Chapter 6: The Nuclear Sector

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6.1 Nuclear Power Plants in the Czech Republic

After coal, nuclear energy is the second most important source of energy in the Czech Republic, generating base-load electricity. The annual production of nuclear power plants has been around 28–31 TWh since 2016, covering one-third of the country's total electricity production of 87 TWh. Nuclear energy also serves as an important emission-free form of energy and accounts for 80% of Czech emission-free electricity production.

There are two nuclear power plants in the Czech Republic, with a total of six pressurized reactors cooled and moderated by light water. The Dukovany nuclear power plant is located in the Vysočina region, with four VVER[1]-440 (V-213 type) pressurized water reactors. It first provided electricity in May 1985. The Temelín nuclear power plant is located in Southern Bohemia and has a pair of VVER-1000 (V-320 type) pressurized reactors. It was completed in December 2002. Both plants are owned by ČEZ, a. s. Both have undergone modernisation to increase their installed capacity, lifetime, and to heighten safety measures.

Tab. 6.1: Review of ČEZ, a. s. Nuclear Power Plants as of December 31, 2012

Locality	Blocks marked as	Installed capacity (MWe)	Type of reactor	Total installed capacity (MWe)	Total installed capacity (MWt)	Start up	Distribution company	Voltage (kV)	Distribution point
Dukovany Nuclear Power Plant	1	510*	VVER 440, V 213 type	2,040	5,776	1985 – 1988	ČEPS	400	Slavětice
	2	510	VVER 440, V 213 type						
	3	510	VVER 440, V 213 type						
	4	510	VVER 440, V 213 type						
Temelín Nuclear Power Plant	1	1,082**	VVER 1000, V320 type	2,164	6,240	2000–2002	ČEPS	400	Kočín
	2	1,082**	VVER 1000, V320 type						

* In May, 2012, all units at the Dukovany power plant were modernized, boosting its installed capacity from 4 × 440 MWe to 4 × 510 MWe.

**In 2013, the Temelín power plant underwent modernization that placed its capacity at the 2 × 1,055 level. Since September 2014, the first block's capacity has been increased to 1,078 MWe. A further modernisation was undertaken in 2018, when installed capacity was increased to 1,082 MWe depending on circumstances (such as, for example, the temperature of the cooling water). Another capacity increase is planned for 2020.

Source: Energetický regulační úřad, 2010b, p. 89; revised and modified by T. Vlček.

1 VVER means water cooled, water moderated energy reactor (or water – water energy reactor), in Russian Vodo-Vodyanoi Energetichesky Reaktor.

6.2 Deposits, Mine Production, Companies and Traders

Uranium mining has a long history in the Czech Republic. Until April 27, 2017, it was one of the last European countries to mine uranium. All seven registered deposits are now closed, with the Rožná Deposit being the last to go. The only company engaged in uranium mining was DIAMO, s. p. (a state enterprise[2], until May 1, 1992, known as the Czechoslovakian Uranium Industry, State Enterprise).

DIAMO was founded in 1946, and was under the full control of the Ministry of Industry and Trade of the Czech Republic. Now that mining has come to a close, DIAMO offers other services connected to mining, specifically, remediation work, neutralization of the consequences and impact of mining and the processing of uranium ores, base metals and coal, and the technical and biological recultivation of devastated properties after decommissioning (see *DIAMO, s. p.*).

The Czech Republic was formerly one of the leading world producers of uranium. Between 1946 and 2009, its production of almost 111,000 tonnes of uranium in the form of sorted ores and chemical concentrates made it the 9th largest producer in the world. Without doubt the dominant source of uranium was the Rožná deposit in Dolní Rožínka. The Rožná mine was supposed to be shut down in the mid-1990s, when uranium sales experienced a crisis when a previously significant customer, Slovenský energetický podnik, š. p. (later Slovenské elektrárne a. s.), refused to purchase Czech uranium and started obtaining enriched nuclear fuel directly. Governmental Decrees from 1994, 1997, 2000, 2002, 2005 and 2007 gradually prolonged the mining period in Dolní Rožínka, while with Decree No. 1086 on December 22, 2014, the government extended the mining and processing of uranium in the deposit for as long as it was economically efficient[3], and the termination of mining was pegged to the results of a profitability assessment[4]. After its closure, there are still around 112,000 tons of un-extracted uranium, mostly in Liberecký region and Vysočina region. But most likely uranium mining will not be renewed, because it is not currently economical. The contemporary global uranium market is large enough to cover demand. The Czech contribution to global production was minimal, decreasing from 1.3% in 2003 to 0.1% in 2017.

Tab. 6.2: Deposits, reserves, and mine production of uranium in the Czech Republic

	2011	2012	2013	2014	2015	2016	2017
Deposits – total number	7	7	7	7	7	7	5
– exploited	1	1	1	1	1	1	1
Total mineral reserves	135,276	135,214	135,144	135,071	135,037	135,015	134,948
– economic explored reserves	1,406	1,323	1,327	1,321	1,330	1,337	1,300
– economic prospected reserves	19,402	19,458	19,427	19,463	19,448	19,448	19,448
– potentially economic reserves	114,468	114,433	114,391	114,287	114,259	114,230	114,200
– exploitable (recoverable) res.	338	312	284	314	308	313	276
Mine production	252	222	232	165	134	128	56
Production of concentrate	216	219	206	146	122	137	59

Note: reserves, mining and the production of uranium concentrate expressed in tonnes; the production of uranium concentrate resulting from remediation works is not included in these values.

Source: Ministerstvo životního prostředí / Česká geologická služba – Geofond, 2012, p. 102; Ministerstvo životního prostředí / Česká geologická služba – Geofond, 2018, p. 172.

The processing of uranium ore consists of several steps. First it must be cleansed of waste rock (clean uranium in the Czech Republic accounted for an average of 0.16% of uranium ore[5]). The cleaned ore is then grounded and, following chemical treatment with sulphuric acid, processed into uranium concentrate – triuranium octoxide

2 The term DIAMO is an abbreviation for ammonium diuranate, in Czech *Diuranát amonný*.

3 According to its methodology, the International Agency for Atomic Energy considers economically efficient such mining as does not exceed a cost of 130 USD per to mine 1 kg of uranium.

4 DIAMO, s. p., carries out a mining profitability assessment every half year, and when it reaches negative figures, activity will be immediately terminated. Mining can be ended in several months on a regular basis, while remediation can, however, last for decades.

5 In the mid-19th century, when uranium mining was first initiated, uranium ores consisted of 65% uranium (see Majer, 2004, p. 183).

U_3O_8 (or yellow cake[6]). DIAMO's intermediate product was purchased by ČEZ, which was one of DIAMO's exclusive users of uranium concentrate. Domestic production, however, did not satisfy ČEZ's demand, and so the company either bought additional supplies on the world market or directly purchased enriched fuel.

At the start of 2000, domestic mining covered approximately 93% of domestic demand. However, as a result of the inhibition program, only around a third of consumption was provided by DIAMO until 2009, with the remaining supplies bought on the global market in the form of a concentrate of previously enriched fuel (see Ministerstvo životního prostředí / Česká geologická služba – Geofond, 2010, p. 200). Since the end of 2009, when the Russian company OAO TVEL began supplying fuel for both the Dukovany and Temelín nuclear power plants, ČEZ has purchased only the final product, enriched fuel, while DIAMO has sold its domestic production on the global market.

Tab. 6.3: Uranium Futures Price of Uranium Concentrate (U_3O_8)

2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
113,41	96,63	140,84	115,32	94,25	77,63	79,65	76,32	48,70	53,35	61,75

Note: Values always as of January of the particular year. Data indicated in USD per kilograms.

Source: indexmundi.com, tradingeconomics.com, calculated by T. Stašáková.

When ČEZ began to make exclusive use of purchased concentrate following the shift to uranium hexafluoride UF_6, it had to seek out processing plants on the global market that could perform enrichment services. These can be obtained in only nine countries in the world[7], and ČEZ bought from France. Enrichment plants are capable of enriching supplied uranium hexafluoride according to the client's requirements. Uranium has a constant ratio of isotopes: 99.284% ^{238}U, 0.711% ^{235}U, and 0.005% ^{234}U. However, it is isotope ^{235}U that is employed in fission reactions and used in the nuclear industry. Enrichment is a process during which uranium gets a greater concentration of the ^{235}U isotope at the expense of ^{238}U, varying, for Czech civilian nuclear needs, between 3.6 and 4.4%.[8] From the point of mining through to enrichment, the volume of exploitable uranium rapidly declines in this manner. For initial processing, only 0.16% of mined material is employable, while during the enrichment process at the level of approximately 4% ^{235}U, the volume of material lessens eight to eight-and-a-half times. In the case of uranium this is nevertheless an enormous energy density, since 1 kg of nuclear fuel generates 2,100 GJ of energy compared to 0.033 GJ for coal[9] (see "*Fyzikální aspekty,*" 2008, p. 24).

Enrichment is followed by fabrication, where fuel gets processed into pellets (roughly 1 cm in diameter and height) which are then fitted into fuel rods[10], a specific number of which are then placed into fuel assemblies (segments, cassettes[11]). In the active zone of each reactor in the Dukovany nuclear power plant, there are 312 fuel assemblies, each weighing 215 kg and consisting of 137 kg UO_2 in 126 fuel rods, while the Temelín nuclear power plant has 163 fuel assemblies (cassettes) in each reactor, each weighing 766 kg and consisting of 563 kg UO_2 in 312 fuel rods (each rod consists of approximately 370 pellets). In the active zone of one unit of the Dukovany nuclear power plant, there is, therefore, 42.7 tonnes of UO_2 fuel, and 91.8 tonnes in one unit of the Temelín nuclear power plant. The fuel made in this manner is then supplied to the client, ČEZ.

6 Yellow cake does not always have a consistent chemical formula U_3O_8 or yellow colour. It got its name from the appearance of uranium concentrate in the early mining and production period. Yellow cake now tends to be brown or black, but U_3O_8, for example, has an olive-green colour. The chemical formula of yellow cake can take forms such as: U_3O_8, UO_2, UO_3, $(NH_4)_2U_2O_7 \times n\ H_2O$ or $Na_2U_2O_7 \times 6\ H_2O$. Yellow cake is transported in blue barrels.

7 Sorted by capacity, the order is: Russia, the USA, France, Canada, the Great Kingdom, China, Iran, Brasil and Argentina. But in all 12 countries are internationally recognized by the nuclear industry as holders of uranium enrichment facilities with different industrial production capacities, adding Pakistan, Netherlands and Germany (see INB 2018; WNFF 2018).

