The Ukrainian Nuclear Industry: Expert review

BELLONA
2017
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<th>Abbreviation</th>
<th>Description</th>
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<tbody>
<tr>
<td>BGI and E</td>
<td>Blocks of Gamma Sources</td>
</tr>
<tr>
<td>CANDU</td>
<td>Pressurized Heavy-Water Nuclear Reactor</td>
</tr>
<tr>
<td>ChNPP</td>
<td>Chornobyl Nuclear Power Plant</td>
</tr>
<tr>
<td>CLTSF</td>
<td>Centralized Long-Term Storage Facility for Disused Radiation Sources</td>
</tr>
<tr>
<td>CP</td>
<td>Capacity Factor</td>
</tr>
<tr>
<td>CSFSF</td>
<td>Centralized Spent Fuel Storage Facility</td>
</tr>
<tr>
<td>DG ENER</td>
<td>Directorate General for Energy of the European Commission</td>
</tr>
<tr>
<td>DSFSF</td>
<td>Dry Spent Fuel Storage Facility</td>
</tr>
<tr>
<td>DTEK</td>
<td>Donbass Fuel-Energy Company</td>
</tr>
<tr>
<td>Eastern MPP</td>
<td>Eastern Mining and Processing Plant</td>
</tr>
<tr>
<td>Energoatom</td>
<td>National Nuclear Energy Generating Company Energoatom</td>
</tr>
<tr>
<td>Energorynok</td>
<td>State Enterprise Energorynok</td>
</tr>
<tr>
<td>ENSDF</td>
<td>Engineered Near-Surface Disposal Facility for Solid Radioactive Waste</td>
</tr>
<tr>
<td>ENSREG</td>
<td>European Nuclear Safety Regulators Group</td>
</tr>
<tr>
<td>FA</td>
<td>Fuel Assembly</td>
</tr>
<tr>
<td>FC&amp;SS</td>
<td>Final Closure and Safe Storage</td>
</tr>
<tr>
<td>FE</td>
<td>Fuel Element</td>
</tr>
<tr>
<td>FEC</td>
<td>Fuel Energy Complex</td>
</tr>
<tr>
<td>HLW</td>
<td>High-Level Waste</td>
</tr>
<tr>
<td>IAEA</td>
<td>International Atomic Energy Agency</td>
</tr>
<tr>
<td>ICSRM</td>
<td>Industrial Complex for Solid Radioactive Waste Management</td>
</tr>
<tr>
<td>ILW</td>
<td>Intermediate-Level Waste</td>
</tr>
<tr>
<td>IPS</td>
<td>Integrated Power System</td>
</tr>
<tr>
<td>KhNPP</td>
<td>Khmelnytsky Nuclear Power Plant</td>
</tr>
<tr>
<td>KIEP</td>
<td>Public Joint Stock Company &quot;Kyiv Research and Design Institute Energoproject&quot;</td>
</tr>
<tr>
<td>LLW</td>
<td>Low-Level Waste</td>
</tr>
<tr>
<td>LRW</td>
<td>Liquid Radioactive Waste</td>
</tr>
<tr>
<td>MPP</td>
<td>Mining and Processing Plant</td>
</tr>
<tr>
<td>NASU</td>
<td>National Academy of Sciences of Ukraine</td>
</tr>
<tr>
<td>NEC</td>
<td>Nuclear Energy Complex</td>
</tr>
<tr>
<td>NEURC</td>
<td>National Energy and Utilities Regulatory Commission</td>
</tr>
<tr>
<td>NF</td>
<td>Nuclear Fuel</td>
</tr>
<tr>
<td>NFC</td>
<td>Nuclear Fuel Cycle</td>
</tr>
<tr>
<td>NPP</td>
<td>Nuclear Power Plant</td>
</tr>
<tr>
<td>Abbreviation</td>
<td>Full Form</td>
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<tr>
<td>NRI</td>
<td>Nuclear Research Institute</td>
</tr>
<tr>
<td>NSC</td>
<td>New Safe Confinement</td>
</tr>
<tr>
<td>OHPP</td>
<td>Oleksandrivka Hydroelectric Power Plant</td>
</tr>
<tr>
<td>OPIC</td>
<td>Overseas Private Investment Corporation</td>
</tr>
<tr>
<td>PChP</td>
<td>Prydniprovsk Chemical Plant</td>
</tr>
<tr>
<td>PJSC</td>
<td>Public Joint Stock Company</td>
</tr>
<tr>
<td>PSPP</td>
<td>Pumped-Storage Power Plant</td>
</tr>
<tr>
<td>Radwaste</td>
<td>Radioactive Waste</td>
</tr>
<tr>
<td>RBMK</td>
<td>High-Power Channel-Type Graphite-Moderated Nuclear Reactor</td>
</tr>
<tr>
<td>RICS</td>
<td>Radioactive Waste Interim Confinement Sites</td>
</tr>
<tr>
<td>RNPP</td>
<td>Rivne Nuclear Power Plant</td>
</tr>
<tr>
<td>RS</td>
<td>Radiation Source</td>
</tr>
<tr>
<td>RWDS</td>
<td>Radioactive Waste Disposal Site Buryakivka</td>
</tr>
<tr>
<td>SAEZ</td>
<td>State Agency of Ukraine on Exclusion Zone Management</td>
</tr>
<tr>
<td>SFA</td>
<td>Spent Fuel Assembly</td>
</tr>
<tr>
<td>SID</td>
<td>Shelter Integrated Database</td>
</tr>
<tr>
<td>SNF</td>
<td>Spent Nuclear Fuel</td>
</tr>
<tr>
<td>SNRIU</td>
<td>State Nuclear Regulatory Inspectorate of Ukraine</td>
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<tr>
<td>SPP</td>
<td>Solar Power Plant</td>
</tr>
<tr>
<td>SRW</td>
<td>Solid Radioactive Waste</td>
</tr>
<tr>
<td>SSE</td>
<td>State Specialized Enterprise</td>
</tr>
<tr>
<td>SSEC CSER</td>
<td>State Scientific and Engineering Center for Control Systems and Emergency Response</td>
</tr>
<tr>
<td>STC NRS</td>
<td>Scientific and Technical Center for Nuclear and Radiation Safety</td>
</tr>
<tr>
<td>SUNPP</td>
<td>South Ukraine Nuclear Power Plant</td>
</tr>
<tr>
<td>SUPC</td>
<td>South Ukraine Power Complex</td>
</tr>
<tr>
<td>TPP</td>
<td>Thermal Power Plant</td>
</tr>
<tr>
<td>TPSPP</td>
<td>Tashlyk Pumped-Storage Power Plant</td>
</tr>
<tr>
<td>UBL</td>
<td>Underground Borehole Leaching</td>
</tr>
<tr>
<td>UkrDO Radon</td>
<td>Ukrainian State Association Radon</td>
</tr>
<tr>
<td>VLLW</td>
<td>Very Low-Level Waste</td>
</tr>
<tr>
<td>VVER</td>
<td>Water-Cooled Water-Moderated Power Reactor</td>
</tr>
<tr>
<td>WENRA</td>
<td>Western European Nuclear Regulators Association</td>
</tr>
<tr>
<td>ZNPP</td>
<td>Zaporizhzhya Nuclear Power Plant</td>
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</tbody>
</table>
This report on the Ukrainian nuclear industry was authored by Ukrainian experts on the initiative of, and with the cooperation of, Bellona.

After the dissolution of the Soviet Union, the enormous atomic industry of the USSR was divided among new and suddenly formed states. Therefore the nuclear industry of Ukraine possesses a large, and at the same time burdensome legacy, which it achieved after 1991 and the dissolution of the Soviet Union. Ukraine found itself among a handful of states wherein nuclear power provided more than 50% of the energy. At the same time the sector, which administered the atomic industry and that remained on Ukraine’s territory, cannot at current fully satisfy atomic energy demand. This primarily owes to a lack of uranium mining capacity and production of necessary metals, as well as a weak infrastructure for the safe handling of spent nuclear fuel and radioactive waste. Ukraine’s burdensome legacy was redoubled by the Chernobyl catastrophe.

Bellona, being a practical non-government organization, continually seeks solutions directed toward preventing nuclear and radiation threats. Bellona devotes special attention to the safe operation of nuclear power plants and to questions of safe radioactive waste and spent nuclear fuel handling. Bellona believes that from the perspective of environmental safety, practically all facets of the nuclear industry – from nuclear power plants to repositories for spent nuclear fuel and radioactive waste to uranium production to reprocessing and conditioning facilities, and so on – represent a potential threat to people and the environment. Therefore, in supporting the work of international and national programs, Bellona wishes to be sure that the government of Ukraine and international organizations contributing funding to nuclear projects are not only assuring and extending the existence of the country’s nuclear industry in its current state, but are actually working to prevent nuclear and radioactive threats.

Considering contemporary reality and understanding that nuclear energy in Ukraine will at least for the next several decades remain the country’s main source of energy, Bellona believes that national and international programs must exert maximum effort to assure the safety of the Ukrainian nuclear sector.

The goal of the current report is to more fully understand the condition of the nuclear sector in Ukraine, to provide information to international organizations and programs such that they are able to decide where to most urgently apply efforts toward assuring the safety of the Ukrainian nuclear sector.

Bellona believes that this report will become required reading for politicians, specialists and non-profits in both Ukraine and the West. Bellona hopes that the interested parties will see the contents of this report as a source of expert information, which will assist them in finding the best decision on the question of safety.
Bellona with respect and understanding curated the opinions of these Ukrainian experts who participated in the writing of this report, and wishes to express its deepest gratitude for their work.

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Bellona also also wishes to express its gratitude to the Ministry of Foreign Affairs of Norway, the Norwegian Radiation Safety Agency and the Embassy of the Kingdom of Norway in Ukraine for supporting our work.
For its entire existence, the nuclear power sector in Ukraine has been closely linked with the military-industrial complex of the Soviet Union (the USSR) and the Russian Federation (the RF), whose sphere of activity included the nuclear industry with all components of the nuclear fuel cycle infrastructure (NFC).

History of the uranium project

Military and energy projects of the Soviet Union required a significant amount of uranium raw materials. In the last years of the Second World War, the leadership of the USSR decided to use the radiometric method to study all possible sources of uranium. These were the radiometric geological explorations that contributed to discovery of a few uranium deposits within the territory of Ukraine [5]. In 1945, the first large uranium deposit discovered in Ukraine was called "Pervomaiske" and remained in operation until 1968. In 1946, the Zhovtorichenske deposit of uranium (also with significant reserves) was discovered, the commercial operation of which was carried out in 1950-1995.

It is these discoveries of uranium deposits within the territory of Ukraine that contributed to the establishment of enterprises of the initial stage of the nuclear fuel cycle in Ukraine.

Ukrainian deposits of uranium are concentrated in Dnipropetrovsk and Kirovograd regions. Since 1945 until now, uranium has been extracted in 11 deposits, which today have different status. The four oldest (Pervomaiske, Zhovtorichenske, Devladovo and Bratske) were exhausted in the 1940-1970s; three more (Safronivske, Severinske and Kvitneve) are either preserved or not developed due to lack of funds. Michurinske, Vatutinske, Tsentraalne and Novokostiantynivske uranium deposits are being extensively developed near Kirovograd [5].

The processing of uranium-containing raw materials on the territory of Ukraine started in late 1940’s in the context of special secrecy. The then production processes were imperfect and were carried out without respecting the basic requirements of environmental safety [6].

Originally, two companies processed uranium ores:

- Production Association "Prydniprovsky Chemical Plant" (JSC "PHZ"), located in Dneprodzerzhinsk, Dnipropetrovsk region (1949–1991).
- State Enterprise "Eastern Mining and Processing Plant" (SE "VostGOK"), located in Zhovti Vody, Dnipropetrovsk region (period of operation: 1951 – to the present day).

Currently, the processing and primary enrichment of uranium ore is carried out only by SE "VostGOK", the only Ukrainian company providing natural uranium extraction and production of its oxide concentrate. It is subordinate to the Ministry of Energy and Coal Industry of Ukraine. Today SE "VostGOK" is one of the 28 uranium-mining centers in the world, among which it is in the top ten, and it is also the largest in Europe.

As you know, the nuclear fuel cycle (NFC) in Ukraine is incomplete, and in this regard, to a considerable extent, the development of nuclear power industry in the existing format of its functioning depends on Russia. At present, Ukraine independently implements only the first stage of the NFC, the extraction of uranium ore and the production of uranium concentrate from it, providing only 30% of the needs of the Ukrainian nuclear power plants, i.e. about 800-900 tons of uranium concentrate from the required 2.5 thousand tons [7, 8]. All uranium concentrate made in Ukraine was recently sent to Russia for processing. Until 2016, Ukraine enriched its uranium concentrate on the facilities of the International Uranium Enrichment Center (Angarsk, Irkutsk Region, Russia).

History of the construction and commissioning of nuclear reactors

The Order of the Council of Ministers of the USSR dated June 29 of 1966 approved the plan for
commissioning the nuclear power plants in the period from 1966 to 1977. It was planned to build a total power capacity of 11900 MW, with the RBMK reactors having a capacity of 8,000 MW. One of the planned nuclear power plants was to compensate for the electricity shortage in the Central Energy District of the USSR, the largest in the United Energy System (UES) of the South. This first NPP within the territory of Ukraine became the Chernobyl NPP. According to the Resolution of the Central Committee of the CPSU and the Council of Ministers of the USSR dated February 2, 1967, it was sited near the village of Kopachi in Kiev region [9].

Construction of the first unit of the Chernobyl Nuclear Power Plant with a LWGR type nuclear reactor, in which graphite is the neutron reflector, the Russian equivalent of RBMK-1000 (1000 MW), started in 1972; and it was put into commercial operation on September 26, 1977. Therefore, it is 1977 that officially is considered the year of the birth of Ukrainian nuclear power industry. The growing demand for electricity, the desire to replace thermal and hydroelectric power plants with more powerful nuclear power plants, helped to speed up their construction. At the time of the man-made disaster on the 4th unit of the Chernobyl NPP (April 1986) there were 10 power units in operation in Ukraine, 8 of them had the capacity of 1000 MW.

In the time since the start of the first nuclear power unit, five nuclear power plants were built in Ukraine, which have 19 power units with a total capacity of 17,880 MW put into operation. (Fig. 1.1). Meanwhile, it should be noted that all installed nuclear reactors in Ukraine were designed and manufactured in the USSR and the Russian Federation.

Four RBMK-1000 type reactors were installed at the Chernobyl NPP only. The PWR type reactors with a water-water cooling system were installed on the other four NPP sites, in which conventional water passing through the core serves as a neutron moderator and coolant. The Russian equivalents of the PWR reactor are called VVER-440 and VVER-1000. It is worth noting that in world practice, the most widely used were light-water type PWR reactors (about 90%).

When discussing the development of nuclear power sector in Ukraine, it is impossible to avoid the fact that in the mid-80s of the last century the Energy Program of the USSR was adopted, according to which it was planned to place 43 atomic reactors of Russian production in Ukraine. During this period, many scientists of the Academy of Sciences of the Ukrainian SSR convincingly substantiated the unrealistic nature of such planning on the placement of such a sizeable number of nuclear power units. According to their projected estimates, considering the resource potential required to ensure the safe operation of the NPPs, it was determined that not more than 23 reactors of the VVER-1000 type could be located on the territory of the republic. The main factor, limiting the placement of these NPPs with existing electricity generation technology, is the water resources in Ukraine. Estimates showed that with a number of nuclear reactors of more than 23, the qualitative indicators of water resources will deteriorate significantly, which will lead to catastrophic consequences for the population of Ukraine [10]. However, design surveys and construction work on the construction of additional units of the NPPs, as directed by Moscow, continued until 1986 (the Crimean NPP, Odesa nuclear heat and power plant, etc.).

Summary data on the current state of the nuclear power industry in Ukraine are given in Table 1.1. and on Fig. 1.2.

According to statistical data on the increase of power generating capacities, it is possible to distinguish three basic periods in the history of the development of nuclear power industry in Ukraine, which can be clearly seen in the diagram of Fig. 1.2.: 1. 1977-1991 – a very fast increase in capacity of the NPPs, an average of about 9% per year. 2. 1992-2010 – a period of practical suspension of the commissioning of new facilities and the full stop of operation of all units of the Chernobyl NPP. 3. 2011-2017 – a period of the status check of NPP units that have worked the design lifetime and extension of their operation beyond the design lifetime over 10-15 years; preparatory work for the decommissioning of NPP units.

At present, 15 nuclear power units with a total capacity of 13 888 MW are operating at the Ukrainian NPPs. Ukraine is on the 7th place in the world by this indicator [11]. All types of NPPs occupy only 25% of the total structure of electric generation capacities of Ukraine (Fig. 1.3). However, in recent years, they produce up to 55% of all electricity in the country, and in some periods up to 70% (Fig. 1.4).

At the present stage, negative processes are occurring in the fuel and energy sector of the country and dangerous trends are observed that threaten the energy and environmental safety of the country. This is due to the following factors:

1. For many years, much of Ukraine’s energy sector has depended on Russia, which supplied natural gas, petroleum products, and fuel for power plants (thermal plants and NPPs). This dependence on imports turned gas, oil, nuclear fuel, and then coal into a lever of pressure on Ukraine from the side of the neighboring state. The loss of facilities of the fuel and energy sector and promising areas in 2014-2017 for the development of hydrocarbon resources has largely weakened the level of energy security of the country.

2. Most of the units of domestic NPPs are reaching their design operational limit and require implementation of life extension procedures. The
Table 1.1. General data on reactor units of Ukrainian NPPs (as of 01.01.2017)

<table>
<thead>
<tr>
<th>Name of the NPP</th>
<th>Number of the NPP unit, type of reactor / its series</th>
<th>Installed power capacity mln. kW</th>
<th>Start of construction</th>
<th>Date of connection to the electrical network</th>
<th>Scheduled year of decommissioning</th>
<th>Date to which the unit life has been extended</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Ne 2 – VVER-1000/V-320</td>
<td>1000</td>
<td>04.1981</td>
<td>02-Jul-85</td>
<td>19-Feb-16</td>
<td>19-Feb-25</td>
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<tr>
<td></td>
<td>Ne 3 – VVER-1000/V-320</td>
<td>1000</td>
<td>04.1982</td>
<td>10-Dec-86</td>
<td>05-Mar-17</td>
<td></td>
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<tr>
<td></td>
<td>Ne 4 – VVER-1000/V-320</td>
<td>1000</td>
<td>01.1984</td>
<td>18-Dec-87</td>
<td>04-Apr-18</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Ne 5 – VVER-1000/V-320</td>
<td>1000</td>
<td>07.1985</td>
<td>14-Aug-89</td>
<td>27-May-20</td>
<td></td>
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<tr>
<td></td>
<td>Ne 6 – VVER-1000/V-320</td>
<td>1000</td>
<td>06.1986</td>
<td>19-Oct-95(1)</td>
<td>21-Oct-26</td>
<td></td>
</tr>
<tr>
<td>South Ukraine (SUNPP)</td>
<td>Ne 1 – VVER-1000/V-302</td>
<td>1000</td>
<td>03.1977</td>
<td>31-Dec-82</td>
<td>02-Dec-13</td>
<td>02-Dec-23</td>
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<tr>
<td></td>
<td>Ne 2 – VVER-1000/V-338</td>
<td>1000</td>
<td>10.1079</td>
<td>06-Jan-85</td>
<td>12-Jun-15</td>
<td>31-Dec-25</td>
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<td>Ne 3 – VVER-1000/V-320</td>
<td>1000</td>
<td>02.1985</td>
<td>20-Sep-89</td>
<td>10-Feb-20</td>
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<td>Rivne (RNPP)</td>
<td>Ne 1 – VVER-440/V-213</td>
<td>440</td>
<td>08.1976</td>
<td>22-Dec-80</td>
<td>22-Dec-10</td>
<td>22-Dec-2030</td>
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<td></td>
<td>Ne 2 – VVER-440/V-213</td>
<td>440</td>
<td>10.1977</td>
<td>22-Dec-81</td>
<td>22-Dec-11</td>
<td>22-Dec-2031</td>
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<td></td>
<td>Ne 3 – VVER-1000/V-320</td>
<td>1000</td>
<td>02.1981</td>
<td>21-Dec-86</td>
<td>11-Dec-17</td>
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<td></td>
<td>Ne 4 – VVER-1000/V-320</td>
<td>1000</td>
<td>?</td>
<td>10-Oct-04</td>
<td>07-Jun-2036</td>
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<td>Khmelnitsky (KhNPP)</td>
<td>Ne 1 – VVER-1000/V-320</td>
<td>1000</td>
<td>11.1981</td>
<td>22-Dec-87</td>
<td>13-Dec-18</td>
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<tr>
<td></td>
<td>Ne 2 – VVER-1000/V-320</td>
<td>1000</td>
<td>1983</td>
<td>07-Sep-05</td>
<td>07-Sep-2035</td>
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<td>Chernobyl (ChNPP)</td>
<td>Ne 1 – RBMK-1000</td>
<td>1000</td>
<td>06.1972</td>
<td>26-Sep-77</td>
<td>1996(2)</td>
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<td>Ne 2 – RBMK-1000</td>
<td>1000</td>
<td>02.1973</td>
<td>21-Dec-78</td>
<td>1991(3)</td>
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<td></td>
<td>Ne 3 – RBMK-1000</td>
<td>1000</td>
<td>05.1977</td>
<td>03-Dec-81</td>
<td>2000(4)</td>
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<tr>
<td></td>
<td>Ne 4 – RBMK-1000</td>
<td>1000</td>
<td>09.1977</td>
<td>10-Nov-83</td>
<td>1986(5)</td>
<td></td>
</tr>
</tbody>
</table>

Notes:

1. ZNPP Unit 6 began commercial operation on April 2, 1997.
2. ChNPP Unit 1 stopped on November 30, 1996, decommissioning mode.
3. ChNPP Unit 2 stopped on 11-Oct-91, decommissioning mode.
5. ChNPP Unit 4 was destroyed because of the accident on April 26, 1986. By November 1986, an insulating structure, called "Sarcophagus", was built over the destroyed Unit 4, and later - the Shelter Object (Fig. ; On November 29, 2016, the construction of another protective shell over the Shelter Object was completed - a confinement named the Arch.)
The economic and political crisis in which Ukraine has found itself in 2014 – 2017 does not allow to intensify work on commissioning new nuclear power plant units. and constrains the implementation of plans for the development of the nuclear industry at planned levels (for example, only 16% of the "Program of radioactive waste management" was implemented in recent years).

3. The construction and commissioning of new NPP units is constrained by the protest actions of the public, who, after the Chernobyl and Fukushima accidents, are frightened by the "peaceful atom".

4. Slowly, replacement of electrical power facilities such as storage hydroelectric power stations (SHPs) is introduced, which are necessary for the stable operation of NPP units.

5. The issue is of handling the the SNF returned from Russia, originating at Ukrainian nuclear power plants with VVER-440 reactors and sent for processing in the RF, has yet to be solved. The complexity of disposal of spent nuclear fuel and high-level waste (HLW) is still a disadvantage. Absence a proper Ukrainian storage facility leads to about $200 million annual loss, which Ukraine has to pay for services from the Russian company Rosatom for the transport and processing of spent fuel.

6. Since 2015, Ukraine’s power system has moved from market relations to manual control of the country’s energy capacities, which is unacceptable.

7. The resolution of the issues of the nuclear industry is aggravated by the absence of a separate state structure in Ukraine, which would take care specifically to resolve these issues (today, the nuclear industry is subordinated to the Ministry of Energy and Coal Industry of Ukraine, which takes care of all energy industries)
These processes have already led to an imbalance in the economy and significantly impede the country's energy development.

Steps to improve the condition of Ukrainian nuclear energy sector

Based on the information-analytical digest reports "ENERGOINFORM-INFORMENERGO" on the state of the fuel and energy system of Ukraine in 2014-2017, some steps are described below, which are taken by the state to improve the state of nuclear power:

• In order to reduce dependence on Russia Ukraine signed a contract with Westinghouse Electric Company on December 30, 2014, for the supply of nuclear fuel, which initiated the diversification of sources of nuclear fuel supply, thus becoming a step towards reducing the risks of full dependence on the Russian monopolist. (In addition to the South Ukrainian NPP, by the end of 2017, after upgrading the in-core monitoring systems, the fuel from Westinghouse will be loaded into the cores of Power Units 1, 3, and 4 of the Zaporozhe NPP).

• It is planned to gradually increase the capacity of existing VVER-1000 type reactors up to 110% of the nominal level at the expense of upgrading the reactor turbines by the domestic turbine manufacturer for the NPPs, HPS and PSPP, i.e. "Turboatom" PJSC.

• A contract has been signed with URENCO for the supply of enriched uranium that will be used to produce nuclear fuel for the Ukrainian NPPs at Westinghouse facility in Sweden.

• An agreement was signed with the Korean company "Korea Hydro & Nuclear", which provides for cooperation on the issues of completion of Power Units 3 and 4 of the Khmelnitsky NPP and the implementation of the "Ukraine-EU Energy Bridge" Project;

• An agreement was concluded with Holtec International and an agreement was reached with the US Nuclear Regulatory Commission to invest in the construction of the Centralized Spent Nuclear Fuel Storage Facility (CSNFSF), the cost of which increased to more than $ 1.4 billion, and it cannot be built solely on state budget funds.

Prospective plans are determined in the Energy Strategy of Ukraine for the Period up to 2035

The Strategy № 605-p, approved by the Cabinet of Ministers of Ukraine on September 18, 2017, outlines the strategic guidelines for the development of the fuel and energy complex of Ukraine for the period up to 2035. The Strategy states that nuclear power will maintain its dominant position in the energy balance of Ukraine in any transformation both in the generation system and in the structure of final consumption, and it will remain the basis of the load curve and the main source of electricity production with no carbon emissions.

The optimistic forecast of energy development in Ukraine up to 2050, which shows the destiny of nuclear power generation, is based on materials from the Institute of Economics and Forecasting of the National Academy of Sciences of Ukraine (Fig.1.5) [13].
2. NUCLEAR POWER PLANTS OF UKRAINE

2.1. Chernobyl Nuclear Power Plant

The first Ukrainian nuclear power plant – Chernobyl NPP (ChNPP) – is located in Ukraine at a distance of 2 km from the town of Pripyat (built simultaneously with the plant primarily for its workers), 18 kilometers from the town of Chernobyl, 16 kilometers from the Belarusian border and 110 kilometers from the city of Kyiv. The name is associated with the town of Chernobyl, the district center of the area at the time the NPP was built. Four nuclear reactors of RBMK-1000 type (high-power channel-type reactor) with an electrical power of 1000 MW each (thermal power of 3200 MW) were constructed and commissioned at the plant over several years (1978-1984) (Table 1.1). Two similar reactors were constructed but never completed: unit 5 (1981–1988) and unit 6 (1983–1988). ChNPP produced electricity from 1977 to 2000. Until 1991, ChNPP was subordinated to the USSR Ministry of Energy and Electrification (USSR Ministry of Energy). It became the third plant in the USSR with RBMK-1000 reactors after the Leningrad and Kursk NPPs, which were commissioned in 1973 and 1976, respectively. ChNPP produced about one tenth of Ukraine’s electricity. As of the beginning of 1986, ChNPP was the most powerful nuclear power plant in European part of the USSR [1].

On 9 September 1982, an accident that involved damage of a fuel assembly and caused rupture of fuel channel No. 62-44 occurred at the final construction stage of ChNPP unit 4 during trial startup of the reactor at 700 MW power (thermal) at rated coolant parameters. The rupture deformed the core graphite layer and a significant amount of radioactive materials was released to the reactor space from the damaged fuel assembly. Severe accident consequences were caused by failure of the emergency protection system and long-term (for 20 min) retention of the reactor at 700 MW power after rupture of the channel. The radioactive release contaminated a substantial territory around the ChNPP industrial site. Mitigation of the accident consequences required about three months of repair activities. Channel No. 62-44 and the core area adjacent to the destroyed channel were permanently withdrawn from operation [4]. According to official data, the accident did not have a significant impact on the environment. Increased levels of radioactive contamination of the environment were short-term. According to unofficial sources, such as experts who were engaged in radio-ecological monitoring of soils, it is known that radioactive traces was observed in the surface soil layer outside the plant industrial site in subsequent years after the ChNPP accident of 1982.

At 1:23 am on 26 April 1986, a fire and explosion occurred at ChNPP unit 4. The reactor was put into the design power mode three months earlier than planned, during an experiment performed to analyze the potential use of turbine generator inertia to produce some amount of electricity in the event of a future reactor emergency shutdown, and this test destroyed the unit 4 reactor (Fig. 2.1). This accident became the largest man-made disaster in the world, which caused global radioactive contamination of numerous territories.

Notification about the Chernobyl accident first appeared in Soviet mass media after almost three days, on the evening of 28 April, in TV program "Vremya". In fact, this brief notification was made

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Research of archival documents of the State Security Committee (KGB) of Ukraine relating to the Chernobyl disaster led to the conclusion that ChNPP was constructed with permanent violations. In particular, documents of poor quality were used for construction because it was carried out with great haste in order to complete the first power unit by the next congress of the Soviet Union Communist Party. Moreover, some construction documents were stolen [2]. Emergencies occurred at ChNPP immediately after its commissioning in 1979; they were sometimes accompanied by serious releases of radiation. According to O. Bazhan, researcher of the KGB documents relating to ChNPP: "During the construction, about 9 accidents and 68 equipment failures occurred at ChNPP. Besides the accident in 1986, an accident that caused significant exposure of plant personnel to radiation occurred in 1982" [3].
under pressure from the international community, which demanded explanations from the USSR about the increased levels of radiation in other countries. Workers of the Forsmark NPP in Sweden, north of Stockholm, were the first to raise alert. The Swedish NPP’s safety system began to issue alarm signals about radioactive contamination. When it became clear that the contamination was not connected with the plant itself, it was suggested that there had been an accident at ChNPP taking into account of the wind direction. Attempts to find out about the situation through diplomatic channels ended in nothing. Only when the Swedes threatened to file an official request to the IAEA, the USSR was forced to issue notification of the accident. The notification included six sentences: “From the USSR Council of Ministers. An accident occurred at the Chernobyl nuclear power plant. One of the nuclear reactors was damaged. Measures have been taken to mitigate the accident. The affected persons are provided with assistance. A government commission has been set up” [5].

