuclear sector estimated these costs at US 0.57 cents per kilowatt-hour in 2009).[95] Japanese NPPs bear the highest fuel expenses. In Britain, two studies pegged their fuel expense estimates at UK 0.72 pence (the Royal Academy of Engineering[96]) and UK 1.26 pence (Sizewell B[97]) – or US 1.28 cents and US 2.25 cents, respectively. And according to WISE Nuclear Project,[98] costs of transportation and temporary storage of spent nuclear fuel range between $60 and $290 per kilogram, and costs of vitrification[99] and interment in a geological repository vary widely between $140 and $670 per kilogram.[100]

Thomas[101] believes that the low SNF management costs in the United States can be accounted for by the obligation that the US administration assumes to dispose of spent nuclear fuel in exchange for a fixed fee of US 0.1 cents per kilowatt-hour. This arrangement has been in place for a long time and will very unlikely reflect the real costs of SNF management: No long-term solution has yet been worked out in the United States for the problem of storage of spent nuclear fuel and radioactive waste, and consequently, it is anybody's guess just how much storage costs will ultimately come to even if such a solution is eventually found.

Added here should be the costs of insurance at the post-burnup stage of the nuclear cycle, which cannot be lower than $100 per kilogram of SNF moved into storage. In all, the estimated realistic SNF management deductions should total around $600 per kilogram.[102]

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[93] For more information on this organisation, please see http://www.iea.org/. – Translator.

[94] According to the organisation's website, the NEI is the policy organisation of the nuclear energy and technologies industry and participates in both the national and global policy-making process. For more information, please see http://www.nei.org/. – Translator.

[95] Please see also http://www.nei.org/resourcesandstats/nuclear_statistics/costs. A typical nuclear power plant operating a 1,000-megawatt BWR or PWR reactor pays on average around $40 million for one refuel (one third of the core reloaded), based on a 18-month refuelling cycle.

[96] For more information, please see http://www.raeng.org.uk/. – Translator.

[97] Sizewell B is a 1,195-megawatt PWR-running nuclear power plant operated by British Energy in Near Leiston, Suffolk, on the East Anglian coast. For more information, please see http://www.british-energy.com/pagetemplate.php?pid=96. – Translator.

[98] For more information on this resource, please see http://www.wise-uranium.org.

[99] Vitrification is a solidification method of disposal of radioactive waste by which liquid high-level wastes are evaporated to solids, mixed with glass-forming materials, melted, and poured into stainless steel canisters then sealed by welding. The vitrified waste from a year's worth of operation of a 1,000-megawatt reactor would fill about twelve canisters, each 1.3 metres high and 0.4 metres in diameter and holding 400 kilograms of glass. Commercial vitrification plants in Europe produce about 1,000 tonnes per year of such vitrified waste (2,500 canisters). (From a description of waste management problems and practices at http://www.world-nuclear.org/education/wast.htm). – Translator.

[100] At the same time, in the US, nuclear energy production companies pay US 0.1 cents per kilowatt-hour. For French nuclear companies, this value is US 0.14 cents per kilowatt-hour (http://www.world-nuclear.org/info/inf04ap4.html).

[101] See Footnote 59.

[102] When in the early 2000s the Russian legislature was discussing a bill proposing importing foreign-produced spent nuclear fuel into Russia, storage costs were estimated at between $600 and $1,000 per kilogram. Because it had been earlier assumed that these costs would not exceed $300 to $500 per kilogram, the bill was eventually

But Rosenergoatom's real expenses on SNF management are much lower. For instance, according to Chuprov,[103] the Zheleznogorsk Mining and Chemical Combine accepts spent nuclear fuel from Russian NPPs at a charge of $60 per kilogram. The cost of SNF and radioactive waste management envisioned in the project of a second line of construction at Balakovo NPP was calculated based on 23.6 percent of the cost of managing fresh nuclear fuel – that is, no more than $150 per kilogram, for our estimates. The yearly consumption rate of nuclear fuel (G) can be calculated according to the following formula[104]:

$$G = {N_T * 365\overline{\varphi}}/{\overline{B}} \ ,$$

where N_T is the reactor's thermal, or gross electric power capacity, in megawatts; $\overline{\varphi}$ is the installed capacity utilisation factor; and $\overline{B}$ is the average specific energy release (burnup rate), in megawatt-days per metric tonne.

If we assume, for reactors of the type VVER-1000, N_T to equal 3,000 megawatts, $\overline{B}$ to equal 40 000 megawatt-days per tonne, and the ICUF at 0.8, then the annual fuel consumption rate will come to around 22 tonnes.

This is a very conservative estimate, one that suggests quite a high burnup rate for nuclear fuel. There are estimates that say a VVER-1000 reactor produces no less than 33.5 tonnes of spent nuclear fuel a year[105] and a preliminary version of the official Environmental Impact Assessment study for Rosatom's NPP project in Belarus estimated this value at 26.7 tonnes of SNF per year for one VVER-1200 reactor.

Yearly fuel expenses for nuclear power plants are computed by multiplying the annual fuel consumption rate by the sum of the price of fresh fuel and the cost of SNF storage:

$$Cost_F = \left(Pr_{fr} + Pr_{st}\right)G \ ,$$

Where $Cost_F$ is the yearly fuel expenditure, Pr_{fr} is the price of fresh fuel, and Pr_{st} is the cost of SNF storage. If we assume the sum of Pr_{fr} and Pr_{st} to be $1,300 per kilogram, then the annual fuel expenses for a VVER-1000 reactor should total around $28.5 million, or US 0.4 cents per kilowatt-hour.

The only thing that can be said about Rosenergoatom's declared fuel cycle costs is that they are part of the company's reported material expenses (see Table 6 above) and cannot therefore exceed US 0.83 cents per kilowatt-hour.

Still, we assume that the total costs incurred by maintaining the nuclear fuel cycle in Russia total no less than US 1.1 cents per kilowatt-hour. This is the value on which we will base our estimates of the cost of power produced by Russian nuclear power plants.

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deemed economically inexpedient. (For more information on this initiative, please see Bellona's coverage here: http://www.bellona.org/subjects/Import_of_nuclear_fuel_to_Russia. – Translator).

[103] Vladimir Chuprov. What is the price of nuclear electricity and should we invest into building new reactors? Greenpeace report, April 1, 2004. (Chuprov V. Skolko stoit yadernoye elektrichestvo i stoit li investirovat v stroitelstvo novykh reaktorov? Greenpeace, 01.04.2004, http://www.greenpeace.org/russia/ru/press/reports/163305/, in Russian).

[104] See Nikolai Sinev. The economics of nuclear energy. Moscow, Energoatomizdat, 1987. (Sinev N.M. Ekonomika yadernoi energetiki. M.: Energoatomizdat, 1987, in Russian).

[105] Andrei Yegorov. Nuclear frauds, news story. NuclearNo.Ru, October 16, 2003 (Yegorov A. Atomniye obmanshchiki, NuclearNo.Ru, 16.10.2003, http://www.nuclearno.ru/text.asp?6991, in Russian).

6. NPP decommissioning costs

The nuclear power industry incurs enormous capital expenses not just at the stage of construction of new capacities, but also after shutting down a nuclear power plant, when the decommissioning process ensues. **The market thus charges both "entrance" and heavy "exit" fees to its investors.** It is hard to imagine any other type of industrial assets whose residual cost enters negative values at some point in the course of operation since owning such a site is associated with gigantic negative cash flows. Such a situation means that for an investment nuclear energy project to effect any profit, it is absolutely essential that the asset be operated at a profit during the entire engineered life span of several dozens of years. But the likelihood that the plant will be shut down before its term expires is high as a multitude of various risks – political, economic, or those related to the technologies in use – threaten its closure before the end of the projected useful life period. **All of this makes construction of nuclear power plants a less attractive option when set against comparable projects for power-generating capacities based on other energy sources – even on the condition that the given NPP project generates a higher expected net cash flow.**

The scope of decommissioning costs can only be estimated in speculative terms since only a handful of such projects exist that have been practically implemented. The related literature cites very rough expert estimates on the subject – on the order of "25 percent of construction costs" – which indicates a very high degree of uncertainty with regard to the real costs incurred.