8 The Dukovany plant has always used fuel supplied by the Russian company OAO TVEL, which went through major developmental changes. Initial fuel with 3.6% ^{235}U enrichment was employed in a three-year cycle, with an average calorific value of 30 MWd/kg U. A gradual improvement brought the plant to the zone of low neutron spillage and 3.8% ^{235}U enrichment. In the further phase, enrichment was lifted on 4.25 resp. 4.38% ^{235}U, while a burning absorber started to be used in the fuel cassettes (see ČEZ, a. s., 2010b, p. 31) lowering fuel reactivity.

9 Calculated by T. Vlček.

10 The length of a fuel rod for the VVER 440 reactor is 242 cm.

11 Cassette is a Russian term for a fuel assembly.

The long-term permanent fuel supplier for the Dukovany plant is the Russian company OAO TVEL, which fabricates the fuel and also provides a comprehensive array of conversion and enrichment services under contract (ČEZ, a. s., n. d.). From 2002, when the plant was launched, to the end of 2009, fuel for the Temelín nuclear power plant was supplied by Westinghouse Electric Company, LLC[12]. In 2010, the selection process for a new supplier was won by the Russian company OAO TVEL, which submitted the best offer from a financial standpoint. The result is that until 2023, OAO TVEL will be the exclusive fuel supplier for both Czech nuclear power plants. Despite the contract, there have been changes to the fuel supplied as ongoing research brings some innovations to the field. Since 2018, OAO TVEL has supplied Czech nuclear power plants with a new type of fuel (Gd2M+) said to be more mechanically resistant and which allows for longer fuel-campaigns, since enrichment levels are slightly higher and the overall amount of uranium is also increased. Also, six new fuel assemblies (LTA – Lead Test Assemblies) from Westinghouse Electric Sweden have been in testing at Temelín NPP since March 2019 as a preparatory step for testing compatibility with the potential supplier before signing a new contract. Licensing this new type of fuel took Westinghouse three years (see ČTK, 2019).

Fuel was formerly delivered to the Czech Republic by air from the USA or Russia[13]; at present, it is also transported by air from the Russian Federation and then by railway to the target power plants[14].

6.3 Spent Fuel and the Nuclear Waste Repository

Fission chain reaction transmutes the uranium isotope ^{235}U. Spent fuel contains approximately a quarter of the original value of that isotope, which means that it remains enriched at a level of around 1% ^{235}U. Spent fuel consists of around 95% of uranium dioxide (UO_2) and of newly emerged ingredients of plutonium oxide (PuO_2) amounting to approximately 1%, along with other compounds (4%)[15], whereas the majority of fission products are highly radioactive isotopes (see Laciok, Marková & Vokál, 2000, p. 190; Otčenášek, 2005, p. 536, adjusted by T. Vlček). Fuel assemblies with spent nuclear fuel that are removed from reactors look like fuel assemblies with fresh fuel. Nuclear reactions take place even after the fuel is discharged from the reactor, as well as the release of alpha, beta and gamma radiation, neutrons, and heat, which must be exhausted out in a controlled manner.

The Dukovany nuclear power plant initiated operation on the basis of a three-year fuel cycle. The increase of ^{235}U's share in cassettes enabled it to reach a full five-year cycle (with a six-year cycle under consideration). Currently, this means that during the annual refuelling, only 1/5 of the spent fuel is replaced out of the overall charge, i.e. 72 fuel assemblies (see ČEZ, a. s., 2010a, p. 31).

The active zone at the Temelín nuclear power plant includes 163 fuel assemblies, while the plant's operation is set on a four-year fuel cycle, meaning a quarter of the spent fuel is replaced each year, i.e. 41–42 fuel cassettes (see ČEZ, a. s., n.d.a).

After removal from the reactor, three phases of fuel deposition follow. The first phase includes the collection of spent fuel after its removal from the primary circuit and subsequent cooling until it reaches treatable form. The second phase includes safe transport to the location of final waste deposition. The third phase, deposition, is understood as the final operation, which is why the depository needs impenetrable protection shields (see Marek, 2007, p. 4).

In *the first phase*, fuel elements are actively cooled in a spent fuel pool next to the reactor. After a minimum five years, they are moved into dry containers and then passively cooled in interim storage. After being removed from the reactor, the thermal capacity of spent nuclear fuel in the Dukovany plant is 223.5 kW and then drops to 1 kW over the course of only one year (see Nachmilner, 2002, p. 12). The Dukovany power plant uses CASTOR 440/84[16]

12 Temelín NPP experienced massive malfunctioning related to the geometric stability of this fuel, which eventually led to the premature unloading of all of Westinghouse's fuel assemblies despite financial losses, and replacement with TVEL fuel. Problems with fuel also occurred in Ukraine to a lesser extent, but still enough to cause a lengthy unscheduled outage at two of the units, which eventually led to technological adjustments to the fuel and consequent relabeling to Robust (TVS-RW). (see Vlček 2016, p. 81)

13 In the 1990s, transport by sea via the Polish port Gdańsk (from Russia) and then by railway to the final destination was also considered.

14 In Dukovany's case, for example, a cargo plane lands at Brno Tuřany International Airport, goes through the requisite customs and technical inspections and is then loaded onto the wagon for transport to the power plant under police escort.

15 Exact numbers depend on the level of original fuel enrichment.

16 Or modernized Castor 440/84M.

containers, which were formerly supplied by the German Consortium GNS Gesellschaft für Nuklear-Service mbH and RWE Nukem GmbH,[17] but are now supplied by Škoda JS. A simple calculation based on this data leads to the conclusion that the Dukovany power plant produces less than a container of spent fuel per year. An empty container weights 93.7 tonnes and 116.1 tonnes when filled.

There are two interim storage facilities for spent fuel at the site of Dukovany nuclear power plant. The total capacity of the original Dukovany storage, opened in 1995, amounts to 600 tonnes of spent fuel stored in 60 CASTOR 440/84 containers. In 2006, once this storage capacity had been completely used, new storage was set up with a capacity of 1,340 tonnes of spent fuel. In comparison to the first storage facility, the newer facility contains approximately twice the capacity. The storage portion of the facility can receive 133 CASTOR 440/84M containers, allowing the Dukovany plant to store spent fuel for 50 to 60 years, that is, for a period exceeding the lifespan of the power plant itself[18] (see ČEZ, a. s., n.d.d; Marková, 1996, p. 626–627).

The Temelín nuclear power plant uses CASTOR 1000/19 containers from the original German supplier and from Škoda JS[19]. These are 5.5 metres tall and when filled weigh approximately 116 tonnes. The Temelín power plant produces two full containers and 3–4 fuel assemblies of the third container of spent fuel per year. In 2010, a new interim storage facility was opened with a capacity of 1,370 tonnes (152 CASTOR 1000/19 containers).[20] The capacity of a dark wet pool for spent fuel is 680 fuel assembly places and 25 places for hermetic cases. Spent fuel may thus be stored in the pool for around ten years, which is why interim storage did not prove necessary before 2010. The Skalka facility for the central dry storage of nuclear fuel in the vicinity of Bystřice nad Pernštejnem was built as backup storage, with an overall capacity of approximately 2,900 tonnes of fuel.

The second phase, transportation, is currently by rail and is subject to very strict monitoring by the State Office for Nuclear Safety. It is likely that spent fuel will also be transported by rail for a few decades if deposited in deep geological repositories. This, however, cannot be claimed with certainty because it will depend on available technologies as well as the locality and access to the future deep geological repository. Fuel is stored in dry interim storage for a period of approximately 80 years. The final deep geological repository (*third phase*) in the Czech Republic will not be available before 2065.

There are three surface repositories in the Czech Republic: the Richard Radioactive Waste Repositories near Litoměřice, Bratrství near Jáchymov, Dukovany, and one closed repository, Hostim near Beroun[21]. These repositories store institutional radioactive waste that comes from medical, industrial, agricultural and research activities and is therefore composed of waste containing natural radionuclides and low-activity radioactive waste from nuclear power plants. One deep geological repository is planned as well.

In 1990–2005, the SÚRAO (Radioactive Waste Repository Authority)[22] originally selected 27 potential localities for building a deep geological repository of radioactive waste. It narrowed them down to 13, then to 11, and finally to the current 9: Březový potok near Pačejovo, Čertovka near Lubence, Horka near Budišov, Hrádek near Rohozná, Čihadlo near Lodhéřov, Magdalena near Božejovice, Kraví hora near Moravské Pavlovice, Janoch near Temelín, and Na Skalním near Dukovany.

But construction has lagged behind schedule. The original plan consisted of four phases: starting with a basic land survey and research phase from 2010–15, a second exploratory phase from 2015–25, and a third detailed exploratory phase from 2025–50. After postponements, four candidate localities were to be chosen in 2018; one is

17 Spent nuclear fuel from the Dukovany nuclear power plant used to be transported to an interim storage site at the Jaslovské Bohunice nuclear power plant in Slovakia. From this location, it was meant to be used up gradually on the basis of an interstate agreement with the Soviet Union. Following the demise of the Soviet Union, the Russian Federation, however, withdrew from these commitments. After 1993, nuclear fuel from Dukovany was brought back to the country and placed in interim storage at the Dukovany plant.

18 The present power plant was licensed only until 2025. The first unit received a prolongation for 10 years and the second unit for an indefinite duration, conditioned upon the submission of regular reports. But Dukovany´s shutdown is expected by 2045 at the latest.

19 CASTOR 440/84 and CASTOR 1000/19 containers are presently produced in the Czech Republic as well. Their licensed producer is Škoda JS, a. s.

20 In addition to the Dukovany and Temelín power plants, another high-activity radioactive waste repository is operated by ÚJV Řež, a. s., where there are two research nuclear reactors in operation (LVR-15 and LR-0). The capacity of the high-activity radioactive waste repository in Řež is substantially lower, as the ÚJV produces only about 15 spent fuel segments per year. In 2007, all waste was transported to the Russian Federation, so this repository is currently empty.

21 The repository was closed in 1997 and has been monitored since.

22 Due to the transience of private companies, the final radioactive waste repository is not ČEZ's but the state's responsibility under Decree No. 263/2016 (the Atomic Law).

to be selected by 2025 as the new location for the repository, with a second chosen as a backup (MPO 2018). But at the end of 2018, the decision was postponed once again and, according to SÚRAO, will be decided in the first half of 2020. After obtaining adequate data to prove the safety of locality finally chosen, submission of the application for a construction permit for a deep geological repository will follow, with construction to take place in 2050–65 (see Správa uložišť radioaktivních odpadů, n.d.). When this period has ended, it will also be decided whether to process spent fuel from nuclear power plants and to use it as energy material for the production of new fuel, or if it is to be permanently stored in a deep geological repository.[23] But the process has so far been delayed, particularly when it comes to shortlisting potential locations.