There were no warnings about the threat to the health and life of the population.

However, on 27 April 1986, the first signs of very high levels of radioactive contamination in the ChNPP accident area were revealed in the Kyiv region. This is evident from the report (marked as classified) prepared by Director of the Nuclear Research Institute, National Academy of Sciences of Ukraine (Kyiv), I.N. Vishnevsky, for the KGB of Ukraine with information on the detection of a car whose radiation exposure exceeded the background by 5000 times (Fig. 2.2) [6].

On the 6th of May 1986, IAEA Director General, Hans Blix, arrived in Kyiv to evaluate the Chernobyl accident, which prompted the Press Center of the USSR Ministry of Foreign Affairs to highlight this visit and provide brief information on the accident that took place at the plant.

It was only 15th of May that USSR leader, General Secretary of the Central Committee of the Soviet Union Communist Party, Mikhail Gorbachev, appeared on central television and officially acknowledged the Chernobyl accident as a tragedy for the Soviet state. However, objective information on the magnitude of the Chernobyl accident and its consequences was concealed for rather a long time as was requested by an instruction sent to various authorities of USSR KGB, whose copy is shown in Fig. 2.5 [7]. Open discussion of the ChNPP accident causes and consequences became possible only in post-Soviet press.

After the accident, a radioactive cloud formed over the European part of the USSR, covering not only modern Ukraine, Belarus and Russia located near ChNPP, but also a greater part of Europe, as well as the eastern part of the United States. Approximately 60% of radioactive substances were deposited on the territory of Belarus. However,
according to another report on the Chernobyl accident (TORCH report), which was made public in 2006, half of the volatile particles landed outside Ukraine, Belarus, and Russia [8]. By 3 May 1986, the population of Pripyat, Chernobyl, and all other settlements within the radius of 30 km around the plant were completely evacuated. About 200,000 people were evacuated from the areas with high levels of radioactive contamination [9-11].

In the first year after the accident, almost 8.5 million people were exposed to radiation, about 160,000 km² of Ukrainian, Belarusian and Russian territories were contaminated, including 52,000 km² of agricultural lands. The reactor continued to emit radiation for three further weeks until it was covered with a mixture of sand, lead, clay and boron.

Fig. 2.5 shows a map of soil contamination with $^{137}$Cs on the territory of Europe, and Fig. 2.6 is a map of zones with different levels of contamination on the territories of the Republics of Belarus and Ukraine and the Russian Federation.

At the time of the explosion, there were about 190 tons of nuclear fuel in the reactor. The reactor cladding was destroyed, and more than 60 tons of uncontrolled radioactive substances were spewed into the air as there was no containment. According to revised estimates, the total activity of radionuclides released into the environment from the unit 4 core from 26 April to 10 May 1986 was about 50 MCi, being about 4% of the total activity of the reactor fuel, including: 42 MCi (1500·10¹⁵ Bq) of $^{131}$I and 3.3 MCi (127·10¹⁵ Bq) of $^{134}$Cs and $^{137}$Cs [11]. The activity of radioactive releases into the air after the Chernobyl accident was 40 times higher than in the explosion of an atomic bomb in Hiroshima [13, 14].

Since the Chernobyl NPP was a water-cooled graphite-moderated reactor, it was graphite that determined the flammability of the entire system. According to estimations, about 800 tons of graphite remained in the reactor after the accident, which then began to burn [14]. The fire lasted 10 days and took the lives of 31 people, and another 299 people were hospitalized with diagnoses of radiation sickness of varying severity [15]. After a series of emergency measures, the graphite finally ceased to burn only on 10 May. The reactor continued to emit radiation for three further weeks until it was covered with a mixture of sand, lead, clay and boron [14].

The major scope of accident mitigation activities was carried out in 1986-1987, the number of people involved in their implementation amounted to 240,000. The total number of people involved in accident mitigation in all years was more than 800,000. Many of them received high doses of radiation [9, 10, 15].

After the disaster, the plant did not work for about six months. During this time, the territory was decontaminated and a sarcophagus (Shelter)
was built over unit 4. Its construction took 400,000 m³ of concrete mixture and 7000 tons of steel structures; the construction period lasted 206 days. 90,000 workers participated in the construction activities. The creation of a protective shell over the destroyed reactor – Shelter – was a major step towards the mitigation of the nuclear and environmental threat to the world caused by the Chernobyl nuclear accident [10, 15].

2.1.1. Chernobyl NPP units 1, 2 and 3 after the accident

The issues related to resumption of operation for the first three power units of the Chernobyl NPP and implementation of associated activities were the most important in terms of mitigating the accident consequences and were solved in parallel with enclosure of the fourth unit.

After the accident, the first two units remained in normal operating condition. They were shut down at 1:13 am and 2:13 am, respectively, on 27 April 1986. The third power unit, technologically connected with the fourth unit, was shut down at 3:00 am on 26 April 1986. All the stopped power units were normally cooled down.

On 2 May 86, according to Order No. 244, ChNPP units 1, 2 and 3 were transferred to temporary shutdown mode with graphite temperature maintained at 100 °C. They were served in 12-hour shifts consisting of 45 people.

After cooldown, the reactors of the three units were transferred to a deep subcritical state. To remove residual heat, all fuel channels and channels for multiple forced circulation remained filled with water. The residual heat was removed by natural circulation. Water temperature in the core was maintained at a level of 20-80 °C, graphite temperature was 30-90 °C.

Decontamination activities at the first two units were completed in the end of September 1986. Decontamination activities at the third power unit led to further improvement of the radiological situation at the existing power units. The planned activities significantly decreased the dose rate in the unit 3 turbine hall to 7-50 mR/h by the end of July 1987.

After completion of the Shelter facility and a series of decontamination activities on the plant’s territory, the radiological situation at units 1 and 2 finally stabilized and was brought to the established standards.

Regarding ChNPP unit 3, according to Order No. 360 dated 15 June 1986 in compliance with the Directive Schedule of Activities for Mitigation of Accident Consequences, approved by Deputy Head of the USSR Council of Ministers, Yu. D. Maslyukov, workshop working commissions were set up with involvement of experts from design and engineering organizations, who prepared expert conclusions about further operation of Chernobyl NPP unit 3. Unlike ChNPP units 1 and 2, a great
The scope of remediation activities was carried out at ChNPP unit 3.

After completion of all emergency and remediation activities, ChNPP units 1, 2 and 3 were commissioned into post-accident operation:
- unit 1 was commissioned on 1 October 1986;
- unit 2 was commissioned on 5 November 1986;
- unit 3 was commissioned on 4 December 1987.

Then there were events that demonstrated how indecisive the government of the USSR and Ukrainian Soviet Republic were in resolving the future of the Chernobyl NPP; the main question to be answered was "to continue or terminate ChNPP operation?"

On 5 December 2000, the unit 3 reactor was shut down because of a failure in the protection system.

The ChNPP shutdown ceremony took place on 15 December 2000, when the entire plant stopped electricity production at 13:17.

### 2.1.2. ChNPP after shutdown of all power units

On 15 December 2000, a completely new phase began for the ChNPP team – decommissioning of the stopped power units, which is an important stage in the entire life cycle of any nuclear power plant. To accomplish this task, the Chernobyl NPP was removed from subordination of the Energoatom Company by a Governmental resolution and transformed into a state-owned specialized enterprise. Energoatom established Atomremontservis as its subordinated enterprise based on the ChNPP repair and maintenance service. 730 people currently work at Atomremontservis, more than 300 of which are former workers of the Chernobyl NPP. The Energoatom emergency training center, based with the ChNPP emergency management department, is also mainly staffed by former ChNPP employees.

To ensure social protection of ChNPP employees in connection with plant closure, the Cabinet of...
Ministers of Ukraine issued Resolution No. 1748 dated 29 November 2000 [32] that provided legal grounds for plant closure and, at the same time, promoted social guarantees to former plant employees and Slavutych residents concerning the retention of their jobs and support from the state.

2.2. Rivne Nuclear Power Plant

Rivne NPP (RNPP) is the first Ukrainian nuclear power plant with a water-cooled water-moderated power reactor of VVER-440 type (model V-213). It is located near Varash (Kuznetsovsk until 2016), which is a town of regional importance in the Rivne region of Ukraine. RNPP is located in western Polissya, near the Styr River (Fig. 1.1). From a geological point of view, the town of Varash together with RNPP was built in complicated engineering-geological conditions – on unstable soils characterized by karst underwashing processes, periodically forming soil holes on the earth’s surface. This factor poses a permanent potential danger to the infrastructure of RNPP and its satellite town Varash and requires systematic geological monitoring.

RNPP is a separated subdivision of the National Nuclear Energy Generating Company Energoatom (Energoatom) of the Ministry of Energy and Coal of Ukraine (Fig. 2.7).

The plant began its history in 1971 with the design of the Western Ukrainian NPP, which was later renamed Rivne NPP. The plant construction started in 1973. The first two power units with VVER-440 reactors were commissioned in 1980-1981, and unit 3 (VVER-1000) was commissioned in 1986.

The construction of RNPP unit 4 began in 1984, and it was planned to be commissioned in 1991. However, the plant construction stopped in 1990 because the Verkhovna Rada (Parliament) of Ukraine put a moratorium on the construction of nuclear facilities on its territory.

The construction of RNPP unit 4 was resumed in 1993 after the moratorium was lifted. Unit 4 was inspected, and both an upgrading program and a completion project for this power unit were prepared. Public hearings were also conducted on this issue. The reactor of RNPP unit 4 was started on 10 October 2004 and introduced into commercial operation in 2006. The reactor of the new RNPP unit is of VVER-1000 type.

The summary data for all RNPP units are provided in Table 1.1. The total power of all RNPP units is 2835 MW. In the recent years, RNPP produces about 11-12 billion kW•h of electricity, which constitutes 16 % of energy production at nuclear power plants.

On 10 December 2010, the Board of the State Nuclear Regulatory Inspectorate of Ukraine approved the decision to extend the life of RNPP units 1 and 2 for 20 years at its meeting in Kuznetsovsk. It became a significant event not only for nuclear power, but also for the entire state.

2.2.1. From RNPP history

During the construction and operation of RNPP units, there were several issues. They were associated with failures of karst and underwashing soils that periodically occur on the industrial site of this plant.

From the report on discussion of surveys on the Rivne NPP territory [3].

"... The results of surveys carried out by experts of the department for hydrogeological problems of the Institute of Geological Sciences under the Academy of Sciences of the Ukrainian Soviet Republic on the topic "Large-scale mapping of potentially unstable tectonic zones and areas of modern activation of geodynamic processes within the territory of Rivne NPP and Kuznetsovsk" were reported at the meeting of the scientific and technical council of the Kyiv Institute Atomteploelektroproekt in March 1983".

In this report, the scientists substantiated in detail and referred to actual geological material, showing that the foundations of Rivne NPP structures and part of the houses in the satellite town were located on unstable soils within the zone of technology-related activation of the chalk karst associated with the development of flooding on the NPP industrial site after commissioning of the first two plant units. One of the conclusions of this report was to prohibit the construction of a cooling pond that was planned at that time for the plant needs. Its construction...
could lead to even more active karst processes, which would have catastrophic consequences for the plant. However, instead of constructive consideration of the hazardous situation described in the report, its authors were accused of breaking the governmental order... A few weeks after the report, a crane truck fell into a karst hole on the site where the foundation for RNPP unit 3 was under construction. This extraordinary situation had its effect, and led to a scandal. The issue was even brought before the Central Committee of the Soviet Unit Communist Party. As a result, activities were carried out to stabilize the foundations for unit 1 and 2 of the Rivne NPP and fundamentally change the design of the foundations for units 3 and 4. A cooling pond was not constructed. It should be noted that active karst processes in the area of Rivne NPP and Kuznetsovsk still continue.*

2.3. South Ukraine NPP

The South Ukraine NPP (SUNPP) is located in the northern part of the Mykolaiiv region of Ukraine, in the steppe area, on the left bank of the Pivdennyi Bug River (P. Bug), 2 km (to the east) of Yuzhnoukraiinsk (Fig. 1.1). The plant is located on the left bank of the Tashlyk reservoir (TP) formed on the inflow of the P. Bug River (Fig. 2.8.).

SUNPP is a leading energy company of Ukraine and a separate subdivision of the Energoatom Company of the Ministry of Energy and Coal Industry of Ukraine.

SUNPP is included as the basic part in the infrastructure of the South-Ukrainian Power Complex (SUPC), the only company in Ukraine with integrated use of basic nuclear and follow-mode hydroaccumulative capacities, as well as water resources of the P. Bug River. Today, the SUPC includes SUNPP, Oleksandrivka Hydroelectric Power Plant (OHPP) and Tashlyk Pumped-Storage Power Plant (TPSPP) (Fig. 2.9).

Construction started in the spring of 1975. The project envisaged a power capacity of 4000 MW, powerful hydroelectric complex TPSPP with a power of 1800 MW, Kostiantynivka HPP-PSPP (430 MW) and OHPP (11.5 MW) with a cascade of reservoirs: Tashlyk in the Tashlyk valley (volume of 86 million cubic meters), Kostiantynivka (442 million cubic meters) and Oleksandrivka (114 million cubic meters) along the P. Bug River.

However, history had other plans* [34]:

- under pressure of the public, designers refused to construct the Kostiantynivka HPP-PSPP and the same-name reservoir;
- construction of OHPP lasted for 14 years (1985-1999). It was commissioned in April 1999 with a total installed capacity of its two hydraulic units of 11.5 MW; from 2003, the Oleksandrivka reservoir was filled to a level of 14.7 m; from April 2010, the Oleksandrivka reservoir was filled up to a level of 16 m (that allowed using it as a water storage for the first time, and additional 10 million cubic meters of water collected during spring floods are used to maintain the necessary health and environmental costs over a certain period of time in the lower reaches of P. Bug and prevent worsening of hydroeconomic situation in the adjacent settlements);
- TPSPP became an uncompleted construction object (1981: construction started, 1991-2001: construction was suspended, 7 June 2002: project of TPSPP construction completion was approved by a Cabinet Order, which determined commissioning of a startup complex with two reversible hydraulic units with a total power of 320 MW using the Oleksandrivka reservoir with a water level of 14.7 m; in December 2006, TPSPP hydraulic unit 1 was accepted for commercial operation; as of 31 August 2007, TPSPP hydraulic unit 2 was accepted for commercial operation; on 21 November 2007 the Cabinet approved the project and the title of TPSPP construction completion until 2011: builders started construction of TPSPP Stage 2 within TPSPP hy-
draulic unit 3. On 3 November, 2011, mounting of a generator/motor of TPSP hydraulic unit 3 started; due to insufficient funding construction is still underway);

- SUNPP consists of three power units: unit 1 was commissioned on 31 December 1982, unit 2 on 6 January 1985, and unit 3 on 20 September 1989 (construction of power unit 4 was suspended by USSR Cabinet Ordinance of 6 August 1989).

SUNPP units 1 and 2 belong to VVER-1000 small series, in which reactor buildings located separately are connected by a common turbine hall.

The reactor building of units 1 and 2 are 76 m leaktight structures of cylindrical form with a spherical dome, constructed on a concrete foundation. The containment is made of prestressed reinforced concrete.

Unit 3 was constructed as a VVER-1000-series project and is a monoblock unit. The main building of the power unit includes a reactor building consisting of a leaktight case, around which other production premises are constructed. These are divided into "strict access area" and "normally occupied area". They are adjacent to the turbine hall, additional building of electrotechnical devices, deaerator building, special building, etc.

In August 2005, for the first time in Ukraine SUNPP-3 core was loaded with 6 Westinghouse (USA) fuel assemblies (FA) along with Russian assemblies. Fuel assemblies were provided under the Ukrainian-American agreement on the implementation of the nuclear fuel qualification project for domestic NPPs.

In March 2006, SUNPP successfully passed the certification audit of the quality management system for compliance with ISO 9001 international standard. SUNPP became a pilot enterprise of the Energoatom Company on the certification of the quality management system.

On 5 February 2010, the final inspection of six Westinghouse test FA (FA-W) was completed, which proved that "... this fuel assembly showed good results during four years of operation and may be used as a basis in designing fuel for Ukrainian NPPs, in particular for VVER-1000 reactors".

On 28 November 2013, SNRIU Board decision extended SUNPP-1 lifetime for the next 10 years (until 2 December 2023).

On 7 December 2015, based on the state nuclear and radiation safety review of the Periodic Safety Review Report and a comprehensive inspection of SUNPP-2 the SNRIU Board stated that unit 2 complies with the safety requirements and recognized justified its safe operation until 31 December 2025.

The necessary preventive maintenance at SUNPP-3, as well as a comprehensive inspection of its preparedness for lifetime extension is performed in 2016-2017.

The Power Complex at P. Bug annually produces 17-20 billion kWh of electric power, which accounts for approximately 10% of the total electric power production in the country and about 20% of its generation at Ukrainian NPPs. The electric power produced by SUNPP, OHPP and Tashlyk HPSPP is enough to ensure normal living conditions of the Mykolaiv, Odessa and Kherson regions, partly of the Kirovograd region and the Autonomous Republic of Crimea, a region with 5 million people.

2.4. Zaporizhzhya NPP

The Zaporizhzhya NPP (ZNPP) is located in the steppe area on the shore of the Kakhovka reservoir in the Zaporizhzhya region of Ukraine near Enerhodar, 150 km from Zaporizhzhya (Fig. 2.10). It is the largest plant in Europe and third in the world. It consists of 6 nuclear power units, each with a capacity of 1 million kW.

The decision to construct ZNPP was adopted in 1978. In 1981, step-by-step construction of the plant units started. During the period 1984-1987, four units 1*, 2, 3 and 4 were commissioned.

Unit 1 was constructed in less than four years, its startup was appointed by the end of 1984. However, on 27 January 1984, a fire occurred at unit 1. The unit's startup was postponed for almost a year, but the fact that the delay was caused by mitigation of fire consequences was concealed from the public, the media did not receive any information. It became possible only six years later, when the period of restructuring and publicity (presetroika and glasnost) started* [35].

2.4.1. From the history of ZNPP-1 construction

...A fire at unit 1 took place during preparation for startup. On 27 January 1984, in a 50 m cable vault there was a self-ignition of one of the relay units, which caused a fire lasting for 18 hours. As it turned out, the fire was caused by the use of polyvinylchloride insulation at the NPP, which ignited, melted and when breaking off, set fire to cable bundles at lower levels. The vault internals were completely burned out: more than 4 thousand control units, 41 electric motors, and 700 km of different cables were destroyed. After this, at all NPP units constructed in the USSR, new insulating materials were used, which do not ignite during fire.

In 1989, unit 5 was commissioned. Then only in 1995, after the abolition of the moratorium on nuclear facility construction in Ukraine, unit 6 was commissioned.

Annually the NPP generates about 40 billion kWh of electric power, which constitutes a fifth of the annual generation of electricity in the country and a half of the production at Ukrainian NPPs.
2.3.2. Storage of spent nuclear fuel

A dry spent fuel storage facility (DSFSF) was constructed [36, 37] at the Zaporizhzhya NPP, the first among Ukrainian VVER-1000 NPPs. Its technology is based on storage of spent fuel assemblies in ventilated concrete containers located at site within the nuclear power plant (Fig. 2.12). DSFSF design capacity at ZNPP is 380 containers, which provides storage of spent fuel assemblies for the next 50 years. They will be retrieved from the reactors during the NPP’s lifetime.

Historical information on DSFSF construction at the Zaporizhzhya NPP is provided in the insert.

In 1992, at the Zaporizhzhya NPP, one started looking for options for spent nuclear fuel disposal. According to experts’ forecasts, due to a lack of free places in spent fuel pools by the beginning of 1998, it would be necessary to shut down ZNPP units and thus, leave a quarter of the public of Ukraine without electricity.

Under agreement with the State Nuclear Committee of Ukraine, the Zaporizhzhya NPP announced an international competition for the best design of the temporary spent fuel storage facility and after a detailed analysis, a design based on the technology of dry ventilated container storage (companies Sierra Nuclear Corporation and Duke Engineering and Services (DE&S)) was selected.

DE&S technology was recognized as the most environmentally safe, practical, efficient, cost effective and that which most fully met specifics at the ZNPP, namely:

- DE&S design is licensed in oversight bodies of the United States and is already implemented on two U.S. NPPs;
- this design takes into account the possibility of manufacturing DSFSF components from domestic materials.

This type of storage facility was approved by the decision of the State Nuclear Committee of Ukraine on 12 January 1995.

In order to reduce dependence on Russia, on 30 December 2014, Ukraine signed a contract with Westinghouse Electric Company for nuclear fuel supplies, which initiated diversification of nuclear fuel supply sources, and thus became a step towards reducing the risks of full dependence on a Russian monopoly. In addition to SUNPP, which will be completely transferred to Westinghouse fuel by the end of 2017 after modernization of reactor internal control systems, it is planned to start loading the specified fuel into the cores on ZNPP units 1, 3, 4 [38, 41].
On the 28<sup>th</sup> of November 1979, the Ministry of Energy of the USSR, by protocol No. 150/PS, approved the KhNPP technical designs with a proposed power capacity of 4000 MW. The NPP was designed for 4 power units.

In 1980, the construction of a cooling reservoir with a total area of a water table of 22 square kilometers was initiated. KhNPP-1 was constructed from 1981 to 1987 and commissioned on 22 December 1987.

On the 25<sup>th</sup> of July 1996, an emergency release of radioactive steam occurred in a containment room, which was caused by damage of a section of pressurizer valve piping [39]. This accident was rated at level 3 by INES: "Release of radioactive products in NPP room". During this accident, the release of radioactive substances into the environment did not occur. One employee of the NPP died [40].

During this period, sites were also prepared for three units. Construction of unit 2 started in 1983, startup was planned in late 1991.

In 1990, the Verkhovna Rada of Ukraine declared a moratorium on the construction of new nuclear power plants, during which KhNPP mounted main process units and trained personnel for work at unit 2.

The reactors of new Kh-2/R-4 belong to another series of power reactors (VVER-1000), similar reactors are installed at 60% of NPPs in the world. Radioactive releases into the atmosphere are strictly controlled with this design.

The construction of KhNPP-2 was resumed in 1993, but due to lack of financing, construction activities were slow and the unit was completed only in 2005. The State Acceptance Commission signed a certificate on the 7<sup>th</sup> of September 2005 on putting KhNPP-2 into commercial operation. This startup took place on the 9<sup>th</sup> of September 2005. Even before KhNPP-2 startup "Modernization Program for Kh-2/R-4" (with the validity term of 2004-2009) was developed.

On the 24<sup>th</sup> of May 2009, IAEA personnel arrived to KhNPP from the Division of Nuclear Installation Safety in Vienna accompanied by an expert from France and a representative of the European Commission. A team of experts from the OSART post-mission conducted a thorough analysis of the measures implemented by the Khmelnitsky NPP and stated that Khmelnitsky NPP meets the international safety standards.

In September 2012, the Verkhovna Rada of Ukraine adopted the Law of Ukraine "On Siting, Design and Construction of Units 3 and 4 of the Khmelnitsky Nuclear Power Plant", which envisaged approval of KhNPP-3, 4 construction. The project cost is estimated at 40 billion UAH, of which 80% was planned to be financed as credit of the Russian Federation, and 20% through an increase of the electric power tariff. However, this plan was not implemented.

### 2.5. Stress Tests

Events at the Fukushima-1 NPP have attracted worldwide attention to the issues of man-made accidents and environmental safety of nuclear power plants. Most nuclear countries have decided to revise their nuclear programs and safety measures at nuclear installations for the cases of natural disasters and other extreme situations. On 24 June 2011, EU member states together with neighboring countries adopted the Declaration on the Comprehensive Risk and Safety Assessment of Nuclear Power Plants (Stress Tests) and relevant measures in Brussels. The stress test objective is a comprehensive one: reassessment of NPP-reserves and NPP-reaction to various extreme situations, NPP safety improvements, and defining the most efficient procedures in case of emergencies.

Taking into account the consequences of the severe accident with nuclear fuel damage at Fukushima-1 NPP, the SNRIU initiated a targeted extraordinary assessment of the safety state and further safety improvement of Ukrainian NPPs, including Chernobyl NPP (stress tests).

On 17 March 2011, the Statement on the SNRIU Intentions in Connection with the Events at Fukushima-Daiichi NPP established the need to learn lessons from the accident and approve a decision on the implementation of additional measures for Ukrainian NPP safety improvement under conditions of design-basis and beyond design-basis accidents in the short term. In addition to revising the regulatory and legal framework of nuclear and radiation safety.

The issues of Ukrainian NPP safety improvement taking into account the accident at Fukushima-1 NPP were discussed during the meeting of the National Security and Defense Council of Ukraine on 08 April 2011. During the meeting, there was a decision made on "the need to conduct an in-depth extraordinary safety reassessment of Ukrainian NPPs, including check of their seismic resistance" (brought into action by Decree of the President of Ukraine No. 585/2011 dated 12 May 2011).

The SNRIU has developed:

- Action Plan for Special Targeted Safety Assessment and Further Safety Improvement of Ukrainian NPP Units Considering Events at Fukushima-1 NPP (approved on 19 May 2011);
- Action Plan for Special Targeted Safety Assessment and Further Safety Improvement of ChNPP Units 1-3 and ISF-1 Considering Events at Fukushima-1 NPP (approved on 05 July 2011).

The stated plans envisaged the implementation of short-term and long-term measures. One of the measures of the above mentioned Action Plans was to conduct targeted extraordinary safety assessment of nuclear installations located on NPP sites (stress tests).
The Action Plans also envisaged:
- targeted check of emergency preparedness;
- review and extension (according to stress test results) of the Comprehensive (Integrated) Safety Improvement Program for Ukrainian NPPs;
- update the Safety Improvement Plan for ChNPP Spent Fuel Storage Facility (ISF-1);
- analyze and improve the regulatory and legal framework of nuclear and radiation safety, improve safety requirements for operating and new power units.

"Recommendations to the Structure and Contents of the Report of the Targeted Safety Reassessment of Nuclear Installations Located on NPP Site Considering Lessons Learned from Fukushima-1 NPP Accident" were developed and introduced to finalize reporting materials on the results of the specified activities. These recommendations were prepared based on the methodology for conducting stress tests at European NPPs (13 May 2011, Declaration of ENSREG, Annex 1 "EU "Stress-test" specifications"), which was approved by the European Nuclear Safety Regulators Group (ENSREG) and European Commission.

In June 2011, Ukraine joined the initiative of the European Commission and ENSREG to conduct stress tests at NPPs in EU member states and neighboring countries, (Declaration on Stress Tests dated 24 June 2011).

According to results of the targeted extraordinary safety assessment of operating NPPs, there were additional safety measures developed for implementation at NPPs in subsequent years.

On 30 December 2011, the SNRIU submitted the National Report of Ukraine of the Results of Stress Tests for Ukrainian NPPs [45, 46] to the European Commission.

The specified report was prepared based on the results of stress tests conducted by the operating organizations for operating NPPs, ChNPP unit 1-3 and ISF-1 according to ENSREG requirements for the structure and contents of the national reports – "Post-Fukushima "stress tests" of European nuclear power plants – contents and format of National Reports".

Within stress tests, the operating organizations (Energoatom and the Chernobyl NPP) analyzed in details the following:

- extreme natural impacts (earthquake, flooding, fire, tornadoes, extremely high / low temperature, extreme precipitations, strong wind, event combinations);
- total blackout and/or loss of ultimate heat sink;
- severe accident management issues;
- for operating NPPs (ZNPP, KhNPP and SUNPP), stress tests were conducted regarding nuclear fuel located in: core, spent fuel pool, fresh fuel units, dry spent fuel storage facilities (ZNPP);
- stress tests at ChNPP were held with regard to spent fuel located in spent fuel pools of units 1-2 and ISF-1; spent fuel pool of ChNPP-3 was also analyzed, since it can be used for storage of spent fuel (as a redundant one).

According to the results of conducted analyses, conclusions followed on resistance of nuclear installations to extreme events and measures were proposed on their safety improvement.

Stress-test results were considered on 24-25 November 2011 during the open meeting of the SNRIU Board with the participation of the representatives of the mass media, public organizations, Cabinet of Ministers of Ukraine, deputies of the Verkhovna Rada of Ukraine, ministries and agencies, regional state administrations and regional councils, in addition to representatives of the nuclear regulatory authorities of the Russian Federation, Slovakia, Germany and Bulgaria.

Following the stress test results, the following was defined:

- sequence of events that occurred at Fukushima-1 NPP is barely possible for Ukrainian NPPs;
- measures taken during last 10-15 years on safety improvement of NPP power units significantly reduced the possibility of core damage and release of radioactive substances;
- no new critical external natural hazards or combinations of hazards were revealed in addition to those considered during NPP design and analyzed in detail in NPP Safety Analysis Reports.

According to stress test results, conclusions of the state review of nuclear and radiation safety, and results of EC peer review, recommendations were made on the areas of safety improvements and corresponding changes to the Comprehensive (Integrated) Safety Improvement Program were introduced. The updated Comprehensive (Integrated) Safety Improvement Program was approved by Resolution of the Cabinet of Ministers of Ukraine No. 1270 dated 07 December 2011.