Financing decommissioning costs is organised in different ways in different countries.[106] In ordinary practice, a special reserve fund is created for these purposes and special deductions are accumulated on such an account in the course of the operation period, paid out of the nuclear power plants' revenues. These funds may operate under very different organisational frameworks or legal forms and, consequently, different forms of management may be applied: The fund can remain under the management of the company that oversees the plants scheduled for decommissioning or it can be transferred to an independent managing company.

The establishment of a special fund to accumulate funds made up with decommissioning deductions is necessary for purposes of ensuring the financing of costs that are set apart from the profits they are directly tied with by time gaps as long as 150 years. **The generating company that bears the undisputed responsibility for handling these costs may over time prove unable to pay them when called upon to do so, and the cost of these very expensive works will then have to be borne by society at large.** Furthermore, not having a specialised reserve fund and charging the price of decommissioning old nuclear power plants against the revenues generated by the current operations of newer stations will mean subsidising older generations of consumers by those of younger ones and will thus be **in contradiction with the strictly understood principles of economic justice**.

The approach used to address this problem follows here the outline of the debate on the principles of organisation of pension systems, where the latter – paying for decommissioning with revenues generated by newer stations – is usually represented by the common "pay-as-you-go" state pension scheme, while the former – maintaining a special decommissioning fund accumulated with NPP's own deductions for their own decommissioning decades later – is based on various defined

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[106] See, for instance: Problems of the nuclear legacy and ways to solve them. Ed. Ye.V. Yevstratov et al. Vol. 1. Moscow, Energopromanalitika, 2010. (Problemy yadernogo naslediya i puti ikh resheniya/ Pod obshch. red. Ye.V. Yevstratova, A.M. Agapova, N.P. Laverova, L.A. Bolshova, I.I. Linge. T. 1. M.: Energopromanalitika, 2010). (Materials related to the Federal Target Programme "Ensuring Nuclear and Radiation Safety in 2008 and for the Period through 2015," http://www.fcp-radbez.ru/index.php?option=com_content&task=view&id=433&Itemid=406, in Russian).

contribution benefit plans, including corporate ones, where the relevant funds are kept segregated from the rest and accrued over time but remain under the company's management.

The only significant difference between the two is that the "pay-as-you-go" scheme, in its known and unmodified form, is unfeasible in the nuclear industry. Targeted deductions and accrual of dedicated reserve funds are inevitable even for an NPP operator company as big as Russia's Rosenergoatom. **If the generation of old power plants due to be decommissioned soon is large enough and the aging is uneven across the existing NPP fleet, then the flow of currently paid deductions to the special NPP decommissioning fund may prove insufficient – which is in fact what we are observing in Russia today.** It is one of the reasons why Rosatom has chosen the highly risky option of granting extensions of 15 or more years on the operational licenses of its old nuclear power plants.

This is largely why we will omit the issues of the organisational structure of the NPP decommissioning mechanisms in Russia – an issue which is otherwise a very important one and by all means deserves a separate detailed discussion – and will only attempt, for the purposes of this report, to estimate the approximate costs of decommissioning works and their impact on electricity pricing (assuming that these expenses are borne only by the consumers of nuclear-generated electricity and not all Russian taxpayers).

What should be noted first and foremost is that the uncertainties linked to the total costs of decommissioning a nuclear power plant are even greater than those associated with the costs of new construction. There is not a single nuclear power plant in Russia that would have by now gone through the entire cycle of operation, mothballing, and final dismantlement. Furthermore, it stands to reason that the relevant expenses will depend on the type of the reactors in use as well as a multitude of other factors whose influence is difficult to predict at this point.

In order to have any estimate at all, decommissioning costs are usually calculated as a share of new construction costs – at 25 percent to 30 percent – even as these expense categories have essentially little to do with one another. According to Thomas,[107] decommissioning Sizewell B, a PWR-running plant, might be expected to cost around $540 million, while the cost of decommissioning a Magnox[108] plant is assumed to stand at $1.8 billion.

In Lithuania, the overall costs derived from shutting down Ignalina NPP[109] are estimated at an approximate amount of between EUR 1.2 billion and EUR 2 billion.[110] In Russia, Rosatom has assessed

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[107] See Footnote 59.

[108] Owned by British Nuclear Fuels (BNFL), the now obsolete Magnox reactors are considered the oldest operating commercial reactors in the world. These are pressurised, carbon-dioxide-cooled, graphite-moderated reactors using natural unenriched uranium as fuel and magnox alloy as fuel cladding. The first Magnox reactors at Calder Hall – the world's first commercial nuclear power plant, at Sellafield nuclear processing and former electricity-generating site on the coast of the Irish Sea in Cumbria, England – were designed principally to produce plutonium for nuclear weapons, rather than for production of power. Previously a BNFL site, Sellafield is now owned by the UK Nuclear Decommissioning Authority, which is responsible for decommissioning Magnox reactors. The reactors have been criticised for economic inefficiency, the huge quantities of nuclear waste produced during operation, and the environmental hazards associated with reprocessing of this waste at Sellafield. From Magnox descriptions at http://en.wikipedia.org/wiki/Magnox and http://www.greenpeace.org.uk/nuclear/background-information-on-magnox. For more information, please see Bellona's coverage, for instance, here: http://www.bellona.no/bellona.org/english_import_area/energy/nuclear/sellafield/34631. – Translator.

[109] Until its Reactor Unit 2 was shut down on December 31, 2009, following the closure of Unit 1 five years earlier, Ignalina was running two reactors of the RBMK-1500 type, built by the Soviets in the 1980s. Closing the plant was a condition set forth by the European Union when Lithuania was a newly ascending member. Apart from it being a very costly process, decommissioning of a nuclear power plant is also one fraught with many risks, as evidenced by an accident at the site that occurred in October 2010, when 300 tonnes of radioactive sludge leaked onto the operations floor of the shut-down Reactor Unit 1 during decontamination works. Decommissioning works at Ignalina have to proceed on no previously accumulated experience of decommissioning an RBMK-1500 reactor, and cleanup costs might drive up the ultimate cost of the procedure. For more information, please see Bellona's

the expenses on decommissioning four VVER-1000 reactors of Balakovo NPP at $942.1 million,[111] which looks like an underestimation. For instance, the general view accepted in the Belarusian nuclear circles is that the costs of taking a nuclear power plant our of operation equal those of commissioning one in absolute values.

A wide variety of assumptions can be found in studies done on the economics of nuclear power with regard to decommissioning costs – estimates ranging between $250 million to over $2 billion. Experts from the International Atomic Energy Agency (IAEA), for instance, hold to a more conservative assessment of between $250 million to $500 million, but the very limited global experience in carrying out the full cycle of decommissioning works at a nuclear industry site has already demonstrated that the actual costs incurred tend to exceed noticeably those anticipated in forecast estimates or project documentation.

Costs of decommissioning a nuclear power plant are high, but they do not play a major role in the formal calculation of profitability of this or that investment project, since, being deferred far ahead into the future, they decrease significantly when discounted.

The issue of the particular discount rate to be applied is another one that leaves much room for speculation. A low discount rate is normally used to calculate the necessary financial reserves to decommission a nuclear power plant with regard to which the main expenses will be effected some 100 or 140 years after its closure. This is a markedly lower rate than the required cost of capital calculated in the estimates of an investment project. This has to do with the gigantic time horizon and the corresponding uncertainty of estimates, as well as the overall risks of investing into the nuclear energy industry.

We shall take for our calculations an assumed site with a typical 1,000-megawatt reactor and an interest rate at 3 percent; the total decommissioning costs calculated based on these parameters and split between decommissioning phases, with the last one envisioned 100 years after closure,[112] are shown in Table 11.

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coverage, for instance, here: http://bellona.org/articles/articles_2010/ignalina_leak and http://bellona.org/articles/articles_2010/ignalina_shut_down. – Translator.

[110] See Footnote 92.

[111] See Footnote 16.