Obstacles for the deep repository are several. First, the localities chosen are close to populated areas, which means 53 municipalities involved in the discussion of the deep nuclear repository. None of them is willing to accept the repository. Quite the contrary: most have started movements[24] against it or organized protests (see Ocelík et al. 2017). One of the main arguments is that the government does not provide enough information or guarantees. It is also seen as a danger to the local environment. Second, there is a criticism towards procedure of the State and the SÚRAO[25]. Third, the political situation is unfavorable. The issue incurs into the discussion of constructing a new nuclear power plant in the Czech Republic and, most importantly, its financing. Finally, there is the economic side of the repository. Plans call for construction to cost CZK 36.7 billion. Together with operating costs and containments, the price tag will reach CZK 111.4 billion[26] (see MPO 2017, p. 42), while the very future of nuclear energy, especially in Europe, remains uncertain.

Processing of nuclear waste is currently technically, energetically, and financially a costly process, one few countries[27] can afford, but the technology and initial costs could change over the next 50 years to bring it within broader reach. A deep geological repository is meant to be a final repository of spent nuclear fuel. It is questionable whether it should be technologically implemented so as make it impossible for already deposited waste to ever be picked up again or to enable deposited waste to be extracted and processed in the distant future. Even though experts incline to the second alternative, because spent nuclear fuel represents a valuable material that can be used as fresh fuel after being processed or even as fresh fuel without previous processing[28], the economic reality is in favour of the first alternative. The most expensive feature of a repository is its operation, which makes it economically infeasible to keep a repository open for decades. This means it is better to store spent fuel on a long-term basis in interim storage facilities and only when so decided, to deposit high-activity radioactive waste at once, and to do so finally (opening the storage facility and using it again would be impossible). A deep geological repository is constructed under the assumption it will work for the next hundred years.

So far there is only deep geological repository of spent fuel under construction in the world. That pioneer project is in Finland, where the first waste management program was initiated in 1983. In 1987, the final disposal of used nuclear fuel was included in the Nuclear Energy Act. Final disposal is managed by Posiva Oy. Following the Government's 1983 policy decision on used nuclear fuel, site selection and environmental impact assessment work was carried out. And four locations were chosen and investigated by Posiva Oy (see WNA 2019). The government approved the project in 2000 and it was ratified by Parliament in 2001. The project has strong local community support. Construction started in 2004, with licensing expected in 2020. The first nuclear waste will be stored in 2023–25 (see WNA 2019).

23 Constructing a deep geological repository is a complicated process that requires sure data about the locality. In terms of radioactivity, spent fuel becomes safe at least 300 years after its removal from a reactor, which is accordingly the period for which a repository must function without difficulty. 300 years is the period of time during which radioactivity decreases to the values of normal radiation in nature. It is also noteworthy that spent fuel is essentially safe from abuse, because to remove it from the protective containers would, during this period, mean a deadly dose of radiation.

24 One of the most important is Platforma proti hlubinnému uložišti, involving 31 municipalities and cities and 14 movements.

25 For example, the dispute from 2017, when SÚRAO wanted to continue in exploratory activities, even though they were authorised to do so only until the end of 2016 (see ČTK iDNES.cz 2017; Lejtnarová 2017).

26 The price of the final waste repository in Finland is estimated at around €3.3 billion for waste from five nuclear reactors. The operation cost will be around another €2.4 billion and decommissioning around €200 million (see WNA 2019).

27 In 2019, this was China, France, the Great Britain, India, Japan, Pakistan, Russia and the USA.

28 Some current fourth generation reactor projects, such as the Fast-Neutron Reactors (also known as Breeders), plan to use previously spent fuel as a fuel.

The owner of spent nuclear fuel in the Czech Republic is ČEZ. It is responsible for storage only, with the final deposition being the responsibility of the state. This was the purpose of founding the Radioactive Waste Repository Authority, which on the basis of the Atomic Act is responsible for treating spent or radioactive fuel into a form adequate either for deposition or for further use. When to deliver spent nuclear fuel to the state is exclusively up to ČEZ. So far, it is not radioactive waste but potentially exploitable material that is involved (see Laciok et al., 2000, p. 190–191).

Tab. 6.4: Scheme of the End of the Nuclear Cycle in the Czech Republic

Spent fuel dwell	App. 5–13 years	App. 80 years	Permanently or until potential reprocessing
Location	Spent fuel pools in the Dukovany and Temelín nuclear power plants	Storage in the Dukovany and Temelín nuclear power plants, backup repository Skalka	Deep geological repository
Responsible	ČEZ, a. s.		SÚRAO
Supervised by	State Office for Nuclear Safety		
Financial means	Corresponding budget ČEZ		Nuclear account (ČEZ contributions)

Source: Otčenášek, 2005, p. 540; modified by T. Vlček.

ČEZ finances the deposition of spent fuel out of its own budget, while the Radioactive Waste Repository Authority (SÚRAO) finances its activities from the nuclear account kept in the Czech National Bank and administered by the Ministry of Finance. The nuclear account is a financial account contributed to by all producers of radioactive waste in the amount laid down in Part V of the Atomic Act , which establishes the amount of the levy and the manner of its payment by radioactive waste agencies to the nuclear account and the annual amount of the contribution for municipalities, as well as the rules for permits to be granted. ČEZ, for example, pays CZK 55 for each MWh produced in nuclear power plants, while other producers of radioactive waste pay CZK 33,189 for each barrel of 200 l, which is the basic depositing unit in repositories. At the end of 2018, there was approximately CZK 28.4 billion on the nuclear account (SÚRAO, n.d.). Besides payments to the nuclear account, each operator of a nuclear facility in the Czech Republic runs an individual financial reserve for dismantling and remediation of that facility, as prescribed under the Atomic Act.

The warranty for temporary deposits of spent fuel is, therefore, provided by ČEZ until the fuel is delivered to the Radioactive Waste Repository Authority. At that point, the state assumes responsibility.

6.4 The Regulatory and Safety Framework of the Nuclear Industry

The key document for the Czech nuclear sector is unquestionably the Atomic Act (Act No. 263/2016 Coll.), which entered into force on 1 January 2017, amending the Act of January 24, 1997 on the Peaceful Use of Nuclear Energy and Ionizing Radiations (the Atomic Act), amended on 1 July 2017, 183/2017 Coll. Also relevant are Act No. 19/1997 Coll., Act No. 281/2002 Coll., and Act No. 44/1988 Coll. on the protection and utilization of mineral resources (The Mining Act) (see “Zákon č. 44/1988 Sb.”).

The Atomic Act regulates basically all aspects of not only the nuclear industry, but of ionizing radiation in general, which includes the regulation of the method of utilizing nuclear energy and ionizing radiation and conditions for the performance of practices related to nuclear energy utilization and radiation-producing activities, conditions for the safe management of radioactive waste, the performance of state administration and supervision within nuclear energy utilization, within radiation activities and over nuclear items, etc.

The Mining Act, by contrast, treats uranium mining and, as in the case of coal, it is the Czech Mining Authority and District Mining Authorities who oversee mining activity, observe working conditions, manage mining waste and supervise adherence to Acts Nos. 44/1988 Coll., 61/1988 Coll. and 157/2009 Coll. and other regulations (see Státní báňská správa České republiky).

Section II, Part IV of The Atomic Act commissions the State Office for Nuclear Safety (SUJB) to carry out the public administration and supervision of nuclear energy and ionizing radiation use for radioactivity and nuclear, chemical and biological protection. The SUJB is the central organ of public administration subordinated to the Government, which means that the regulatory role in the nuclear industry is held strictly by these two bodies, the Government and the SUJB.

The SUJB implements the regulation process through decrees, addressing the physical protection of nuclear materials and facilities; then quality in nuclear energy use and radiation-generating activity, the criteria for facilities and the distribution of selected facilities across safety categories as well as criteria for siting nuclear facilities and of sources of significant ionizing radiation. It furthermore treats the issue of radiation protection and the emergency preparedness of nuclear facilities and workplaces exposed to sources of ionizing radiation. The SUJB is responsible for the functioning and organization of the National Radiation Monitoring Network. Organization of the National Radiation Monitoring Network as amended by Decree 360/2016 Coll. currently consists of 495 different monitoring points (the early warning network, thermoluminescent dosimeter networks, and the air contamination monitoring point network), 12 laboratories, and a range of mobile groups (see *Státní ústav radiační ochrany, v. v. i.*).

Tab. 6.5: Regulatory and Safety Bodies for the Czech Nuclear Sector and Their Role

Body	**State Office for Nuclear Safety (SÚJB)**
Headquarters	Prague, Senovážné namesti 9
Web	www.sujb.cz
Role	Its scope of authority, given under the Atomic Act No. 263/2016 Coll., Act No 19/1997 Coll. and Act No. 281/2002 Coll., among others, includes the state supervision of nuclear activity and items, the physical protection of nuclear facilities, radioactivity protection and emergency preparedness at nuclear facilities and work sites with sources of ionizing radiation; issuing authorizations for activities governed under Act No. 18/1997 Coll., for example, the siting and operation of nuclear facilities and work sites exposed to sources of high-level ionizing radiation; the management of sources of ionizing radiation and radioactive waste; transporting nuclear materials and radionuclide emitters; and approving documentation with reference to nuclear safety and radioactivity protection set by the Atomic Act; to limits and terms of nuclear facility working procedures, the means for assuring physical protection, emergency rules for the transportation of nuclear materials and particular radionuclide emitters, internal emergency plans of nuclear facilities and workplaces exposed to sources of ionizing radiation; monitoring the level of radiation affecting residents and workers utilizing sources of ionizing radiation; working together competently with the International Atomic Energy Agency; coordinating and securing activities while following the mandates of the Convention on the Prohibition of the Development, Production, Stockpiling and Use of Chemical Weapons and on their Destruction within the meaning of Act No. 19/1997 Coll. and from the Convention on the Prohibition of the Development, Production and Stockpiling of Bacteriological (Biological) and Toxin Weapons and on their Destruction within the meaning of Act No. 281/2002 Coll., as well as performing the function of a national authority according to the Comprehensive Nuclear Test Ban Treaty, from the Convention on the Prohibition of the Development, Production, Stockpiling and Use of Chemical Weapons and on their Destruction, and the Convention on the Prohibition of the Development, Production and. Stockpiling of Bacteriological (Biological) and Toxin Weapons and on their Destruction.
Organ	**The National Institute for Nuclear, Chemical and Biological Protection (SÚJCHBO)**
Headquarters	Milín, Kamenná 71
Web	www.sujchbo.cz
Role	The National Institute for Nuclear, Chemical and Biological Protection is a public research institution founded by the State Office for Nuclear Safety on the basis of Act No. 281/2002 Coll. aimed at providing research and development activity involving chemical, biological and radioactive substances, ensuring the safety of technical support for the supervision and inspection work performed by the Office in radioactivity protection and monitoring the ban on the development, production, stockpiling and use of chemical and biological weapons. Research activity targets the identification and quantification of radioactive, chemical, and biological materials and assesses their impact on people and the environment, including the assessment and development of individual and collective means of human protection from these substances, and decontamination and safety research as part of the fight against terrorism and protecting against severe industrial accidents.
Organ	**National Radiation Protection Institute (SÚRO)**
Headquarters	Prague, Bartoškova 28
Web	www.suro.cz