The specified Comprehensive Program clearly defines challenges with the implementation of measures as a result of the stress tests. To illustrate, a list of some of them can be found below:

**Measures on improvement of NPP resistance to seismic hazards**

- the system of continuous seismic monitoring was implemented only for SUNPP site. Due to this, there is an uncertainty with seismic levels of KhNPP, RNPP and ZNPP sites. The situation is the most critical for the ZNPP site, since seismic studies for it were not fulfilled to the required extent. According to different sources, ZNPP seismicity can vary from 7 to 8 magnitudes (from 0.1g to 0.2g). Seismic assessment of structures, systems and components shall be performed for SSE > 0.1g and shall envisage required compensating measures;
• qualification of equipment and seismic assessment of piping, structures, buildings and constructions for established levels of seismic impact (0.1g – KhNPP, RNPP; 0.12g – SUNPP; >0.1g – ZNPP) were not completed for any power unit; seismic resistance margin was not assessed.

Measures to ensure heat removal from core and spent fuel pool in conditions of total blackout and loss of ultimate heat sink
• the vast majority of measures are at the concept stage. Specific project decisions and computer and analytical justifications have not been developed;
• there is no phased schedule of implementation of measures that makes it impossible to ensure efficient control from the SNRIU;
• despite the measures taken to define a unified technical policy, there is still inconsistency between certain NPPs with similar installations. There are still general unresolved issues: ensuring subcriticality of spent fuel pool in case of feeding by non-borated water, confirm integrity of equipment, piping and structures that shall be used to perform safety functions in case of extreme hazards.

Measures on severe accident management
• absent justified technical concept on the implementation of the system for steam-gas mixture pressure reduction in the containment;
• absent technical means for instrumental monitoring of unit parameters during an accident and implementation of accident management strategies;
• there has not been performed computer and analytical assessment of efficiency and possibilities for the implementation of technical decisions to keep the melt within reactor and containment;
• unavailable validation of computer models used to justify organizational and technical measures on severe accident measures.

The full text of the National Report of Ukraine on the Results of Stress Tests for Ukrainian NPPs can be found on the SNRIU website: http://www.snrc.gov.ua/nuclear/uk/publish/article/171599
[46].

On the 7th of December 2010, joint Order No. 517/172 of the Ministry of Energy and Coal Industry of Ukraine and SNRIU launched the implementation of the Comprehensive (Integrated) Safety Improvement Program envisaged for the period to 2017. Within this program, a comprehensive safety assessment was performed in 2011 and practical implementation of 28 measures of this program has been approved. The events at Fukushima-1 NPP and the results of stress tests contributed to the emergence of new data on NPP safety issues and the rapid implementation of additional NPP safety measures that were implemented within the already updated Comprehensive (Integrated) Safety Improvement Program (2011-2017) approved by Resolution of the Cabinet of Ministers of Ukraine No. 515-r dated 13 December 2005.

2.7. On events at Ukrainian NPPs under operation

Despite NPP safety measures introduced after the ChNPP accident in 1986 and the implementation of the Comprehensive Program for Upgrading and Safety Improvement of Ukrainian NPPs (2002-2005), the number of emergencies at plants remained quite high. In connection with this, the Concept for Improving Safety of Operating Nuclear Power Plants has been developed (2006-2010) and then approved by Resolution of the Cabinet of Ministers of Ukraine No. 515-r dated 13 December 2005.

On the 7th of December 2010, joint Order No. 517/172 of the Ministry of Energy and Coal Industry of Ukraine and SNRIU launched the implementation of the Comprehensive (Integrated) Safety Improvement Program envisaged for the period to 2017. Within this program, a comprehensive safety assessment was performed in 2011 and practical implementation of 28 measures of this program has been approved. The events at Fukushima-1 NPP and the results of stress tests contributed to the emergence of new data on NPP safety issues and the rapid implementation of additional NPP safety measures that were implemented within the already updated Comprehensive (Integrated) Safety Improvement Program (2011-2017) approved by Resolution of the Cabinet of Ministers of Ukraine No. 515-r dated 13 December 2005.

One of the key means of ensuring NPP operation safety and its further improvement is to consider operational experience that includes accounting and analysis of NPP operational events. This can turn a methodological basis for the implementation of corrective measures and elimination of revealed causes and the prevention of event recurrence. NPP operational events are one of the most important indicators of the operational safety level. According to the SNRIU [48], Fig. 2.12 presents diagrams on the total number of events at operating Ukrainian NPPs (without ChNPP) from 2000 to 2016, and Fig. 2.13 presents the distribution of the number of these events by operating NPP sites for the period from 2000 to 2016.

Fig. 2.14 presents the distribution of the number of events at operating Ukrainian NPPs that occurred in 2000-2016, which were classified according to the International Nuclear Event Scale (INES). The Figure indicates that there were no events in recent years that had an impact on safety.

Fig. 2.15 presents the contribution of each group of root causes to the total number of events in 2000-2016. Traditionally, the largest contribution is made by causes related to equipment failures (86%).

On the 7th of December 2010, joint Order No. 517/172 of the Ministry of Energy and Coal Industry of Ukraine and SNRIU launched the implementation of the Comprehensive (Integrated) Safety Improvement Program envisaged for the period to 2017.
Fig. 2.12. Number of events at operating Ukrainian NPPs in 2010-2016

Fig. 2.13. Distribution of events by sites of operating Ukrainian NPPs in 2000-2016

Fig. 2.14. Distribution of the number of events at operating Ukrainian NPPs according to INES scale in 2000-2016

Fig. 2.15. Distribution of root causes for abnormal events in 2000-2016
2.7. NPP Decommissioning

The lifecycle of any nuclear installation consists of the design, construction, operation and decommissioning stages. When the design life expires, the nuclear facility shall be transferred into a safe nuclear state and decommissioned.

According to the international practice and IAEA recommendations, three decommissioning strategies for a certain power unit are possible:

- immediate dismantling;
- deferred dismantling;
- entombment concept (burial).

Operation may be terminated for other reasons: economic, operational or technological, or as a result of an accident.

The decommissioning process should be performed in accordance with the decommissioning project approved by the regulatory authority. Such a decommissioning project shall include a radiation protection program, a radioactive waste management program, a quality assurance program, an action plan for the case of radiation accident and an action plan on physical protection of an installation.

License for decommissioning of the installation envisages the receipt of separate permits on the implementation of each decommissioning stage.

According to rough estimates, the total cost of decommissioning and dismantling of one nuclear power unit may vary from 20% to 30% of the costs required for the construction of a new power unit. National peculiarities have a significant impact on the costs. They include the scope of required activities and method of radioactive waste management. The total costs largely depend on the amount of radioactive waste, processing methods, etc. [50].

It has been 16 years since the last operating ChNPP unit 3 has been shut down according to the Memorandum of Understanding between the Government of Ukraine and Governments of G-7 and the Commission of the European Community on Chernobyl NPP Closure of the 15th of December 2000.

After the final shutdown of unit 3, ChNPP became the first national nuclear power plant to start the decommissioning process. The following nuclear installations and facilities for radioactive waste and spent fuel management located on ChNPP site are subject to decommissioning:

- ChNPP units 1, 2 and 3;
- wet spent fuel storage facility (ISF-1) commissioned in 1986 with unidentified operation period in the design documents;
- interim storage facilities for liquid and solid radioactive waste.

Other general purpose facilities are also subject to decommissioning: auxiliary buildings, electrotechnical and hydrotechnical structures, cooling pond.

Unit 4 damaged by the beyond design-basis accident is also located on ChNPP site (the Shelter with the New Safe Confinement above it, which is an arch constructed over the damaged ChNPP reactor). This facility is a nuclear hazardous facility and interim storage facility for unstructured radioactive waste.

Measures implemented at the Shelter are qualified as its transformation to the environmentally safe system. The activities at this facility are regulated by an individual license for the right of Shelter operation (License EO No. 000033) [49].

On 22 March 2002, the State Nuclear Regulatory Committee provided the ChNPP with the license to perform activities at the lifecycle stage "Chernobyl NPP decommissioning". The validity of the license was established "till completion of activities on decommissioning of ChNPP nuclear installations".

License EO 000040 for ChNPP decommissioning is the first license in Ukraine, which provides the operating organization with the right to perform a set of actions and operations related to decommissioning of nuclear installations, including activities envisaged by the stage of termination of nuclear installation operation. The license establishes requirements for the operating organization to obtain (within this very license) individual written permits of the SNRIU for each subsequent stage of decommissioning and for the conduct of certain activities or operations related to the design, construction, commissioning and operation of radioactive waste management facilities, and implementation of a set of measures on the removal of spent and fresh nuclear fuel, liquid and solid radioactive waste accumulated during the ChNPP's operation period from existing facilities.

Therefore, the SNRIU regulated the status of nuclear installations located on the site, and the issued license became a kind of a guarantee that the ChNPP units will never be operated in the future.

By 2009, the Comprehensive Program of the Chernobyl NPP Decommissioning approved by Cabinet Resolution No. 1747 on 29 November 2000 was the main document of the state level that defined the content of the decommissioning activities for ChNPP units and transformation of the Shelter into the environmentally safe system.

According to the said program and conditions of license EO No. 000040, ISF-1 was planned for decommissioning after removal of all spent nuclear facility from it to the dry spent fuel storage facility (ISF-2), which had to be constructed until 2004. However, it was still under construction as of October 2017, and the completion of the construction is still far away.

Taking into account that 8-9 years will be needed for the transfer of spent fuel to ISF-2, it is necessary to ensure safe operation of ISF-1 during at least 15 years. Considering the abovementioned, during the SNRIU Board meeting (No. 13 dated 28 September 2006), a decision was made on the removal of conditions on ISF-1 operation from license EO No. 000040 – "Chernobyl NPP decommissioning" and provision of ChNPP with an individual license for a lifecycle stage "ISF-1 nuclear installation operation".
The following documents were developed, approved and put into force during the period of 2006-2009:

- Program of activities on the establishment and justification of the terms and conditions of ISF-1 further operation, which defines (according to the comprehensive assessment) the terms and conditions of ISF-1 further operation (considering possible modernization).
- ChNPP decommissioning program;
- Radiation, health and safety criteria for the end state in ChNPP decommissioning.

These documents contain a detailed description of the planned activities of decommissioning till its completion (up to 2064) and define numeric values for radioactive contamination of ChNPP site after decommissioning completion.

Activities are underway on the development of the "Project on Temporary Shutdown and Final Closure of ChNPP Units". This project will be the main document for obtaining a permit for the start of ChNPP decommissioning at the first stage. The project contains a large set of documents. These consist of nine separate projects related to the closure of units 1, 2, 3, and a set of safety justification documents. The program consists of step-by-step implementation according to which the activities within the temporary shutdown and final closure will be performed. The program is a detailed plan of activities for the period from 2013 to 2022.

The Program of Scientific and Technical Support of ChNPP Decommissioning and Shelter Transformation into an Environmentally Safe System is under development. Efforts were completed on the revision of the Integrated Program of ChNPP Radioactive Waste Management.

According to the General Safety Provisions for Nuclear Power Plants (NP 306.2.141-2008), the operating organization shall adapt the information support system for the decommissioning process to new conditions before the start of activities and operations on the decommissioning of the nuclear power plant (power unit).

The following databases were created and put into force at ChNPP:

- INFODEC database on the comprehensive engineering and radiation survey;
- Radioactive waste inventory database;
- Shelter integrated database.

Efforts are underway to create and put the following databases into force:

- Unified system for decommissioning information support;
- Center for visualization of Chernobyl NPP-decommissioning.

With regard to issues on the decommissioning of operating NPPs the Energoatom Company, the main operating organization (operator) of nuclear facilities, is now at the preparation stage for decommissioning. According to the Law of Ukraine "On Arrangement of Nuclear Safety Issues" No. 1868-IV dated 24 June 2004, the Energoatom Company (starting from 2005) accumulate costs to finance measures related to the termination of operation and decommissioning of nuclear installations (financial reserve) through allocation of funds to a special account.
General view of the South-Ukrainian Power Complex: Tashlyk PSPP – in front, South Ukraine NPP - behind
3. MANAGEMENT OF THE NUCLEAR POWER INDUSTRY AND SECTOR OF UKRAINE

Management of the Nuclear Power Industry and Sector of Ukraine is organized according to the following pattern: the highest executive body (the Cabinet of Ministers), the branch ministry, business entities.

This system has undergone significant changes since 1991.

By the time of the collapse of the USSR there were 5 NPPs on the territory of Ukraine (Chernobyl, Rivne, South-Ukrainian, Zaporozhe and Khmelnitsky) under the auspices of the Ministry of Atomic Energy of the USSR, as well as enterprises of the fuel complex (the Eastern Ore Mining and Processing Enterprise and the Pridneprovsky Chemical Plant), which were under the jurisdiction of the Ministry of Medium Machine Building of the USSR. In Ukraine, construction and installation organizations and factories of the construction industry were a part of the Ministry of Energy and Electrification. By the time the USSR collapsed, several large design institutes and design organizations of the energy sector, located in Kiev, Kharkov, Lvov, Dnipro (Dnepropetrovsk) and in Zhovti Vody were under the jurisdiction of various ministries.

Because of organizational changes, all the NPPs, the Eastern Ore Mining and Processing Enterprise and the Pridneprovsky Chemical Plant were included into the Ministry of Energy and Electrification of Ukraine. Several institutions were also subordinated to the ministry. The construction and installation organizations were partially privatized or ceased to exist. The last significant load on builders and installers fell in 2002 – 2004 during the completion and commissioning of power units at the Khmelnitsky and Rivne NPP. After that, due to the lack of work, the "nuclear" construction and assembly system, unique in its capabilities, was actually destroyed.

In the early 1990s, after the collapse of the USSR, uranium production within in a huge system of the Pridneprovsky Chemical Plant (PCP) was suspended, and the plant was divided into several enterprises, some of which were privatized, while some were delegated to the Ministry of Energy. The PCP itself (as a legal entity) was liquidated. The government left the newly created enterprises on the site of the former PCP without support in a difficult transition period, which resulted in the loss of most of the unique industries, e.g. zirconium ones. In fact, half of the site is today an unregulated storage of radioactive and chemical waste from uranium production with an entire range of specific problems related to public health and environmental protection.

Uranium production in Ukraine today is preserved at the Eastern Ore Mining and Processing Enterprise, but it is difficult to discuss any development of it. With more than enough reserves of uranium ores, the Eastern OM&PE produces uranium raw materials equaling to no more than one third of the needs of Ukrainian NPPs. There are no proper financial resources necessary for the development of uranium production in the country, and the status of a state-owned enterprise does not allow the Eastern OM&PE to independently attract the resources necessary for its development. To create its own fuel production, the concern "Nuclear Fuel" was created, which now includes the Eastern OM&PE. Many years of bureaucratic transformation in the uranium sector, lack of sufficient funding and personnel issues, despite the considerable number of adopted development programs, "froze" the Eastern OM&PE at the level of the late 80’s of the last century. Moreover, the destruction of production capacities continues. As a good example, acid production was practically destroyed, without which it is difficult to consider long-term prospects. It is not worthwhile discussing the creation of nuclear fuel production in Ukraine today because such production has no obvious economic viability, especially when the zirconium production is destroyed and the prospects for its restoration have not been seen yet.

The design institutes are partially privatized. Some design institutes and design organizations disintegrated or were liquidated. The situation has become much more complicated in recent years, since ties with Russia have been torn, and there are no custom orders for designing large facilities.
The absence of large-scale design work, obviously, leads to a reduction in the potential of these organizations.

At present, the Ministry of Energy and Coal Energy of Ukraine operates the Department of Nuclear Energy and the Atomic-Industrial Complex, which is headed by NNEGC "Energoatom", which includes the Rivne, South-Ukrainian, Zaporozhe and Khmelnitsky NPPs (as separate subdivisions) and other subdivisions. NNEGC "Energoatom" is the operator of all NPPs in Ukraine. The Department is also responsible for the Nuclear Fuel Concern with the Eastern OM&PE incorporated in its structure, the "Smoly" (i.e. "resins") Plant, the Institute of Industrial Technology and the Hafnium Production Workshop (a preserved part of the zirconium production of the former PCC). In addition, the Department manages the enterprises of physical protection ("38-VTCH"), the company "Barrier", which is responsible for the maintenance and decontamination of the territory of the former PCC, as well as the Scientific and Technical Center SSECCERS (State Scientific and Engineering Center for Control and Emergency Response Systems). The staff of the department is 20 people.

Global changes in the system of public administration are expected. A new structure of ministries is being introduced, oriented towards the European system. The new structure of the ministry will have several directorates, whose names today make it difficult to understand which of them will perform what functions within the nuclear park. But the main thing is still the issue of skilled personnel in the system of public administration, the functions of managing structures and resources that they can dispose of.

For over 20 years discussions have been held on the intentions of corporatization of enterprises of the nuclear sphere of Ukraine. According to another plan, it is expected that the corporatization of NNEGC "Energoatom" will begin in the next 1.5-2 years. It is hard to say how this activity will affect the industry management pattern. There are currently no documents on this issue. Moreover, there are no visible signs of corporatization of other enterprises of the nuclear sphere, in particular, those that are much smaller in scale than NNEGC "Energoatom". There is no talk about privatization at all. Therefore, the prospects for the development of the nuclear sphere are not clear. Experts believe that without corporatization and privatization it will be practically impossible to find the necessary means to renovate and develop the nuclear sphere of Ukraine.

The development of the nuclear sphere is significantly hampered by the tariff policy of the government.

The system for regulating electricity tariffs is the main instrument that defines the state's policy in the power industry, including nuclear power, with the absence of a real electricity market in the country. The tariff policy demonstrates discrimination against nuclear power sector as a strategic policy of the state. This is absolutely and incredibly disproportionate (the tariff for electricity generated by the Ukrainian NPPs is 2.5-3 times lower than the tariff for electricity generation by the classical thermal power plants) if compared with international experience, which clearly indicates that this policy has been implemented for the benefit of the "classical thermal power" sector of Ukraine, which is basically privatized. The nuclear sphere has none of its own means for renovation, development and safety improvement.

The current tariffs for electricity generated by NPPs do not cover many expenses provided for by the laws of Ukraine. Actually, all the activities on provision of NPP safety and prolongation of the life of the power units are carried out at the expense of loans. NNEGC "Energoatom" is actually depleted, which creates significant risks for its future.

The numerous measures that have been in place for more than a decade to construct the two new units at the Khmelnitsky NPP are more likely to be a simulation rather than substantiated activities. It is worth noting that electricity consumption in Ukraine is less than 2/3 of that which was consumed in 1990 and, based on the pace of economic development, the demand for electricity will not soon reach the rates of the late Soviet Republic.

The plant ratio of Ukrainian NPPs today is almost 20% less than that achieved in the practice of the world nuclear power industry. The increase of the plant ratio to the world indicators is equivalent to the commissioning of 2000 MW of new capacity.

Experts believe that to consider the management structure and prospects of the nuclear sphere of Ukraine beyond its connection with the fuel and energy sector of the country is a dead-end. The updated strategy of fuel and energy sector development until 2035 does not provide and specific practical content and is likely to be considered today only as a statement of intent.
4. UKRAINIAN AND INTERNATIONAL LEGISLATION IN IMPLEMENTATION OF NUCLEAR ENERGY PROJECTS IN UKRAINE

"The energy strategy of Ukraine for the period up to 2035 Safety, Energy Efficiency, Competitiveness" (hereinafter — the Strategy) approved on August 18, 2017 by Order No 605-p defined the strategic guidelines for the development of the fuel and energy complex of Ukraine for the period up until 2035. Nuclear power continues to play a key role in implementing the Strategy. This is because Ukraine continues to consider nuclear power as one of the most cost-effective low-carbon energy sources.

According to the Strategy, further development of the nuclear energy sector for the period until 2035 is projected on the basis that the share of nuclear generation in the total volume of electricity production will increase. And this means that implementation of projects in the field of nuclear energy is still relevant.

4.1. National legislation on nuclear energy

When analyzing legislation in the field of nuclear energy, it should be emphasized that it is divided into horizontal legislation in the field of environmental safety and monitoring, urban planning and special nuclear legislation. Keeping the balance between nature protection interests that are socially significant and the interests of an individual nuclear facility or establishment, along with providing people with electricity and heat, which is nevertheless aimed at earning profit, is a key issue in the implementation of nuclear projects. The study and prevention of potential risks of such projects is a requirement of international laws.

4.1.1. Horizontal environmental legislation

Article 16 of the constitutional law of Ukraine determines that ensuring the ecological safety and maintenance of ecological balance on the territory of Ukraine, overcoming the consequences of the Chernobyl catastrophe (a disaster of a planetary scale), and preservation of the gene pool of the Ukrainian people is responsibility of the state.

The Constitution of Ukraine in its Article 92 states that only the laws of Ukraine determine the bases of social protection, health care, ecological safety, as well as the use of natural resources, organization and operation of energy systems.

The Law of Ukraine "On Environmental Protection" Article 50 specifies that ecological safety is a condition of the environment in which the prevention of deterioration of the ecological situation and the emergence of danger to human health is ensured.

In accordance with Article 51 of this Law, general requirements are set for design, placement, construction and commissioning of new as well as reconstruction of existing enterprises, structures and other facilities, improvement of existing and introduction of new technological processes and equipment; including ensuring the ecological safety of the population during the operation of these facilities, efficient use of natural resources, observance of norms of harmful influences on the environment are also ensured. Meanwhile, this should include the capture, disposal and deactivation of harmful substances and waste or their complete elimination, and fulfillment of other requirements for the protection of the environment and human health.

1 http://mpe.kmu.gov.ua/minugol/control/uk/doccatalog/list?currDir=50358
3 http://zakon2.rada.gov.ua/laws/show/254%0D%0A/96-%0D%82%D1%80/conv/print1494074786673867
4 http://zakon2.rada.gov.ua/laws/show/1264-12
It is prohibited to commission enterprises, buildings and other facilities that do not fully ensure compliance with all environmental requirements and implementation of the measures provided for in the projects for construction and renovation (expansion and technical re-equipment).

Of course, legislators also took care to ensure the prevention of accidents by considering the possibility of such accidents occurring at the design stage, so as to maximize the ways to avoid such cases.

In addition, Article 66 of this law contains the norms, concerning which the central executive body implementing state industrial safety policy (the State Service of Ukraine for Labor5), and the central executive body, which implements the state policy in the field of security of nuclear energy use (the State Nuclear Regulatory Inspectorate of Ukraine 6), together with the central executive authority, which implements the state policy on state supervision (monitoring) in the field of environmental protection, efficient use, reproduction and protection of natural resources (the State Environmental Inspectorate of Ukraine7) are obliged to regularly check the status of environmentally hazardous facilities as well as implementing appropriate measures and requirements for their safe operation. In fact, this norm laid the basis for the supervision of environmentally harmful activities.

**On May 23, 2017, the Parliament of Ukraine adopted the Law “On the environmental impact assessment”**. This Law establishes the legal and organizational principles of environmental impact assessment, aimed at preventing environmental damage, ensuring environmental safety, environmental protection, efficient use and recovery of natural resources while making decisions on carrying out economic activities that may have significant environmental impacts, while considering the state, public and private interests.

According to Article 3 of the law, environmental impact assessment is mandatory in the decision-making process on planned activities for nuclear power plants and nuclear reactors. This includes the construction, phasing out (decommissioning) of such power plants or reactors (except for research facilities for the production and conversion of nuclear fuel and raw materials to get secondary nuclear fuel, materials that are fissile and renewable, the capacity of which does not exceed 1 kilowatt of constant thermal load), as well as installations for production or enrichment of nuclear fuel, installations for processing spent nuclear fuel and high level waste, facilities for radioactive waste disposal, storage (over 10 years) or processing of spent fuel or radioactive waste outside the place of their generation.

In addition, strategic environmental assessments should be applied to the strategies, plans, schemes, urban planning documentation, national programs, state target-oriented programs and other programs and program documents, including changes to them, which are developed and / or subject to approval by the public authority, local government and which relate to the facilities and activities, for which the laws provide for procedures for environmental impact assessment, as defined by the Law of Ukraine “On Strategic Environmental Assessment”8, which was adopted in its first reading on May 23, 2017, and the Protocol on Strategic Environmental Assessment to the Convention on Environmental Impact Assessment in a Transboundary Context, which was ratified by Law № 562-VIII dated July 1, 20159.

Strategic environmental assessment is applied to nuclear power plants and other nuclear reactors (except for research facilities for the production and reprocessing of materials that are fissile and renewable, the maximum capacity of which does not exceed 1 kilowatt of constant thermal load), the installations designed exclusively for the production or enrichment of nuclear fuel, regeneration of irradiated nuclear fuel or for the collection, removal and processing of radioactive waste, also, the installations for production or enrichment of nuclear fuel, for processing of irradiated nuclear fuel, for the final disposal of irradiated nuclear fuel, exclusively for the final disposal of radioactive waste, exclusively for storage (planned for more than 10 years) of irradiated nuclear fuel in other places outside the territory of an industrial facility, or for processing and storage of radioactive waste.

Consequently, horizontal legislation regulates the risk assessment of planned activities in the nuclear energy sector and forms the basis for the safety of such activities.

### 4.1.2. Special nuclear legislation

The law of Ukraine “On utilization of nuclear power and radiation safety”10 along with declarations on the priority of human and environmental safety and the rights and obligations of citizens in the field

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10. [http://zakon2.rada.gov.ua/laws/show/995_b99/paran2#n2](http://zakon2.rada.gov.ua/laws/show/995_b99/paran2#n2)
11. [http://zakon2.rada.gov.ua/laws/show/39/95-%D0%B2%D1%80/conv/print1494074786673867](http://zakon2.rada.gov.ua/laws/show/39/95-%D0%B2%D1%80/conv/print1494074786673867)
of nuclear energy, regulates activities related to the use of nuclear installations and sources of ionizing radiation and establishes the legal framework for the international obligations of Ukraine regarding the use of nuclear energy.

This Law applies to all activities in the field of nuclear energy use, including placement, design, construction, commissioning, operation and decommissioning of nuclear installations, sources of ionizing radiation; carrying out work and providing services that influence safety during the use of nuclear energy, management of nuclear materials and sources of ionizing radiation, among other things in the exploration and extraction of minerals containing these materials and substances, carrying out scientific researches using nuclear facilities, sources of ionizing radiation, nuclear materials, management in the field of nuclear energy use, state regulation of safety during the use of nuclear energy, physical protection of nuclear facilities, nuclear materials, facilities intended for radioactive waste management, other sources of ionizing radiation, state registration of nuclear materials and sources of ionizing radiation, state control over the radiation situation on the territory of Ukraine, staff training for activities related to the use of nuclear energy, international cooperation and provision of compliance with Ukraine's international obligations in the field of nuclear energy use.

It establishes a procedure for making decisions on the placement of nuclear facilities and facilities for the management of radioactive waste. The state authorities and local self-government bodies, as well as separate legal and natural persons have the right to make proposals about placement of nuclear facilities and facilities for the management of radioactive waste. Proposals are submitted to the Cabinet of Ministers of Ukraine.

In accordance with the Law of Ukraine "On Regulation of Urban Development" (Article 31), the design documentation for the construction of nuclear facilities should be subject to state expert review and to the environmental impact assessment procedure. Starting from December 18th, 2017, such a procedure will be implemented in accordance with the Law of Ukraine "On Environmental Impact Assessment".


According to Article 92 of the Constitution of Ukraine, Article 2 of the Law states that the decision on the placement, design, construction of nuclear installations and facilities intended for radioactive waste management of national importance shall be adopted by the Parliament of Ukraine by adopting a relevant law, upon recommendation of the Cabinet of Ministers of Ukraine and concurred with local executive authorities and local self-government bodies.

The following is added to a draft law on placement, design and construction of a nuclear installation or facility intended for the treatment of radioactive waste of national significance: the feasibility study for the creation of such a nuclear installation or facility intended for radioactive waste management and selection of a proposed site for their placement; the conclusion of the state environmental expert review, the results of an advisory referendum regarding the location of a nuclear installation or facility intended for radioactive waste management if it was conducted in administrative-territorial units, or a decision of the central executive authority, whose competence is the issue of the legal regime of the territory that was exposed to radioactive contamination as a result of the Chernobyl catastrophe, once they are located in the Exclusion Zone and Area of Absolute (Mandatory) Resettlement, report on measures to inform neighboring states on possible impact in a transboundary context in accordance with the law; other documents, if provided by law.

Considering the Protocol on Strategic Environmental Assessment ratified by Ukraine and the Draft Law "On Strategic Environmental Assessment", the adoption by the Parliament of a law on placement, design, construction of a nuclear installation or a facility intended for radioactive waste management falls under the category "Plans and Programs" and is subject to mandatory "Strategic Environmental Assessment", which provides for an assessment of the probable environmental consequences, in particular those related to the health of the population, which combines the definition of the scope of the environmental report and its preparation, provision of public participation and consultations, as well as consideration by the plan or program of the provisions of the environmental report and the results of public participation and consultation.

It is also not possible to decide on extending the lifetime of existing nuclear facilities and facilities intended for radioactive waste management of national importance, as well as deciding on an expansion of existing nuclear installations and facilities without strategic environmental assessment, since its adoption implies changes in previous strategic assessments. For example, if calculations were made for 30 years of any NPP unit operation, then they would usually be substantially different after 30 years, so it would not be appropriate to apply them automatically without a new environmental impact assessment, since under such conditions environmental safety and health could not be guaranteed.
Among other important laws in the field of nuclear energy there are such laws as:
- Law of Ukraine "On licensing activity in the field of utilization of nuclear power",
- Law of Ukraine "On management of radioactive waste",
- Law of Ukraine "On protection of humans from impact of ionizing radiation",
- Law of Ukraine "On physical protection of nuclear installations, nuclear materials, radioactive waste, other ionizing radiation sources",
- Law of Ukraine "On civil liability for nuclear damage and its financial provision",
- Law of Ukraine "On managing the issues related to the provision of nuclear safety".