[112] NPP decommissioning strategies vary depending on a particular approach to decommissioning time frames. For instance, a choice between an immediate start of dismantlement operations at the shutdown site, mothballing the site until radioactivity levels subside enough to allow for the desired safety level of dismantlement works, and an entombment option is offered in the US to power companies envisioning closure of a nuclear power plant (see the US Nuclear Regulatory Commission's Fact Sheet on Decommissioning Nuclear Power Plants, http://www.nrc.gov/reading-rm/doc-collections/fact-sheets/decommissioning.html). In the case of Magnox plants at Berkley (Gloucestershire, shut down in 1989) and Oldbury (South Gloucestershire, scheduled for shutdown in June 2011), for instance, a 25-year and a 100-year decommissioning strategies were discussed in November 2006 (http://www.sitestakeholdergroups.org.uk/oldbury/upload/oldbury_and_berkeley_joint_meeting_minutes_01_nov_06.pdf#page=7). Thomas (see Footnote 59) writes that conventionally, decommissioning is split into three phases: Under Phase I, fuel is removed and the reactor is secured; this mostly represents a continuation of the operations that were under way while the plant was in operation. In the second phase, the uncontaminated or lightly contaminated structures are demolished and removed. (In economic terms, the incentive is to delay it as long as possible to minimise the amount that needs to be collected from consumers to pay for it—the longer the delay, the more interest the decommissioning fund will accumulate. The limiting point is when the integrity of the buildings can no longer be assured and there is a risk they might collapse, leading to a release of radioactive material. In Britain, it is planned to delay Phase II until 40 years after plant closure, Thomas writes). Phase III is the removal of the reactor core and is the most expensive and most technologically challenging, requiring remote robotic handling of materials. As with Phase II, the economic incentive is to delay the work until it is no longer safe to do so and in Britain, this is expected to result in a delay of 135 years. Accordingly, Thomas estimates the total cost of decommissioning a Magnox plant ($1.8 billion) as split between phases as above – Phase I carried out immediately after closure, Phase II after 40 years, and Phase III after 135 years. – Translator.

Table 11. Costs of decommissioning one 1,000-megawatt nuclear reactor unit split between phases of decommissioning.

Time of start of decommissioning phase counting from closure, in years	Costs before discounting, in million US dollars	Costs discounted at 3 percent rate, in million US dollars
0	150	150
40	300	92
100	550	29
	1,000	271

Thus, by the time the power unit is closed down, a reserve fund of $271 million should be accumulated. If we take the service life of the reactor unit to equal 40 years, and the same rate is applied, then the amount of annual deduction should be $3.48 million, or, multiplied by the industry's total installed capacity, $81 million for the nuclear industry as a whole.

In reality, there is no separate targeted reserve in Russia that would accumulate decommissioning deductions from one individual nuclear power plant for the future decommissioning of that same power plant. Rosenergoatom is expected to finance the decommissioning costs of its nuclear power plants from a special reserve account where 1.3 percent of gross revenue is allocated as per Government Directive No. 68 of January 30, 2002 ("Rules of effecting by enterprises and organisations engaged in operation of especially radiation-hazardous and nuclear-hazardous production facilities and sites (nuclear power plants) of deductions paid to reserve funds maintained to ensure safety of nuclear plants at all stages of life cycle and development"). As of end 2009, this reserve fund totalled RUR 3.06 billion, with RUR 2.1 billion ($70 million) entered on the account throughout that year alone. This means that the amount of deductions is basically commensurate with the anticipated costs, but in order to cover the decommissioning costs in full, this money has to be preserved and accrued at a tangible interest rate – one that would exceed the rate of inflation – of over 3 percent annually for 150 years. In what way these funds are being accrued today – if at all – is unclear. **Most likely, the targeted deductions are going into an all-purpose financial "melting pot" that serves to pay, among other things, for works carried out as part of the decommissioning plan at the sites that have exhausted their useful life.**

It is obvious, meanwhile, that there will be no time left, at these rates, to accumulate an adequate reserve fund to pay for the decommissioning of the plants that are currently still in operation.

If decommissioning and reactor dismantlement costs are to be estimated at 10 percent to 30 percent of new construction costs, then the expenses will total between RUR 12 billion and RUR 25 billion per one gigawatt – or RUR 50 billion to RUR 60 billion to be accumulated before 2020. The difference will have to be covered from the federal budget[113] – or the amount of deductions will need to be increased to at least double the current level.

[113] As of early 2010, there was around RUR 2 billion left in the reserve fund, while the amount of annual credit to the account was also at a level of RUR 2 billion. If we assume that until 2020, the reserve fund will only be growing and no spending will be done using these funds, the accumulated amount will not exceed RUR 20 billion (not counting the interest) – i.e., the overall amount will still be no less than RUR 30 billion short of the desired target.

7. Insurance and liability in the nuclear power sector

The potential damage resulting from accidents occurring at sites of application of nuclear energy can be colossal in scope, both that sustained by the extremely expensive sites themselves and damage suffered by a third party – the population at large, their health, their property, even their lives. If the risks associated with nuclear energy were insured in full and coverage was bought at market prices, the liability premiums would be much larger than the insurance expenses the industry pays today.[114]

There exists a multitude of types of insurance in the nuclear energy industry where full coverage is not provided. These include insurance of various liabilities, medical insurance, first-party insurance of the sites themselves and the personnel they employ. Likewise, insurance is not provided to cover liability to other nations in case of transboundary effects, such as atmospheric transport of radioactive substances as a result of possible accidents at domestic nuclear sites, including during transportation of nuclear and radioactive materials and spent nuclear fuel.

Consequently, it is the state that bears ultimate liability for the entire enormous range of uninsured risks associated with the functioning of the nuclear industry.

At present, the liability of owners of nuclear sites is limited by provisions of international conventions, and should a major accident occur, their expenses will constitute but a meagre percentage of the total scope of expenses incurred by the accident. Furthermore, the detrimental consequences of a nuclear or radiation accident may only fully show themselves when a significant period of time has passed after the event, when neither the organisation responsible for it nor its insurance carrier can no longer be held liable for the damage.

Yet even though only a small part of the existing risks are being insured, the premiums paid for these risks are too large. **There is a number of factors that contribute to the rising costs in nuclear risk insurance compared to other, non-nuclear, technological risks that could be deemed commensurate in terms of their probability or scope of potential damage incurred.**

Firstly, applied in the nuclear industry is the principle of absolute and exclusive liability of the insurer – that is, damages shall be paid without exception since no right of recourse is reserved for the insured.[115]

Secondly, an especially long statute of limitations is provided for initiating legal action or effecting indemnity payments for damage incurred as a result of impact of radiation, both for reasons of the high levels of secrecy prevailing in the industry and because of the deferred nature of consequences of nuclear and radiation accidents.

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[114] There are limits set to nuclear power plant operators' liability. The amended Vienna Convention set this limit at no less than 300 million special drawing rights. Under the amendments of the Paris and Brussels Conventions, the limit was raised to no less than EUR 700 million. Liability limits are, of course, a way to provide major subsidies to the industry. (The International Monetary Fund (IMF) describes the "special drawing rights" (SDR) as an international reserve asset, created in 1969 to supplement IMF member countries' official reserves. Its value is based on a basket of four key international currencies, and SDRs can be exchanged for freely usable currencies. (http://www.imf.org/external/np/exr/facts/sdr.htm). The international liability regime stems primarily from the adoption of two instruments: The IAEA's Vienna Convention on Civil Liability for Nuclear Damage of 1963 (entered into force in 1977 and then amended in 1997; Russia has been party to the Vienna Convention since 2005), and the Organisation for Economic Co-operation and Development (OECD) and the Nuclear Energy Agency's Paris Convention on Third Party Liability in the Field of Nuclear Energy of 1960, which entered into force in 1968 and was bolstered by the Brussels Supplementary Convention in 1963. The original Vienna Convention, of 1963, set the lower liability limit for operators at $5 million (value in gold on 29 April 1963). Additional documents and improvements were later adopted as well. From a description of the historical background of international liability for nuclear damage at http://www.world-nuclear.org/info/inf67.html – Translator).

[115] In other words, no claim can be brought against a third party as the NPP operator is held liable irrespective of fault. – Translator.

And thirdly, traditional approaches that exist in calculating insurance premiums are not applicable in the nuclear industry for reasons of the nearly non-existent statistics on severe accidents and on account of the large amounts insured.