Role	The main subject of the Institute's activity is research into protection from ionizing radiation, including the infrastructure of this research, specifically in the fields of safety research, research into the Radiation Monitoring Network and research into exposure to artificial sources of ionizing radiation (nuclear facilities foremost), research into medical exposure and research into exposure to natural sources of radiation. Other activities include supporting state supervision and monitoring prevention efforts, and supporting inspectors in their monitoring work in radiation protection and emergency preparedness, including departures and interventions, serving as an analytical and conceptual site for the analysis of impact following nuclear and radioactive accidents, drafting measures, and providing advisory and consulting services, education and public enlightenment, etc.
Organ	**Radioactive Waste Repository Authority (SÚRAO)**
Headquarters	Prague, Dlážděná 6
Web	www.surao.cz, www.rawra.cz
Role	The Authority's major tasks and activities are to prepare, construct, operate, initiate, and shutdown radioactive waste repositories and to monitor their environmental impact; to ensure that spent or radioactive nuclear fuel is processed into a form adequate for depositing or further use; to keep records of received nuclear fuel and of fuel producers; to manage levies of radioactive waste sources on the nuclear account; to prepare proposals with reference to the establishment of payers' levies on the nuclear account; to manage radioactive waste brought to the Czech Republic from abroad that cannot be returned, etc. Since 2000, it has regulated all radioactive waste repositories in the Czech Republic: Richard, Brotherhood, Dukovany, and Hostim. It coordinates all work aimed at preparing and constructing a deep geological repository of high-activity radioactive waste and spent nuclear fuel, the launch of which is estimated in around 2065.

Sources: *Zákon 458/2000; Zákon ze dne 24. ledna 1997; Státní úřad pro jadernou bezpečnost.; Státní ústav radiační ochrany, v. v. i.; Správa úložišť radioaktivních odpadů*; composed by T. Vlček.

The SÚJB is the founder of two public research institutes, namely the National Institute of Nuclear, Chemical and Biological Safety (SÚJCHBO) and the National Radiation Protection Institute (SÚRO). Their role is not regulatory, but they play a vital role in protecting against ionizing radiation. The Radioactive Waste Repository Authority (SÚRAO) has a similar protective role.

The important agents at the level of the supranational legal framework are the European Atomic Energy Community (EURATOM) and the United Nations mediated by the International Atomic Energy Agency (IAEA).

EURATOM was founded on March 25, 1957 in Rome and it has its headquarters in Brussels. Given that nuclear safety, naturally, represents one of the priority fields of EURATOM, it issues a vast number of directives and recommendations aimed at unifying the practice of radiation protection in all member states, and the directives cover radiation protection in comprehensively, from basic principles and medical use of radioactive materials through to the transport of radioactive substances. These directives were implemented in the Czech legal framework on the *acquis communautaire* basis either through the Atomic Act amendments or SUJB decrees.

The most complex legislative changes imposed from the outside took place as a result of the accession negotiations of the Czech Republic to the European Union, on which occasion a White Paper of the European Commission on Preparing the Associated Countries of Central and Eastern Europe for Integration into the Internal Market of the Union was adopted in 1995 (see Commission of the European Communities, 1995). The White Paper brought several important directives with reference to the nuclear energy field: the Directive on shipments of radioactive waste No. 92/3/EURATOM, supplemented by Directive No. 93/552/EURATOM (both were then altered by Directive No. 2006/117/EURATOM), the Directive on basic safety standards No. 96/29/EURATOM (later altered by 2013/59/EURATOM), referring to maximum permissible doses of radioactive contamination of food arising after a radioactive emergency (accident), the import of agricultural products following the accident in Chernobyl and shipments of radioactive materials. Besides the White Paper, the Czech Republic also adopted a string of directives addressing the radioactive protection of the public, workers, patients and the information standard for residents.

The IAEA emerged on June 29, 1957, in Vienna, which is also its current location. The former Czechoslovakia was a member from the Agency's founding, while the Czech Republic joined on January 1, 1993. The Mission of the Agency is to enforce the safe and peaceful use of nuclear technologies. Unequivocally the key bearer of this mission is the Treaty on the Non-Proliferation of Nuclear Weapons (NPT), which entered into effect on March 5th, 1970 and was prolonged in 1995 for an indefinite period. With respect to nuclear safety, one of the goals of the Treaty is monitoring and cooperation in peaceful nuclear activities (see Závěšický 2005, p. 132). IAEA is the exclusive monitor in the field of the peaceful use of nuclear energy, resting on a unique monitoring mechanism based on the political will of states to make their nuclear facilities available for monitoring. By doing so, states demonstrate that they have fulfilled their obligations under the Non-Proliferation Treaty and its additional protocols.

By its mandate given by the Articles of Association/Statute, the IAEA is obliged to promote the peaceful use of nuclear energy and to make sure that secret abuse for military purposes does not take place. A special inspectorate was set up for monitoring on the basis of bilateral agreements called Safeguard Agreements between member states and EURATOM that executes regular inspections of all declared nuclear facilities in countries do not possess nuclear weapons and non-military facilities in countries that do (see "*Stálá mise,*" 2010). Until 2009, the initial agreement between IAEA and Czechoslovakia from March 1972 was in effect; on October 1, 2009 the Czech Republic approached a Trilateral Safeguard Agreement (INFCIRC/193 or also 78/164/EURATOM). The Czech Republic, therefore, accepted the commitment to approach trilateral agreements between EU member states not possessing nuclear weapons, EURATOM and IAEA as part of the IAEA safeguard system (see SÚJB, n.d.a). Based on the Trilateral Safeguard Agreement and within the meaning of Commission Decree No. 302/2005/ EURATOM from February 8, 2005, on the implementation of EURATOM safeguards, starting from 2005, inspections of nuclear facilities are performed by both IAEA and EURATOM inspectors.

In speaking of supranational regulation, the influence of the European Nuclear Safety Regulators Group (ENSREG), an independent body established in 2007 under from a Decision of the European Commission should not be underestimated. ENSREG consists both of EU members and officials from national nuclear safety offices, radioactive waste management offices, and radioactive protection offices in all EU member states. ENSREG's goal is to reach mutual understanding and development in the fields of nuclear safety and management of radioactive waste (see The European Nuclear Safety Regulators Group).

6.4.1 The safety framework after the Fukushima accident and change in the perception of nuclear power in the European Union

After the devastating earthquake in Japan on the 11th of March 2011, which caused a major nuclear accident rated at 7 on the International Nuclear Event Scale (INES) at the Fukushima Daiichi nuclear plant, the safety measures of nuclear power plants were widely discussed around the world[29]. Many states, including the member states of the European Union, underwent a major re-examination of nuclear reactor safety, and a series of stress tests were carried out in 2011 and 2012 in the EU[30]. The accident was also followed by reconsideration of using nuclear power and some Member States (including Germany, Belgium, and Spain) decided to abandon nuclear energy entirely. The most important directive related to nuclear safety reflecting the Chernobyl accident (also INES 7) was Nuclear Safety Directive 2009/71. In the wake of the Fukushima accident, the directive was rapidly revised, and it was amended by Directive 2014/87. This directive "reinforced the role and effective independence of the national regulatory authorities. It has enhanced transparency on nuclear safety matters. It has strengthened principles, and introduced new general nuclear safety objectives and requirements, addressing specific technical issues across the entire life cycle of nuclear installations, and in particular, nuclear power plants. It has extended monitoring and the exchange of experience by establishing a European system of peer reviews. Finally, it established a mechanism for developing EU-wide harmonized nuclear safety guidelines" (see Dehousse 2014, p. 3–4).

Despite the increased security measures, nuclear energy remains controversial among the Member States. Nuclear power plays an important role in 14-member states, and around 25.1% of electricity was generated from nuclear plants in the EU in 2017. But production is o the downslope: between 2009 and 2017, total production of heat from nuclear sources fell by 10%. France, Germany, the UK, Sweden, and Spain are the largest nuclear producers, but only the UK plans to further develop its nuclear sector, while Germany will be the most rapid at phasing out nuclear energy, intending to do so by December 2022. The nuclear accident in Fukushima speeded up the nuclear phase out in Germany and Belgium. By contrast, 12 EU states joined together to form the *Nuclear Like-Minded Group* to promote the role of nuclear energy in the EU's energy mix in March 2013. With the Czech Republic coordinating the group, with the participation of the UK, Bulgaria, Finland, France, Hungary, Lithuania,

29 As regards the nature of the Fukushima accident, it should be added that each Czech nuclear unit has backup sources of power in the form of three separate diesel aggregates that are further secured with batteries.

30 These tests were done in three parts. The first was implemented on individual nuclear plant operators (i.e. ČEZ), the next executed by national regulators (SÚJB), and the third involved monitoring inspectors from other countries (European Nuclear Safety Regulators Group, hence the European Commission) (see Macková, 2011; SÚJB, n.d.b). The final report following the process of mutual evaluation of nuclear plant resistance by the members of the EU27 both for Temelín and Dukovany power plants was as follows: "No conditions were identified that would require immediate resolution. The power plant is able to safely manage even highly improbable extreme emergency conditions without posing any threat to its vicinity" (see ČEZ, a.s., 2011a; ČEZ, a.s., 2011b).

the Netherlands, Poland, Romania, Slovakia, and Spain. Nine of these countries plus Slovenia sent a letter to EC in July 2014, demanding "a level playing field for nuclear power among other low-emission sources in the EU so that it could play a greater role in energy security, sustainability, and emissions reduction" (see WNA 2019b).

Recently, support for nuclear power has been uncertain in Spain and France. There are tendencies towards phase-out, but nuclear power plays a major role in generating electricity in both countries. In February 2019, the government of Spain decided to close all seven nuclear plants between 2025 and 2035, but this step will require a large investment into RES and also depends on the strong position of the Socialist party to uphold its commitment (see Binnie 2019). In France, a plan to cut nuclear energy reliance by 50% was postponed from 2025 to 2035 and the future is uncertain, as French power plants face water shortages during the summer months. By contrast, construction of new power plants is being considered in the Czech Republic and Poland, and construction is underway or about to start in the UK, Slovakia, Finland, France, and Hungary.