4.2. International Legislation

As to international law, one should separately mention the Association Agreement\textsuperscript{12}, which envisages cooperation in the field of nuclear energy specifically through the implementation of the three directives:
- № 96/29/Euratom, which sets the basic safety standards to protect the health of workers and the population from ionizing radiation,
- № 2006/117/Euratom on supervision and control over the transportation of radioactive waste and spent nuclear fuel,
- № 2003/122/Euratom on control of high-level radioactive sources, which are put to long storage and abandoned.

In June 2017, Euratom ratified the Association Agreement between Ukraine and the EU, which means the implementation of joint projects in nuclear energy, including scientific ones.

In addition to the already mentioned international instruments, Ukraine has ratified:
1. Convention on Environmental Impact Assessment in a Transboundary Context\textsuperscript{13}.

As to decision-making and access to justice in environmental matters, the following multilateral international conventions should be mentioned:

1. Convention on Nuclear Safety\textsuperscript{14}.
2. Convention on the Physical Protection of Nuclear Material and Nuclear Facilities\textsuperscript{15}.
4. Vienna Convention on Civil Liability for Nuclear Damage\textsuperscript{17}.
5. Convention on Early Warning of a Nuclear Accident.
6. Convention on Assistance in the Case of a Nuclear Accident or Radiological Emergency.

The following agreements with international organizations should be mentioned separately:
1. Agreement between Ukraine and the International Atomic Energy Agency on the application of safeguards regarding the Treaty on the Non-Proliferation of Nuclear Weapons.
2. Additional Protocol to the Agreement between Ukraine and the International Atomic Energy Agency on the application of safeguards regarding the Treaty on the Non-Proliferation of Nuclear Weapons\textsuperscript{18}.
3. Memorandum of Understanding between Ukraine and the Commission of the European Communities on the implementation of technical assistance programs in the field of nuclear safety\textsuperscript{19}.
4. Framework Agreement between Ukraine and the European Bank for Reconstruction and Development concerning the activities of the Chernobyl Shelter Fund in Ukraine\textsuperscript{20}.
5. Grant Agreement (Chernobyl NPP Nuclear Safety Project) between the European Bank for Reconstruction and Development (as Grant Manager on the Nuclear Safety Account), the Cabinet of Ministers of Ukraine and the State Nuclear Regulatory Committee of Ukraine (as the Beneficiary)\textsuperscript{21}.

In addition, there are also international agreements on the transportation of nuclear materials, bilateral intergovernmental agreements, bilateral inter-agency agreements, and arrangements.
South Ukraine NPP
www.sunpp.mk.ua
Since its independence, Ukraine has lacked a strategic vision for the future of its nuclear industry. This owes to a certain extent to collective memories of the Chernobyl disaster. The disaster occasioned a declaration in 1990 of a moratorium on building nuclear power plants in the country. This even suspended construction on plants that were already in the process of being built, such as units 3 and 4 at the Khmelnysatska NPP, and the Crimean NPP. The disaster has become a burden on all new initiatives for developments in the nuclear industry, and society has been more opposed to development, so new initiatives have a hard time finding support.

As a consequence of this lack of vision, important decisions are often postponed, which impacts negatively on both the current status and future prospects of the industry in Ukraine. The recently adopted Ukrainian energy strategy, "Security, Energy Efficiency and Competitiveness" is no exception. While the strategy declared the importance of nuclear energy for Ukraine's future, it fails to provide a list of benchmarks for further nuclear energy development.

For instance, the strategy defines nuclear energy as an important and efficient way to decarbonize the power sector and the economy in general (p. 16 in the Energy Strategy (until 2035)), and it stipulates increasing the share of nuclear power in generating electricity (p. 16). The attitude of Ukraine to developing nuclear power is described in the Strategy as "permanent". The Strategy lays out plans for nuclear power to cover 29.3% of Ukraine's primary energy supply by 2020 (comparing to 25.5% in 2015), 32.2% of the supply by 2025, 29.7% by 2030 and 25% by 2035. Total volumes of electricity generated by NPPs will increase according to the plans outlined in the Strategy. Despite this, the Strategy fails to provide a wide range of indicators and benchmarks, and those that are detailed are not fully defined.

At the same time, the Strategy stipulates further development of two other strategic documents, which will define the future of Ukrainian nuclear industry more accurately, and correspondingly, probably will provide a better vision of its future development. Aside from that, in order to support the Strategy's implementation, three action plans must be developed (for 3 periods: until 2020, 2020-2025 and until 2035). Those, obviously, will provide more detailed indicators and benchmarks for further development of the Ukrainian nuclear industry. In this way, the Strategy does not currently provide answers to all questions regarding the future of the Ukrainian nuclear industry and its role in future of Ukrainian energy. It is likely that answers will be provided in other state plans and documents.

During the first stage of implementation (until 2020), considering the probable lack of electricity generating capacities, the Strategy defines the feasibility of expanding the term of operation of existing NPP units at the rate of 6 GWT (p. 25). The period until 2020 will see the development of decisions and plans regarding the substitution of capacities that should be taken out of service after 2025 (p. 26) and decisions about new technologies that can be used in nuclear power after 2030 (p. 27). At the same time, information about decisions regarding capacities that would be taken out of operation after 2025 is less clear. During this stage, according to the Strategy, a Long-term Program for Nuclear Power Sector Development would be adopted (p. 27).

During this stage, projects on increasing the level of rated capacity usage at NPPs units would be carried out (p. 26). However, what is unclear is the threshold value and desired levels of the increase with respect to current record levels. For instance, during the first quarter of 2017 the level of rated capacity usage was 79.6% – the highest in the last decade.

Up to 2020, issues of supplying NPPs with nuclear fuel have to be resolved. Among the main tasks at this stage are (p. 47-48): further diversifying of fuel supplies; developing preconditions for increasing capacities for uranium extraction in Ukraine; exploring the feasibility of establishing nuclear fuel producing capacities in Ukraine; stocking uranium concentrate in Ukraine. By the end of 2020, it is expected that the share of a single nuclear fuel supplier will not exceed 70%, and won’t exceed
During this stage a repository for spent nuclear fuel and radioactive waste is expected to be built (p. 29), and the State Concept for Nuclear Waste Treatment will be developed (p. 48).

**During the second stage of implementation** (until 2025) the main tasks for the nuclear power sector, according to the Strategy, are: defining the target dates for expanding the terms of operation for existing NPP’s; putting into operation 1 GWT of new capacity; designing and constructing new units according to the above mentioned State Program for Nuclear Power Sector Development (p. 51).

**During the third stage of implementation** the Strategy (until 2035) no specific steps for nuclear power sector development are planned (except for those under development in accord with the steps planned during the first two stages).

Thus, the Strategy defines future development of Ukrainian nuclear power sector in only a general way, and does not provide any specific and detailed decisions. The Strategy defines plans for development and adoption of other programs and projects for future of the nuclear industry. From this point, it should be mentioned that the previous edition of the strategy (discussed in the beginning of 2017 but not adopted) spelled plans for nuclear power sector development in more detail. In that edition, for instance, the following issues were defined:

- target dates for extending projected operation terms of reactors at the Khmelyntska and Zaporizka NPPs;
- target usage levels of the rated capacity for NPP units;
- start of capital and investment formation to finish construction of third and fourth units of Khmelyntska NPP;
- capacity development for electricity grids in order to “unlock” the closed energy flux loop of NPPs;
- begin developing possibilities to construct electricity bridge from Khmelyntska NPP to Poland to connect ENTSO-E; incomes received from trading electricity by this route were supposed to be put to use financing the construction of the 3rd unit of Khmelyntska NPP.

From the point of view of defining benchmarks for developing the Ukrainian nuclear industry, the previous, not-yet adopted edition of the energy strategy was more detailed than the current, recently adopted strategy. The existing strategy postpones specific decision until new programs are adopted. But such postponements of decisions until new programs are adopted and the corresponding delays could bring about postponement of important steps in developing the nuclear industry and covering energy needs in the future. However, Ukraine’s experience of following adopted programs and strategies and defining important milestones and benchmarks doesn’t ensure implementation of those programs in future. For instance, neither the previous Energy Strategy until 2030 (which was in force until the current one was adopted in 2017), nor the National Renewables’ Development Plan until 2020 were fully implemented.

Ukraine’s current system of strategic planning for nuclear industry development (including the adopted energy strategy) does not provide decisions to important problems in the current state of the nuclear industry. Among these, for instance are:

- approaches to change tariff determination in order to increase profitability of the nuclear energy;
- Still undetermined are sources for financing further steps in nuclear industry development, listed in the Strategy (firstly, extending the term of reactor operation and construction of new units).

**Summary**

Despite of the importance of the nuclear industry to Ukrainian energy, the recently adopted energy strategy until 2035 – “Security, energy efficiency, competitiveness” – does not define a wide range of indicators and benchmarks for nuclear energy development in the future. According to the Strategy, nuclear power will as before play an important role in Ukrainian energy and the share of electricity generated by NPPs is set to increase. At the same time, the strategy does not provide specific solutions to current problems and uncertainties, such as the development of nuclear energy generating capacities, building capacities to produce nuclear fuel, and reprocessing and storing spent nuclear fuel. According to the Strategy these and most other problems would be solved after adopting other programs in the future. Therefore, the current energy strategy promotes postponing solving important issues that would define further development of Ukrainian nuclear industry.
6. URANIUM PRODUCTION

6.1. History and Structure of Uranium Production

The share of power generation at NPPs within the Ukrainian power system stably exceeds 50%. Ukraine holds one of the first places in Europe for uranium reserves. In addition, there is a resource of zirconium ores on the territory of Ukraine and the production of the zirconium cycle is established. All these factors repeatedly caused the desire to develop in Ukraine its own nuclear fuel cycle. In the early 1990s, a completely closed fuel cycle was even considered. There were other options, for example regarding transition to Canadian CANDU reactors, which could use natural uranium.

However, during almost a quarter of a century of program existence (the first ones were developed in 1995) today, we see very modest outputs. Ukraine could not solve even the simplest process task: providing the nuclear industry with uranium oxide.

From 2000 to 2017, the level of provision with own concentrate increased by only 8%: from 32% to 40%. Today, about 1000 tons of uranium oxide are produced, an annual increase is only about 200 tons, while about 2480 tons of uranium oxide are needed to maintain current generation of electricity at NPPs (85 billion kWh).

This situation is mainly caused by the acute shortage of resources for development, as well as low quality of uranium reserves available on the territory of Ukraine.

According to the IAEA estimates, as of 1 January 2015, in the price category below 130 $/kg, explored uranium reserves in Ukraine are estimated as about 117.7 thousand tons, confirmed: 84.8 thousand tons. Only a half of these reserves has a cost below 80 $/kg. At the same time, the most of these reserves are located in undeveloped deposits.

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**Fig. 6.1. Current structure of nuclear-fuel cycle**

- **Mining and processing production**
  - Mining of uranium ore
  - Processing of natural uranium
- **Uranium**
  - UF4 production
  - 2400 t of uranium per year
- **Separation production**
  - Enrichment of UF4, by U235
  - 1.5 mln. of SWU per year
- **Nuclear fuel production**
  - Production of pellets
  - Production of UO2 powder
  - Production of UO2 fuel rods
  - Production of UO2 powder
  - Production of pellets
  - Fuel rods and FA
  - 375 t of uranium per year

- **Mining of zirconium ore**
  - Production of zirconium concentrate
  - Production of zirconium alloy
  - Production of pipe material
  - Production of zirconium rolled products
  - Production of zirconium components of FA
  - 150 t of zirconium per year

- **Ukrainian NPPs**
  - Production of stainless components of FA
  - SNF storage facility
  - Spent fuel pools
  - SNF

**Power**
- 90 billion kW/h

**Parameters**

- **Mining of uranium ore**
  - Production established in Ukraine
  - 830 t of uranium per year

- **Production of natural uranium**
  - Production of natural uranium
  - 2400 t of uranium per year

- **Enrichment of URx, by U235**
  - Production of UF4, by U235
  - 1.5 mln. of SWU per year

- **Production of UO2**
  - Production of UO2 powder
  - Production of UO2 fuel rods
  - Production of UO2 fuel rods
  - 375 t of uranium per year

- **Production of zirconium**
  - Production of zirconium concentrate
  - Production of zirconium alloy
  - Production of zirconium rolled products
  - Production of zirconium components of FA
  - 150 t of zirconium per year

- **SNF storage facility**
- **Spent fuel pools**
- **SNF**

**FA**
- fuel assemblies

**SNF**
- spent nuclear fuel
Uranium mining in the country is conducted by state enterprise Eastern Mining and Processing Plant (MPP) (Zhovti Vody, Dnipropetrovsk region), which is a part of the state concern Nuclear Fuel Company. This is the only enterprise in Ukraine for uranium ore mining and processing.

Now, Ukraine has three mines (Inhulska, Smolinska and Novokostiantynivska mines), which develop four deposits (the Inhulska mine covers two of them simultaneously).

Hydrometallurgical plant of the Eastern MPP in Zhovti Vody is engaged in ore processing into uranium oxide, which is then transferred to Russia for enrichment and manufacturing fuel assemblies for Ukrainian NPPs.

The main tasks of the Nuclear Fuel Company established in 2008 was to increase uranium output, establish a nuclear fuel plant and manufacture zirconium. Today, among three tasks only uranium mining (97% of the company turnover) and a small production of hafnium (about 12 tons per year) are implemented.

According to the State Service of Geology and Subsoil of Ukraine, there are 46 uranium deposits in Ukraine including 22 with industry level reserves. The cadaster of industrial uranium deposits in Ukraine identified 53 sites with deposited uranium ores with different degree of survey and estimate. Uranium lies mainly in the granite layers of the Ukrainian crystalline shield. According to the geological conditions, 36 sites for the formation of uranium ores have the potential for exploration of deposits in a traditional underground way, 13 sites: using a technology of in-situ leaching, and four sites are already worked out.

Ore reserves are considered at depths from 50 to 1300 meters. The mines of the Eastern Mining and Processing Plant are operated filling voids with a solid mixture, which prevents soil failure. Almost all industrial (and most of promising) deposits are concentrated on a compact area (80*20 km) within the Kirovograd region with a developed infrastructure.

According to the classification, processed ore mainly belongs to poor ore and only its part belongs to raw ore. Uranium content in the ore ranges from 0.08 to 0.14% (Table 6.2). This is lower by times than that of competitors on the world market of uranium.

The cost of Ukrainian uranium at present ranges at a level of $ 130 per kg, which is almost three times higher than current spot quotations.

### Table 6.1. Structure of uranium reserves in Ukraine by mining cost

<table>
<thead>
<tr>
<th>Costs of Uranium extraction per 1 kg</th>
<th>thousand tons</th>
<th>in % of reserves</th>
</tr>
</thead>
<tbody>
<tr>
<td>Below 80 $</td>
<td>59.6</td>
<td>26%</td>
</tr>
<tr>
<td>80-130 $</td>
<td>58.1</td>
<td>27%</td>
</tr>
<tr>
<td>130-260 $</td>
<td>105</td>
<td>47%</td>
</tr>
<tr>
<td>Total (below 260 $)</td>
<td>222.7</td>
<td>100%</td>
</tr>
</tbody>
</table>

---

**Note:**

According to international classification (IAEA), uranium is divided into three categories by its cost:

- **Low:** cheap natural uranium ((<40 $/kg)
- **Low medium:** not expensive uranium (40-80 $/kg)
- **High medium:** not expensive uranium (40-80 $/kg)
- **High:** expensive uranium (80-130 $/kg)
- **Very high:** very expensive uranium (130-260 $/kg)
The strategy for uranium production in Ukraine is that the availability of own uranium raw materials provides better predictability of fuel prices and independence of external suppliers. In addition, current prices for uranium in Ukraine are considered understated and everyone is waiting for

6.3. Economy and Potential

The electric power of Ukrainian NPPs is now the cheapest in the world. With current tariff of about 2 cents per kilowatt-hour, the electric power of Ukrainian NPPs is three to four times cheaper than in other countries. However, such a low cost does not allow accumulating resources for the development of uranium production nor for its safe decommissioning with subsequent bringing the sites to a safe condition.

In fact, replacement cost decreases and issues are transferred to future generations. This raises a pessimistic scenario: lifetime of NPPs will be expired (most likely considering long-term operation) and they will be closed. For uranium miners this means that local consumers of uranium will not be presented in the 2050s.

Currently, Ukraine purchases lacking uranium dioxide (about 1.5 thousand tons per year) from Russian, European and Kazakh suppliers. According to the calculations of the Ministry of Energy and Coal Industry of Ukraine, to produce 90 billion kilowatt-hours of electricity, it is necessary to produce 2480 tons of uranium dioxide, from which 375 tons of energy uranium will be produced in future.

A new concept of the State Target Economic Program for the Development of the Nuclear Industry Complex up to 2020 presents the information that "... the costs to purchase nuclear fuel is about 40% of the cost of electric power produced by NPPs ...".

The cost of uranium and services on the production of fresh nuclear fuel to meet the needs of Ukrainian NPPs (including zirconium components) is about 350 million USD per year (or more than 50% of the cost of nuclear fuel). At the same time, most of costs are the costs for uranium conversion, which is not performed in Ukraine.

The prices in 2011 are presented as indicated in Fig. 6.4. There are no special changes in the estimation for today.

In 2008, rather ambitious program "Nuclear Fuel of Ukraine" was adopted with plans to increase mining to 1880 tons, to construct a nuclear fuel plant and produce 270 tons of zirconium rolled products. Its estimated cost was 13.5 billion UAH (2.4 billion USD). The third part of the money (4.3 billion UAH) had to come from the state budget. In fact, the implementation of this program (also as previous of 1995) did not start, since it was financed only by 5.5%.

\[
\text{Table 6.2. Uranium content of deposits of the Eastern Mining and Processing Plant (2016)}
\]

<table>
<thead>
<tr>
<th>Deposit</th>
<th>Mine</th>
<th>Uranium content in ore kg/t</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Michurinske</td>
<td>Inhul'ska</td>
<td>0.81</td>
<td>0.081</td>
</tr>
<tr>
<td>Tsentralne (Eastern area)</td>
<td>Inhul'ska</td>
<td>0.87</td>
<td>0.087</td>
</tr>
<tr>
<td>Vatutinske</td>
<td>Smolinska</td>
<td>1.09</td>
<td>0.109</td>
</tr>
<tr>
<td>Novokostantynivske</td>
<td>Novokostantynivska</td>
<td>1.38</td>
<td>0.138</td>
</tr>
<tr>
<td>Serednie at the Eastern MPP</td>
<td></td>
<td>0.96</td>
<td>0.096</td>
</tr>
</tbody>
</table>

![Fig. 6.4. Components of nuclear fuel cost](image)

\[
\text{Table 6.3. Comparison of the funding plans of program 2008 and concept 2016}
\]

<table>
<thead>
<tr>
<th>Source of funding</th>
<th>2008 billion UAH</th>
<th>%</th>
<th>2016 billion UAH</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Budget</td>
<td>4.335</td>
<td>32</td>
<td>0.303</td>
<td>3.3</td>
</tr>
<tr>
<td>Other sources</td>
<td>9.215</td>
<td>68</td>
<td>8.820</td>
<td>96.7</td>
</tr>
<tr>
<td>Total</td>
<td>13.550</td>
<td>100</td>
<td>9.118</td>
<td>100</td>
</tr>
</tbody>
</table>

In the new version of the State Target Economic Program for Development of the Nuclear Industry Complex, direct funding from the budgets is almost totally absent. The funding has decreased in size from 32% to 3.3%, and now only includes scientific support.

Indirect subsidization is maintained through the state Energoatom Company, who is operating NPPs. However, according to a contract signed for 2008-2018, purchases were made for extracted uranium concentrate at prices that provide a profit for the producer, which is much higher than current market prices. Nevertheless, the plan for the output of 630 assemblies per year is still indicated, i.e. the plan for full NPP supply with own fuel.
The reality of these plans is doubtful. Zirconium production even under availability of money will have to be restored starting from an extremely low level. Moreover, possible difficulties may be even with raw materials. Despite large reserves, the main supplier of zirconium products Vilnohirsk MPP (Malyshevskoe deposit of the Dnipropetrovsk region) is currently almost exhausted available reserves, and new sites are owned by private companies.

6.4. Characteristic of mines

The resource potential of the Eastern MPP is located in the Kirovohrad region. It covers Michurinske and Tsentralne (its Eastern areas) deposits developed by the Inhulskaya mine, Smolin'ska mine of the Vatutinske deposit and the slowly completed Novokostiantynivska mine (Novokostiantynivske deposit).

MPP task is to support current production volume in old deposits at the level of 650-670 tons and commission a startup complex (500 thousand tons per year at the Novokostianivska mine).

It is planned to construct a new sulfuric acid production installation at the hydrometallurgical plant (Zhovti Vody, Dnipropetrovsk region). The old installation is extremely deteriorated and excessively powerful (approximately twice as much), and today it is operated not under optimal mode.

The uniqueness of the Ukrainian mining is that a significant part of ore is mined directly under the regional center Kropyvnytskyi (former Kirovohrad) with a population of 230 thousand people. There is the Inhulskaya mine, which during a half a century formed on the outskirts of the city an underground labyrinth at a depth from 160 to 650 meters. The mine has five vertical shafts and an underground tunnel with a length of almost 6 km along the Inhul River used to connect both Michurinske and Tsentralne uranium deposits.

The penetration in the mine is implemented using a method of underground explosions. The technology of in-situ block leaching is also used to process poor ore. The diagram of the block leaching site of the Inhulskaya mine (see Fig. 6.5). The Inhulskaya and Smolinska mines have already spent the bulk of reserves. Each of them produced over 28 million tons of ore during the whole period. The reserves of the Inhulskaya mine will be enough for at least 2030.

In the vicinity there is a large deposit Tsentralne (western), which is not developed yet. However, its reserves go to the city center, which naturally does not cause enthusiasm of local residents.

There are much more issues regarding the Smolinska mine located 80 km to the west (see Fig. 6.6). Currently it is on the point of closure. This mine was a key one for the MPP for a long period providing up to 60% of uranium, since uranium content in the Vatutinske deposit was quite high. However, very intensive deposit development accelerated the exhaustion of available reserves. The last ore horizon (640 m) put into operation seven years ago only slowed down mining decrease at this mine. Company capacity has recently decreased from 650 thousand tons of ore to less than 300 thousand. In order to reduce the cost and maintain concentrate output the Smolinska mine processed accumulated waste piles (about 6 million tons). Today, this processing is completed.

A heap leaching landfill put into operation (in two stages) allows implementing poor (0.05%) ore. This allows additional extraction of more than 30 tons of uranium concentrate from poor ore per year. However, in general, mining decreases.

Prior to the Fukushima events, in the period of high prices, the option of developing the lower horizons of the deposit (820-730 m) and tunnel driving for opening small neighboring Pivdenne
deposit was considered. However, reduction of uranium prices made these plans unprofitable.

In 2016, a decision was made by state corporation Nuclear Fuel to prepare documents to justify the inexpediency of the further functioning of the Smolinska mine. This spring a formal statement was made that the residual resource of the Vatutinske deposit of uranium ore (under working out by this mine) did not exceed 1.4 tons of uranium. According to the corporation, exhaustion of this deposit is expected within 3-5 years and a draft feasibility study for its decommissioning is under development.

This is a severe blow to Smolino village where the mine is a city-making enterprise. The story on decommissioning of the Zhovti Vody mines, which previously were included to the Eastern Mining and Processing Plant also did not add much optimism. They are flooded, one of them (Nova) went under water having iron ore reserves of almost a billion tons.

The main hopes are related to the development of the neighboring Novokostiantynivska mine. In fact, in recent years, its completion is financed by the plant but extremely irregularly.

In 2016, total investment of the Eastern MPP to support existing mines and to further develop Novokostiantynivska deposit amounted to only 116 million UAH ($ 4.5 million). At the same time, the minimum cost estimates to put the startup complex of the Novokostiantynivska mine into operation with an output of 500 thousand tons of ore per year are estimated at over one billion hryvnias.

Reaching design capacity of 1500 tons of ore per year by the mine (with subsequent increase to 2500 thousand tons of ore) will require investing in this project up to 6 billion hryvnias.

The Novokostiantynivska deposit is complex represented by 178 separate deposits and forms three ore zones scattered from each other on the territory of 3 km². Balance uranium reserves are

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**Table 6.4. Structure of ore mining of the Eastern MPP in the first half of 2017**

<table>
<thead>
<tr>
<th>Mine</th>
<th>Ore mining, thous. tons</th>
<th>Share of mines</th>
</tr>
</thead>
<tbody>
<tr>
<td>Inhulska</td>
<td>146.9</td>
<td>46%</td>
</tr>
<tr>
<td>Smolinska</td>
<td>57.4</td>
<td>18%</td>
</tr>
<tr>
<td>Novokostiantynivska</td>
<td>113.0</td>
<td>36%</td>
</tr>
<tr>
<td>Total of Eastern MPP</td>
<td>317.3</td>
<td>100%</td>
</tr>
</tbody>
</table>

**Table 6.5. Overview of deposits of the Eastern MPP**

<table>
<thead>
<tr>
<th>Deposit</th>
<th>Scheduled period of ore mining</th>
<th>Planned method to work out reserves</th>
<th>Capacity, tons per year, by natural uranium concentrate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vatutinske</td>
<td>2015-2021</td>
<td>Mining + heap leaching</td>
<td>300</td>
</tr>
<tr>
<td>Michurinske</td>
<td>2015-2026</td>
<td>Block leaching from 2016</td>
<td>180</td>
</tr>
<tr>
<td>Tsentralne (Eastern area)</td>
<td>2015-2026</td>
<td>Mining</td>
<td>280</td>
</tr>
<tr>
<td>Novokostiantynivska</td>
<td>2015-2035</td>
<td>Mining</td>
<td>2500</td>
</tr>
<tr>
<td>Tsentralne (Western area)</td>
<td>2026-2035</td>
<td>Mining</td>
<td>1200</td>
</tr>
<tr>
<td>Lise</td>
<td>2028-2035</td>
<td>Mining + heap leaching</td>
<td>450</td>
</tr>
<tr>
<td>Safonivske</td>
<td>2018-2027</td>
<td>In-situ borehole leaching</td>
<td>150 (300)</td>
</tr>
<tr>
<td>Kvitneve</td>
<td>2019-2027</td>
<td>Mining</td>
<td>550</td>
</tr>
</tbody>
</table>
approved in the amount of 67.5 million tons of ore and 93.6 thousand tons of uranium (with average uranium content in ore 0.139%). The miners themselves give more conservative estimates. According to them, "occurrence of ore bodies in the Novokostiantynivske deposit is extremely complex" and his previous geological survey was not entirely accurate.

Currently activities are underway in the first ore zone, where five groups of deposits are concentrated. The design depth of the first stage mining of reserves is 700 m. The mining activities are conducted on the floor of 240-300 meters. To the surface, excavated rock mass is raised by two trunks. Lack of funding does not allow developing a deeper horizon (480 meters). The second and third ore zones are at the design stage. This year, ore mining at this mine even exceeded mining of Vatutinske deposit for the first time.

6.5. Redundant Capacities

For the period after 2025, Severnske (along with Pidgaitsevska site) and Tsentralne (Western area) deposits are considered as a mining reserve. Total uranium reserves of these deposits are about 98 thousand tons. Deposits are proposed to be worked out by mining.

6.6. Acidic Production

According to the Eastern MPP, 98% of uranium reserves are located in solid rock. The sandstone type is only 2% of reserves. Until recently, the management of the Eastern MPP estimated reserves in the neighboring Mykolaiv region of the sandstone Safonivske uranium deposit as "insignificant" (3 thousand tons), with a mining potential of 100-150 tons per year. Today, MPP already understands that such volume is not so few. Sandstone deposits may be worked out by a much cheaper method of in-situ leaching (this is approximately 40-42% cheaper).

To get uranium by leaching, it is necessary to drill a network of boreholes. Through them uranium deposits are pumped with sulfuric acid, it is mixed with its salts. This solution is pumped onto the surface. To reach the required concentration of uranium salts the solution is repeatedly passed through sorption columns.

Thus, the structure of uranium mining by in-situ leaching is as follows (see Fig. 6.7): 1 – pumping out borehole; 2 – pumping in borehole; 3 – sorption installation; 4 - desorption installation; 5 - addition of reagents; 6 – settling in the form of uranium oxide.

There was an experience of such mining in the country (Eastern MPP worked out Bratske
Table 6.6. History of uranium mining by acid in-situ borehole leaching

<table>
<thead>
<tr>
<th>Deposit</th>
<th>Period</th>
<th>Mined uranium, t</th>
<th>First mined uranium, year</th>
<th>Current state of deposit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Devladivske (PV-1)</td>
<td>1961-1984</td>
<td>1634</td>
<td>1965</td>
<td>worked out</td>
</tr>
<tr>
<td>Bratske (PV-2)</td>
<td>1966-1989</td>
<td>1070</td>
<td>1970</td>
<td>worked out</td>
</tr>
<tr>
<td>Novohurivske (PV-3)</td>
<td>1978-1980</td>
<td>2</td>
<td>1979</td>
<td>survey, research activities</td>
</tr>
<tr>
<td>Partizanske (PV-4)</td>
<td>1983-1984</td>
<td>-</td>
<td>-</td>
<td>survey, research activities</td>
</tr>
<tr>
<td>Mykhailivske (PV-5)</td>
<td>1975-1987</td>
<td>-</td>
<td>-</td>
<td>survey, research activities</td>
</tr>
<tr>
<td>Safonivske (PV-6)</td>
<td>1981-1987</td>
<td>40</td>
<td>1982</td>
<td>survey, research activities</td>
</tr>
<tr>
<td></td>
<td>2007-2009</td>
<td>-</td>
<td>-</td>
<td>No information in the source document</td>
</tr>
<tr>
<td>Sadove</td>
<td>1968-1971</td>
<td>-</td>
<td>-</td>
<td>survey</td>
</tr>
</tbody>
</table>

(1.1 thousand tons of uranium were mined) and Devladivske deposits (1.6 thousand tons) using this method.