Because of the enormous scale of the insured risks and the specifics of providing these types of insurance, only a handful of outfits working under the umbrella of a joint insurance pool are capable of rendering these services professionally on the market. In Russia, such a pool was created in 1998 out of 20 insurance companies that had undergone a "closed" screening initiated by what was then the Ministry of Atomic Energy of Russia and the now-defunct federal nuclear safety oversight agency, Gosatomnadzor (predecessor to the current Federal Service for Ecological, Technological, and Nuclear Oversight, Rostekhnadzor). Only the members of this insurance pools have the right to underwrite nuclear risks.

The choice of insurance carrier is now limited by Rostekhnadzor to only those companies it specifically makes it possible to buy coverage from. In practical experience, this means that only those companies are allowed to operate on the nuclear insurance market that enter into consulting services contracts with the intermediary – a company called Atomconsulting – that was specially established for these purposes by Rostekhnadzor's predecessor. This contributes significantly to the high costs of insurance services.

The limitations imposed on healthy competition and the need to serve the interests of bureaucrats result in growing premiums in the Russian nuclear insurance market.

At the moment, nuclear liability in Russia is insured for much lesser amounts than the liability limits instituted by the Paris Convention on Third Party Liability in the Field of Nuclear Energy, of 1960,[116] or the 1997 Protocol to Amend the 1963 Vienna Convention on Civil Liability for Nuclear Damage.[117] Should it finally be adopted, the new bill "On Civil Liability for Nuclear Damage and its Financial Assurance"[118] – the draft law was proposed for the Russian legislature's consideration as far back as in 1997 but has not yet been passed in its second reading – will likely increase the amounts of insurance payments manyfold. The Vienna Convention of 1963 placed the lower limit on the operator's liability at $5 million in what was then gold standard dollars – corresponding, today, to around $214.6 million in current US currency, or around RUR 6 billion – for one event that causes nuclear damage. This is exactly the amount specified in Concern Rosenergoatom's contract of insurance against civil liability for nuclear damage. The bill "On Civil Liability for Nuclear Damage and its Financial Assurance" proposes establishing the maximum limit of the operator company's liability for nuclear damage at an amount equivalent to $150 million (RUR 4.2 billion) for one radiation accident.

In any case, should an accident occur, any damages that go beyond the existing liability caps will have to be paid by the state – or, by extension, the Russian taxpayers.

As of 2007, the combined earned premium of the Russian insurance pool paid under insurance contracts providing civil liability coverage for nuclear damage caused by Rosenergoatom (leading insurers MAKS and SOGAS) and the Murmansk Shipping Company[119] (leading insurer UralSib), as well as

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[116] Please see http://www.oecd-nea.org/law/nlparis_conv.html to view the full text of the Convention. – Translator.

[117] Please see IAEA's page here http://www.iaea.org/Publications/Documents/Conventions/liability.html to read about or view the full text of the convention. – Translator.

[118] See Draft No. 96700118-2 of Federal Law of the Russian Federation "On Civil Liability for Nuclear Damage and its Financial Assurance" (http://www.docs.cntd.ru/document/901833467, in Russian).

[119] Until 2008, Murmansk Shipping Company – a commercial fleet operator based in Murmansk in Russia's North – was responsible, through its outfit called Atomflot, for the Russian fleet of nuclear-powered icebreakers. In 2008, Atomflot was transferred over to Rosatom and is now under the nuclear corporation's purview. Atomflot is also responsible for the operation and technological support of the nuclear icebreaker fleet's service vessels. – Translator.

under the reinsurance agreement concluded with Ukraine's National Nuclear Energy Generating Company Energoatom,[120] totalled RUR 149.2 million.[121]

It is quite difficult to assess the scope of risks that remain uninsured – and the insurance premiums that thus remain unpaid – but in most conservative estimates, they should probably be increased multifold.

8. Calculations and estimates

Estimates of individual cost items determine the level of price for the power supplied that allows a typical nuclear power plant to operate at normal profit.

We shall make the following general assumptions:[122]

Used for analysis will be a nuclear power plant running two Reactor Units with two VVER-1000 reactors with a combined installed capacity of 2,086 megawatts. The following parameters will also be assumed:

- Total cost of construction at $5 billion[123] (at $2.5 billion per one reactor unit);
- Total construction period at 8 years;[124]
- Service life at 40 years;
- Installed capacity utilisation factor at 84 percent.[125]

Table 12. Construction costs distributed across years of construction.[126]

Year	Share	Undiscounted investment funds
1	14 percent	714,566,993
2	3 percent	138,778,289
3	12 percent	624,478,899
4	16 percent	777,626,475
5	21 percent	1,035,649,560
6	17 percent	859,068,034
7	12 percent	596,551,621
8	5 percent	253,280,129
Total		**5,000,000,000**

With the parameters assumed above, the annual power output would equal 15.35 billion kilowatt-hours.

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[120] Ukraine's Energoatom is the national NPP operator company. For more information, please see the enterprise's website at http://www.energoatom.kiev.ua/en/index_eng.htm. – Translator.

[121] More information about the insurers mentioned here can be found at these links: http://www.makc.ru/ (in Russian), http://en.sogaz.ru/, and http://www.uralsibins.ru/index.wbp (in Russian). – Translator.

[122] All data that are examined here are either taken from official sources or are the most conservative estimates possible, in line with the lower limit of accepted expert estimates.

[123] As per the design characteristics and declared projected construction cost of Baltic NPP.

[124] Construction period estimated by project designers for Reactor Units 5 and 6 of Balakovo NPP. A goal of completing construction works within five years has been declared, but calculations done here will be based on realistic, rather than desired, construction time frames.

[125] This is a typical value for new nuclear power plant projects.

[126] Breakdown of investment funds over the years of the construction period is taken from the Balakovo NPP project.

The discount rate will be the variable calculation parameter. Two discount rate values have been used in economic feasibility studies done for new nuclear power plant projects – a rate of 4.5 percent, the minimal rate used to estimate the costs of specially socially significant projects (projects that are financed with funds from the federal budget, such as the project of floating nuclear power plants, where this rate was applied to estimate the economic efficiency of the project), and a rate of 8 percent, which was used in the project of construction of Reactor Units 5 and 6 of Balakovo NPP.[127]

We shall first calculate the net cash flow required to cover the capital costs – i.e. the annual proceeds with the deduction of operating expenses. The total discounted cash flow during the construction period equals the total discounted cash flow during the plant's operation period.[128]

Table 13. Capital costs of power generation at different values of the cost of capital.

Cost of capital	**Required cash flow (in million US dollars)**	**Capital costs of power generation (in US cents per one kilowatt-hour)**
10 percent	727.06	4.7
8 percent	555.54	3.6
4.5 percent	318.20	2.1
0 percent	125.00	0.8

The required annual cash flow has to equal the amount of profit after income tax plus accumulated depreciation.

In addition, the operation and maintenance costs have to be covered, which include:

A) Compensation of labour – i.e. payroll and various deductions for social benefits.
The average headcount at Reactor Units 5 and 6 of Balakovo NPP is 1,109 people.
Average pay stands at $700.[129]
Benefits-related charges on payroll account for 34 percent.
B) Total costs incurred by the fuel cycle, at US 1.1 cents per kilowatt-hour.
C) Deductions to the decommissioning reserve fund, at $7 million (1.3 percent of gross proceeds, the share of Rosenergoatom's revenue in 2009 that accounted for this item).
D) Deductions for maintenance repairs and major overhauls, at 2 percent of projected construction costs.
E) Insurance premiums, at $15 million.
F) Depreciation (straight-line basis), projected cost distributed over 40 years.[130]
G) Income tax, at 20 percent of accounting income.

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[127] The cost of capital cited in studies done on the costs of nuclear-generated energy by Western experts ranges between 5 percent and 15 percent depending on the author's overall attitude to the nuclear industry and, possibly, on special terms of financing such as state guarantees. The only study where the cost of capital was assumed at 5 percent – carried out by Finland's Lappeenranta University of Technology (http://www.lut.fi/en) – also assumes in its calculations other values that are extremely favourable to the nuclear energy industry. The difference in the costs of capital between Russia and countries where these studies were undertaken – the United States, Great Britain, and Finland – also should be taken into account.

[128] Generation of heat accounts for some 5 percent of a nuclear power plant's product and will be ignored here for the purpose of simplifying the calculations.