The Czech Republic is cooperating closely with the Visegrad countries (V4) on nuclear energy at the EU level and an important ally used to be the United Kingdom[31]. All (apart from Poland, which has no nuclear power plant at present) are planning to continue producing electricity and heat from nuclear power plants and must maintain a strong common position within the EU. The V4 countries are all keen on increasing or sustaining their energy self-sufficiency and reducing dependency on Russian natural gas through the nuclear power (see Szalai 2013; Szalai 2018; Denková et al. 2017).

However, the clash between these two opposing camps is reflected at the EU level, as there is no support for nuclear energy comparable to that for renewable energy, even though it is a zero-emission source of energy. Further, there is an effort by the European Parliament to label nuclear power a polluting industry. The European Parliament voted on the 28th of March 2019 to exclude nuclear power from being acknowledged as a clean technology, thus complicating the approval of investments into this sector on the financial markets. Together with the strong opposition and problems with financing and completing construction, the nuclear sector is in a crisis and further development is in jeopardy.

6.5 Demand Forecast

According to long-term forecasts, power use will increase in the Czech Republic and electricity demand will increase by 25–33% by 2050. The energy mix of installed power is currently 46% dependent on coal, with 19% of the installed capacity from nuclear energy, 19% RES, and 8% natural gas. The share in electricity generation is 82% from coal and nuclear energy and only 11% from RES (see OTE 2019). Table 6.6 displays a comparison of goals declared in the State Energy Policy and its revisions with reference to the consumption of energy sources by 2050. It is evident that the role of the nuclear sector in the Czech power industry will likely improve to make up a third of all energy sources in the Czech Republic. In terms of the installed capacity of nuclear power plants, scenarios also count on the increased capacity of existing units, with the actual installed capacity of nuclear power plants at 4,204 MWe as of the 31st of December 2018 (see table 6.1); under the State Energy Policy, which calls for Dukovany to be completed in 2037 and 2039 and Temelín's to be completed in 2043 and 2045, by 2050 installed capacity will be approximately 7,050 MWe.

Tab. 6.6: The Shares of Solid, Liquid and Gas Fuels in Energy Resource Consumption According to the State Energy Policy of the Czech Republic of August 2012 and Its Revisions of December 2014 (in %)

Type of Fuel	Long-Term Goal (SEP 2004) by 2030	SEP (8/2012) Target Values by 2040	SEP (12/2014) Targets by 2040
Solid	30–32	12–17	11–17 %
Gas	20–22	20–25	18–25 %
Liquid	11–12	14–17	14–17 %
Nuclear	**20–22**	**30–35**	**22–33 %**
Renewables	15–16	17–22	17–22 %

Source: *Státní energetická koncepce, 2014*, p. 44; Ministerstvo průmyslu a obchodu, 2012, p. 20–21; *Státní energetická koncepce*, 2004, p 40–49.

31 With the complicated situation around Brexit the pro nuclear group has lost an important ally.

The Government has declared a clear stance on the development of the nuclear sector (and completion of the Temelín or Dukovany nuclear power plants) under several prime ministers, beginning with Petr Nečas, who declared at the 11th Energy Congress of the Czech Republic that the country "intends to continue to run the Temelín and Dukovany nuclear power plants and to continue the process that will lead to the construction of additional nuclear units" (see Nečas, 2011, p. 199), continuing with Bohuslav Sobotka (of the political party ČSSD) and so far enduring with Andrej Babiš (from political party ANO. All have agreed on the necessity of building the new nuclear, but had differing opinions on financing. Current plans call for the construction of new unit(s) in the Dukovany nuclear power plant, which has a much greater potential as there is, according to its ex-chairman, Tomáš Žák, "producing potential at the site of Dukovany given by exterior conditions of around 3,000 to 3,500 MW by applying existing technologies, and there are more possibilities than that" (see Cieslar, 2010e).

Confidence in nuclear energy and interest in its development and completion stable, as visible in the consensus among political parties on the issue and wide acceptance and support by the people.

In 1980, Ludvík Kopačka wrote that "nuclear energy is truly becoming a developing energy source in the Czechoslovak context that will gradually assume the role of covering increasing energy demand and gradually the increasing consumption of primary sources, as well" (see Kopačka 1980, p. 214–215). This basically remains applicable even in the second decade of the third millennium. The Pačes Commission argues that "around 2020–30, the lifespan of existing nuclear power plants should be prolonged for at least 60 years, while the increase in energy consumption in the Czech Republic and the replacement of gradually closing coal-fired power plants in terms of their basic capacity should be covered by building new nuclear power plants, reaching the share in power production already present in France, for example (77%)", and "around 2040–2050, starting construction of fast reactors" (see Úřad vlády ČR & Nezávislá energetická komise 2008, p. 108–109). Ten years later the perception is similar, though a share of nuclear power is projected by around 50–60% by 2050 and the rest is planned to be covered by RES and natural gas.

Based on this, it is evident that the Czech Republic has a firm position regarding the development of the nuclear industry, that the sector is not indifferent to it and that it has important potential for energy and the supply safety of the Czech Republic and that the Czech Republic counts on increasing its use of this type of energy both over the short- and long-term. We may state that state energy policies as well as the State Energy Policy and their revisions support the development of the nuclear industry. There is a gradual growth in share in primary sources consumption, from 20% under the 2004 State Energy Concept to 34% in primary sources consumption and 50–60% in final consumption in the revised version of State Energy Policy.

Unlike with coal and natural gas, there is no international legal obligation to keep reserves of uranium (see OECD Nuclear Energy Agency / IAEA 2008, p. 171), not even resulting from the membership in IAEA or EURATOM. Nor was there under Czech law until the 2014 State Energy Concept. In the 2004 State Energy Concept, there was a non-binding recommendation to have "nuclear fuel strategic reserves in a form adequate for loading the reactor" (see SEP 2004, p. 27). In the new State Energy Concept, under Priority V related to energy security, the target is to "permanently ensure adequate emergency stocks of all the basic primary sources" (SEP 2014, p. 57) and to "ensure that nuclear power plant operators maintain stocks of fuel assemblies that guarantee facilities will be able to operate at full capacity for four years, or use reserve capacity backup contracts for fuel supplies or maintain the corresponding stocks of enriched uranium and the country's own fuel fabrication within the Czech Republic. The accomplishment of this objective is to be scheduled in line with increasing the proportion of nuclear energy to a target level of 50–60 % of final consumption" (see SEP 2014, p. 58). With regard to the high density of nuclear power plant fuel, the relative stability of its price and the vast number of active producers of uranium concentrate, as well as the substantial number of processing institutions, it is possible to stock up for a decade in advance.

Tab. 6.7: Forecast of Uranium Concentrate Demand in the Czech Republic (tonnes per year)

2015	2016	2017	2020	2025	2030	2035
582	566	700–705	700–705	725–730	725–730	725–1,120

Source: OECD Nuclear Energy Agency 2018, p. 199.

6.6 The long road to a new nuclear source of energy for the Czech Republic

Building a new nuclear power plant has been under discussion in the Czech Republic since 2004. To make a long story short, the plan was included in the State Energy Policy of 2004, with a new unit at each location under consideration, a public tender for construction at Temelín in 2009 prepared then cancelled in 2014, and a new State Energy Policy presented in 2014 that highlighted once again a plan for a new nuclear unit and a waste repository to be built. By 2019, both plans had already been delayed for three years.

Since the financial crisis of 2008, the nuclear industry has suffered its own "nuclear crisis". Conditions for financing have worsened due to new bank policies, the electricity price has decreased due to electricity generation from renewable sources, many projects have been delayed and have gotten more expensive. Also, the Fukushima accident represented a limit on nuclear sector development.[32] Because of this and some failed projects, two of the biggest companies, Westinghouse and Areva, faced deep structural problems. As a result, Chinese companies and the South Korean company KEPCO increased their share on the world market. Russia's Rosatom also found its way by means of construction works and complete supply chain offers as well as the financing of their projects. This constitutes a strategy for building and eventually exploiting path dependence to secure orders for future years (see Minin, Vlček 2018; Jirušek et al. 2015).

The majority of the Czech Republic (including government, industry, and a high percentage of population[33]) is convinced that a new nuclear source is needed in order to secure electricity production in upcoming years, especially after the closure of Dukovany power plant and most of the coal plants, around 2037 – depending on its lifetime extension[34]. The question of whether to build or not is not the issue; the consensus is clear. The problem is who is going to pay for it. This proved to be an issue in 2014 and it is proving to be an issue again today.

6.6.1 First attempt, an unsuccessful tender for Temelín nuclear power plant

On August 3, 2009, ČEZ announced a tender for two new nuclear blocks for the Temelín nuclear power plant. To some extent it was based on the investment plan for the construction of the Temelín power plant with 4 × 1,000 MWe of installed capacity, adopted in February 1979, replicating the construction site itself and some already existing auxiliary systems. Total capacity of the new nuclear plant remained at 2 × 1,200 MWe after elimination of AREVA SA from the tender[35]. It is not just the project that is part of the tender, but the construction work itself, which makes the entire endeavour, therefore, a turnkey power plant.

After it was awarded, the overall administrative tender process should have lasted for roughly 7 to 8 years (together with the construction, 15 years), which meant that the connection of new Temelín units was estimated for around 2024. The tender's finale and the signing of the contract by the winning bidder were planned for the end of 2011. In October 2010, however, everything was postponed until 2013 due to the unpreparedness of suppliers, which would naturally lead to a delay in the entire process. But the deadlines were impossible to meet without altering the applicable construction and permit legislation. The job of the Government's Commissioner for the ČEZ nuclear tender was given to Václav Bartuška, Special Envoy for Energy Security of the Czech Republic.

Three entities took part in the tender. These included a consortium of the companies ŠKODA JS, a. s., of the Czech Republic, Atomstrojexport, a. s., from the Russian Federation (a subsidiary of the Russian company

32 On the other hand, the accident in Fukushima Daiichi means new business and development for Czech nuclear physicists as the escalation of monitoring and various tests of existing nuclear power plants will most probably become an interesting business, which the ÚJV Řež is preparing for at the level of the Czech Republic (for more details see Korbel & Kostka 2011, p. 30).

33 In May 2018 49% supported construction of new nuclear unit, 32% were against and 19 % undecided. Comparing to the previous two years, the number of people supporting the new unit decreased, people against stayed and percentage of people who do not know increased (see cvvm 2018).

34 The lifetime of Dukovany power plant was designed to be 30 years but it has been extended until the power plant will not stop comply the safety test. Expected lifetime is 50 years, some are speculating about 60 years, but the pressure from the European Commission is to decommission nuclear power plants after 40 years. Nevertheless, the institutional approach could change as for example IEA is supporting nuclear power plants as a clean source of energy (see IEA 2019).