However, the experience is ambiguous. Uranium was relatively inexpensive (although the Soviet military program did not pay much attention to the production cost), but at the same time there were leakages of radioactive fluids on the surface. In addition, slowly drifting lenses of radioactive solution were formed underground. Several hundred boreholes were drilled to control them. The history of uranium mining by the acid in-situ borehole leaching is presented below in Table 6.6.

Summary

In general, the uranium industry of Ukraine is in a difficult situation. It lost a period of high uranium prices for development. The prediction for their rise after 2020 seem not realistic.

In the world, renewable energy sector develops intensively reducing the interest in nuclear power plants. In addition, there are a number of suspended projects of mining low cost uranium, which may quickly increase production.

Current price situation in the world regarding uranium along with a sharp shortage of resources excludes the implementation of expensive large-scale projects.

At the same time, development of less ambitious but more remunerative projects are not excluded. This is mainly development of deposits by in-situ leaching. Thus, development of Safonivske deposit is estimated at 35-37 million USD.

In the medium term, the possibility of processing associated metals is not excluded, for example recovery of scandium project in the Zhovti Vody region.

In the near future, the main efforts, in addition to the Novokostiantynivska mine will be aimed at implementing the projects of in-situ borehole leaching and acid processing of ores of operating mines. The need to maintain strict control over compliance with the environmental legislation, for example depth of deposits in sandstones, which is relatively close to the surface.

Further closure of one of mines requires an analysis of social consequences and resources for their decommissioning.
7. ABOUT NUCLEAR REGULATORY SYSTEM IN UKRAINE

7.1. Stages in creation of the nuclear regulator of Ukraine

The State Committee of the Ukrainian Soviet Socialist Republic for Supervision of Safe Conduct of Work in Nuclear Energy was formally created by Decree of the Cabinet of Ministers of the Ukrainian SSR No. 12 on May 24, 1991. In fact, the work of the committee began only in the autumn, in the context of the process of disintegration of the USSR.

In accordance with the requirements of Law of Ukraine No.1540-XII dated September 10, 1991, "On enterprises, institutions and organizations of the Soviet Union subordination located on the territory of Ukraine", there began activities on transferring the enterprises, institutions and organizations of federal Soviet Union subordination to the authorities of Ukraine. By Order of the State Nuclear Supervision Committee of Ukraine No. 1/A dated November 1, 1991, the South-Western District and Department for the improvement and development of the Scientific and Technical Center for Security in Nuclear Power Engineering were transferred as legal entities from the structure of the USSR State Committee for Nuclear Inspection to the State Nuclear Supervision Committee of Ukraine.

The first organization chart of the State Nuclear Supervision Committee was approved on December 12, 1991. A working group was set up to develop a draft Law of Ukraine "On the Use of Atomic Energy" by Order of the State Nuclear Supervision Committee of Ukraine No. 5 dated January 23, 1992.

By Resolution of the Cabinet of Ministers of Ukraine No. 52 dated February 3, 1992, "On the Establishment of the State Committee of Ukraine for Nuclear and Radiation Safety" the State Nuclear Supervision Committee of Ukraine was transformed into the State Committee of Ukraine for Nuclear and Radiation Safety (hereafter – the Regulator). The Provision on the State Committee of Ukraine for Nuclear and Radiation Safety was approved by Resolution of the Cabinet of Ministers of Ukraine No. 416 dated July 21, 1992. The State Committee has seen transformations inside itself. The following was created: the General State Inspection for Supervision of Nuclear and Radiation Safety, the State Center for Supply Quality Control for Nuclear Energy Facilities, the Scientific and Technical Center for Nuclear and Radiation Safety. The Provision on the General State Inspection for Supervision of Nuclear and Radiation Safety was approved by Resolution of the Cabinet of Ministers of Ukraine No. 458 dated August 10, 1992.

On December 15, 1994, the State Committee of Ukraine for Nuclear and Radiation Safety was dissolved by Decree of the President of Ukraine No. 768/94 "On the Establishment of the Ministry of Environmental Protection and Nuclear Safety of Ukraine". Instead, the State Administration for Nuclear Regulation was created within the Ministry (Decree of the President of Ukraine No. 250/99 dated March 13, 1999).

As a result, the "Ministry of Environmental Protection and Nuclear Safety of Ukraine" was transformed into the "Ministry of Ecology and Natural Resources of Ukraine", which included the State Administration for Nuclear Regulation formed by another Decree of the President of Ukraine No. 1573/99 dated December 15, 1999.

On December 5, 2000, under the pressure of Western governments and international organizations, an independent State Nuclear Regulatory Committee of Ukraine was created (actually, restored) by Decree of the President of Ukraine No. 1303/2000.

The "restructuring" of the Ukrainian Regulator continued even after 2000, including the change of its name. The last of them is the State Nuclear Regulatory Inspectorate.

7.2. Difficulties and successes of the formation of the nuclear regulator of Ukraine

Almost six years, 1995 – 2000, were in fact lost to bureaucratic games, rewriting a lot of instructions and regulations. The main thing is that during these years those specialists left the regulator, who in...
1992 – 1994 got good training in the regulatory bodies and organizations of scientific and technical support of the USA, Germany, France and other countries.

The nuclear safety regime, built based on supervisory practice, with all its advantages and disadvantages, was inherited from the USSR. Immediately after the formation of the Ukrainian regulatory authority, the task emerged to gradually shift the nuclear safety regime to licensing regulation, which was recognized throughout the world.

In 1992 – 1995, a significant amount of work was done, which allowed to start the process of gradual transition from supervisory to regulatory practice of the nuclear safety regime. Due to the high qualification of specialists, as well as assistance and support of the nuclear regulatory bodies of both the G-7 nations and other Western nations, they managed to accomplish this task. A significant role was also played by the cooperation with the nuclear regulatory bodies of the countries of Eastern Europe, which at the same time were passing from the supervisory system of the nuclear safety regime to the licensing one.

Despite the high potential of Ukrainian science and technology, especially in the nuclear industry, the nation happened to have no organizations that specialized in a broad range of nuclear safety issues. A significant role in the implementation of the licensing regime of nuclear safety played the attention paid to the creation and development of an organization of scientific and technical support, the State Scientific and Technical Center for Nuclear and Radiation Safety (hereinafter – the SSTC). Enormous support, first of all, in the training of staff, was provided by the regulators of the United States, Germany and France. Moreover, these bodies also created the material basis for efficient operation of the SSTC – the supply of computing and other equipment, their sharing with analytical codes, etc. Equally important was support from other countries. The creation and development of its own system of scientific and technical support allowed the Regulator to form the basis of the licensing regime – granting the permits (licenses) for the use of nuclear energy based on the results of an independent assessment of safety of nuclear installations.

At the same time, a state system for nuclear materials control and accounting and the regulation of physical protection was created. In this regard, the support of the Swedish nuclear regulatory body and the IAEA played an exceptional role.

In the second half of the 1990s, the pace of development of the Committee and the system of nuclear regulation as a whole was insignificant, which was the consequence of the "restructuring" of the nuclear regulatory body initiated in 1995 and the loss of part of its powers and independence. The Regulator’s management refused to implement the world-renowned system of safety analysis reports (SAR), which was launched in 1992. The Regulator opted for creation of surrogates based on the existing volumes of "Technical safety justification" and additional materials to them. It also helped to preserve the rudiments of the old system, making it difficult to work with safety documentation.

7.3. The nuclear regulator of Ukraine today

Nuclear safety regulation includes several principal areas of activity:

- Regulatory control
- Licensing
- Supervision
- Enforcement

7.3.1. Regulatory control

It is known that in the USSR, nuclear activities were not actually regulated at the legislative level. Therefore, first of all, the huge amount of work should be noted, which is done in Ukraine to form the legislative basis for the use of nuclear energy. Laws were developed that defined the legal framework for the use of nuclear energy, protection of the population and the natural environment from the negative effects of ionizing radiation, as well as compensations for nuclear damage and regulation of activities in emergency situations, which could result in the negative impact of ionizing radiation on the population and the environment.

Much effort was made to approve and further adapt for Ukraine the international agreements (conventions) both on safety issues of nuclear energy use, and related to compliance with the requirements of the non-proliferation regime, as well as international transportation of nuclear materials. Even though today nuclear legislation is quite perfect, there are still inconsistencies and contradictions in it. These are the consequences of significant transformations that took place in the 1990s and, as a result, there are many adopted legislative instruments. Today it is objectively necessary to concentrate efforts on the codification of nuclear legislation. Unfortunately, this work is not planned yet.

The Regulator made significant efforts to improve the nuclear and radiation safety requirements, especially in the field of radioactive waste management, spent nuclear fuel and decommissioning of nuclear facilities. A large amount of work was performed about the necessity
of introducing into the legislative and regulatory field all activities related to the liquidation of the consequences of the Chernobyl accident.

A significant amount of work was carried out in terms of the Regulator’s activities in all areas related to the formation of its own inner procedures.

Regardless of success, regulatory activity remains, unfortunately, the weakest link in the work of the regulatory body. To address these issues, it is necessary to upgrade the scientific and technical base, to raise the level of training of specialists and to finance fully this important direction. For example, the state budget of 2017 has not provided for funds to develop normative documents at all.

The review of normative documents has not been completed, the need for adjusting which became apparent after an assessment of the causes, circumstances and consequences of the accident at the Fukushima-Daiichi NPP in 2011. The reason is not so much in the limited funding, but rather in the rather lukewarm attitude of the Regulator’s management towards this matter. Ukraine remains the only nation in the world that has not incorporated into the basic regulatory document (NPP General Safety Regulations) the new safety regulations adopted by the world nuclear community as measures allowing additional obstacles to possible serious accidents into the main regulatory document. In addition, in the list of the normative documents on nuclear and radiation safety effective in Ukraine, there are still documents of the nation (the USSR) that has gone already for a long time.

Ukraine is not a reactor-building country. In any scenario of the development of nuclear energy for many decades to come, the country will be an importer of technologies and basic reactor equipment, including nuclear fuel. We should be ready for this. All nuclear units operated in the country were built based on the regulatory framework that was uniform for both the supplier and the operator (initially at the time of the USSR, and then even in the independent Ukraine that continued to work on the Soviet regulatory framework). New power units, even if they are of Russian manufacture, will be created based on regulatory instruments different from those currently used in Ukraine. This is a significant issue, and it has already been faced during implementation of the projects on eliminating the consequences of the Chernobyl accident. The problem also resides in the fact that the construction of new units should be licensed. And if a potential investor and / or technology provider feels high licensing risks, they will not come to Ukraine. Though construction of new nuclear units in Ukraine is clearly not feasible in the coming decades at the expense of Ukraine’s own funds.

7.3.2. Licensing

A lot of work has been done in this field of activity, especially in the organizational and managerial domain. It is safe to say that Ukraine has introduced a worldwide recognized nuclear safety regime. The system of conducting an independent safety assessment, consideration and approval of conditions and limits of safe operation, verification of readiness of applicants for the functions of the licensee is worked out. Extensive experience has been gained in the consideration of the entire range of issues related to the assessment of the safety of the units, the operation of which is extended for 10 years or more beyond the lifetime provided for by the initial design. Significant volumes of work are carried out and are being carried out in an estimation of measures of improving safety developed by the licensees. Ukraine has prepared and incorporated the practice of licensing the personnel of nuclear facilities who have a direct impact on nuclear safety. Of course, there are tasks that require improvement, but this is the routine of any organization.

7.3.3. Supervision

This is a traditional area of activity that has been well matured as early as within the Soviet nuclear security regime. The Nuclear Regulatory Authority of Ukraine has put much effort into further improving the supervisory practices. It is regrettable that during the initial period, the efforts to introduce a methodology for the systematic evaluation of the activities of licensees (based on the experience of the US Nuclear Regulatory Commission) were blocked in the process of numerous "restructuring" of the regulatory body. Since the year of 2000, the Regulator has been entrusted with the function of regulating the safety of utilization of all sources of ionizing radiation, which are used in the national economy, medicine, scientific research and education system of Ukraine. This new task required the development and incorporation of specific procedures by the Regulator and, in general, they successfully coped with this task.

7.3.4. Enforcement

The system of coercive measures in Ukraine is formally in place (Resolution of the Cabinet of Ministers of Ukraine №708 dated June 29, 1996) but the level of sanctions applied to a licensee for violating licensing conditions and safety limits as well as other violations of safety requirements give grounds to doubt the fact that they have an effective impact on the Operator.
7.4. Future of the nuclear regulator of Ukraine

Assessing the future of the nuclear regulatory body of Ukraine is extremely difficult today. Another surge of reforms in the economy has led to totally unpredictable results. Deregulation of economic activity led to the fact that the Nuclear Regulator of Ukraine, in fact, has lost its independence today.

According to the new legislative instruments on licensing and supervision of economic activities, the Regulator has now limited powers in issuing orders to licensees on violation of their conditions and safety limits as well as termination or cancellation of licenses for activities in the field of nuclear energy use, if the activity of the licensee constitutes a threat to health and the safety of the population or the environment.

The main restrictions imposed by these laws lead to the fact that:

• Supervisory inspections cannot do any checks more than once every two years and it should be within one scheduled event.
• The following types of unscheduled inspections are excluded, such as responding to non-standard situations, failures and accidents, extraordinary inspections due to lessons learned in other facilities, including those abroad.
• Sudden checks and inspections in extra-time are excluded (which is absurd for continuous production).
• The possibility is excluded to suspend the activity of a licensed facility in case of violation of the safe conditions and safety limits, when it poses a real threat to health and life of the population and to the environment. Suspension (prohibition) of hazardous activities is possible only by a court decision.

These restrictions disable many provisions of international conventions – the Convention on Nuclear Safety and the Joint Convention on the Safety of Spent Fuel Management and on the Safety of Radioactive Waste Management, which have been ratified by Ukraine and have unconditional priority over the domestic laws of the country.

Therefore, today the main task is to restore the independence of the Regulator, as provided for by the nuclear legislation of Ukraine and international conventions signed and ratified by Ukraine.

In principle, the strategic tasks for the future are known – to improve the nuclear safety regime and to improve the safety of nuclear activities. However, improvement activities (and it never ends) should be conducted in accordance with a well thought out program that should be brought to the attention of each employee, understood by them and accepted for implementation. Unfortunately, there is no such program yet. The main aspect that determines the future of the Regulator is the personnel, for whose training there should be a permanent program of training and advanced training of specialists of the nuclear regulatory body.

7.5. Conclusions

Ukraine’s nuclear safety regime started out in its development from the regime inherited from the former USSR, based on rigorous regulatory state supervision. Numerous organizational disturbances have slowed down, but failed to stop the transition of Ukraine to the generally accepted world-wide regime of licensed nuclear regulation, which undoubtedly requires its improvement in the process of development. The financial provision of regulatory activity continues still to be constrained, especially as to the codification of nuclear legislation and the improvement of the regulatory framework, which constitutes the legal basis for the nuclear safety regime. The Regulator’s material and technical basis, the software and hardware systems used by it, are created mainly due to the support of developed countries of the world and international organizations. The support of this basis at the up-to-date level is also limited by unsatisfactory financial provision. The same reason restricts the Regulator in conducting safety research independent from licensees, which, in turn, holds back the development of the regulatory framework.
8. ECONOMICS OF UKRAINIAN NUCLEAR POWER

8.1. Historical background

After the disintegration of the Soviet Union, the Ukrainian energy sector found itself in rather difficult circumstances that included a host of financial and economic problems. Disruption of logistics and the value chains existing within USSR, and especially within enterprises located in the newly formed Russia Federation (where the main nodes of the nuclear industry were located) brought Ukraine to almost total dependence on a single nuclear fuel supplier. That actually impacted negatively on the future of Ukraine’s energy security.

The indemnity paid to Ukraine for its nuclear non-proliferation was only a short-term solution for nuclear fuel supplies to Ukrainian Nuclear Power Plants (NPP). But finally, that had a very negative impact on Ukraine’s further development of nuclear energy. In 1991, the complete shortage of money at all NPPs reached 682.778 mln rubles. In the beginning of 1990s, the government declared a moratorium on building new NPPs in Ukraine. This step brought huge financial losses totaling 67.32 bln rubles.

Under these conditions of financial and economic crisis, political instability, rapid shifts from a command economy to a market economy, and the specific technical features of existing soviet-type reactors, the problems of the nuclear energy field were complicated for the Ukraine’s newly formed government. Under such conditions, Russia maintained a dominant position in most areas of Ukraine’s nuclear industry, including supplies of nuclear fuel and necessary technologies, and treating spent nuclear fuel and radioactive waste. It is clear that this negatively impacted further development of Ukraine’s nuclear power sector and complicated Ukraine’s attempts to diversify services for its nuclear power sector in general, including supplies of the fuel, establishing partnership with companies from other states, and establishing transparent and competitive approaches to pricing for all those services.

The situation within the Ukrainian nuclear power sector became critical after tensions between Russia and Ukraine emerged in 2014. The already existing risks to Ukraine’s energy security became even sharper, primarily those related to supplies of energy resources, since Russia was almost a monopoly supplier of natural gas, oil and petroleum, and nuclear fuel. This pushed Ukraine to search for new suppliers, which impacted the economic indexes of Ukraine’s nuclear power sector as well. Research on opportunities for new suppliers to enter the Ukrainian market started a long time before the 2014, but at that moment the necessity to diversify was crucial.

8.2. Main technical and economic indices of producing energy by nuclear power stations in Ukraine

The nuclear power sector plays an important role in generating electricity in Ukraine, covering more than a half of demand. In the first quarter of 2017 it accounted for 58.4% of all electricity produced in the country. It was lower before: 52.4% in 2016 and 55.7% in 2015.

Currently, the State Enterprise “Energorynok” (literally translated as state enterprise Energy Market) is the only enterprise responsible for buying electricity produced by all energy generating companies at fixed prices. Those prices are determined by the state committee that oversees regulating energy and utility services. But this approach should be changed soon. On April 13, 2017 the the Ukraine parliament Verkhovna Rada adopted a new law “On the Electricity Market”. According to the new law, a new model of competitive energy market will be stipulated: currently existing monopolies will lose their status.

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1 Central State Archives of the Supreme Authorities and Governments of Ukraine, Fund No. P-2, description 15, case number 2333 Correspondence with Allied, Republican and regional organizations on the design and construction of nuclear power plants in the Ukrainian SSR / June 19, 1991 No. 06-4 / 12-161 from the head of the Commission on the development of basic sectors of the national economy of the Verkhovna Rada of the USSR V. Yevtukhov, to the Cabinet of Ministers of the Ukrainian SSR, Comrade Fokin V.P.
2 http://www.energoatom.kiev.ua/ua/actvts/financial/resume_2016/
and final consumers will be able to choose a supplier. The new law is due to be implemented by the beginning of 2019.

In the first half of 2017, the state enterprise Energoatom, which operates all Ukrainian NPPs, sold SE Energorynok 24 543,0 mln UAH worth of electricity, which is 25 % more than the first half of 2016. Electricity generated by NPPs grew too: 45 726,0 mln kWh during the first half of 2017 and 40 323,0 kWh during 2016. In 2016 SE Energoatom sold 43 128,7 mln UAH worth of electricity, which is 9,6 %, more than in 2015.

Increases in electricity production by NPPs were achieved with an eye to saving coal and decreasing dependency on external supplies of energy resources (for instance, disrupted anthracite supplies from Donbas) in order to strengthen energy security, and with the goal of avoiding increasing prices to electricity for consumers (the share of imported, more expensive energy in general. Now, as it was a few years earlier, the coal power sector has a strong lobby and this poorly impacts the nuclear power sector. By turn, this limits capacities for accumulating resources necessary to solve the nuclear industry’s existing problems, and contributes to accruing those unresolved issues in the future.

Despite the particular importance of the nuclear power sector for Ukrainian energy, it is still in rather complicating economic circumstances. That was caused by the tariff determination policy and a lack of strategic thinking about future of Ukrainian energy in general. Now, as it was a few years earlier, the coal power sector has a strong lobby and this poorly impacts the nuclear power sector. Despite the increase in production and sales of electricity by NPPs, the net profit of SE Energoatom amounted 187.12 bln UAH in 2016 which was 4.4 times less compared to 2015 (833.3 bln UAH). At the same time, the state-owned company Centerenergo (operating 3 coal power stations with a total capacity of 7 690 MWt) earned 386.8 bln UAH in profits, which was 17.7 time more compared to 2015 profit (21.85 bln UAH). The aforementioned differences in profits emerged when Centerenergo produced only 9.9 bln kWh in 2016, and Energoatom generated 81.2 bln kWh during the same period of time. According to date from State Fiscal Service of Ukraine, SE Energoatom paid 6 861 928 270 UAH in taxes, giving it the top spot among Ukraine’s 100 biggest taxpayers for 2016.

8.3. The tariff setting policy

Currently the average tariff (the price that SE Energorynok pays for energy) for electricity generated by NPPs is the lowest compared to other types of conventional energy generation. In 2000, nuclear origin electricity was 48 % cheaper compared to energy coming from coal. In the first half of 2017, the tariff for SE Energoatom was 0.4729 UAH per kWh and 1.6688 UAH per kWh at coal powered stations. For years there was a disparity in tariffs. But the biggest gap occurred during 2016-2017 when delivery of anthracite coal from Donbas region became a especially complicated and the state energy regulation commission established so called "Rotterdam" approach. According to this method, coal-origin electricity prices are calculated as if the coal were purchased in Rotterdam and Germany and then transported to Ukraine. Thanks to this approach coal power stations (including the largest, DTEK, and the above mentioned state owned Centerenergo) began trading electricity at prices that were 15-20% higher. In 2017, tariffs rose 80.6% over 2015 (from 0.8801 UAH per kWh to 1.6688 UAH per kWh). Meanwhile, tariffs for electricity generated by nuclear facilities have increased by only 19.8 % (Fig. 8.1). Meanwhile, steps to diversify nuclear fuel suppliers, prolonging operation terms of NPP reactors, and providing safety at NPPs require additional spending. Under these circumstances, the current tariff setting approach might cause stagnation for the Ukrainian nuclear power sector.

The rate of the tariffs for electricity and heat produced at NPPs is defined by a methodology that was developed and adopted by the state energy regulating commission in June 1, 2017. According to the methodology, the tariff is calculated by taking into account price of nuclear fuel, the cost of treating spent nuclear fuel and radioactive waste, the cost of providing nuclear safety and prolonging reactor operation times, salaries, capital consumption depreciation and so on. And the most of these costs depend on the policies of Russia (because of above-mentioned reasons and the absence in Ukraine of necessary technologies for production, storage, reprocessing and treatment).

In 2016 the tariff for nuclear origin electricity was changed a number of times: from 0.419 UAH per kWh on 01 January 1, 2016 to 0.5102 UAH per kWh on August 1, 2016. The tariff change was caused by additional expenditures for nuclear fuel
imports, the devaluation of Ukrainian currency, and the necessity of funding the construction of a centralized repository for spent nuclear fuel. But considering the pattern of tariffs and their leveling, this is not enough for the further development of the Ukrainian nuclear power industry, especially when considering its importance.

The breakdown for tariffs collected in 2016 is as follows: 48% paid for nuclear fuel; 14% paid salaries; 5% went to capital allowances and 11% were used for other purposes10 (Fig 8.2). Now, changes in nuclear fuel prices are affecting tariffs thanks to diversified supplies.

8.4. Supplies of nuclear fuel

The Ukrainian nuclear power sector relies on many Russian technologies. All reactor units are of the VVER type, which were developed in USSR and are now maintained by Russian state nuclear corporation Rosatom. As such, the nuclear fuel supply also comes from Russia, which means critical dependence by the Ukrainian nuclear sector on one supplier, and that threatens Ukrainian national energy security.

In an attempt to resolve this issue, Ukraine in 2000 began reviewing opportunities to use fuel supplied by other foreign companies. Since 2005, fuel supplied by Westinghouse has been tested at the South-Ukrainain NPP. But after an incident in 2012, tests on this fuel were suspended.

Upgraded Westinghouse TVZ-WR fuel assembly proved to be safe, passed all tests and was granted a license by State Nuclear Regulatory Inspectorate of Ukraine.

In 2013 Ukraine purchased nuclear fuel only from Russia, and spent $ 600 596 140 on it. But on April 11, 2014 an earlier signed agreement between SE Energoatom and Westinghouse Electric Sweden AB was prolonged until 2020. So, in 2014 total Ukrainian spending for nuclear fuel reached $ 628 175 920 ($ 39 345 230 was paid

10 ibid
for Westinghouse and $ 588 830 690 was paid to a Russian company). Currently the share of Westinghouse fuel by total consumption is 49% and in 2016 it was 39%. According to the State Statistics Service of Ukraine, in the period from January to July in 2017, the total cost of nuclear fuel imports amounted $ 275 114 200 (cost of Russian TVEL fuel was $164 916 210; the cost of Swedish Westinghouse fuel was $110 198 080). In 2016, the total cost of nuclear fuel imports amounted $ 548 706,860,(§ 386 781 980 paid for Russian fuel and $ 161 924 880 for Swedish Westinghouse). The diversification of nuclear fuels supplies positively impacted the economic indexes of the nuclear power sector: despite the increase in imported fuel, total costs have been decreasing. In 2013, Ukrainian paid $ 600 596,140 for 369 359 kg of imported nuclear fuel, and in 2016, it paid $ 548 706 860 for 450 489 kgs.

8.5. Economics of spend nuclear fuel management

Particularly important to the nuclear product cycle is spent nuclear fuel (SNF) treatment. And this is not available in Ukraine to a full extent. Every year Ukraine delivers its spent nuclear fuel to Russia for further processing. Annually, this costs about $ 200 million. But according to the contract, Russia, after 2018, both reprocessed fuel and the fission products arising from reprocessing will be sent back to Ukraine for storage. Aside from that, as per the Joint Convention On the Safety of Spent Fuel Management as well as the law On the Safety of Radioactive Waste Management, all SNF must be stored in the country where it was produced. Yet SNF is a rich resource: after it is burned as fuel, it contains about 95 % uranium-238, 1 % uranium-235, 1 % plutonium, 3 % radioactive waste comprised of neptunium, americium, curium and others. Because of this, the Zaporizka NPP in 2001 introduced a new technology for dry storage of SNF coming from VVER-1000 reactors. This made it possible to save money on SNF storage — savings that assessments said added up to $10 million. But prospects of using new storage technologies and facilities for the nuclear waste form Ukraine’s other NPPs remains unclear.

To solve this problem, SE Energoatom in 2005 signed a contract with the US company Holtec to build a centralized storage facility for spent nuclear fuel from VVER type reactors operating at domestic nuclear power plants (CSNFP) within Chernobyl Exclusion Zone. On July 6, 2017 SE Energoatom obtained a license from State Nuclear Regulatory Inspectorate of Ukraine to perform activities at all stages of construction and implementation of the CSNFP. This was preceded by 12 years of discussions and negotiations. According to an engineering-and-economical performance evaluation (undertaken by Cabinet of Ministers decree № 380-p "On Approving the Project "Construction of the centralized repository of spent nuclear fuel from Ukrainian VVER NPP units ", date June 7, 2017) the estimated cost of the project was 37.22 bln UAH. However, the cost has risen 9.5 times over the one calculated in 2009 ($148 million), due to the devaluation of UAH and increasing inflation (in 2009 one dollar equaled 7.98 UAH, however, today one dollar equals 26.81 UAH).

According to current plans, the centralized repository will consist of 458 containers for storing 16 530 spent fuel assemblies. Term of delivery is planned to last 16.5 years and will consist of 15 stages. During each of those, 33-34 containers will be installed. The first 94 are planned to be delivered to the facility in early 2019. Annually, 42 spent fuel assemblies are extracted from VVER-1000 reactors and 78 are extracted from VVER-440 reactors, thus it is expected that the repository will fulfill Ukraine’s needs.

Financing for the project is expected to come from SE Energoatom’s internal funds (and as it mentioned above electricity tariffs include a component to finance repository construction). Aside from that, he Corporation for Foreign Investments agreed in September 2017 to ensure $ 250 million toward design, construction and use of the CSNFP.

8.6. Economics of radioactive wastes management

The issue of radioactive waste management in Ukraine is not yet entirely resolved and there
has been no tangible progress. The main reason for this is inefficiency is Ukraine’s State Fund for Radioactive Waste Treatment (SFRWT). It was established in 2009 to provide an effective and reliable procedure for financing radioactive waste management. It is funded by fines on environmental pollution. The Procedure to use those funds as regulated by Cabinet of Ministers decree № 473 entitled "On Approving the Procedure of Spending Funds of Ukraine State Fund for Radioactive Waste Treatment" dated April 20, 2009. But after amendments were introduced to the law "On Radioactive Waste Treatment" in 2010, and to the "Tax code" in 2015, the fund stopped accumulating money this purpose. As a result, the fund stopped operating properly and money to finance nuclear waste treatment became harder to come by. Ukraine, incidentally, is in second place in Europe, and fourth worldwide, in the amount of nuclear waste it produces23. The biggest problem is lack of funds to finance construction of facilities that store waste that is due to be returned to Russia in 2018 after a bilateral agreement expires. Insufficient financing for the State Corporation Radon (which is responsible for operating radioactive waste storage sites) negatively impacts on the future capabilities to store such waste and radiation safety in general.

To resolve the financing issue, Ukraine’s parliament on July 11, 2017 adopted law law № 2125-VIII "On Amending the State Budget Code of Ukraine Regarding Improving the Procedure of Financial Provision for Radioactive Waste Treatment." It comes into force on January 1, 201820. The law is formulated to settle issues of state procedures of funding, designing, building, commissioning and decommissioning facilities for processing radioactive waste.