[129] The nuclear energy sector needs its influx of highly qualified personnel and, furthermore, is a hazardous industry with a poor reputation. The enormous shortage of workforce is bound to result eventually in a staggering hike in labour costs – possibly, to the level now holding in the oil and gas industry.

[130] To simplify this analysis, we will ignore the difference between the projected cost of construction estimated in the design and the cost of key assets that arise as the result of the construction and are depreciated accordingly.

The required annual net cash flow, N, generated by the plant can be calculated from:

$$\sum_{i=1}^{40} \frac{N}{(1+r)^n} = I\ ,$$

where *I* is the total discounted amount of investment and *r* is the discount rate.

To calculate the required electricity tariff, we need the total positive cash flow, or the revenue from sale of product, *R*.

R can be found from the following:

$$N = R - K - T = 0{,}8(R - K) + 0.2D\ ,$$

where *K* is the sum of all real expenses (without depreciation), *D* is depreciation, and *T* is income tax: $\mathrm{T} = 0.2(R - K - D)$.

Table 14. Calculated operating costs (compared with operating costs as per Balakovo NPP project).

Cost item	**Estimate (in thousand dollars)**	**Balakovo NPP project (in monetary units)[131]**	**Estimated share in total costs**	**Share in total costs in Balakovo NPP project**
Payroll[132]	12,483	9,036	2 percent	4 percent
Fuel	168,845	126,548	54 percent	56 percent
Deductions for decommissioning	7,000		1 percent	
Insurance	15,000		3 percent	
Deductions for maintenance and repairs	100,000	32,004	18 percent	14 percent
Other expenses		19,451		9 percent
Total without depreciation	303,329	187,039	78 percent	82 percent
Depreciation	125,000	40,005	22 percent	18 percent
TOTAL	**428,328.8**	**227,044**		

Depreciation here is higher, but the calculations concern a new nuclear power plant, and its replacement cost per unit of production is noticeably greater than that found with respect to older stations.

The operating costs without depreciation can therefore be estimated at $303,328,750, or US 1.98 cents per kilowatt-hour.

Calculation results are shown in Table 15.

[131] Operating costs taken from the Balakovo NPP project are, nominally, in thousand dollars but, as they correspond to early 1991 prices, their conversion to any currency will unlikely result in very accurate values – hence the “monetary units.” More important here, however, are the shares of particular cost items in total costs.

[132] Labour costs are five times as little as average values per one unit of installed capacity (see also Table 4 in this report) across the structure of Rosenergoatom as a whole. This says little about the distribution of salaries in the organisation. Yearly income figures for top managers look as follows: Rosatom head Sergei Kiriyenko, RUR 16.36 million (or around $580,350, as per the rouble-to-dollar rate current as of mid-April 2011. – Translator); Deputy Director General, HR Management, Tatiana Kozhevniekova, RUR 29.71 million; Rosatom Deputy Director General, Public Authority Execution and Budgeting, States Secretary Tatiana Yelfimova, RUR 24.06 million. Researchers and engineers at Rosatom’s State Scientific Centre Research Institute of Atomic Reactors (NIIAR) earn RUR 150,000 (from Passing off ideas as facts, plans as results, and words as deeds, Bulat Nigmatulin’s interview given to PRoAtom.Ru (Zamysel vydayotsya za fakt, plan za rezultat, slovo za delo www.proatom.ru/modules.php?name=News&file=article&sid=2660, in Russian)).

Table 15. Price of electricity generated by Russian nuclear power plants as calculated to cover all industry expenses.

Cost of capital	Required net cash flow (in million US dollars)	Required revenue (in million US dollars)	Cost of unit of production (in US cents per kilowatt-hour)
10 percent	727	1061.6	8.1
8 percent	555.5	890.1	6.7
5 percent	318.2	652.8	4.8
0 percent	125	459.6	3.2

At a 5 percent discount rate, nuclear-produced electricity costs, as shown above, US 4.8 cents per kilowatt-hour; at an 8 percent discount rate, the cost of power generation is US 6.7 cents; and with the cost of capital equalling zero, that value is US 3.2 cents, without VAT.

Fuel management costs account for a large part of operating costs and therefore have the biggest impact on the final result. But even if fuel cycle costs were assumed to be zero, we would see that the tariff needed to ensure that a nuclear power plant does not operate at a loss should be US 3.67 cents for the discount rate at 5 percent, US 5.6 cents for the discount rate at 8 percent, and US 2 cents for the zero rate.

To compare with other assessments, this is what the overall cost structure of nuclear power production looks like, roughly, in estimates done by the Bank of Moscow:

Table 16. Bank of Moscow's estimates of costs of nuclear power production.

Cost item	Cost of production, in US cents per kilowatt-hour	Share in total NPP prime cost
Fuel	0.80	24 percent
Operation and engineering maintenance	1.93	58 percent
Capital costs, present value	0.60	18 percent
TOTAL	**3.33**	**100 percent**

SNF management costs are apparently, here, part of the operation and maintenance costs. And the discounted capital expenditure can only be in such low values here if much more optimistic, industry-favourable assumptions are made with regard to the construction cost and construction time frame and/or cost of capital than estimated in this report.

According to Vladimir Milov,[133] "in order to recoup the investor's expenses on building a nuclear power plant at capital costs ranging between $3,000 and $4,000 per kilowatt of new capacity, the tariff must equal RUR 1.5 to RUR 2[134] [per kilowatt-hour] of [electricity produced]." We assume construction costs to be at much lower values, of around $2,400 per kilowatt-hour, but in reality, costs can, of course,

[133] Vladimir Milov. Why is development of nuclear energy harmful for Russia? Moscow, 2009. (Milov V. Pochemu razvitiye atomnoi energetiki vredno dlya Rossii? M., 2009, http://www.rusolidarnost.ru/pochemu-razvitie-atomnoi-energetiki-vredno-dlya-rossii, in Russian).

[134] Between US 5.3 cents and US 7.1 cents as per current exchange rate. – Translator.

grow to the cited levels and an assessment of US 5 cents to US 7 cents will then be an adequate estimate of the cost of nuclear-generated electricity.

We must keep in mind that examined here is the average tariff for electricity sold, to which various grid expenses and suppliers' mark-ups are added to form the final price for the end consumer. Therefore, the level of market prices at which the nuclear energy industry would be able to recover its expenses without state subsidies should be higher still.

It will now be interesting to run a comparison of the results of calculations we have made with the "visible" part of the nuclear electricity costs – namely, the tariff in place for Russian nuclear power plants. For instance, the following tariffs are currently applied with respect to the energy produced by Rosenergoatom's Balakovo NPP and sold on the wholesale market at regulated prices[135]:

Electricity tariff rate at RUR 180.03 per megawatt-hour (excluding VAT);

Capacity tariff rate at RUR 390,829.01 per megawatt-hour (excluding VAT).[136]

Recalculated for an NPP with the parameters examined here, this would correspond to $326.1 million as payment for capacity and $92.1 million as payment for electricity supplied (if we assume that all of the power generated is supplied within the range of threshold trade volumes). Altogether, this comes to $418.2 million, or US 2.7 cents per kilowatt-hour (excluding VAT).

That said, the threshold volumes of trades concluded at regulated prices are decreasing gradually for Rosenergoatom enterprises, and the concern is starting to sell more and more electricity on the open day-ahead market, where trading is done at higher prices – at the level of RUR 800 to RUR 1,000 per megawatt-hour (or between US 2.7 cents and US 3.5 cents per kilowatt-hour), but the revenue generated on this market so far does not influence Rosenergoatom's overall financial results in any principal way.

For comparison with a non-nuclear capacity, we shall take an energy-generating site that is listed right below Rosenergoatom's enterprises in the Federal Tariff Service's November 2009 order[137] establishing tariffs for electric power (capacity) sold at regulated prices in the wholesale market – Permskaya GRES.[138] The electricity tariff for power produced by Permskaya GRES is RUR 642.09 per megawatt, and the capacity tariff is RUR 89,295.20 per megawatt. The direct price of electricity established for the site is, therefore, around US 2.14 cents per kilowatt-hour, while capacity payments add almost nothing to this value – only US 0.05 cents.[139]

As we can see, **a typical gas-fired power plant built in the early 1970s survives on the power market with a tariff of US 2.19 cents per kilowatt-hour without any funding from the federal budget, state guarantees, or any special measures of tax relief or tax incentives.** And the peculiarities of NPP

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[135] See Order No. 326-e/3 of November 24, 2009 by the Federal Tariff Service of Russia, "On tariffs for electric power (capacity) sold in the wholesale market under contracts concluded within the framework of threshold (maximum and minimum) volumes of trade in electric power (capacity) at regulated prices (tariffs)."