35 AREVA SA had a variante of 2 x 1,700 MWe unit.

ZAO Atomstroyexport[36]) and OKB Gidropress, a. s.[37] from the Russian Federation, offering the project a MIR 1200 (Modernized International Reactor) with 1,198 MWe of capacity[38]; the French company Areva SA[39], which offered an EPR (European Pressurized Reactor) with 1,700 MWe of capacity[40]; and the American Westinghouse Electric Company, LLC[41], which offered an AP1000 with 1,200 MWe of capacity. In each case, the reactors were of the III or III+ generation.

Tab. 6.8: Technical Characteristics of the Projects Proposed by Single Nuclear Tender Applicants

Company	Westinghouse Electric Company, LLC	Areva SA	ŠKODA JS, a. s., Atomstrojexport, a. s., OKB Gidropress, a. s.
Project	AP1000	EPR™	MIR 1200 (AES 2006)
Thermal capacity(MWt)	3,415	4,590	3,200
Electrical capacity (MWe, net / gross)	1,117 / 1,200	1,590 / 1,700	1,113 / 1,198
Efficiency (%)	33	36	33.7
Capacity factor (%)	93	90.3	>98*
Number of cassettes in the active zone	157	241	163
Number of rods in cassettes	264	265	312
Number of steam generators	2	4	4

* Such a high value results from shorter maintenance and refuelling breaks and prolonged fuel campaigns.

Source: Bílý, 2011, p. 268; Company's official documents; selected and modified by T. Vlček.

On October 5, 2012, ČEZ announced the elimination of the French company Areva from the competition for building new blocks at the Temelín nuclear power plant because it did not meet the basic commercial and legal terms of the competition (see "*ČEZ vyřadil AREVU*"). Areva submitted an appeal to the Czech Office for the Protection of Competition, but in February 2013, it upheld the decision.

In the first round of the tender, the subjects of evaluation included technology, price, and safety. According to the results of March 2013, the American company Westinghouse Electric Company, LLC, was the first in this aspect, but the lowest price was offered by the Russian-Czech consortium. The AP1000 reactor was in many aspects revolutionary, with an advantage stemming from its modular construction, which, on the other hand, posed a problem in that it had not been tried before and could, therefore, limit the inclusion of domestic companies in the project. MIR was an evolutionary reactor based on the long history of VVER reactors as well as on Russian experience with breakdowns. It is a tested and reactor and is cheaper, but it is technologically older.

Although ČEZ argued that the construction of new nuclear blocks arose from the State Energy Concept, Policy of Spatial Development, and the conclusion of the Paces energy commission (see ČEZ, a. s., 2009a), the company

36 ЗАО Атомстройэкспорт is the leading Russian organization building and modernizing nuclear power plants abroad. It is supervised by the Federal Agency for Nuclear Energy, Rosatom (Федеральное агентство по атомной энергии России, РосАтом). A majority of its shares (50.2%) are held by VPO Zarubezhatomenergostroy (44%; Всероссийское производственное объединение "Зарубежатомэнергострой") and OAO TVEL (6.2%; ОАО "ТВЭЛ"), which Rosatom controls on behalf of the state. 49.8% of shares are held by Gazprombank (ОАО "Газпромбанк").

37 A subsidiary of the Russian company OAO OKB Gidropress (ОАО ОКБ "Гидропресс").

38 Based on talks with the Russian side, it is interesting that the tender should have included a serious offer to build a manufacturing plant in the Czech Republic, i.e. a plant for assembling fuel cassettes out of single pallets. According to the Russian calculation, this sort of plant proves profitable for the state if there are at least eight reactors, which is the number the Temelín power plant will reach upon completion. This is accordingly an opportunity for fuel fabrication for the Russian type of power plant in Slovakia and elsewhere. The paradox is that in this manner the most frequent comment on the Russian project, i.e. intensification of Czech energy dependence on Russia, to some extent ceases to be logical.

39 The ownership structure at the time of the tender was as follows: 73.03% Commissariat à l'énergie atomique (technological research institution financed by the French Government); 10.17% French state; 4.82% Korean car industry Kia Motors and the remaining 11.98% other companies, employees and publicly traded stocks.

40 The great advantage of this reactor may be found in the high rate of capacity maneuverability.

41 At that time belonging to the Japanese companies Toshiba Corporation (67%) and Ishikawajima-Harima Heavy Industries Co. Ltd. (3%), American mechanical companies The Shaw Group (20%) and Kazakh state company Kazatomprom NAC (Казатомпром НАК 10%).

was criticized for its poor communication with the majority stakeholder in preparing the tender. At that time, it was the largest tender in the world and, according to Deputy Minister of Industry and Trade Tomáš Hüner, the state was planning to have its own part in it to ensure full control: "The state has very strong options. It can change the Statute and it can directly express its opinion regarding the tender, bypassing the General Meeting of Stakeholders, where 70% of shares are owned by ČEZ It also has the bluntest tool in its hands; that is the ability to replace the management" (see Rafaelová, 2009).

In terms of the nuclear sector, the Government's policy statement was clear during the first tender. It expresses the state's will to support both the construction of new blocks at the Temelín nuclear power plant and the modernization of the Dukovany nuclear power plant, including the accompanying range of buildings so as to achieve a balanced energy mix. The state will furthermore proceed with its transparent approach while searching out sites for radioactive waste repositories, including supporting other options leading to their decommissioning (see VČR, 2010a, p. 37). The Government, with respect to the development of the nuclear industry, behaved in a very coherent and conceptual manner, based on from state energy policies and the State Energy Concept and its so far unapproved revision.

When the Expert Working Group for Energy Security submitted its conclusions in 2006 regarding Czech energy to the Committee for Foreign Security Policy Coordination, it recommended prolonging the lifespan of the Dukovany and Temelín nuclear power plants, for the state to create the conditions for further quantitative and qualitative development of the nuclear sector, and seeking to increase electricity production through the framework of the existing localities–in other words, to complete the Temelín nuclear power plant and, more broadly, the facilities in the originally planned localities (Blahutovice), as well. For diversification reasons, the recommendation was to have the new technologies supplied by EU countries (see Odborná pracovní skupina pro energetickou bezpečnost [OPSpEB], 2006, p. 14). The document also recommended "the restoration of uranium mining, because for the major construction of nuclear sources in the Russian Federation and unchanging capacity of nuclear fuel production, there could be a shortage of that fuel. A country capable of supplying its own uranium and asking only for its processing into fuel will be unambiguously at an advantage compared to those who must ask for the complete purchase of fuel" (see OPSpEB, 2006, p. 8–9). The discussed revision of the Atomic Act also advocated the development of uranium mining, which would enable the allocation of funds from the nuclear account also to municipalities affected by mining exploration related to a deep geological repository, which could be a good way to reach a consensus between state and municipal interests while searching for a proper to build this deep geological repository.

"Preparation of and proceeding with a schedule of a supplier selection process for the completion of Temelín nuclear power plant has been approved, and I hereby wish to confirm that this plan remains unchanged. 'The Government wishes and, because of its share in ČEZ, will be able to arrive at a winning bidder by the end of 2013', were the words of Prime Minister Petr Nečas at the 11th Energy Congress of the Czech Republic (see Nečas, 2011, p. 199–200). ČEZ had been preparing very seriously for the Temelín project. The preparations included, on April 1, 2009, a new division, called the Division for the Construction of Nuclear Power Plants, to coordinate the preparation of nuclear projects not only within the Czech Republic (Temelín and Dukovany), but also abroad (Jaslovské Bohunice – Slovakia) (see ČEZ, a. s. 2010b, p. 5). Circumstances such as the expected shut down of large coal power plants in the Czech Republic, Poland and Germany by 2020, difficulties with building any larger units (only the Počerady combined cycle power plant and Ledvice power plant were built), problems with the integration of renewables, and the political decision to depart from nuclear energy in Germany,[42] played into the hands of the Temelín's completion with nuclear blocks of 2 × 1,700 MWe of installed capacity.

Final offers for the tender were submitted in July 2012 and an agreement was supposed to be signed by the end of 2013, but the final decision was postponed by 18 months. In the meantime, ČEZ was deciding on the form of financing and searching for a strategic partner. Rosatom offered full financing and in the middle of 2013, while the American Exim bank offered to finance half the project if Westinghouse technology was used. In the end,

42 After the accident in Fukushima Daiichi, Germany immediately suspended the operation of its eight oldest nuclear power plants, while the expert commission assessing their re-launch in May 2011 recommended leaving them closed. The Ethics Commission then decided to shut down all nuclear power plants by 2021, resp. 2022. The departure from the nuclear industry is not new for Germany, as it had six nuclear reactors closed within the territory of German Democratic Republic immediately after the unification of Germany in 1990, while the construction of five reactors already in the building process (Stendal nuclear power plant) was postponed and then entirely terminated a year after.

the Czech government under with Prime Minister Petr Nečas planned to offer a contract for difference for the electricity from the new units. The Ministry of Finance was offering a strike price of 60 EUR per MWh, while ČEZ requested 70 EUR per MWh (the price of electricity was around 40 EUR in 2013). The situation changed after elections. The Government of Prime Minister Bohuslav Sobotka decided against state aid to the project, especially after the poorly handled state aid to RES. ČEZ announced that it would not be possible to build a new nuclear unit without state aid and cancelled the project in April 2014 (see WNA 2019a).

According to Ladislav Blažek, Former Development Deputy of the Federal Ministry of Energy and one of the leading Czech experts in the field of mechanical mine installations, energy, and gasworks, the prospects for this sector are evident. "Without developing the nuclear industry, the Czech Republic can barely make do, if it wishes to achieve energy independence, and complete its commitments to do with emissions reduction if it does not wish to waste the experience gained. No responsible politician can deny the need to construct additional sources of nuclear energy in the shortest time possible if he or she does not wish to speculatively weaken the hard-won energy self-sufficiency of the Czech Republic" (see Blažek 2009, p. 68).

6.6.2 Second attempt, the new trajectory

On the 1st of January 2015, the new *State Energy Policy* came into force, showing a clear trajectory for the nuclear sector. "Within the timeframe of the State Energy Policy, what is important in terms of predicting the balance of production and consumption is completing the construction of additional nuclear power units to produce around 20 TWh by 2035, extending the lifetime of the existing four units at the Dukovany power plant (to 50 to 60 years) and later the possible construction of another unit to compensate for the decommissioning of the Dukovany plant. In the long term, nuclear energy could provide in excess of 50% of the electricity generated, thus replacing a large proportion of the coal sources. It is also advisable to start making greater use of heat energy from nuclear sources to heat larger urban agglomerations" (see SEP 2014, p. 14). The document also sets long-term priorities in relation to the EU, since the goal for nuclear energy is to "promote nuclear energy as an accepted carbon-free technology which may be supported in the policies of the various member countries" (see SEP 2014, p. 98). Among other things, it sets a deadline for selecting sites for the final repository of spent nuclear fuel, which are to be submitted to the government so a decision may be made by 31.12.2025 (see SEP 2014, p. 93).