SE Energoatom contributes the most to the fund. In 2016, it paid in 777,054 mln UAH. The total income of the fund was 4 589.42 mln UAH21.

8.7. The economics of extending reactor lifespans and decommissioning NPPs

The average engineer lifespan for Ukraine’s nuclear reactors is 30 years. After that, reactor units enter the decommissioning phase, or receive engineered lifetime extensions of 10 to 15 years.

Ukraine’s Cabinet of Ministers on April 29, 2004 adopted a decree called "The Complex Program of Steps for Extension the Lifetime of NPPs". According to the decree, lifespan extensions are granted in accordance with nuclear and radiation safety.

Extending reactor lifespans is technically and economical preferable to building new reactors. According to studies, lifespan extensions cost on average some 3.3 bln UAH (though the cost of extending the lifespan of the VVER-440 unit in use at the Rivenska NPP reached 4.4 bln UAH), where building a new reactor costs as much as 185 bln UAH.

Most reactors at Ukraine’s NPPs were built during the Soviet period. All reactors operating in Ukraine will reach the end of their engineered lifespans before 2055 (including extensions of lifetimes beyond the 30 years originally proposed). Correspondingly, all of them will be put into the decommissioning phase. The decommissioning of reactors № 1 and № 2 at the South Ukrainian NPP began in 2023 and 2025 respectively.

Existing electricity tariffs stipulate the collection of funds for this purpose. By Ukraine’s law № 1868-IV "On Regulating Issues of Providing Nuclear Safety" signed on June 24, 2004, SE Energoatom must collect these funds in a separate bank account.

The main normative document that regulates preparation of NPP units for decommissioning is "The Concept on Decommissioning NPPs" (set in force by adcre № 798 of the Ministry of Energy and Coal Industry on December 10, 201523). This document provides for the assessment of financial and labor costs for decommissioning reactors from 2012 on. Those costs are now higher, thanks to inflation, but it still makes clear what the estimated costs for this are. The standard price tag for the postponed decommissioning of a VVER-440 unit is 2 303,0 mln UAH, and is 2 934,5 mln UAH for the postponed decommissioning of a VVER-1000. The immediate decommissioning of a VVER-440 unit costs 1 808,3 mln UAH, and 2 328,7 mln UAH is the immediate decommissioning cost for a VVER-1000 unit (Fig. 8.3). Taking into account that 13 VVER-1000 units are operating in Ukraine, decommissioning costs for their postponed dismantlement is expected to be 8 149 mln UAH, with another 6 909 mln UAH for dismantling the three VVER-440 units. Therefore, in 2013 prices and conditions, Ukraine needs 45 058 mln UAH to take all units out of service. According to SE Energoatom data, on September 1, 2017 the

23 http://www.kmu.gov.ua/control/publish/article?art_id=249989423
21 http://www.kmu.gov.ua/control/publish/article?art_id=249989423
company has amassed only 3,198,418 mln UAH for those purposes.23

Table 8.1 Evaluation of the cost of decommissioning NPP units’ (on December 30, 2012)24

<table>
<thead>
<tr>
<th></th>
<th>Costs</th>
<th>Costs per KWt</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>mln UAH</td>
<td>mln USD</td>
</tr>
<tr>
<td>Postponed decommissioning</td>
<td></td>
<td></td>
</tr>
<tr>
<td>VVER-440</td>
<td>2303,0</td>
<td>288,1</td>
</tr>
<tr>
<td>VVER-1000</td>
<td>2934,5</td>
<td>367,1</td>
</tr>
<tr>
<td>Immediate decommissioning</td>
<td></td>
<td></td>
</tr>
<tr>
<td>VVER-440</td>
<td>1808,3</td>
<td>226,3</td>
</tr>
<tr>
<td>VVER-1000</td>
<td>2328,7</td>
<td>291,3</td>
</tr>
</tbody>
</table>

8.8. Economics of new reactor construction

The strategic uncertainty for the future role the Ukrainian nuclear industry will play negatively impacts investment in the field. The most promising project currently underway is the completion of the 3rd and 4th units of the Khmelnitska NPP. At present, the 3rd unit is 75% complete, and the 4th is 28% complete. Yet because the 4th unit has stood idle for so long, repairs and construction have to be resumed practically from anew. Meanwhile, according to reports from SE Energoatom, some 80% of repairs and construction were completed between 2008 and 2013. The cost for finishing the two units is estimated at 3.7 bln euro, about 50-60% less compared to the cost of building a new reactor. Energoatom is scheduled to construction on the 3rd unit in 2025 in partnership with Czech company Skoda.25 As to the 4th unit, Korea Hydro & Nuclear Power is being viewed as a likely partner.

The development of small module reactors with an installed capacity of 150 or 300 MVT is a potentially promising sector in Ukraine when compared to the financial and technological difficulties with VVER-1000 reactors. As of today, SE Energoatom’s management is actively exploring this sphere and holding negotiations with the American firm Holtec.

Summary

Retaining the nuclear industry to cover all of the country’s energy demands is a priority for Ukraine. Taking a reactor out of service reveals the need to fill the resulting deficit with other energy sources. Considering the current poor economic circumstances within Ukraine’s nuclear energy sector (which is also an important source of state funding) the sector’s further development is unclear. And because electricity tariffs have been underestimated, the industry is receiving less than its due. This, by turn, causes delays to other important work: nuclear and radioactive waste management, providing maintenance and development for reactor functioning, etc. In order to enhance nuclear safety, Ukraine must turn toward international financial institutions. Nuclear power sector, as one of strategic importance to Ukraine, requires deliberated policy with respect of further development and approaches to financing.

23 http://www.energoatom.kiev.ua/ua/actvts/decomission/23595-dyalnst_dp_naek_energoatom_schodo_pdp_gotovki_do_zMYKATC_dyuchih_ues_ukran/
9. MANAGEMENT OF RADIOACTIVE WASTE AND RADIATION SOURCES IN UKRAINE


9.1.1. Policy of Radioactive Waste Management in Ukraine

The main principles of a national policy for radioactive waste (radwaste) management are outlined by Ukrainian legislation, in particular, Ukraine's law "On Radioactive Waste Management" [1].

The state policy for radwaste management is implemented in compliance with the Strategy for Radioactive Waste Management in Ukraine [2], the National Target Ecological Program for Radioactive Waste Management [3], and National Program for Chernobyl NPP Decommissioning and Shelter Transformation into an Environmentally Safe System [4].

The Strategy for Radioactive Waste Management in Ukraine [2] identifies major areas and tasks for development of a radwaste management system for a period of 50 years. To develop the Strategy [2], the status of radwaste management in Ukraine was analyzed and best international practices as well as IAEA and European Union safety standards were taken into account.

The selected strategic option for development of the radwaste management system in Ukraine envisions:

- on-site processing of radwaste from nuclear power plants (NPP) into a condition that will be acceptable for disposal or long-term storage in centralized facilities on the Vektor site;
- collection, conditioning, transport, and interim storage of radioactive waste and disused radiation sources (DRS) generated in medicine, science, and industry at state interregional specialized plants (SISP) of the Radon Corporation;
- centralized disposal of low- and intermediate-level short-lived waste and long-term storage of long-lived and high-level waste from all Ukrainian producers in storage/disposal facilities on the Vektor site;
- disposal of long-lived and high-level waste in a geological repository;
- establishment of a national organization for radwaste management, including long-term storage and disposal of radwaste;
- stable and adequate funding for radwaste management measures;
- development of legislative and regulatory frameworks and international cooperation.

The following projects are underway for the period up to 2017 in compliance with the National Target Ecological Program for Radioactive Waste Management [3]:

- improve radioactive waste management system at NPPs;
- reassess safety, reequip and convert the Radon SISPs into sites for radwaste collection and interim storage in containers;
- commission and operate near-surface radioactive waste disposal facilities of Vektor Stage I;
- design and construct facilities for long-term storage of long-lived and high-level waste of Vektor Stage II, particularly DRS, vitrified radwaste to be returned from the Russian Federation after spent fuel reprocessing, and other long-lived and high-level waste;
- design radwaste processing facilities of Vektor Stage II;
- support the system for management of Chernobyl-origin radwaste and monitor and improve safety of storage facilities for accident-related waste created during the first years of Chernobyl accident mitigation;
- conduct surveys and research efforts to select a site for a geological repository;
- ensure personnel training and professional development;
- improve state system for radwaste accounting and control;
- ensure a legislative and regulatory framework and international cooperation.
The deadline for implementing the National Target Ecological Program for Radioactive Waste Management [3] expires in 2017. The State Agency of Ukraine on Exclusion Zone Management (SAEZ) works to update measures stipulated by the national program and to extend project deadlines through subsequent periods by developing relevant draft laws in cooperation with stakeholders.

9.1.2. Implementation Status of Radioactive Waste Management Strategy

The specific strategic tasks identified in [2] are implemented in compliance with the National Target Ecological Program for Radioactive Waste Management [3], and National Program for Chernobyl NPP Decommissioning and Shelter Transformation into an Environmentally Safe System [4].

Information on the status of the radwaste management strategies in Ukraine is provided below.

Radwaste processing plants are under construction at operating NPPs with the aim of minimizing waste amounts and bringing waste into a state acceptable for disposal or long-term storage in the centralized facilities at the Vektor site:

- at Zaporizhzhya and Rivne NPP, a significant part of equipment for the processing plants has already been supplied, mounting and acceptance tests are underway, and plant lines are to be put into trial commercial operation in 2018;
- at Khmelnitsky and South Ukraine NPPs, buildings for a future location for the plants have been inspected and plant designs have been developed and subjected to regulatory review;
- search for safe technologies for immobilization of salt fusion cake generated at liquid radwaste deep evaporation facilities into a solid matrix is underway;
- selection of a technology for processing of evaporation bottoms without production of salt fusion cake is ongoing.

Chernobyl NPP (ChNNP):
- decommissioning of units 1, 2, 3 and dismantling of systems and equipment are underway;
- construction of the New Safe Confinement for the Shelter is in its final stage;
- radwaste management infrastructure is under development;
- interim storage facility for packages with high-level and long-lived waste is in operation within the Industrial Complex for Solid Radioactive Waste Management (ICSRM);
- solid radioactive waste processing plant within ICSRM is under construction;
- liquid radioactive waste processing plant is under construction;
- line for fragmentation of high-level long-length components retrieved from the reactor compartments is being mounted;
- plant for manufacture of metal drums and reinforced concrete containers for radioactive waste is in operation;
- additional Chernobyl NPP (ChNPP) radioactive waste processing facilities are being designed: facility for liquid radwaste processing to remove organics and transuranic elements, areas for storage, fragmentation, and decontamination of dismantled structures, and facilities for release of dismantled materials from regulatory control.

Vektor site: (15 km southwest of ChNPP):
- engineered near-surface disposal facility (EN-SDF) for ChNPP radwaste packages is in operation;
- construction of two near-surface disposal facilities for solid radwaste (SRW-1 and SRW-2) is in its final stage;
- development of the infrastructure required to ensure safe operation of the disposal facilities is reaching completion;
- centralized facility for long-term storage of DRS has been completed and is awaiting commissioning;
- storage facility for vitrified high-level radwaste arising from reprocessing Russian origin fuel used in Ukrainian NPPs and a radwaste processing facility are being designed.

Chernobyl Exclusion Zone (outside ChNPP and Vektor site):
- measures on radiation monitoring and monitoring of the environment within the exclusion zone are taken on a permanent basis according to agreed procedure;
- near-surface radwaste disposal facilities of the Buryakivka radioactive waste disposal site (RWDS) are in operation; an expansion of this RWDS is planned;
- projects have been implemented to stabilize and improve safety of facilities where radwaste was placed during the first years after the Chernobyl catastrophe, namely Pidlisny RWDS and ChNPP Stage III RWDS;
- survey of the radioactive waste interim confinement sites (RICS) is ongoing to find/specify locations of trenches and pits with radwaste, the effect of RICS has been reassessed to optimize further decisions on their remediation, radwaste retrieval from the most hazardous trenches and pits is underway.

Measures are under implementation at Radon SISP's to:
- convert and reequip specialized plants into facilities for collection and interim storage of radwaste;
- reassess and improve safety of operating and shut down legacy storage facilities;
- create new radwaste management facilities;
- renovate the fleet of vehicles and containers;
- upgrade radiation monitoring and physical protection systems.
9.2. Disused Radiation Sources

A radiation source is defined radioactive material that is used as a source of radiation. Radiation sources are widely used in medicine, science, industry, agriculture, etc.

Disused radiation sources are no longer used and are not intended for use in practices implemented under an official permit. After DRS are transferred to Radon SISPs, they are labeled as radioactive waste. Information on the quantity of DRS stored at Radon SISPs is provided in Section 3 of this Report.

Radwaste resulting from the use of radiation sources in medicine, science and other industries is collected and placed for interim storage at Radon SISPs in located in the relevant regions of Ukraine. More detailed information is provided in Subsection 4.1 of this Report.

The Dnipropetrovsk SISP, which provides services to an industrial regions in Ukraine where a substantial number of radiation sources were and continue to be used; operates a mobile unit equipped to safely remove DRS from BGI and E type (Fig. 9.1) shielding blocks. This unit is a facility for processing of radwaste representing disused gamma radiation sources. This will minimize the amount of such radwaste, increase the safety of its storage, and optimize its transport to the Vektor site (number of shipments will reduce tenfold).

It is further planned to use this mobile unit at the sites of other SISPs.

A centralized long-term storage facility built to house disused radiation sources (CLTSF) for more than 50 years has been built at the Vektor site in the Chernobyl exclusion zone. DRS from Radon SISPs are planned to be transferred to CLTSF. CLTSF is currently in the commissioning stage (hot tests are underway). More detailed information is provided in Subsection 4.2 of this Report.

9.3. Amounts and Classification of Radioactive Waste

9.3.1. Radioactive Waste Amounts in Ukraine

The state system for accounting for radwaste and control of its movement and location consists of two main elements: the State Register of Radwaste and the State Cadaster of Storages and Sites for Interim Radwaste Storage.

Radon Corporation, which includes the Chief Information and Analytical Center for the Radwaste State Accounting System and Regional Centers for Radwaste Accounting, is responsible for the State Register and State Cadaster.

State Agency of Ukraine on Exclusion Zone Management (SAEZ), as a state authority for radwaste management, is responsible for accounting for radwaste and storage facilities, as well as conducting state radwaste inventories.

State inventories of radwaste are taken every three years. The first state inventory was taken in 1999-2000, second in 2003, third in 2007, fourth in 2010, fifth in 2013 and sixth in 2016.
Radwaste inventories as of 1 July 2017 are presented in Tables 9.1–9.7.

More detailed information on the inventory of radwaste in Ukraine can be found in the National Report of Ukraine on Compliance with Obligations under the Joint Convention on the Safety of Spent Fuel Management and on the Safety of Radioactive Waste Management [5].

### 9.3.2. Radioactive Waste Classification in Ukraine

In compliance with Ukraine’s current regulatory documents radwaste is divided into groups (by release levels), categories (by specific activity), forms (by radwaste generators), and types (by acceptable type of disposal) [6–8].

In the current classification, two types of radioactive waste are distinguished: short-lived and long-lived. The first type of radwaste can be disposed of in surface or near-surface facilities, and the second type only in stable deep geological formations [1].

There is no direct relation between the groups, categories, forms and types of radwaste in national regulatory documents. There are neither clear and unambiguous classification criteria used by waste generators nor criteria for the separation of radioactive waste by type of acceptable disposal. Therefore, the classification of radwaste into categories (low-, intermediate- and high-level) is aimed primarily at the safety of personnel in the management of radioactive waste and does not actually take into account the acceptable type of disposal. This may lead to the need for re-sorting waste, and its additional conditioning and repackaging prior to disposal. Accordingly, this additional work will entail additional costs for disposal. The specifics of classification and disposal for Chernobyl-origin radwaste are not reflected in the current regulations either.

Taking into account new IAEA Safety Standard GSG-1 "Classification of Radioactive Waste" [9] and international experience, Ukraine has initiated a revision and improvement of its radwaste classification. This is aimed at implementing a radwaste classification system according to the waste’s final disposal option. In 2011-2013, project INSC U4.01/08-C "Improvement of the radwaste classification system in Ukraine" was implemented. Efforts are continuing to implement recommendations obtained within this project for modifying existing radwaste classifications within the national legislative and regulatory framework.

Bringing updated radwaste classifications to bear will allow for the optimization of waste disposal and for classification according to criteria for radwaste disposal in four types of facilities: surface, near-surface, intermediate-depth, and
Table 9.5. Data on Chernobyl-Origin Radioactive Waste Stored at CRME as of 1 July 2017

<table>
<thead>
<tr>
<th>Waste state</th>
<th>Waste category</th>
<th>Location</th>
<th>Weight, t</th>
<th>Volume, m³</th>
</tr>
</thead>
<tbody>
<tr>
<td>Solid radwaste</td>
<td>Low- and intermediate-level waste</td>
<td>Nova Budbaza RICS</td>
<td>29960</td>
<td>21950</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Stara Budbaza RICS</td>
<td>62550</td>
<td>40150</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Naftobaza RICS</td>
<td>180600</td>
<td>95430</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Pischane Plato RICS</td>
<td>91534</td>
<td>57288</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Yaniv Station RICS</td>
<td>15000</td>
<td>30000</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Rudy Lis RICS</td>
<td>250000</td>
<td>500000</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Prypiat RICS</td>
<td>11000</td>
<td>16000</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Kopachi RICS</td>
<td>90000</td>
<td>110000</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Chystohalivka RICS</td>
<td>1500000</td>
<td>874</td>
</tr>
<tr>
<td><strong>Total:</strong></td>
<td></td>
<td></td>
<td>956,154</td>
<td>871,692</td>
</tr>
</tbody>
</table>

Table 9.6. Data on Radioactive Waste Stored at Radon SISPs as of 1 July 2017

<table>
<thead>
<tr>
<th>Waste material</th>
<th>Location</th>
<th>Volume*, m³</th>
<th>Weight*, t</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low- and intermediate-level solid radwaste</td>
<td>Kyiv SISP</td>
<td>2105.0</td>
<td>2493.3</td>
</tr>
<tr>
<td></td>
<td>Dnipropetrovsk SISP</td>
<td>591.5</td>
<td>935.5</td>
</tr>
<tr>
<td></td>
<td>Odessa SISP</td>
<td>525.6</td>
<td>343.8</td>
</tr>
<tr>
<td></td>
<td>Lviiv SISP</td>
<td>698.2</td>
<td>730.5**</td>
</tr>
<tr>
<td></td>
<td>Kharkiv SISP</td>
<td>2122.6</td>
<td>2091.7</td>
</tr>
<tr>
<td></td>
<td>Kyiv SISP</td>
<td>480</td>
<td>-</td>
</tr>
<tr>
<td>Low- and intermediate-level liquid radwaste</td>
<td>Dnipropetrovsk SISP</td>
<td>124</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>Odessa SISP</td>
<td>183</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>Kharkiv SISP</td>
<td>2</td>
<td>-</td>
</tr>
<tr>
<td>Tubing contaminated by technologically enhanced naturally occurring sources</td>
<td>Kharkiv SISP</td>
<td>812</td>
<td>780.2</td>
</tr>
</tbody>
</table>

* Weight and volume of solid radwaste take into account shielding of DRS.
** Weight of solid radwaste takes into account material used for the layer-by-layer cementing of facilities.

Table 9.7. Data on Disused Radiation Sources Stored in Radon SISPs as of 01.07.2017

<table>
<thead>
<tr>
<th>Waste material</th>
<th>Location</th>
<th>Number</th>
<th>Activity**, Bq</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sealed DRS placed in well-type storages</td>
<td>Kyiv SISP</td>
<td>6611</td>
<td>1.39E+14</td>
</tr>
<tr>
<td></td>
<td>Dnipropetrovsk SISP</td>
<td>8391</td>
<td>1.02E+14</td>
</tr>
<tr>
<td></td>
<td>Odessa SISP</td>
<td>19312</td>
<td>5.49E+13</td>
</tr>
<tr>
<td></td>
<td>Lviiv SISP</td>
<td>8151</td>
<td>3.84E+13</td>
</tr>
<tr>
<td></td>
<td>Kharkiv SISP</td>
<td>15348</td>
<td>8.09E+13</td>
</tr>
<tr>
<td></td>
<td>Kyiv SISP</td>
<td>114053</td>
<td>1.44E+15</td>
</tr>
<tr>
<td>Sealed DRS in shielding</td>
<td>Dnipropetrovsk SISP</td>
<td>212376</td>
<td>7.07E+14</td>
</tr>
<tr>
<td></td>
<td>Odessa SISP</td>
<td>38485</td>
<td>5.72E+14</td>
</tr>
<tr>
<td></td>
<td>Lviiv SISP</td>
<td>96765</td>
<td>2.36E+14</td>
</tr>
<tr>
<td></td>
<td>Kharkiv SISP</td>
<td>93719</td>
<td>2.41E+14</td>
</tr>
<tr>
<td>Sealed high-power DRS (RITEG)</td>
<td>Odessa SISP</td>
<td>15</td>
<td>1.97E+16</td>
</tr>
</tbody>
</table>
This approach is in harmony with IAEA requirements [9] and best international practices. As was assessed within this project, implementation of the updated classifications will have a significant economic impact on radwaste disposal in Ukraine. SAEZ, in cooperation with the Ministry of Health, Ministry for Energy and Coal Industry, and SNRIU, developed a draft law on the radwaste classification system to ensure the correspondence of radwaste classes with the selected disposal options.

In the transition period until the updated classification system is introduced, the existing radwaste classification is used for operating facilities.


9.4.1. Storage/Disposal Facilities of Radon Corporation

Radioactive waste originating from the use of radiation sources in medicine, science and different industries in Ukraine’s regions is collected and placed for interim storage at six State Interregional Specialized Plants for Radioactive Waste Management (SISP) of Radon Corporation: Kyiv SISP, Kharkiv SISP, Dnipropetrovsk SISP, Odesa SISP, Lviv SISP, and Donetsk SISP.

As it is impossible to transfer materials from the Donetsk SISP to territory controlled by Ukraine, SAEZ Order No. 33 dated 24 March 2015 temporarily suspended its activities until military actions there cease, and the Ukrainian authorities’ control is restored. At the same time, the services in the Donetsk region that are beyond control of the Ukrainian authorities have been transferred to the Dnipropetrovsk SISP. Relevant changes to the institutional and administrative documents were made.

SAEZ activities related to management of DRS include:

- collection and transport of DRS to relevant facilities;
- operation of facilities for solid radwaste storage in containers;
- maintenance, inspection and monitoring of closed radwaste disposal facilities that were filled in the previous period (to 1996).

Containers with radwaste and DRS are stored in hangar-type facilities (Fig. 9.2). These buildings were constructed at SISP sites in the 1990s after a decision on SISP transfer to radwaste container storage technology.

There are also well-type facilities on SISP sites (Fig. 9.3) for the storage of disused radiation sources. These are deep stainless steel tanks with a corrugated reception tubes for lowering of capsules containing radiation sources. In accord with regulations, disused radiation sources are no longer placed into these well-type facilities.

At present, these well-type storage facilities, as well as the radwaste and disused radiation sources stored within them, are undergoing inspections. Data from these inspections will inform decisions about retrieving the DRS they contain, and in further decommissioning efforts undertaken at the facilities.

In 2016, the Swedish Regulatory Authority (SSM) assisted Ukraine with funding to begin developing a standard method for retrieving DRS from well-type storage facilities. The method will take into account the results of ongoing inspections. A pilot project for this retrieval method will be undertaken at the Kyiv SISP as soon as it is approved.
As per the National Target Ecological Program for Radioactive Waste Management [3], measures are being undertaken to reequip and convert Radon SISPs with an eye to ensuring the collection and interim container-type storage of radwaste.

The surface module-type reinforced-concrete facility for container storage of radwaste and DRS has been in use at the Dnipropetrovsk SISP since 2013. As a condition of their licenses, SISPs have carried out safety evaluations of their radioactive waste/disposal facilities at their sites. Both large storage facilities and interim container-type storage facilities were reassessed, as were closed legacy disposal facilities operated in the previous period.

New facilities for managing radwaste are under construction at SISPs, and technologies for reprocessing are likewise being introduced at some of these facilities.

9.4.2. Vektor Site

Ukraine’s "National Target Ecological Program for Radioactive Waste Management" law [3] and its Strategy for Radioactive Waste Management in Ukraine [2] govern the construction of radwaste storage and reprocessing within the exclusion zone surrounding Chernobyl and at the Vektor site. They envision construction of radwaste reprocessing facilities, as well as long-term storage for disused radiation sources. They also govern the construction of near-surface disposal facilities for short lived low and intermediate level wastes resulting from the Chernobyl disaster. It is ultimately planned to transfer nearly all of Ukraine’s radwaste to the Vektor site, including waste from Radon’s SISPs, as well as from operating nuclear power plants, and from the Chernobyl nuclear power plant and waste from the Chernobyl exclusion zone.

Facilities for Long-Term Storage of Radioactive Waste

The centralized long-term storage facility for disused radiation sources (CLTSF) is currently under construction. CLTSF (Fig. 9.4) is intended to accept, identify, sort, process, package, certify, and subsequently store disused sealed alpha, beta, gamma, and neutron sources for a period to 50 years until they are transferred for disposal.

It is currently planned to transfer DRS that are currently stored at Radon SISPs to CLTSF.

According to the revised CLTSF design, DRS are divided into five process flows:
- flow 1 – radioisotope thermoelectric generators (RTGs);
- flow 2 – units of gamma sources (BGI and E);
- flow 3 – neutron sources;
- flow 4 – other (except for BGI and E) γ sources, β sources, intensive α+γ sources;
- flow 5 – α sources, low-level α+γ sources, β sources subject to activities of classes II and III in compliance with OSPU [8].

Each DRS flow will be managed according to a separate process. DRS of flow 1 (RTGs) will likely be put directly into long-term storage. DRS of flows 2-4 will be managed in hot cells, and DRS of flow 5 will be managed shielded boxes.

In 2015, the systems and equipment for managing DRS acceptance, processing and preliminary storage were installed at the CLTSF, as were systems for radiation monitoring and ventilation. At present, hot tests (with use of individual DRS with known characteristics) are underway at CLTSF.

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The following facilities are being planned, designed, and constructed:
- storage facility for vitrified high-level waste to be returned to Ukraine after reprocessing of spent fuel from Ukrainian NPPs;
• storage facility for high-level waste;
• storage facility for long-lived intermediate-level waste.

**Disposal Facilities**

The engineered near-surface disposal facility for solid radioactive waste (ENSDF, the so-called Lot 3) is currently in operation.

ENSDF (Fig. 9.5) is designed for disposal of Chernobyl NPP conditioned radwaste. Its design capacity is 50,210 m³ of radwaste. ENSDF consists of two parallel sections, each including 11 reinforced-concrete compartments (modules). ENSDF is outfitted with a central drainage gallery, two movable frame structures with bridge cranes for filling the modules, and radiation monitoring and environmental monitoring systems.

The SNRIU provided CRME with regulatory decisions on the acceptance of packages with radwaste produced by other radwaste processing facilities (except for ChNPP) to ENSDF.

The following facilities are being designed and constructed:

- facility SRW-1 (for disposal of radwaste in reinforced-concrete containers);
- facility SRW-2 (for disposal of unpackaged and large radwaste in bulk).

**9.4.3. Radioactive Waste Disposal Site ‘Buryakivka’**

The Buryakivka RWDS has been in operation since 1987. The Buryakivka RWDS consists of 30 near-surface radwaste disposal facilities (trenches). The main engineering barrier is a compacted clay layer one meter thick, which confines radwaste from the environment. About 687,000 m³ of Chernobyl-origin radwaste with a total activity of 2.54x10¹⁵ Bq has been placed into the Buryakivka RWDS disposal facilities (trenches) since the beginning of its operation.

The Buryakivka RWDS (Fig. 9.6) is an important element in the system for management of large amounts of radwaste resulting from the Chernobyl accident. The site was in fact created as a result of emergency mitigation measures following the Chernobyl accident. Until now, operation of this RWDS has ensured disposal of large amounts of low-level radwaste resulting from activities at ChNPP site and from contaminated areas in the exclusion zone. The Buryakivka RWDS has practically exhausted its capacities. Taking into account the safety reassessment of the Buryakivka RWDS carried out with assistance of the European Commission, expansion of its capacities for disposal of low-level waste are under consideration.

**9.4.4. Geological Repository**

The strategic task of radioactive waste disposal is to isolate waste from people and the biosphere for the entire period that it remains dangerous. People and the biosphere should be protected not only against direct potential contact with radioactive waste, but also against indirect contact, such as in the case of radionuclide migration from disposal facilities.

The Law of Ukraine "On Radioactive Waste Management" [1] introduces the term "generators of radioactive waste" and establishes that long-lived radioactive waste is to be disposed of only in a solid state within stable geological formations, and by transferring it into form that is not explosive, flammable or radioactively hazardous.

There are plans under discussion to create a geological repository for final disposal of high-level and long-lived waste, including waste resulting from spent fuel reprocessing, as is called for in the Strategy for Radioactive Waste Management in Ukraine [2]. At present with support of the European Union (Project INSC U4.01/09 B),
activities are underway to develop the concept for geological disposal of radwaste in Ukraine. The advanced experience of other countries informs this discussion.

Engineering support for surveys, assessments, scientific research, and design activities for siting for a geological repository is provided by the Institute of Environmental Geochemistry and Science and Engineering Center for Radiological Field Surveys of the National Academy of Sciences of Ukraine.

9.5. System and Structure to Govern Management of Radioactive Waste and Radiation Sources (Responsible, Control and Other Authorities)

By law, Ukraine separates state control of nuclear energy, radwaste disposal and long term storage into several spheres. These spheres are established by Article 5 of Ukraine’s law "On Nuclear Energy Use and Radiation Safety" [12].