[136] Or $6.39 and $13,881, respectively. – Translator.

[137] See Footnote 135.

[138] For Permskaya State Regional Power Plant, a gas-fired power plant located in Perm Region in the Urals. For more information about the plant, see the website of Permskaya GRES's operator company, First Power-Generating Company on the Wholesale Energy Market (OGK-1), at http://www.ogk1.com/en/?ch=pl&id=1&art=2. – Translator.

[139] The installed electric power capacity of Permskaya GRES is 2,400 megawatts. In other words, total capacity payment is RUR 214.3 million. If we divide this amount by the volume of the plant's output – at 14.252 billion kilowatt-hours, as of 2007 – capacity payment would account for RUR 0.015 per one kilowatt-hour of output, or US 0.05 cents out of the total amount of capacity payment.

operation as a baseload generating capacity[140] mean that the economically justified average price of nuclear-generated power should be even lower than the average market one.

Thus, the power produced by nuclear power plants already now costs more to the Russian consumer than the electricity generated by power plants running on gas, while the electricity tariff is still far below the level needed to cover the true expenses of the nuclear energy industry. The deficit is compensated for by the state, which essentially provides cost-free capital to the industry, bears liability for those nuclear risks that are not covered by insurance premiums, and participates, to a significant degree, in direct subsidisation of the nuclear fuel cycle.

All assumptions made in this report with respect to calculated parameters have been as favourable as possible to the nuclear industry, given the current situation. **Still, however, the conclusions we can make with regard to the economic aspects of the nuclear energy industry hold little promise.**

Yet, a certain potential for improvements exists and, should it be taken advantage of, it can influence the results of calculations and offer more optimistic estimates of economic possibilities.

1. Construction time frames, *Ct*. Nuclear power plants can generally be built faster than they are at present. This is evidenced by the examples of such countries as South Korea and, especially, China. Standardisation, accumulation of experience, and other factors can facilitate efforts to reduce construction time frames to, say, five years as opposed to today's seven or eight years. Reducing construction time frames can have the same effect as lowering the discount rate, since it results in a shorter waiting period until the expected periods with positive cash flows.
2. Fuel costs, *Fc*. The expenses incurred by managing spent nuclear fuel and radioactive waste make for an extremely debatable issue, since no one really knows the real costs involved. If we disregard, for the moment, all the many external factors at play, state subsidies provided in the guise of limited liability for SNF storage risks, etc., then the after-burnup fuel costs can be considered lower than we assume them to be. Furthermore, a real decrease in the true costs of SNF management can happen as well, triggered, for instance, by advances in modern technologies that might lead to more efficient (higher) fuel burnup. Costs can also be reduced here by organisational decisions or change in policy, such as a decision to phase out the closed nuclear cycle or, on the contrary, opt for the closed cycle instead if its shows dramatic improvements in its economic performance. Costs reported by the US nuclear power plants in the category of SNF management currently account for less than US 0.6 cents per kilowatt-hour, which, of course, is less than the "real" costs, but opinions differ as to how big the discrepancy. We shall thus assume, for our calculations, the value of US 0.6 cents per kilowatt-hour as the minimal estimate of fuel costs. They are among the most important of operating expenses and impact directly the prime cost of electricity produced.
3. The installed capacity utilisation factor, *ICUF*. The average ICUF across Rosenergoatom enterprises is less than 80 percent, but it approaches 90 percent at more efficient nuclear power plants (Balakovo and Rostov NPPs), which corresponds to average values in the foreign nuclear energy industries. We can assume it as a realistic goal to increase this value from the 84 percent estimated in new NPP projects to the 90 percent shown by more

[140] Baseload supply means, essentially, the availability of at least the minimum supply of power to consumers, and baseload plants are expected to produce energy at a constant rate to provide for some or all of the continuous consumer energy demand – normally, at a lower cost than other supply capacities in the grid. – Translator.

efficiently used capacities. A capacity utilisation rate increased to a value of 0.9 improves all other performance factors by 7 percent.

4. Useful life, *Ul*. The engineered life span of new nuclear power plants is now increased from 30 to 60 years. Sixty years is the standard design-basis operating life span of American nuclear power plants and we can more or less accept this time frame as a realistic one on the condition that designers, manufacturers, and project supervisors can guarantee the desired resource of the equipment to be used for the entire duration of the station's useful life term. This will have a triple significance for future calculations: The period during which decommissioning reserve funds are accumulated will extend in time; a longer time period will be available to earn from investing the accumulated reserves; and decommissioning expenses will be deferred to periods farther ahead into the future, while their present-value cost decreases.[141]

Table 17. Influence of longer useful life periods and shorter construction time frames on the prime cost of nuclear-produced power, as compared with baseline calculations (with *r* as cost of capital equalling 0.1 and *Fc* equalling US 1.1 cents per kilowatt-hour).

Parameter combinations	Cost of electricity, in US cents per kilowatt-hour
Ct = 8 years, ICUF = 0.84, Ul = 40 years	7.97
Ct = 5 years, ICUF = 0.84, Ul = 40 years	7.94
Ct = 8 years, ICUF = 0.84, Ul = 60 years	7.86
Ct = 5 years, ICUF = 0.84, Ul = 60 years	7.83
Ct = 8 years, ICUF = 0.9, Ul = 40 years	7.51
Ct = 5 years, ICUF = 0.9, Ul = 40 years	7.48
Ct = 8 years, ICUF = 0.9, Ul = 60 years	7.41
Ct = 5 years, ICUF = 0.9, Ul = 60 years	7.38

We see that in and of itself, the impact of such improvements is not very large. We should also note, of course, that construction time frames do not just play an important role from the point of view of improving cash flows, but they are also linked directly with construction costs.

Table 18. Cost of electricity after a significant cut in fuel costs (with *Fc* equalling US 0.6 cents per kilowatt-hour, *Ct* at 5 years, *Ul* at 60 years, and *ICUF* equalling 0.9) and calculated for different costs of capital, *r*.

Cost of capital	Required net cash flow, in million US dollars	Required revenue, in million US dollars	Cost of unit of production, in US cents per kilowatt-hour
10 percent	886.7	1,131.0	6.88
8 percent	651.5	895.8	5.45

[141] Decommissioning deductions have been assumed here as equalling $7 million, as per the standards in force at Rosenergoatom. Our calculations show that if by the end of the useful life period an amount of $271 million needs to be accumulated (this might be an underrated value), then, taking the useful life term to be 40 years, the deductions should be around $3.5 million. If the service life period is 60 years, these deductions should be $1.6 million. These changes look quite impressive, but if we take into account that $7 million accounts for no more than 2 percent of the calculated operating costs of a nuclear power plant, then even a significant decrease in the deductions will not influence the final result in any major way. We will thus ignore these changes just as we did in our main calculations.

5 percent	367.0	614.3	3.74
0 percent	91.5	335.8	2.04

As follows from Table 18, a decrease in fuel costs will have a much more noticeable influence on the resulting cost of electricity – but will still hardly change the overall picture in any principal way. At a cost of capital at 0.05, the prime cost of nuclear electricity equals US 3.74 cents per kilowatt-hour – which still means that under any scenario, nuclear power in Russia remains a more expensive option than the existing alternatives and cannot recoup its expenses with the tariffs currently in force.

Conclusions

Examined in this report were various economic aspects of the nuclear power industry. The main objective of the analysis done in this study was to estimate the "true" costs borne by the industry and calculate the cost of electricity produced by nuclear power plants with all such expenses taken into account.

The estimates we have drawn from our analysis show that as of today, the nuclear energy industry is an economically unviable sector and is incapable of developing on a commercial basis – even with state guarantees in place that eliminate some of the market risks existing for the industry.