The document refers to the *National Action Plan for the Development of Nuclear Energy in the Czech Republic* (NAPJE) of May 2015 which converts the targets of the State Energy Policy into concrete implementation steps. It says 'to ensure the energy security of the Czech Republic and overall social benefit, from the perspective of the state preparations must begin immediately for the siting and construction of one nuclear unit at the Temelín site and one unit at the Dukovany site, while protecting against potential risks by obtaining the necessary permits/licences for the possible construction of two units at each site. In particular, maintaining the continuation of production at the Dukovany site, constructing a unit at the Dukovany site, and commissioning it by 2037 are crucial in order to ensure the continuity of the operation of a nuclear facility and human resources at the site until 2037, when the shutdown of the existing NPP is expected" (see NAPJE 2015, p. 6).

NAPJE is discussing three options for financing the new units and has drawn up a SWOT analysis. The options are:

- Construction of a facility/facilities through the investor ČEZ and possibly its 100% owned subsidiary: from the perspective of the state, investment through the existing owner and operator of nuclear power plants, ČEZ and possibly its 100% owned subsidiary
- Association of investors: a private investor consortium, i.e. an association of investors formed in order to achieve a certain goal (ČEZ, financial investor, large customer, contractor of nuclear unit, etc.).
- State-owned enterprise: direct construction by the state through a newly established state-owned enterprise (NAPJE 2015, p. 74–76).

From the state's perspective, the first option is the preferred option for the investment model for constructing new nuclear facilities, but not for ČEZ. But the document also says that 'in the event that the investor plan drawn up by ČEZ is not implemented through ČEZ for any reason whatsoever, in line with the procedure according to the first option, the state may ensure the construction of new nuclear facilities in accordance with the time schedule defined in SEP, through the selection of two alternative options' (see NAPJE 2015, p. 6). The third option involving direct construction by the state through a newly established state-owned enterprise is, due to the large number of negatives entailed, chiefly the high impact on the state budget and the increased national debt, 'the least likely and it is therefore mentioned only for the sake of completeness' (see NAPJE 2015, p. 76). A Contract for Difference is considered as a possible guarantee mechanism; the document suggests three scenarios, for 15 years, 35 years, and 60 years (see NAPJE 2015, p. 84–85).

The document sets tasks and priorities for the development of the nuclear energy sector and related to the construction of a new nuclear unit. The most important are: make sure that strategic partners are identified and contacted for the construction of a new nuclear facility in the Czech Republic by 31/12/2015; open negotiations with the European Commission on the method of supplier selection, financing, rate of return guarantee and state support by 31/12/2016; and decide on the investment and business model for the construction of a facility by 06/2016 (see NAPJE 2015, p. 97–115). Expected costs and a projected timetable are shown in table 6.9.

Tab. 6.9: Limit costs incurred from 01/2015 in individual sub-milestones of the project

Milestone	Anticipated date (ETE / EDU)	Costs of 1 project (Temelín NPP or Dukovany NPP)	Costs of parallel preparation of both projects
Selection of the EPC contractor, EPC contract signature with partial effectiveness	2019	2.5–2.6	4.3
Issue of a planning permit	2022	10.7–10.9	17.5
Issue of a licence for construction (SUJB)	2024	16.4–17.2	27.2
Issue of a building permit (readiness of the project for implementation, i.e. for the issuance of a full effectiveness notice for the EPC contract)	2025	19.1–20.2	31.9

Note: costs in billion CZK

Source: National Action Plan for the Development of Nuclear Energy in Czech Republic 2015, p. 91, modified by T. Stašáková

6.6.3 Second attempt, who is going to pay?

The motivation for the construction remains the same as for the first tender. In addition, there is less time to start the construction project and more pressure on clean energy sources. Yet the Czech Republic is lagging behind schedule, frozen on deciding on the investment and business model for construction of a new nuclear unit, three years behind schedule as of June 2019.

In June 2015, by approving NAPJE, the Czech Republic government decided on reopening preparations for a new nuclear power plant to be built under the government of Prime Minister Bohuslav Sobotka and Minister of Finance Andrej Babiš (the current Prime Minister). But this time, the new construction was planned for Dukovany, as Dukovany will be decommissioned sooner; it is more strategic to have a nuclear power plant in two locations than it is to have one big unit; employment is also provided this way at both locations. New construction at Temelín has not been completely cancelled; it remains under continuous preparation next to the Dukovany construction and follows the development of nuclear energy in the Czech Republic.

According to newspaper headlines in 2015, the new units were supposed to be finished by 2025. Reports also mentioned potential obstacles such as financing, the changing European attitude to nuclear energy, disagreement from Austria and a water shortage in the Jihlava River, which is the main source of water for cooling the Dukovany plant. (see Voříšek 2015, Budín 2015, Ševeček 2015). In 2015, the Prime Minister was expecting to open the tender by the following year and the Minister of Finance had a clear view as to how the project should be financed. Babiš said that since ČEZ operates both nuclear plants, it should also complete/secure the new construction; the government would not offer a contract for difference or any financial support (see Budín 2015). And although the schedule for the whole process was given by NAPJE, the final decision about the new nuclear unit and its financing was and still is seen as a sensitive political topic and thus was not broached before the parliamentary elections of 2017.

In 2016, ten companies were addressed by the Ministry of Trade and Industry, six of which showed interest in building a new nuclear unit in the Czech Republic. These were the Russian state company Rosatom, EDF from France (Electricité de France), the American-Japanese Westinghouse Electric Company, Korea's KHNP (Korea Hydro&Nuclear Power), China's General Nuclear Power, and a joint project submitted by Areva and Mitsubishi Atmea. These companies started bilateral discussions with the Ministry of Trade and Industry in the form of consultations and with involved municipalities in the form of roundtables. But they were strictly discussions, mostly of technical particulars, because prior to the government decision on financing, none of these companies was able to provide an offer (see ČTK 2016b). During these discussions an intergovernmental agreement was considered, following the example of Hungary and its agreement with Russia on financing the Paks II nuclear power plant. Petr Závodský (Director of ČEZ Group's Nuclear Power Plant Construction Department) stated that the intergovernmental agreement allows more flexibility than a tender and could include the form of financing (see ČTK 2016a). But in the end, a tender was chosen because it is more transparent and does not require European Commission approval.

Among the parties included in the discussion was a group of ČEZ minority shareholders representing 30% of the company's stock (the remaining 70% is owned by the Ministry of Finance) and were mostly against this risky investment. One possible solution was to divide the company into smaller firms (se ČTK 2017a). In 2018, the question of breaking up ČEZ once again arose, with six possible variants. After a SWOT analysis, the option of the state owing the "dirty" part (including the nuclear, coal, and trade sections of the company) and shareholders the "green" part was, according to ČEZ, seen to be optimal (see ČTK 2018a).

Discussions continued with the six companies during 2017 on the location of the project and the involvement of Czech companies. In addition to discussing the financial model, the companies said that they could not envision the project proceeding without some level of state involvement (see Žižka 2017). Even though the project received government support, this has consisted only of a declaration of support, since nuclear financing was considered too risky and the length of time required by legal procedures to approve the project was perceived to be another obstacle by PM Sobotka (see ČTK 2017b). Moreover, in the middle of January 2017, the Minister of Finance, Andrej Babiš, stated that as long as he was Minister of Finance, the state would not financially back a new nuclear unit (see ČTK 2017c). An important milestone for the new nuclear power plant at Dukovany was the beginning of the EIA process on the 13 November 2017. ČEZ wished to have all administrative documentation prepared in case the government decided on the financial model (see ČTK 2017d).

The decision process was also influenced by governmental instability. After the autumn elections in 2017, won by the political party "ANO" of ex-Minister of Finance Andrej Babiš, who became Prime Minister, found itself unable to form a new government. A second election was held, which ANO once again won, and they were finally able to form a government on 27 June 2018. This government continued the rhetoric of CSSD from the previous term.

In March 2018, Jan Štuller, the Special Envoy for Nuclear Energy, said 'the Standing Committee on Nuclear Energy supports the financial model of state financing of the new power plant' (see ČTK 2018c). By contrast, after the second elections, the new Minister of Trade and Industry, Marta Nováková, replacing Tomáš Hüner in June 2018, spoke again about an intergovernmental agreement and opposed further state involvement. Also, the Standing Committee on Nuclear Energy changed its structure and name on 18 February 2019. It was now called the Standing Committee on New Nuclear Construction and would be chaired by the Prime Minister (instead of the Minister of Industry and Trade) and the Minister of Industry and Trade and the special envoy for nuclear energy were to be the two vice-chairpersons of the committee. Membership of the committee was extended to include the relevant ministers (instead of deputy ministers), representatives of the opposition political parties, and representatives of the NPP operator – ČEZ to secure broad agreement on all sides (see MPO 2019).

The question of the financial model remained opened until June 2019, four years after approval of the NAPJE. The tender is now planned to begin by the end of 2020 or the start of 2021 and should not be open for more than three years. The main criterion will not be only the price according to the new Special Envoy for Nuclear Energy Jaroslav Míl[43] (see ČTK 2019). The first phase is expected to be finalized by 2024, when the result of tender should be known. The first phase also means obtaining permission from SÚJB and a zoning decision. Since the construction of a new nuclear unit is far away but the reasons for building it remain, a partial solution in the form of prolonging the lifetime of Dukovany up to 60 years is being considered.

6.6.4 Opposition to the new nuclear unit

The strongest protest against the first attempt of the Temelín nuclear power plant completion came from the Green Party, Greenpeace, South Bohemian Mothers, Calla - Association for Preservation of the Environment,

43 Jaroslav Míl was formerly a general director of ČEZ, a. s. and president of the Confederation of Industry of the Czech Republic.

the Citizens' Initiative for Environmental Protection, Green Circle and the DUHA Movement. These organisations have also been active during the second attempt at completing the Dukovany nuclear power plant.

The idea common to all these organizations are summed up by the words of Martin Sedlák of the DUHA Movement: "The Czech Republic will make do without additional reactors. Green sources in combination with the enormous potential of increased efficiency can ensure enough energy for Czech households and industry. The new nuclear power plant looks like a mere footnote in comparison to these clean solutions. They also have an indisputable advantage, as the costs of renewables decline. Over the course of a decade, they will be at the heels of atomic power" (see Jihočeské matky 2011).