The State Agency of Ukraine on Exclusion Zone Management (SAEZ) is entrusted with managing radwaste for long-term storage and disposal. It also implements state policy for radwaste management. To perform its functions, the SAEZ controls the specialized radwaste management enterprises at Chernobyl NPP, including the decommissioning of Chernobyl’s 1-3 reactors. It also answers for Shelter transformation into an environmentally safe system. Ukraine’s Ministry of the Environment and Natural Resources coordinates the work of SAEZ.

The Ministry of Energy and the Coal Industry of Ukraine (MECI) is in charge of the establishment and implementation of state policy for fuel and energy, including nuclear energy.

The MECI controls the operators of NPPs (Energoatom) and nuclear research facilities. The MECI arranges and coordinates the safe management of spent fuel and radioactive waste from nuclear facilities until such time as radwaste is transferred to specialized radwaste management enterprises for long-term storage or disposal.

In compliance with the main principles of state policy for radwaste management, those who generate radwaste are responsible for management of waste before its transfer to specialized radwaste management enterprises. Radwaste disposal by radwaste generators is prohibited.
Waste generators in Ukraine currently include operators of nuclear facilities as follows: Energoatom oversees operating NPP; the Nuclear Research Institute of the National Academy of Sciences (Kyiv) oversees the research reactor; the State Specialized Enterprise ChNPP oversees the Chernobyl NPP. There are various other enterprises and organizations that use and produce radiation sources as well.

The Centralized Radioactive Waste Management Enterprise (CRME) is the national organization that manages radwaste at the stage of long-term storage and disposal. Radwaste generated at enterprises that use radiation sources, as well as at research reactors, is collected and temporarily stored by Radon SISPs. CRME is the main enterprise of the Radon Corporation.

The State Specialized Enterprise for Capital Construction Management of the Exclusion Zone (CCMEZ) is responsible for designing and building radwaste disposal facilities at the Vektor site. It oversees all construction in the exclusion zone, except for that occurring at the Chernobyl NPP proper.

The State Nuclear Regulatory Inspectorate of Ukraine (SNRIU) is a central executive body that develops and implements state policy on the safe use of nuclear energy. It is overseen by the Ukraine’s Cabinet of Ministers.


Outstanding issues of radwaste and radiation source management are set fourth by the following factors:

- Cabinet of Ministers approved the Energy Strategy of Ukraine until 2035 "Safety, Energy Efficiency, Competitiveness" [10];
- Concept of the National Environmental Program for Radioactive Waste and Spent Fuel Management is under development;
  - implementation of Directive 2011/70/Euratom is ongoing [11];
  - new classification of radwaste that takes into account the disposal method is being introduced (through amendment to legislation);
  - development of the concept for radwaste geological disposal in Ukraine is currently underway.


Analysis revealed the following issues and drawbacks in current programs for radwaste and spent fuel management:

- activities related to radioactive waste and spent fuel management need to be updated;
- systematic approach is lacking, in particular, current regulations do not take into account all sources of radwaste and spent fuel in Ukraine;
- prospective long-term period has not been considered, but is required for strategic planning;
- there is no interrelation between management of spent fuel and radioactive waste, which is due, in particular, which owes to its eventual geological disposal;
- clear options for planned activities are not identified, which does not allow for decisions on near/short-term storage periods;
- there are no required interrelations between national and industrial programs.

Fig. 9.7. Administrative structure of radwaste management in Ukraine
In this regard, there is an objective need to develop a national environmental program for radioactive waste and spent fuel. Efforts are underway to create the concept for such a program that would take into account the above-mentioned shortcomings and issues.

9.6.2. Energy Strategy of Ukraine until 2035

In August of 2017, the Cabinet of Ministers approved the "Safety, Energy Efficiency, Competitiveness" until 2035 [10].

The Strategy envisions, in particular, the completion of storage facilities for spent nuclear fuel and high-level waste resulting from its reprocessing by 2035, as well as the completion of studies on the identification of sites in Ukraine suitable for the construction of facilities for the disposal of long-lived radwaste in deep geological formations.


This Directive [11] obliges European Union countries to maintain strategies and financial resources for managing spent fuel and radioactive waste. This approach is recognized by the international community and allows for problematic issues for future generation to be minimized.

The Directive [11] obliges the member states to establish and maintain a national regulatory framework for spent fuel and radioactive waste management. To this end, it is necessary to develop and implement appropriate national mechanisms to ensure a high level of safety in spent fuel and radwaste management in order to protect workers and the public from the dangers of ionizing radiation. The document envisions providing necessary information and public participation on the management of spent fuel and radioactive waste.

9.6.4. Implementation of New Radioactive Waste Classification

In the framework of radwaste management optimization in Ukraine and in view of the recommendations provided in IAEA documents, a new classification of radwaste has been developed and is being implemented in Ukraine (by amendment of legislation), which focuses on the waste disposal method.

According to the new classification, radwaste is divided into four classes:
- very low-level waste (VLLW);
- low-level waste (LLW);
- intermediate-level waste (ILW);
- high-level waste (HLW).

Introduction of the new classification will significantly reduce the cost of radioactive waste disposal, and stipulate unconditional compliance with safety objectives. Implementation of the new classification involves improvement of the methods for waste sorting and characterization at generation sites. It likewise introduces changes to existing legislative documents.

The introduction of this classification will allow for the proper interconnection between the various stages of radioactive waste management from waste generation to transfer for disposal.

9.7. Responsibilities and Obligations of Enterprises Generating Radioactive Waste

The law "On Radioactive Waste Management" [1] introduces the term "generators of radioactive waste" – which means legal entities or individuals whose activities lead to the generation of radioactive waste.

One of the main principles of state policy for radioactive waste management is that the generators of radwaste are responsible for waste safety during its management prior transfer to specialized enterprises for radwaste management.

Likewise, the law "On Radioactive Waste Management" [1] prohibits radwaste disposal by legal entities and individuals whose activities result in radwaste generation and which use radioactive materials and employ nuclear facilities.

Radwaste generators transfer waste to specialized enterprises for radwaste management in accordance with approved regulations, rules and standards.
The safe management of spent fuel is one of the most important factors in sustainable development of nuclear energy in the state according to the Energy Strategy of Ukraine.

### 10.1. Spent fuel management policy

#### 10.1.1. The principles of state policy

The principles of state policy for spent fuel management are set forth in Article 5 of the Law of Ukraine "On Nuclear Energy Use and Radiation Safety".

The Energy Strategy of Ukraine establishes the so-called deferred decision for spent fuel of Ukrainian NPPs, involving long-term (50 years and more) storage of spent fuel and subsequent definition and approval of the final decision on fuel reprocessing or disposal. The design procedure for spent fuel management (transport of spent fuel for reprocessing to the Russian Federation) and the procedure that envisages storage of spent fuel with subsequent approval of the final decision on fuel reprocessing or disposal are both implemented for Ukrainian NPPs.

#### 10.1.2. Strategic areas for spent fuel management at Ukrainian NPPs include:

**For VVER reactors:**
- temporary storage of spent fuel in on-site spent fuel pools;
- transfer of Ukrainian spent fuel (except ZNPP) for long-term storage and reprocessing;
- operation of on-site dry spent fuel storage facility at Zaporizhzhya NPP;
- study on diversification of spent fuel supply and reprocessing services;
- construction, commissioning and operation of the centralized spent fuel storage facility (CSFSF) for spent fuel of RNPP, KhNPP and SUNPP power units;
- activities on developing the Concept of the state spent fuel management program, including spent fuel of Ukrainian NPPs taking into account defining possible areas of nuclear fuel cycle development for a long-term perspective and determining the final stage of nuclear fuel cycle, selection of a method for spent fuel safe management after the period of its long-term storage.

**For Chornobyl NPP RBMK reactors:**
- completion of construction, commissioning and safe operation of ISF-2 for storage of all amounts of ChNPP spent fuel;
- measures to upgrade and improve safety of the existing wet interim spent fuel storage facility, ISF-1.

The following efforts are planned:
- transport of spent fuel from Rivne, Khmelnitsky and South Ukraine NPPs to the Russian Federation for temporary storage and reprocessing until the CSFSF in Ukraine is commissioned;
- safe operation of the dry spent fuel storage facility at Zaporizhzhya NPP;
- construction and safe operation of CSFSF for spent fuel of VVER-440 and VVER-1000 of operating NPPs and spent fuel of new nuclear units;
- solving the issue of long-term storage and reprocessing of spent fuel produced by Westinghouse Electric Sweden AB;
- development of regulatory and procedural issues on return of waste resulting from reprocessing of spent fuel from Ukrainian NPPs and their approval by the Russian Federation;
- development of a national program for spent fuel management to identify the objectives, strategies and scenarios for spent fuel management and define the key provisions of scientific and technical policy and implementation of the main stages of spent fuel management.

### 10.2. Spent fuel management practices

Spent fuel is managed in Ukraine at facilities listed in Annex 1. The inventory of spent fuel is presented in Annex 2.

#### 10.2.1. Spent fuel management at operating NPPs

The implementation of the second-generation fuel started at RNPP-2 in 2010 and at RNPP-1 in
2012. The design of cores with reduced neutron leakage has been developed.

At Zaporizhzhya NPP, spent fuel storage racks in spent fuel pools were compacted to increase capacity of the ZNPP spent fuel pools.

According to the Comprehensive (Integrated) Safety Improvement Program for Ukrainian NPPs regarding the management of nuclear fuel, including spent fuel, the operating NPP units are equipped with mast sipping systems to monitor the integrity of fuel claddings. As of 01 July 2017, mast sipping systems have been introduced into commercial operation at RNPP units 1, 2, 3, 4, KhNPP units 1, 2, SUNPP unit 1 and ZNPP units 1, 2.

Trial operation of nuclear fuel produced by Westinghouse Electric Sweden AB is underway at SUNPP units 2, 3 and ZNPP unit 5. By the end of 2017, trial operation is to be extended to ZNPP units 1, 3, 4. Currently, this spent fuel is stored in on-site spent fuel pools of ZNPP 2, 3.

Energoatom holds negotiations with the French company AREVA to solve the issue of Westinghouse Electric Sweden AB spent fuel management and diversify suppliers of services related to transport and reprocessing of NPP spent fuel.

10.2.2. Dry spent fuel storage facility (DSFSF)

Starting from 2005, ZNPP spent fuel is unloaded for storage to the dry spent fuel storage facility at ZNPP for not less than 50 years. As of 1 April 2017, there are 139 containers with 3330 SFAs on the DSFSF site. The design capacity of DSFSF is 380 containers, each for 24 SFAs.

Since Zaporizhzhya DSFSF Stage I, which was put into commercial operation in 2004, was filled in accordance with the design (100 containers), licensing of DSFSF Stage II was completed and the SNRIU issued an individual permit for its commissioning. Starting from January, DSFSF Stage II with design capacity of 280 containers is under operation.

A remote temperature control system (RTCS) was put into commercial operation for Stage I containers to improve storage safety. RTCS for Stage II containers is installed in accordance with the design.

The DSFSF design was modified to consider operating experience and implement components produced in Ukraine. The safety of design modifications was justified in a series of technical decisions agreed upon by the SNRIU. The ventilated concrete containers and multi-place sealed baskets for spent fuel storage are currently manufactured at national enterprises using Ukrainian materials and technologies. The results of operation indicate that DSFSF complies with the safety criteria presented in SAR.

After the Fukushima accident in Japan, within the targeted safety reassessment of NPPs using stress tests according to the European Council and WENRA proposal, extraordinary target safety reassessment (stress tests) of Zaporizhzhya DSFSF was carried out.

During 2015-2016, Energoatom performed a regular safety reassessment of DSFSF, whose results were presented in the periodic safety review report. In August 2016, this report was approved by the SNRIU based on the state nuclear and radiation safety review. The next reassessment will be performed in 2025.

10.2.3. Centralized spent fuel storage facility (CSFSF)

The Law of Ukraine "On Spent Fuel Management for Siting, Design and Construction of the Centralized Spent Fuel Storage Facility for Ukrainian NPPs with VVER Reactors" establishes a legislative framework for the decision to construct the CSFSF and defines the territory of its location in the Chornobyl exclusion zone.

Currently, the CSFSF construction is completed. The project was approved by all interested bodies, positive conclusions of the Comprehensive State Review and Environmental Review on the possibility of its implementation were obtained. Due to this, the Cabinet of Ministers of Ukraine approved the CSFSF construction project.

The Energoatom operator continues efforts on upgrading spent fuel management systems at Ukrainian NPPs to modify spent fuel management procedures, to include containers envisaged by the CSFSF design into transport flow charts for spent fuel management.

Further plans include:
- hold a tender in 2017 to select a contractor for construction activities at CSFSF,
- commission Stage I in 2019 and supply four containers with spent fuel by the end of 2019,
• supply 90 containers from 2019 to 2022 that will allow refusing from spent fuel transport from Ukraine.

Equipment for spent fuel management is manufactured and supplied in accordance with the contract with Holtec International and scheduled for 2017-2018, with a view to timely CSFSF commissioning.

Energoatom carried out significant informational and explanatory work in order to inform the public of Ukraine on safety issues during the CSFSF construction and operation, in particular:
• a statement was published on the intentions and environmental consequences of CSFSF construction, documents on CSFSF were presented in mass media, information on the selected spent fuel storage technology, construction and operation of the storage facility, information and analytical review of the feasibility study for CSFSF construction investment, etc. was posted on the Energoatom web-site;
• public meetings (briefings, round tables with representatives of the public and mass media), public discussion in Ivankiv (with the participation of the public of Polissya region) and Slavutych of the Kyiv region were held; informational support of public hearings in Slavutych conducted with the participation of the public of Slavutych, Ivankiv and Polissya regions was ensured, an excursion was arranged for representatives of the public of the abovementioned regions to ZNPP where a similar spent fuel storage facility is operated to cover CS-FSF design safety issues;
• results of events, issues of the public were processed, responses to them were developed and posted on Energoatom’s website.

10.2.4. Spent fuel management at Chornobyl NPP

At present, the ChNPP in accordance with the conditions of license EO No. 000040 is at the decommissioning stage, namely at the stage of final closure and temporary storage. In order to reduce risks during decommissioning and transformation of the Shelter into an environmentally safe system, as well as to reduce the costs to maintain ChNPP-1, 2, 3 in a safe condition, from 2006 to 2016 spent fuel was transferred from the units into ISF-1 (including damaged spent fuel).

Activities and operations on damaged spent fuel unloading from units No. 1, 2 and its transfer to ISF-1 for safe placement and storage were carried out by Chornobyl NPP in 2016.

ISF-1 located on the Chornobyl NPP site and intended for interim storage of RBMK-1000 spent fuel, has been in operation since 1986. ISF-1 is a wet storage facility.

As of 31 March 2017, 21,284 SFAs are stored in the ISF-1 spent fuel pools.

Safety justification for SFA storage in ISF-1 SFP is presented in the “Safety Analysis Report for Spent Fuel Storage Facility (ISF-1)”. To load compartments 1-5 of ISF-1 SFP, Keff neutron multiplication factor is calculated taking into account fuel burnup.

Efforts are continued in the exclusion zone on construction of ISF-2 intended for preparation for storage and storage of ChNPP RBMK spent fuel. A significant scope of activities has been performed on the ISF-2 construction project:
• majority of equipment, systems and components was supplied to ISF-2 site, other equipment is under supply;
• factory of the general contractor for the project (U.S. Holtec International Company) continues to manufacture double-walled shielded casks;
• general contractor and subcontractors perform construction and mounting activities in accordance with the schedule;
• individual acceptance testing is performed for the equipment whose mounting and adjustment is completed.

10.2.5. Spent fuel management for research reactors

Spent fuel management on the site of the Nuclear Research Institute (NRI) of the National Academy of Sciences is described in Subsection B.2.3 NRU-2011. In 2009-2010, spent fuel from the NRI VVR-M research nuclear reactor was transported to the Russian Federation for reprocessing. As of 01 July 2017, NRI has no spent fuel on its site.

10.3. Allocation of responsibilities for bodies involved in different stages of spent fuel management

According to the principles of state policy in nuclear energy use and radiation protection established in Article 5 of the Law of Ukraine "On Nuclear Energy Use and Radiation Safety", Ukraine separates state control over nuclear energy use and state control.

10.4. Spent fuel management safety

10.4.1. General requirements

The Ukrainian legislation provides for compulsory licensing of operating organizations during construction and commissioning, operation and decommissioning of spent fuel management facilities.

General safety requirements at all stages of spent fuel management are established in the Laws of Ukraine "On Nuclear Energy Use and Radiation Safety" and "On Authorizing Activity in Nuclear Energy Use".

Requirements and rules for spent fuel management are established by regulations that cover spent fuel management on NPP sites, research reactors and interim spent fuel storage facilities, specifically:
• General Safety Provisions for Nuclear Power Plants;
• Nuclear Safety Rules for Nuclear Power Plants and Pressurized Water Reactors;
• General Safety Provisions for Design, Construction and Operation of Research Reactors;
• Nuclear Safety Rules for Research Reactors;
• Safety Rules for Nuclear Fuel Storage and Transport at Nuclear Facilities;
• Basic Safety Provisions for Dry Interim Spent Fuel Storage Facilities;
• Requirements for Modifications of Nuclear Facilities and Procedure for Their Safety Assessment;
• Requirements for Systems for Emergency Cooling of Nuclear Fuel and Heat Removal to Ultimate Heat Sink.

10.4.2. Safety of existing facilities

The safety of existing spent fuel management facilities is ensured by current technical regulations, design decisions, technical specifications, operating and maintenance procedures, technical decisions and quality assurance procedures.

All spent fuel management facilities are designed to be equipped with surveillance and monitoring systems.

The automated radiation monitoring system Koltso and a network of observation wells to monitor underground and ground waters are in operation on the territories around the Zaporizhzhya DSFSF. Radiation parameters on the site and adjacent territory around the storage facility are monitored with the periodicity established in radiation monitoring procedures. The results are analyzed and compared with reference levels.

10.4.3. Requirements for siting of proposed facilities

• evaluate all relevant site-related factors likely to affect the safety of such a facility during its operating lifetime;
• evaluate the likely safety impact of such a facility on individuals, society and the environment;
• inform the public on the safety of such facilities;
• conduct consultations with neighboring countries.

10.4.4. Design and construction of facilities

• ensure limited possible radiological impact of spent fuel management facilities;
• use conceptual plans and technical provisions for the decommissioning of a spent fuel management facilities;
• confirm technologies used in the design by available experience, testing or analysis.

10.4.5. Assessment of Safety of Facilities

• conduct safety assessment and environmental assessment;
• perform safety reassessment in construction and commissioning.
10.4.6. Operation of facilities:

- license operation of facilities
- define and revise operational limits and conditions
- operating procedures
- engineering and technical support of operation
- notify the regulatory authority on incidents important to safety
- analyze information on facility operation
- plan decommissioning of facilities

10.5. Disposal of spent fuel

The Energy Strategy of Ukraine established the so-called deferred decision for spent fuel management, which includes long-term storage (50 years and more) and subsequent definition and approval of the final decision on spent fuel reprocessing or disposal.

10.6. Transboundary movement

Transboundary movement of spent fuel is performed in accordance with the intergovernmental agreements on the transport of nuclear materials:

- Russia – Ukraine since 1996;
- Russia – Bulgaria – Ukraine since 2006;
- Ukraine – Russia – Hungary since 2013.

Transboundary movement of spent fuel from Kozloduy NPP and Paks NPP through the territory of Ukraine (as a transit state) is performed by railway transport according to conditions of the "Agreement on International Railway Freight Communication" dated 1951, which is obligatory for railways, consignors and consignees of Ukraine, Bulgaria, Russian Federation.
New sarcophagus over ChNPP unit 4

11. PRESENT AND FUTURE OF THE CHERNOBYL ZONE

11.1 Exclusion zone

The territory that suffered from intensive contamination by long-lived radionuclides after the accident at Chernobyl NPP (Fig. 11.1 - 11.3) is currently prohibited for free access and has the status of an exclusion zone. The boundaries of the exclusion zone were established in 1986 after evacuation of the population from the 30-km zone around the nuclear power plant.

The legal regime of radioactively contaminated zones was established by the Law of Ukraine No. 791a-12 dated 27 February 1991 "On the Legal Regime of the Territories Affected by Radioactive Contamination after the Chernobyl Accident" [1]. This law underwent numerous changes and revisions, the latest of 14 July 2016. According to this law, Ukraine was recognized as an ecological disaster area.

The Chernobyl Zone includes northern part of the Ivankiv district of the Kyiv oblast, where the nuclear power plant is located, the cities of Chernobyl and Pripyat, the eastern part of Polissia district of the Kyiv oblast (including the former district center, Poliske village, and Vilcha village), and a part of the Zhytomyr oblast to the border with Belarus.

The abovementioned law provided for the regulation of issues related to the division of the territory into the respective zones, the mode of their use and protection, living and working conditions for the population, economic, scientific, technical and other activities in these zones.

By taking into account the landscape and geochemical features of soils, the radionuclide accumulation in the environment, possible negative impact on the health of the population, requirements for radiation protection of the public and other special measures, the territory that suffered from radioactive contamination after the Chernobyl accident was divided into three zones classified according to the degree of contamination:

1) The exclusion zone is the territory from which the population was evacuated in 1986.

2) The zone of unconditional (mandatory) resettlement is the territory that suffered from intensive contamination by long-lived radionuclides with a density of soil contamination by cesium isotopes exceeding pre-emergency level from 15.0 Ci/km² and above, or by strontium from 3.0 Ci/km² and above, or by plutonium from 0.1 Ci/km² and above, where calculated effective equivalent exposure dose taking into account factors of radionuclide migration in plants and other factors may exceed 5.0 mSv (0.5 rem) per year beyond the dose that a human received in the pre-emergency period;

3) Zone of guaranteed voluntary resettlement is the territory with a density of soil contamination by cesium isotopes exceeding pre-emergency level from 5.0 to 15.0 Ci/km², or strontium from 0.15 to 3.0 Ci/km², or plutonium from 0.01 to 0.1 Ci/km², where calculated effective equivalent exposure dose taking into account factors of radionuclide migration in plants and other factors may exceed 1.0 mSv (0.1 rem) per year beyond the dose that a human received in the pre-emergency period.

Zone boundaries are established and reviewed by the Cabinet of Ministers of Ukraine based on expert conclusions of the National Commission for Radiation Protection of the Population of Ukraine, National Academy of Sciences of Ukraine, Ministry of Health of Ukraine, Ministry of Agrarian Policy and Food of Ukraine, Ministry of Ecology and Natural Resources of Ukraine.

Fig. 11.1. Map of Chernobyl exclusion zone contamination with cesium-137, Ci/km² (as of 1998). Compiled by M. Nahorskyi, V. Tiepikin and others http://Chernobyl.in.ua/map.html
Radioactively contaminated territories need radiation protection measures and other special interventions aimed at limiting additional exposure caused by the Chernobyl accident and ensuring normal economic activities.

According to official data, about 3.3 million people, where every third was a child, suffered from the Chernobyl accident in Ukraine. Inhabitants of 80 settled areas were evacuated from the zone contaminated by radiation (about 100,000 people). 92 settled areas were included into the zone of unconditional resettlement. The territory, from which the population was evacuated, refers to the exclusion zone and is about 2.598 km². The exclusion zone perimeter is 196 km². Together with the zone of unconditional resettlement the total perimeter is 377 km², which is about 8.8% of the territory of Ukraine.

A variety of diverse problems, namely social, economic, technical, environmental, radiation, medical, biological, arose after the Chernobyl accident. Their amount does not decrease with time, but increase with changes in areas and tasks that adjust to life needs.

One of the most important components to solve these problems was to establish legal, legislative, organizational and scientific foundations for the protection of victims.

The urgency of solving these problems caused by the Chernobyl accident was described in "Concept of Population Living on Territories of Ukraine with Increased Levels of Radioactive Contamination after the Chernobyl Accident", Laws of Ukraine "On Legal Regime of the Territories Affected by Radioactive Contamination after the Chernobyl Accident" and "On Status and Social Protection of People who Suffered from the Chernobyl Accident".

These and other documents became the foundation for the national "Chernobyl" legislation and they certify that in Ukraine there is regulatory and legal framework for ensuring the constitutional human right to a decent life and health.

Protection of the population against consequences of the Chernobyl accident in Ukraine today is based on three areas: radiation, social, and medical.

Many problems still remain in the exclusion zone and their solution requires scientific justification, field testing, laboratory and model research, new technical decisions, robust work on accumulation, analysis and synthesis of monitoring information from various aspects of radioecology to determine patterns and trends in the development of biosphere objects under radiation loads.

The most relevant issues cover management of radioactive waste, including those in the Shelter, decommissioning of ChNPP units, construction of radioactive waste and spent nuclear fuel storage facilities, siting for the construction of geological
repository for high-level and long-lived radioactive waste with justification of its structural peculiarities and safety measures during operation. There is a need to perform new radiological surveillance of this territory to specify the radiological situation within the exclusion zone and its internal zoning. It is necessary to consider that a significant part of the exclusion zone, where plutonium release is fixed, will not be suitable for living and economic activity during the next millennium.

11.2. Main facilities designed for radioactive waste and spent nuclear fuel management in the exclusion zone

There are a number of specialized facilities, technical buildings and production departments in the exclusion zone to deal with the abovementioned problems. Brief information on them is provided below.

The main facilities of the Chernobyl NPP industrial site (Fig. 11.8) include:
- Chernobyl NPP units 1, 2 and 3;
- Shelter and New Safe Confinement (NSC);
- Liquid radioactive waste treatment plant (LRTP);
- Industrial complex for solid radioactive waste management at ChNPP (ICSRM);
- Interim spent nuclear fuel wet storage facility (ISF-1);
- Interim spent nuclear fuel dry storage facility (ISF-2).

At the end of November 2016, the New Safe Confinement was moved above ChNPP unit 4 damaged by the accident and above the Shelter. This is the largest moving land structure ever built (165 m long, 110 m high, 36.2 thousand
The NSC was moved by a special system that consisted of 224 hydraulic jacks which facilitated moving the NSC by increments of 60 cm per cycle. After installing the NSC in its intended position, gamma radiation in the near zone had been reduced by an average of ten times.

A liquid radioactive waste treatment plant is planned to be commissioned in December 2017. According to information of ChNPP, the facility will be used for processing of liquid radioactive waste accumulated during operation and radioactive waste generated during decommissioning of the ChNPP, as well as operational liquid radioactive waste from within the Shelter. Currently, liquid radioactive waste (more than 20,000 m³) is stored in existing storage facilities at the ChNPP’s industrial site. The plant is intended for liquid radioactive waste processing during 20 years. Its minimum design capacity is 2,500 m³ of unprocessed liquid radioactive waste per year. After processing at this plant, waste will be packaged and transferred for disposal to the Vektor Complex.

Construction of the complex was started in 2001; the cost of ICSRM is €27 million, €43.5 million of which were allocated by the European Commission and €3.5 million came from Ukraine. In April 2009, the Nukem Technologies GmbH (Germany), which constructed ICSRM, transferred the facility for commercial operation. The industrial complex is intended for accepting, processing and/or disposal of solid radioactive waste accumulated during the operation and decommissioning of the ChNPP, and operational radioactive waste of the Shelter.

Interim spent nuclear fuel wet storage facility (ISF-1) of the ChNPP was commissioned in 1986. The storage facility is intended for the acceptance and interim storage of spent fuel assemblies received from reactor compartments of power units after preliminary storage. More than 17 thousand fuel assemblies are stored in four out of five compartments of ISF-1 spent fuel pool. That is about 99% of the design capacity of the storage facility. The fifth compartment of ISF-1 compartment (with a capacity of 4,300 spent fuel assemblies) is a redundant one. ISF-1 lifetime will expire at the end of 2025. Therefore, a new interim storage facility of a dry type (ISF-2) is under construction on the ChNPP site for long-term storage of all spent nuclear fuel. After ISF-2 is commissioned, nuclear fuel from ISF-1 will be transferred to ISF-2. The design of the existing storage facility does not envisage the procedure of spent nuclear fuel retrieval from ISF-1. The main objective of the reconstruction of ISF-1 handling system is to ensure safe handling operations on spent nuclear fuel retrieval from ISF-1, its loading into transport container and transport to ISF-2. The activities are financed from Ukraine’s state budget.

The new dry type storage facility for spent nuclear fuel (ISF-2) at the ChNPP is to be
commissioned in the third quarter of 2018. At the end of 2017, hot testing with real nuclear fuel will be held in the storage facility. ISF-2 is intended for acceptance of spent fuel assemblies and spent additional absorbers accumulated at ChNPP, their preparation for storage and storage itself. According to plans, the new storage facility will ensure acceptance for storage, preparation for storage and storage of spent nuclear fuel for 100 years.

### 11.2.1. Vektor Site

The facility was constructed to minimize the threat to the environment related to the territories radioactively contaminated after the accident at Chernobyl NPP: Stage I – disposal of short-lived low- and intermediate-level radioactive waste generated after the Chernobyl accident; Stage II – processing of long-lived low- and intermediate-level radioactive waste, long-term storage of long-lived and high-level radioactive waste and temporary storage of spent radiation sources.

Currently, the Vektor Site includes the following facilities:
- Engineered near-surface disposal facility for solid radioactive waste is designed for 55,000 m³ of radioactive waste and is intended for the disposal of low- and intermediate-level short-lived radioactive waste transferred from the solid radioactive waste treatment plant (SRTP) and cemented liquid radioactive waste from liquid radioactive waste treatment plant (LRTP) located at ChNPP site. The disposal facility was commissioned in 2008. The construction of the disposal facility was funded by the European Commission.
- Centralized long-term storage facility for radiation sources (CLTSF) was constructed within technical assistance from the Department of Energy and Climate Change of Great Britain and the European Commission. CLTSF is designed for the acceptance, identification, sorting, processing, certification, conditioning and further storage of disused sealed radiation sources. The storage facility is constructed for the storage of 500,000 radiation sources with the total activity up to 1 million Ci during 50 years.
- Near-surface radioactive waste disposal facility (SRW-1) is intended for 9,800 m³ of radioactive waste (95% completed).
- Near-surface radioactive waste disposal facility (SRW-2) is intended for 9,400 m³ of radioactive waste (85-90% completed).
- Building for container preparation to disposal, changing rooms with laboratory, vehicle wash, infrastructure.