At this time, there are too many problems that the industry is facing for it to be the best bet that the country can make in its energy policies. The very fact that the civil nuclear programme (the commercial sphere) is so intertwined with that of the defence sector (which is financed from the state budget) leads to cross-subsidisation, while the state – which remains heavily involved at all stages of management – relieves the industry from the better part of the decision-making responsibility, thus fostering an environment that is conducive to inefficient choices.

The economy of the nuclear energy industry depends to a great degree on the amounts of capital investments it attracts. This – combined with the unique design characteristics of each new power plant, the declining workforce and the losses the material resources of the industry have suffered in the post-Soviet period, as well as the traditional ethos of secrecy still prevalent in the nuclear industry – makes it especially susceptible to risks associated with operating in an environment fraught with corruption and lack of healthy competition and does not allow it to control its costs, first and foremost those incurred during construction.

Furthermore, costs borne by the nuclear energy industry are growing even as non-nuclear energy alternatives are becoming increasingly cheaper, both in conventional energy sectors and those employing renewable sources of energy.

Russia can avail itself of almost no competitive advantages that other countries with nuclear energy have. For instance, the weak resource base that the industry has at its disposal places an additional cost burden on the output produced and makes the country dependent on foreign supplies.

Finally, the problem of spent nuclear fuel still remains unsolved and the costs of dealing with this problem – the price that future generations will eventually be forced to pay – may prove overwhelming.

Appendix: The Economics of Floating Nuclear Power Plants

The following is a detailed treatment of the economic considerations and liabilities behind the floating nuclear power plant project, an idea first proposed in the former USSR that has lately gained considerable traction in modern Russia. Floating nuclear power plants are devised as a means of providing a convenient supply of energy to remote and barely accessible regions of Russia's Far North, and Rosatom has been engaged in a massive propaganda campaign extolling their virtues. Construction of a first such unit is currently being completed at a shipyard in St. Petersburg, and at least six more units are envisioned in the series. This endeavour comes, however, equipped with a multitude of safety and other risks – examined in detail in Bellona's 2011 report "Floating Nuclear Power Plants" – as well as a number of economic uncertainties, an analysis of which is presented below.

A large land-based NPP is a unique project with a considerable number of contractors and a large volume of construction and assembly works, which on the whole results in implementation timeframes and expenses that are difficult to predict.

It has been suggested to make floating nuclear power plants (FNPPs, or FNTPPs, or LC NPPs), which began to be developed actively in Russia in the 1990s, as standardised as possible, and thus promote them on the world market. It is thought that because of the lower scale of the project, the client has better control over expenses. In practice, however, the cost of the first FNPP project, now nearing completion at Baltiisky Zavod in St. Petersburg, grew from the $150 million declared by the former Ministry of Atomic Energy in 2001 to a $550 million (RUR 16.5 billion) announced by Rosatom head Kiriyenko in 2010, i.e. by more than 3.5 times. The situation is such that the atomic industry today intentionally underestimates the cost of a floating nuclear power plant, because in projects that were developed in the 1990s, a cost of between $192 million and $254 million was initially established.

As a result of a tender held in 2006, a contract was signed between Rosatom and the Severodvinsk-based shipyard Sevmash on the construction of the first such movable plant to be deployed in the town of Vilyuchinsk in Kamchatka Region. The deputy head of Rosatom at the time, Sergei Obozov, said then the project cost RUR 9.1 billion, or EUR 226.8 million. But according to the feasibility study of the project done in 2007, the total cost, including capital expenses, cost of project preparation works, research and development, planning and surveying and design works, was to reach already RUR 10.540 billion in 2007 prices.

When in 2010, the first reactor unit was floated, Kiriyenko finally revealed the cost of the unit to be RUR 16.5 billion, of which RUR 14.1 billion was the cost of the unit proper, and RUR 2 billion was the cost of the onshore and offshore infrastructure planned in the place of deployment to ensure the FNPP's safety and security and connect it with the local grid; the entire project was thus estimated at $550 million. Project preparation works were financed from the federal budget, and on the whole it is difficult to judge to what extent RUR 80 million – the cost of these works as specified in the feasibility study of the project – is an adequate estimate, since this included work done by several organisations that was spread out over a period of time.

It is likewise not very clear to what degree the project includes financing of the social infrastructure. According to V.M. Kuznetsov et. al,[1] these expenses should add another 10 percent to the total costs.

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[1] Vladimir Kuznetsov, Alexei Yablokov, Alexander Nikitin et al. Russia's Floating Nuclear Power Plants: A Threat to the Arctic, World Ocean, and Nuclear Non-Proliferation (http://www.bellona.ru/reports/floatnpp, in Russian).

The idea to develop the sector of small-scale nuclear energy installations has received the status of a socially significant project. It is financed under a federal target program and, accordingly, has extremely low requirements for economic indicators. For example, the required discount rate was set at 4.5 percent per year. This rate is extremely low, and simple calculations show that applying rates that are even slightly closer to commercial rates - for example, 6 percent – would make the project unprofitable.

As in the case of ordinary nuclear power plants, capital expenses are enormously significant for the profitability of a project, but here, the uncertainties stemming from the project's subsequent operation play an even more important role.

The volume of turnover, as expressed through the installed capacity utilisation factor (ICUF), depends mainly on two factors – demand for energy in the region and the uninterrupted operation of the plant itself. The project is based on two estimates of electricity sales volumes to consumers of the closed administrative territorial entity[2] of Vilyuchinsk and the Central Power Distribution System of the Kamchatka grid – 455 million kilowatt-hours and 410 million kilowatt-hours per year starting from 2015, which means 74 percent and 67 percent, respectively. These estimates seem to be excessively optimistic. The total installed capacity of power plants feeding electricity to the Kamchatka grid's Central Distribution System is 477 megawatts, but output levels stand at just 1.37 billion kilowatt-hours. Given the current demand, it can be assumed that the floating nuclear power plant should provide for exactly a third of the region's needs.

For a closed energy system that does not have the possibility of selling surplus energy outside the region during periods of low energy consumption, lower ICUF values are realistic – not more than 50 percent. A considerable stake is made on auxiliary projects that should enable a general increase of power demand in the region.

Besides demand restrictions, there are technological ones as well, as the plant must regularly undergo routine maintenance and then overhaul maintenance in dry dock every 10 to 12 years, which makes it impossible to attain ICUF values of more than 82 percent.

The installed capacity utilisation factor has enormous importance for the prime cost per unit of production, as the majority of operating expenses do not depend on the sales volumes. Current operating expenses can be divided into expenses connected with the fuel cycle, salaries, and various deductions as per existing standards and regulations to provide for future obligations.

A number of expenses require adjustment, as several of them, according to some experts, have been deliberately underestimated. These include expenses incurred by the nuclear fuel cycle, decommissioning expenses and the associated annual deductions, and insurance deductions. In particular:

1. Deductions tied to replacement costs for key assets (first and foremost, depreciation) are significantly higher because of the greater final cost of the project.
2. Deductions (in semi-variable expenses) which are calculated based on the sales volume may be lower because of the overestimated ICUF, but as the electricity tariff may well be higher

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Moscow, Center for Russian Environmental Policy, 2000. (Kuznetsov V.M., Yablokov A.V., Nikitin A.K. i dr. Plavuchiye AES Rossii: Ugroza Arktike, Mirovomu okeanu i rezhimu nerasprostraneniya. M.: TsEPR, 2000).

[2] Known under the Russian abbreviation of ZATO, "closed administrative territorial entities" are restricted-access areas used for classified military or nuclear research. As part of the USSR's atomic-drive legacy, they have been serving as a kind of "reservations" created for the country's scientific community by the top Soviet nuclear authority in the mid-20th century to conduct highly sensitive research and experiments. There are 42 such towns spread across Russia with a combined population of over two million; most of these locations are known by combinations of a name and digit only, such as, for example, Krasnoyarsk-66. – Translator.

than the one that the project bases its calculations on (expenses must be covered somehow in any case), it is difficult to judge whether they need to be adjusted up or down.