Their arguments should definitely be taken into consideration, as one of the pressing issues these organizations are warning about is the limited liability of the operator running nuclear power plants across the Czech Republic for nuclear damage. "Should a serious accident occur in Temelín, all affected would together receive only six billion CZK. ČEZ would in such a case, paradoxically, receive 35 billion CZK from the insurance companies," said Sedlák (see Sedlák 2009, p. 31). According to environmental organizations, ČEZ must assume full financial responsibility for nuclear damage, because the current limit of 8 billion CZK is insufficient and does not correspond to international conventions (see Jihočeské matky 2011).

According to Edvard Sequens of Calla, "the politicians are looking into a rearview mirror and want to deal with challenges of the 21st century with tools of the 20th century" (see ČTK, 2018c).

South Bohemian Mothers and Calla sued the state, opposing new nuclear power plant construction in Temelín, first in 2015 and after failure again in 2017 and 2018 because of procedural mistakes by SÚJB and flaws during the EIA process (see ČTK 2018b).

There is also a strong opposition on the international level from Austria. In 2000, the Austrian parliament passed a resolution against Temelín and the issue was later discussed at the European level. The solution was the Melk Protocol of 12 December 2000, increasing cooperation between the two countries and increasing security and environmental measures. But even though this document improved the cooperation between the two states at the diplomatic level, Austria is still against any new construction of nuclear units in Europe. This results in many protests, citizen´s initiatives, and lobbying at the European level for a European nuclear phase-out (*Atomausstieg*), with no exception. The Upper Austria region even financially supports Czech non-governmental organizations that are against nuclear energy (including the DUHA Movement, South Bohemian Mothers, Calla, and others).

Tab. 6.10: Comparison of Some Economic and Environmental Advantages and Disadvantages of Nuclear and Thermal Power Plants

Subject of Comparison	Nuclear Power Plant	Thermal Power Plant
Fly ash emissions	No	Only coal power plants
SO_2 and NO_x emissions	No	Yes
Operational spillage of radioactive materials	Yes (small amount)	Yes (small amount)
Ratio of produced energy per mass unit of fuel	2,100 GJ / kg	0.033 GJ / kg
Costs of fuel transport	Low	High
Exhaustibility of fuel sources	Yes (later than in the case of fossil fuels)	Yes
Amount of "ash", or spent fuel	Small	Great
Costs of spent fuel liquidation	High (mainly resulting from the danger and necessity of long-term deposition)	High (mainly resulting from greater volume)
Risk of a significant accident	Small	Great
Consequences in case of big accident	Great	Small

Source: *Fyzikalni aspekty zatězi zivotniho prostredi*, 2008, p. 24; modified by T. Vlcek.

The safety of nuclear power plants has also come under criticism, especially when it comes to spent nuclear fuel. Table 6.10 clearly illustrates that nuclear power plants are much less risky during regular operation than thermal plants under conditions of notable energy density. In the event of a major accident, a nuclear power plant is, nonetheless, unequivocally the riskiest type of power plant and the criticism is here substantiated. The State Office for Nuclear Safety regularly and strictly monitors existing nuclear power plants.

6.7 New development in nuclear sector: smaller and modular

Thoughts about a nuclear reactor for every municipality were popular during 1970s and 1980s, when nuclear technology was expected to be the future of the energy sector. Development, though, went in a different direction, towards bigger, more efficient units, mostly due to economies of scale. But in the face of current issues in the sector such as construction delays and rising prices, small modular reactors (SMR) have once again come under discussion. They are also an interesting option for remote locations.

Though still in the early stages, the number of countries developing their own model is indicative. There are around 50 SMR designs in development around the world and 20 of these are in the advanced research phase. Leading countries are the United States, Russia, the United Kingdom, South Korea, China, Canada and Argentina.

According to the IAEA classification, all reactors with installed power of 15–300 MWe are to be considered small reactors. The main characteristic of SMR is modularity and an integrated system[44]. The main idea is to simplify the technology to allow manufacturing and thus simplifying construction on site. This would also allow the installed power to the site to be adapted to needs and allow reaction on demand in the future by adding an additional unit. Also, the exchange of fuel is easier, and some models have longer fuel cycles. It is possible to build them on a brownfield and is easier to connect them to the grid. This is also a suitable option for power and heat generation for island operations (see IAEA 2018; ÚJV Řež 2014).

SMRs are supposed to be safer due to passive security measures such as cooling without the need for operator involvement. Another advantage lies in the smaller installed capacity and lower radiation danger in case of an accident. The emergency planning zone (EPZ) is also smaller: while the EPZ for a normal unit is 16 km in radius in the US (around 20 km in Europe), the plan for SMRs calls for 16 hectares in US. In Europe, it has not yet been specified. To minimize the impact of an accident, some models are planned for underground (NuScale). This requires that more attention be paid to the geological surface.

From the economic standpoint CAPEX (capital expenditures) are lower and financing is thus easier compared to normal units. But it is expected that the investment per kW will be higher, at least at the beginning. The price could decrease as the units are standardized and manufactured, but this is an assumption. The price of current models is influenced by the technology and the development of new components. Models using known and already marketed technology are supposed to be competitive (NuScale); models using novel technologies, where additional research has been done and which are considered FOAK[45] (Carem or KLT-40) are not planned at the current stage, due to bad economics.

In terms of licensing and regulation, SMRs are not treated in Czech regulations or law, nor in the regulations or law of the European Union. The situation has only been monitored by the EU since 2017 (see EC 2017). IAEA established a regulatory forum in 2015 and working groups in November 2017. IAEA identified a number of problems for licensing and design certifications related to the wide number of designs and many possible construction variants. But in general, SMRs based on marketed technology, with PWR designs, are going to have a shorter licensing period than SMRs that utilize new technologies. Also, it is possible to expect that models with lower installed capacity will obtain a license faster (see IAEA 2018). An easier licensing process will have a positive impact on the final price or SMR model and might increase its competitiveness.

Four of the most developed projects are worth mentioning:

The KLT-40 is a small-scale Russian floating nuclear cogeneration plant. It is a part of the RITM-200 series reactors developed by Afrikantov OKBM. The unit can generate up to 70 MW of electric energy. This SMR was already installed on icebreaker Akademik Lomosov at the end of 2018 and is planned to be connected to the grid in December 2019. It is going to be connected to the coastal infrastructure in Pevek and, after being put into operation, will replace the Bilibino nuclear plant and Chaunskaya thermal power plant, which are technologically outdated. Its lifecycle is 40 years, with the option of being extended. The project is FOAK and so far, it is not competitive on the market due to a high construction and development price (see Rosatom 2018; Rosatom 2019). Apart from this project, there are several others under development in Russia: ELENA by the Kurchatov Institute National Research Centre, RUTA-70, KARAT-45 and 100 by NIKIET, and others. Most of these are developed for the military (see IAEA 2018).

44 Integrated system means that all primary components are in the reactor pressure vessel.

45 First of a kind.

Carem 25 is an Argentinian FOAK project, a small pressurized water reactor with an installed capacity of 25 MWe and 100 MWt. Its lifecycle is 40 years. It is being developed and built by Combustibles Nucleares Argentinos jointly with other leading nuclear companies in Argentina and coordinated by the National Atomic Energy Commission. The project was licensed in 2009 and has been under construction since February 2014. It is located close to Buenos Aires next to the Atucha nuclear power plant, and it is expected to be connected to the grid in 2020. Following successful operation, Argentina intends to build units (CAREM 100 and CAREM 300) for domestic use and export (see WNN 2018; Nuclear Engineering International 2018; IAEA 2018, p. 7).

HTR-PM is a Chinese project developed by Tsinghua University. It is a high-temperature gas-cooled reactor with an installed capacity of 2 × 210 MWe and 2 × 250 MWe. The project has been under construction since December 2012 in the Shandong area and is expected to be connected to the grid in 2019.

ACP100 is also a Chinese project, developed by China National Nuclear Corporation. It is an integral PWR, cooled and moderated by light water. With an installed capacity of 125 MWe and 385 Mwt, the ACP100 is based on existing PWR technology adapting verified passive safety systems (see IAEA 2018, p. 11). Other Chinese projects include CAP200, DHR, ACPR50S by CGN. Also, Japan and South Korea (SK) are developing their own SMR, DMS by Hitachi-GE Nuclear Energy and IMR by Mitsibishi Heavy Industries in Japan, as well as SMART by KAERI in SK (see IAEA 2018).

NuScale, an American project involving a light-water-cooled pressurized-water reactor, developed by NuScale Power Ic. with installed capacity of 50 MWe and around 160 MWt. The project will likely be licensed in September 2020. The construction period is planned for three years and the first reactor should be connected to the grid in 2025 in Idaho Falls (see Nuscale n.d.). There are also other projects in the USA, such as SMR160 by Holtec International or Westinghouse SMR by Westinghouse Electric Corporation (see IAEA 2018).

There is also one SMR model under development in the Czech Republic, called **Energy Well**, a project of ÚJV Řež. It is supposed to be a model of the fourth generation, a high temperature reactor cooled by molten salt with an installed capacity 20 MWt and 8.4 MWe, the size of a shipping container. The fuel cycle is seven years and the type of fuel is TRISO, enrichment 15% (see Research Centre Řež 2018).

6.7.1 SMRs in the Czech Republic

In 2012–2014 ÚJV Řež, a. s. prepared a study for the Czech Ministry of Industry and Trade, analysing the suitability of SMRs for the Czech Republic. The study considers the technology to be highly suitable for the country and selected a list of power plants generating electricity and heat using coal that would be appropriate for replacement by an SMR. The criterion for inclusion was that it be a heat source burning solid fuels, supplying heat to a centralized heat system, and with an installed thermal output over 100 MWt. Accordingly, the following sites were recommended as optimal for such a substitution:

- Elektrárna Opatovice – Elektrárna Opatovice, a.s. (9 km from Pardubice),
- Elektrárna Melnik I – ČEZ, a. s. (expected in areal EME III),
- Elektrárna Porici – ČEZ, a. s. in Trutnov,
- Teplárna Komořany – United Energy, a.s. in Most (ÚJV Řež, 2014).

Currently, the discussion of SMRs in the Czech Republic is once again active as a part of the discussion of a new nuclear unit. Considering the current trend towards decentralisation, an SMR could be used particularly as an important source of heat in a decentralised system in the future. Optimistic talk (by SMR innovators, construction companies, and enthusiasts) targets 2030; the more realistic view (of investors, transmission system operators, and lawmakers) sees it happening around 2050, but only if the technology succeeds on the market. ČEZ might be considering an SMR in its next tender.

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