3. Higher expenses on nuclear fuel should be expected. Firstly, there is concern over the possible depletion of uranium reserves and profitability problems in the uranium ore production industry, so all fresh fuel may at some point have to be purchased at market prices. Without attempting to forecast global prices for uranium ore, we may nevertheless say that no phase-out of world nuclear energy is yet taking place and the demand for uranium is not dropping, while the supply is limited by the capacities of existing mines. And development of new fields translates into a higher level of prices. Secondly, charging rates for treatment (transport, storage, and processing) of spent nuclear fuel and radioactive waste are clearly underestimated and do not cover the real expenses of specialised organisations engaged in these activities. Storage and transport of spent nuclear fuel and radioactive waste in remote regions are particularly expensive. The difference is covered by state subsidies, commercial foreign orders, and redistribution of resources within the industry – meaning, ultimately, again by state financing. It is clear that a more realistic estimate of the actual expenses associated with the nuclear cycle is one and a half times higher than the one planned in the project.
4. It is suggested that expenses for decommissioning the plant are to be funded via annual deductions accumulated on a special account. The project estimates these costs at RUR 28.5 million per year, which translates into RUR 1.0277 billion over 36 years. According to V.M. Kuznetsov et al,[3] however, the decommissioning costs should be estimated at around $150 million, i.e. around RUR 4.5 billion. Of course, if an annual interest rate of 4.5 percent is factored in, the accruements can be expected to result, over the 36 years, in an amount of RUR 2.57 billion, but the final sum will still be around RUR 2 billion short of the more realistic target.
5. There is practically no correlation between the size of a nuclear power plant or the volume of production output and the majority of risks and the scope of potential damage, which should mean a greater percentage of insurance payments in the structure of expenses for a low-capacity NPP compared with an ordinary one. If one takes into account the fact that at present, only some of the risks are insured against that are linked with nuclear energy, and in case of an accident, the state will bear the better part of the liability, the actual expenses for insurance premiums will almost certainly have to be estimated as one and a half times as high.

Uncalculated expenses

1. One specific problem of a floating NPP is that every 10 years (or 12 years, according to the project) it must be put in dry dock for repairs. This involves considerable direct expenses (lease of the dock, towing to the dock, and the actual repair works) and indirect expenses (the need, for the grid, to replace the resulting loss of electricity supply with more expensive power supplies and to maintain reserve capacities, which also require maintaining fuel supplies). The entire procedure takes about a year and the project provides for other capacities substituting for the absent nuclear power plant according to a flexible schedule. The idea is that the entire fleet of floating NPPs will consist of several (eight, on the whole) plants. Of course, it is possible that by the time that the term of overhaul repair for the first plant comes around, a second plant will be built which will replace the first, but so far this second plant does not exist, and we must assume that during overhaul maintenance, the region will have to put up with a year-long loss of capacity.

[3] See Footnote 1.

Even if we assume that the direct expenses are covered by deductions for these purposes (which is disputed by V.M. Kuznetsov et al[4]), then the indirect expenses still cannot be accounted for and calculated as part of the prime cost of production.

To make a rough estimate of expenses the grid will incur owing to the peculiarities of the FNPP's operation, we can multiply the volume of production at the capacities to be removed from the grid, divided over the period of the plant operation, by the difference in the prime costs with the replacing capacities. We should also add here the expenses the grid will have to bear to maintain these replacement capacities for the period that they stand idle in cold reserve. It is most likely that one of the existing thermal power plants (TPPs) will be used as a reserve facility. As of 1997, the prime cost for producing 1 kilowatt-hour of electricity at Kamchatka TPP-1 was RUR 2.87. According to project documentation, the prime cost of electricity produced at a gas thermal power plant is RUR 3.6. The weighted average cost of power capacity paid for by consumers in Kamchatka as of 2010 was RUR 557,333 per megawatt per month, but these figures clearly exceed the real expenses for maintaining the cold reserve in working condition. For a modest estimate, we will take one tenth of the declared cost.

2. Payments to the owner of invested funds are not provided for in the project at all. It is assumed that the state receives profit through increasing tax payments and a reduction in expenses it usually bears delivering goods to the remote and barely accessible territories in the Russian North. Nevertheless, from an economic standpoint, funds invested at the low rate of 4.5 percent should be paid back. If one assumes that a loan at a 4.5 percent interest rate was taken out to implement the project, then the interest on the loan should accordingly be included in the prime cost.

Thus, the structure of operating expenses and the prime cost, if the needed adjustments are done in the calculations and factored in accordingly, will look as follows:

Table I. Constant and semi-variable expenses.

Expense item	Value, in million roubles per year	Adjusted value
Salaries	84,480	
Unified social tax	21,965	
Ongoing maintenance of fixed assets	33,604	
Rent payments for land	4	
Fire prevention services	300	
Health rehabilitation services for personnel	590	
Mess expenses for the crew	3,390	
Other expenses for ensuring normal work conditions and industrial safety measures	4,510	
Primary and additional training for the personnel	118	
Expenses of service facilities	1,500	
Unforeseen expenses	10,987	
Environmental pollution tax	2,700	
Service water	2,119	
Communications services	1,200	
Charges for the use of water area	15,178	
Physical protection	2,022	
Deductions for overhaul maintenance	145,584	
Decommissioning	28,547	49,977
Depreciation	273,840	462,000

[4] Ibid.

Nuclear fuel supply	209,026.4	313,539.6
Personnel insurance	3,078	
Deductions to the FNPP reserve fund[5]	34,889.2	
Property and liability insurance	18,470.75	27,706
Interest on loan		742,000
TOTAL	**887,795**	**1,981,681**

These expenses do not include the indirect costs incurred to the Kamchatka grid, which come to RUR 105 million annually.

Thus, taking into account the adjusted total costs and keeping the cost share allocated to each product, we can now estimate the production cost of electricity and heat as follows:

Table II. Calculation of prime cost.

Net generation of:		
– Electric power, in million kilowatt-hours per year	455	307
– Thermal energy, in thousand gigacalories per year	270	219
Prime cost of production of:		
– Electric power, in roubles per kilowatt-hour	1.54	4.9
– Thermal power, in roubles per gigacalorie	730	2,169

With indirect expenses factored in, the prime cost of heat and electrical energy will be RUR 2,284 per gigacalorie and RUR 5.1 per kilowatt-hour, respectively.

Taking into account all the costs stated above, it appears that a low-capacity nuclear power plant that the project envisions is in fact one of the most expensive alternatives there may be to gas-powered plants. According to official data, the projected costs of building one floating nuclear power plant total around RUR 16.5 billion ($550 million). The unit cost of FNPP construction comes to about RUR 240 million ($7.8 million) per one megawatt of installed capacity. At the same time, the unit construction cost of the land-based nuclear power plant that is currently being completed in Finland,[6] for instance, is $3.3 million per one megawatt.

In 2007, the issue of the FNPP's economic expedience drew this harsh criticism from the economist German Gref, former head of the Russian Ministry of Economy and Trade, during a government meeting convened to examine a three-year programme of investment into the Russian power generation industry: "*The cost of one kilowatt of installed capacity of the floating nuclear power plant is $7,200. […] this will never pay off. It's seven times as high as in heat generation*." Today, experts have been heard pegging this figure at $10,000 per kilowatt – ten times as high as the cost of one kilowatt of installed capacity of a thermal power plant. Given that Rosatom's experts say the FNPP is to pay off within 12 years – and one must add to the capital costs involved the running expenses incurred by maintaining physical security at the plant and other expenses described above – two pertinent questions clamour to be asked: How high a price will Rosatom's calculations have to result in for one kilowatt of power? And who will buy such expensive electricity?

[5] A special account set aside for various expenses arising from the operation of the FNPP's nuclear reactors.
[6] See Footnote 42 in the main part of this report (3. Problems of Nuclear Power Industry Regulation).

Furthermore, the total cost of building an FNPP should probably also include the expenses the Russian Ministry of Emergency Situations will bear creating additional means of emergency management and keeping related equipment, infrastructure, and forces ready in case it needs to respond to a nuclear or radiation accident in the area of anticipated FNPP operation. Expert findings must be taken into account as well that state that the costs of physical protection measures provided for an FNPP sold for export and stationed abroad may reach 50 percent of the total construction costs. It seems self-explanatory, therefore, that given all these factors, the FNPP endeavour is patently loss-making, and no investor – apart from the state – will risk investing anything into a hopelessly unprofitable project such as this.

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