Efforts are underway on the design of facilities within Vektor Stage II. The design of near-surface storage facility for high-level vitrified radioactive waste returned from the Russian Federation after reprocessing of spent nuclear fuel from Ukrainian NPPs is under review. The near-surface storage
facility for long-lived low- and intermediate-level radioactive waste and near-surface storage facility for high-level radioactive waste are in the design stage.

11.2.2. Radioactive waste disposal facilities (RWDS): RWDS Buryakivka, RWDS Pidlisny, ChNPP Stage III

RWDS Pidlisny and ChNPP Stage III were created during the first years of management of the ChNPP accident. They contain the most hazardous high-level and long-lived emergency radioactive waste that further shall be retrieved from these facilities and re-disposed in the geological repository.

11.2.3. Radioactive waste interim confinement sites (RICS) in the form of trenches and pits with radioactive waste with the total area of about 10 ha

Nine RICS are located in the exclusion zone: Yaniv Station, Naftobaza, Pischane Plato, Rudyy Lis, Stara Budbaza, Nova Budbaza, Prypiat, Kopachi and Chystohalivka, where activities on survey, service and maintenance of trenches and pits in a safe state are conducted.

11.3. Planned facilities

The Law of Ukraine "On Management of Spent Nuclear Fuel for Siting, Design and Construction of the Centralized Storage Facility for Spent Nuclear Fuel from Ukrainian VVER Nuclear Power Plants" of 09 November 2012 established the legal decision on the construction of such a storage facility in the exclusion zone. The objective of building the CSFSF is to store spent nuclear fuel of three Ukrainian NPPs (Rivne, Khmelnitsky and South-Ukraine).

On 12 October 2016, SNRIU Board approved the conclusion of the state review of nuclear and radiation safety of the Preliminary Safety Analysis Report on the CSFSF.

Active preparation to the facility construction is underway. The CSFSF will be constructed to reduce energy dependence on the Russian Federation. It is necessary to state that annually Ukraine spends $150-200 million to transport nuclear fuel to the Russian Federation for storage and processing.

11.4. Prospects for exclusion zone development

The Decree of the President of Ukraine of 13 April 2016 "On Additional Measures for Transformation of the Shelter into an Environmentally Safe System Resulting from Chernobyl Disaster" covered the most important scientific and practical tasks on the solution of Chernobyl problems. This list also includes those issues that have not been solved during 30 years after the accident at Chernobyl NPP.

The priority tasks include the revision and approval of the new Strategy for Overcoming Chernobyl Accident Consequences and Remediation of the Radioactively Contaminated Territories:

- resolve issues of radiation remediation of radioactively contaminated territories;
- implement measures on the improvement of radiological situation, environmental and social development of radioactively contaminated territories and ensure state support of social activities of relevant territorial communities;
- improve quality of radiation monitoring and radioecological monitoring of radioactively contaminated territories;
- conduct scientific research in the nuclear and radiation safety area, impact of radiation on human and the environment;
- create conditions for alternative energy sources in the exclusion zone and zone of unconditional (mandatory) resettlement and involve investments to implement energy efficiency projects at facilities located in these areas;
- strengthen independence of Ukraine in the sphere of management of national nuclear power plants and high-level radioactive waste.

The Decree of the President of Ukraine also offers to revise and submit some amendments to Ukrainian regulations under the consideration of the Verkhovna Rada of Ukraine:

- on keeping updated the National Targeted Program for ChNPP Decommissioning and Transformation of the Shelter into an Environmentally Safe System, in particular with regard to tasks, measures and financing of the Program;
- improve classification system for radioactive waste for its disposal and acceptance criteria for disposal in the relevant type disposal facilities;
• define boundaries of special industrial area in the exclusion zone that will always be unsuitable for living.

The following issues shall also be immediately solved:

• measures to improve functioning of the radioactive waste management system considering the best international practice;
• solve problematic issues related to the completion of construction of Vektor Stage I, construction of the centralized storage facility for spent nuclear fuel of national nuclear power plants and storage for long-term storage of vitrified high-level radioactive waste after processing of spent nuclear fuel;
• implement measures on the development of the national system for training and professional development of experts on nuclear energy, nuclear and radiation safety, radioactive waste management;
• involve interested international organizations to solve issue on the creation of international research center as an open international site for research on radiation safety issues, radiation impact on human and environment;
• gain relevant knowledge.

On 12 October 2016, during the joint meeting of the Presidium of the National Academy of Sciences of Ukraine and the State Agency of Ukraine on Exclusion Zone Management, the exclusion zone was discussed in detail. It is planned to transform the exclusion zone into a modern multipurpose field for national and foreign scientists. In the nearest future, the Agency plans to create good conditions for this scientific research.

The government considers the possibility to implement projects on the generation of solar energy in the exclusion zone, which will attract new investments and strengthen energy safety of the state. The development of alternative energy, including solar energy, is one area in which to use the exclusion zone, since there are high-power electric networks and relevant infrastructure, which was earlier used for the needs of Chernobyl NPP.

On 23 November 2016, the Cabinet of Ministers of Ukraine approved Resolution No. 912 "Certain Issues of Stimulating the Development of the Exclusion Zone and Zone of Unconditional (Mandatory) Resettlement", which defines the amount of rental investment for the use of state property located in the exclusion zone and which shall stimulate attraction of investments to alternative energy projects. According to the presentation, it is planned to build solar power plants in within a 10 km zone to the south from the ChNPP. Areas located near roads and power lines are prepared for construction. The solar radiation in the territory is 1,300 kWh/km². It has been stated that it is possible to connect 200 MW of generating capacity to the existing infrastructure. If investments are realized, capacity can be increased to 1200 MW. According to the data, the Ministry of Ecology and Natural Resources of Ukraine has already received 44 applications from potential investors for the construction of solar power plants in the Chernobyl Zone.
12. International cooperation in the field of nuclear energy

12.1. Key tasks of Ukraine in the framework of international cooperation

Among important tasks for Ukraine in the field of international cooperation are: affording nuclear and radiation safety; sharing of experience; strengthening of energy security by diversifying supplies of nuclear fuel and technologies; increasing nuclear energy generating capacities. It is important to mention, that Ukraine has unique experience and developed decisions in the area of nuclear industry, especially in the field of overcoming aftermaths of nuclear incidents and removing post-breakdown objects of service. These lessons can be especially useful for international partners.

Ukraine is a member of the International Atomic Energy Agency (IAEA) and applies best practices in the field of nuclear and radiation safety supported by the agency at full extent. In 2015 Ukraine became a member of Western European Nuclear Regulators’ Association (WENRA) and this helps in introducing high standards for nuclear and radiation safety. In 1994 Ukraine accedes to a Treaty on the Non-Proliferation of Nuclear Weapons having dismantled nuclear weapons by 1996. Ukraine is collaborating with the European Atomic Energy Community (EAEC or Euratom) within EU-Ukraine Association Agreement that came into force on September 1, 2017.

Beside, Ukraine is a member of other international organizations with whom has a close bilateral collaboration: WANO NPP, WNA, FORATOM, IFNEC, EUR. This gives better opportunities for introducing new technologies and best practices in Ukrainian nuclear industry, improve its investment attractiveness, strengthen nuclear and radiation safety.


12.2. International collaboration for strengthening nuclear and radiation safety

For the purpose of NPP units’ security level enhancement according to new standards of IAEA and EU, Ukraine put in force the Complex Program for Enhancing Safety of NPP units’ on December 7, 2010. Security arrangements defined by the program were developed by Ukraine together with international partners (under the trilateral EU, IAEA and Ukraine project "Evacuation of Ukrainian NPPs’ security") considering lessons learnt after the incident at Fukushima NPP. Initially, the program’s implementation was planed by 2017, but in 2015 the decision was taken to postpone in till 2020. According to decree of the Cabinet of Ministers "About Approving the Complex Program for Enhancing Safety of NPP units" necessary funding’s were estimated at the rate of 20,101 bln UAH. Partly this amount will be covered by SE Energoatom with its own means and the rest part with loan provided by EBRD and Euratom (600 mln euro). In the beginning of 2017, 688 steps were implemented (54 % of all 1,275 planned).

According to the article 342 of the EU-Ukraine Association Agreement, Ukraine closely collaborates with EU and European Atomic Energy Community (and its member-states). According to the order of Cabinet of Ministers № 110-p on

1 http://zakon5.rada.gov.ua/laws/show/1270-2011-%D0%8F
2 http://mpe.kmu.gov.ua/minugol/control/uk/publish/article?art_id=245209780&cat_id=245070653
3 https://www.slideshare.net/energoatom/ss-73581561
12.3. International collaboration for overcoming consequences after the Chornobyl disaster

Overcoming consequences after the Chornobyl disaster is an important issue of Ukrainian international collaboration in the field of nuclear industry. In November 29, 2016 construction of the New Safe Confinement, covering the 4th unit of Chornobyl NPP, was finished. The cost of the confinement amounted 1.5 bln euro. Those funds were donated by and administered by EBRD as a manager of the Chernobyl decommissioning funds. Building the confinement is only one of all stages of conducting "The Plan of Steps for Implementation "Shelter" Project" that costs about 2.14 bln euro. Confinement is technologically unique: 150 meters in width and 257 lengthways with the system of hoisting cranes inside that is 96 in length with 50 tons carrying capacity. Now is being finishing of putting New Safe Confinement into operation is planned by December 2017. In 2018 start of dismantling of unstable constructions is planned.

As the result of international cooperation depository of spend nuclear fuel from the 1st, 2nd and the 3rd units of Chornobyl NPP – the Interim Spent Fuel Storage Facility (ISF-2) was constructed. During exploitation of those units more than 21 000 units of spend nuclear fuel were stored. Now those are stored in the first depository (ISF-1) but its operating life is expiring. operation life of New depository ISF-2 will be 100 years for more than 21000 spent nuclear fuel assemblies of the RBMK-1000 under the capacity of 2500 spent nuclear fuel assemblies per year. Total cost of the project amounts 381 mln euro and will be funded by Nuclear Safety Account of the EBRD.

Existing experience is the field of revitalization of Chornobyl Exclusion Zone has a unique value for international cooperation. A very promising option is a project of construction solar power plant on the area. List of areas (with total square of 1 172 hectares) are selected already for installing PV panels. These areas have access to energy grids and necessary infrastructure.

12.4. International Cooperation on Attracting Investments to Ukrainian Nuclear Industry

In order to keep to the best practices in the field of nuclear industry, to improve investment attractiveness and in accordance to agreement between Ukraine and EBRD the project of corporatization of SE Energoatom started. This have to be done in accordance with the road map, which is being developed now by experts lead by Deloitte&Touche LLC. The first stage of the project proved that to provide efficient corporatization specific law is necessary. The law has to stipulate particular features of creating and further operation of newly established joint-stock company on the basis of existing SE Energoatom.

In the scope of European integration prospective is a project "Energy Bridge: Ukraine – European Union". According to the project, 2nd unit of Khmelnitska NPP will be disconnected from United Energy System of Ukraine and then be connected to European grid with 750kW power line to substation either in Zheshuw, Poland or in Albershtina, Hungary. Implementing the project will be a step toward integrating Ukrainian energy system into European.
Summary

International collaboration in the field of nuclear industry is not only the option for Ukraine to share and gain experience but also an opportunity to obtain funds for providing nuclear and radiation safety under conditions of lacking funds in state budget. Active participation of in international nuclear regimes and organizations demonstrates to the world Ukraine’s adherence to high standards in the field. Beside, nuclear industry in an attractive one for investing. Sustained development of the industry in Ukraine (proved by main indexes) and its growing role in Ukrainian energy are good indicators for investors. At the same time future corporatization of SE Energoatom will open up new possibilities for investments and development of the industry.
Until the mid-1980’s, Ukrainian environmental NGOs had been developing the same way as all environmental organizations in the Soviet Union. However, the political events that took place in the Soviet Union in the second half of the 1980s resulted in a new policy focused on publicity and democratic change, which led to the democratic changes and the development of non-governmental nature protection movement. Often, and more publicly, environmental NGOs began to talk about the bottlenecks in the use, management and protection of natural resources in the Soviet state. More and more people took to the streets at rallies to march in protest against the so-called ecological policy of the Soviet regime (Annex 1).

13.1. Chernobyl “turn”

Thus, the accident, which happened on April 26, 1986 at the Chernobyl nuclear power plant, radically changed the situation not only in the society, but also in the non-governmental environmental movement in the Soviet Union, and especially in Ukraine, Belarus and Russia, which suffered the most from this accident. From that date, let’s say, the confrontation began between the non-governmental environmental movement, on the one hand, and the state energy lobby, on the other, under the slogan "for a safe future society without nuclear power”.

Concealing the truth about the accident from the public, inadequate emergency activities on mitigating the consequences of the accident, which led to a large number of casualties, and further ignoring the needs of people in terms of aid, gave rise to a broad civic movement. The process of establishing new environmental NGOs was underway.

These new organizations were grouped in areas in focus depending on the goals they set. Some organizations were established to help victims of the Chernobyl disaster. Their main goal was to help those who directly participated in the liquidation of the accident and fell ill- assistance with medicines, medical care, establishment of rehabilitation centres, provision of psychological and social aid, etc. Other organizations assisted the internally displaced people (IDPs) in helping to arrange their lives at new places, as well as in job searches, rehabilitation and treatment, and so on.

The range of non-governmental organizations was established that provided assistance exclusively to children-victims of the accident and children of liquidators or children of IDPs. They were the Chernobyl Union, the Chernobyl Association, the Children after Chernobyl, the Children of Chernobyl, Salvation from Chernobyl, Fund for the Disabled as a Result of Chernobyl, Chernobyl and Chernobyl Residents. Most of these organizations had affiliates in various regions and cities.

Together with these organizations, other non-governmental organizations were founded and, although the reasons for their creation were similar, they set the goal to address a wider range of problems. The problems they addressed were related to the environment and the causes of its critical condition. It is important that these were fundamentally new environmental protection organizations that saw not only the hazardous facilities management mistakes in the Chernobyl catastrophe, but also the political and economic faults and believed it necessary to address them in order to prevent repetition of the catastrophe.

13.2. The years of independence

In the first years of its independence, the Ukrainian environmental movement had a large number of supporters. However, it is necessary to take into account the peculiarities of environmental NGOs’ activities and their resources, which have always been limited. And this applies to all kinds of resources- human, expert, technical, informational, and especially financial. Availability or lack of certain resources had an impact on NGO’s operations. Of course, for two decades the environmental organisations have adapted to the permanent lack of resources. And thanks to modern information
technologies, in some areas they are even ahead of governmental, business or private organisations. However, this advantage provides merely a chance to maintain operations at a certain level in the discourse with their opponents, but does not give opportunities to win and achieve the goal – Ukraine’s nuclear-free future.

Most environmental NGO’s activities are based on volunteer principles, and the impossibility to engage experts on a permanent financial basis today is the biggest problem for non-governmental organizations. Despite these difficulties, the organizations that have succeeded in getting donor funds for anti-nuclear efforts are implementing important activities aimed at public participation in the development of nuclear energy policy in Ukraine. After all, in the permanent dialogue on nuclear energy, the public should deal with the government, its ministries, their local divisions, management and personnel of nuclear power plants, research centres and think tanks that develop analytical studies, programs, reports, and reviews for government agencies.

In recent years, the above-mentioned supporters of the nuclear power industry also expanded to include non-environmental civic organizations that fully support the policy aimed at the development of nuclear energy. Newly created civic organizations supporting today’s governmental policy towards nuclear energy development create significant problems for environmental organizations that stand for the future of Ukraine free of the “peaceful atom”. In their activities, environmental NGOs have always tried to use all available tools of public opinion influence on political decisions. The Convention on Access to Information, Public Participation in Decision-Making and Access to Justice in Environmental Matters (the Aarhus Convention) all played an important role in enabling environmental policy. With the ratification of the Convention in 1999, the Ukrainian environmental community and their organizations received a powerful legal mechanism for participating in national environmental policy-making. Although before the Convention ratification the public had appealed to the constitutional rights and the applicable laws for active promotion of environmental views via mass media, rallies, demonstrations, pickets, round tables, conferences, festivals, referenda, but some procedures, e.g. compulsory debates on planned activities, were not in place. This led to societal tension between the public and the authorities. A striking manifestation of such tension was the debate on the decision of the Government of Ukraine to complete the two nuclear power units at the Khmelnitsky NPP. In 1990, the government adopted the decision on a moratorium on the completion of power units Nos. 2, 3 and 4 at the Khmelnitsky NPP, which had been constructed to 85%, 27% and 7%, respectively. However, the Government and the Verkhovna Rada changed their decision and resolved to continue the completion of the reactors. This governmental decision caused indignation among the public and environmental NGOs.

Environmental non-governmental organizations started a large-scale campaign against the reactor completion. The “Green World” NGO played an active role in organizing this movement. In order to undercut the civic environmental movement, the Government adopted Resolution No. 1122 “On the Procedure of Public Hearings on the Use of Nuclear Energy and Radiation Safety”. The document set forth the rules that, firstly, provided local authorities with the powers to decide on the feasibility of holding public hearings, and secondly, it was emphasized that the conclusions of public hearings would be of advisory and non-binding nature, and thus could merely be taken into account when authorities make a final decision.

Following this procedure, the local authorities held the public hearings in the villages and towns directly neighbouring the power plants in the Khmelnytsky and Rivne regions. Administrative resources were engaged and the interests of the personnel at the NPPs were involved, and the majority of the public that came to the hearings voted to complete the reactors.

Attempts of environmental NGOs to hold the hearings in Kyiv were rejected by the Kyiv authorities based on the Procedure, which gave the authorities the powers to independently decide whether it was reasonable to hold the hearings. Attempts by the public to prove the absurdity of such an approach, namely, that the operations and consequences of the accident at nuclear power plants are not limited to the areas around the plants, but are of global nature and affect the interests of all Ukrainian citizens (as the Chernobyl accident demonstrated), did not change the position of the authorities in Kyiv.

This was one episode that demonstrated that the positions of the environmental activists and the state nuclear-energy complex were polar opposites on questions of whether to develop the nuclear power industry. Since the mid-1990s, the government has ceased promising the nuclear-free development of the Ukrainian energy sector and has openly embarked on increasing energy generating with the help of nuclear technology.

13.3. The toolkit of the civic environmental movement

For a better understanding of the contemporary anti-nuclear activities of Ukrainian environmental organizations, it is necessary at least to briefly analyse the tools used by environmental NGOs in their activities.

At the beginning of the 1990s, the environmental movement in Ukraine gradually lost
its broad support in the society. This happened because of the economic crisis experienced by all post-Soviet countries and the rapid creation of political parties, as the large number of active citizens, which in the 1980's were adherents of the green movement, began to find new political parties and joined their ranks. Therefore, although the citizens in sociological surveys indicated their continued concern about environmental problems, they nonetheless put economic problems, social issues, safety of children and families etc. above them. The latter problems are now always related to the environment, but indirectly, as a rule, and not all citizens perceive them as environmental problems.

Consequently, loosening public support, such instruments of influence on the power that be as marches, rallies, and pickets have become more narrow, and consequently, the publicity of the environmental movement in society is lost. Simultaneously, the mass media has lost interest in the environmental issues.

The violent political and economic events in Ukraine's life in the 1990's and at the beginning of the 2000s and continuing to the present have eclipsed environmental matters and draw most of the attention of most mass media sources. Ukrainian journalists pay attention only to extraordinary natural calamities or man-made accidents. Therefore, most environmental NGOs in Ukraine have begun to look for other ways of working with authorities. It was after the signing and ratification of the Aarhus Convention that the environmental community in Ukraine achieved an effective tool for defending environmental interests and other mechanism for influencing national environmental policy. Environmental NGOs have been increasingly relying on the Aarhus Convention in their work with the authorities, in particular Articles 6, 7 and 8, which set forth mandatory public participation in decision-making, in development of environmental plans and programs and regulations.

At the beginning of 2000s, Aarhus centres were established in some regions, and in 2004, one such centre was formed at the Ministry of Ecology. Although these bodies have not yet been formalized by law, they demonstrate the ability of the public to influence environmental policy at both the regional and national levels. And in 2009, the Cabinet of Ministers of Ukraine adopted a resolution on public councils at the Cabinet of Ministers, ministries, other executive authorities, regional, city councils and state administrations. Consequently, this advisory body of the public and the authorities was institutionalized. Therefore, when we are researching and analysing the civic environmental movement, we must analyse activities of the public councils formed at the state authorities and local self-governments.

13.4. Public Councils at the central executive authorities

1. Ministry of Ecology and Natural Resources (https://menr.gov.ua/)

Five Committees have been established within the structure of the Public Council of the Ministry of Ecology, including the Committee on Climate and Ozone Layer and the Committee on Waste and Hazardous Substances, which were empowered to consider the issues related to nuclear power industry.

The meetings of the Public Council at the Ministry of Ecology have several times addressed the issues of the nuclear power industry, where the work plans of the expert commission were discussed with an eye to conduct a public environmental expert assessment of the EIA documents and materials regarding the service life of unit No. 2 at the South Ukraine NPP. Besides that, the findings of the public environmental expert assessment of the EIA documents for the reactor lifetime extension were discussed. Following the Public Council's discussion, the recommendations of the Ministry of Ecology of Ukraine were approved – which were to return the EIA documents for further refinement and elimination of the deficiencies and violations.


The Public Council at MECI takes an active part in the activities of the Ministry. Commissions were formed in the structure of the Public Council to focus on various activities, such as the Commission on the Nuclear Power Industry, which directly deals with the nuclear energy issues. In particular, the meeting of the Public Council addressed a separate issue "On the current state and measures in the nuclear industry complex of Ukraine", where the President of the state-owned enterprise NNEC "Energoatom" Yuriy Nedashkovsky was the speaker.

3. State Nuclear Regulatory Inspectorate of Ukraine

The Public Council with the State Nuclear Regulatory Inspectorate of Ukraine comprises 11 organizations, including environmental NGOs. They are both grassroots and all-Ukrainian environmental NGOs with experience in working with the authorities.

13.5. Public Councils at local self-governments

As already mentioned, public councils formed at local self-government bodies so far remains the most important mechanism for environmental NGOs' to influence environmental policy, in particular, the policy on the use of nuclear energy in Ukraine. The activities of public councils at the regional state administrations of those regions
where nuclear power plants are located are important.

The Public Council, which was established at the Rivne Regional Administration, comprises representatives of 35 non-governmental organizations. But only one environmental NGO has been represented there until recently, while the new council has no environmental organizations represented at all. In recent years, the matters discussed by the Rivne Public Council have not covered the operations of the Rivne Nuclear Power Plant and its impact on the environment.

In Zaporizhzhya region, the Public Ecological Council was established at the Department of Ecology and Natural Resources of the State Regional Administration. The Council includes the members from seven environmental organizations.

The Public Ecological Council of Dnipropetrovsk Regional State Administration was established in 2014 with the aim of developing and implementing state environmental policy in the Dnipropetrovsk region and engaging the public for addressing environmental problems. Fourteen non-governmental environmental organizations are represented within it. Nuclear power industry issues were among the issues considered at the public council’s meetings. In particular, the Council discussed the issue of the lifetime of the Zaporizhzhya NPP.

The Public Council at the Khmelnytsky Regional State Administration is comprised of 35 organizations, including three environmental NGOs. In May 2017, the meeting of the public council considered the issue of the planned construction of a nuclear waste storage facility to store the nuclear waste generated by the Khmelnytsky nuclear power plant. The decision of the Council was to appoint two representatives of the Public Council to monitor how the public proposals would be incorporated in the design documentation and to oversee the construction of the waste storage facility.

The Public Council at the Mykolaiv Regional Administration, like other public councils, has 35 organizations represented, including three environmental NGOs.

In other regions of Ukraine, public councils have also been established with the public authorities and they may hear various matters related to environmental policy at their meetings, including nuclear power industry matters.

13.6. Environmental NGOs

The following main organizations can be distinguished among environmental NGOs that have long been dealing with nuclear energy issues. Many of them are members of the public councils:

1. Ukrainian environmental association "Green World"—the oldest environmental NGO in Ukraine. It has been addressing nuclear energy problems since 1980s. The UEA "Green World" program included the demand to stop the development of the nuclear power industry in Ukraine, as well as the adoption of laws on nuclear energy and provision of social, medical and other assistance to the victims of environmental accidents and disasters. The organization is a member of the Public Council at the State Nuclear Regulatory Inspectorate of Ukraine.

2. National Ecological Centre of Ukraine (NECU) is a national environmental protection organization. The energy sector is among the NECU’s areas of focus as is a particular focus on the Nuclear Power Industry. The NGO stands for the rejection of nuclear energy, explaining that the reactors operating in Ukraine remain dangerous and the human factor in their control does not make their operation safer, despite new technologies. Besides that, the threat remains that radioactive materials may fall into the terrorists’ hands, so far no nuclear power plant decommissioning plans are in place, and the state has to spend too much money for their operation. The NECU also says that existing units are running on old technologies, and that the problems of accumulation and safe storage of nuclear waste have not been resolved yet. And although the NPPs do not contribute to greenhouse gas emissions, the above problems put the shutdown of the plants on the top of government’s agenda. As part of its work in this area, the NECU carries out various activities. Among them are public hearings, in which discussions and opinions on the regulations and governmental programs are discussed. They also release the results of international expert to the public, and they conduct their own research and public opinion polls on nuclear energy issues, hold contests, deliver lessons for schoolchildren and youth, and hold other events. The NGO is also an active member of the Public Council at the State Nuclear Regulatory Inspectorate of Ukraine.

3. The Rivne-based NGO "Ecoclub" has been operating for more than 20 years. The implementation of the energy policy and novel solutions in the energy sector is among its priorities. To achieve these goals, the NGO engages in law-making, participates in conferences, holds workshops, and participates in the advisory bodies composed of the authorities and the public. Specifically, it is also a member of the Public Council at the State Nuclear Regulatory Inspectorate of Ukraine. For many years, the NGO has been publishing Nuclear Monitor magazine. It has also published and released to the public and the authorities the Concept of the "Non-Nuclear" Development of the Energy Sector in Ukraine drafted by Ukraine’s environmental NGOs, the text of the Internet conference "Energy
Strategy of Ukraine for the period until 2030", "Nuclear Energy - a Myth or a Reality" and many other publications devoted to the issue of nuclear power industry in Ukraine.

4. The All-Ukrainian NGO "MAMA-86" may be named among the organizations founded in connection with the environmental problems of Ukraine, in particular, the problems of nuclear energy. The organization was established in 1991 to provide social assistance to the victims of the Chernobyl accident - children and young mothers. The first projects of the NGO were of a humanitarian nature - they distributed humanitarian aid donated by foreign partners and others. Today, MAMA-86 promotes the democratization of Ukrainian society and the transparent formulation and implementation of environmental policies that take into account the views of the public and stakeholders. The NGO conducts case studies and widely disseminates their findings, carries out campaigns for civic dialogue and lobbies for a comprehensive integrated socio-economic development policy. The NGO consistently advocates the establishment and stable functioning of the stakeholder system of dialogue about compliance with the requirements of the international treaties on the issues related to nuclear power facilities operation. The NGO also lobbies for public participation in discussing and adopting environmentally significant decisions at the local, regional and national levels. It is an active member of the Public Councils at the Ministry of Ecology and Natural Resources and the State Nuclear Regulatory Inspectorate of Ukraine. Although the NGO does not have national nuclear policy among the areas of its activities, it has been constantly monitoring this area and voicing its position on specific issues both within the collegial bodies of the councils and independently. Currently, the NGO's website offers the content related to "New Energy Strategy of Ukraine: Security, Energy Efficiency, and Competitiveness". In general, the NGO proposes not to approve this version of the Strategy, because it is inconsistent with the environment protection priorities and the basic principles (strategy) of the state ecological policy of Ukraine.

Besides the above-mentioned NGOs, there is a wide network of NGOs that do not declare nuclear energy as a specific area in focus of their activities, but they take part in the actions or events on this issue. These organizations include:

5. The All-Ukrainian Ecological League (VEL), which has been working for 20 years on improving the environmental situation in Ukraine and organizing and carrying out activities aimed at terminating the activities that jeopardize ecological safety, biodiversity and public health. Regarding nuclear issues, VEL, on its website, released its position as to the updated Energy Strategy, in which VEL does not support this draft strategy, and in particular opposes the further development of the nuclear power industry. The NGO has regularly published the "Ecological Bulletin" journal, which releases the articles by well-known Ukrainian and foreign scientists on various environmental, socio-environmental issues, including articles on the issues of the nuclear power industry. Also, VEL has published a number of maps of Ukraine on various environmental aspects, including the "Radiation Hazard in Ukraine" map.

6. International charitable organisation "Environment. People. Law" declares "Nuclear Energy" as one its activities. The organization believes it important for Ukraine to use the comprehensive approach to the operation of nuclear reactors, to ensure competent handling of nuclear materials, and to combat against illegal trade in nuclear waste. Therefore, EPL takes part in improvement of the national nuclear energy legislation to ensure its compliance with international law and international rules on the operation of nuclear power units, monitoring and prevention of aging processes at the power units. The organization posts at its website nuclear energy related content, legal analysis of draft legal acts, proposals and observations, analysis of reports, expert opinions, international reviews on the operation and use of nuclear power facilities. Over the years, the organization has been publishing an eco-legals magazine "Environment. People. Law", which offers publications of legal, environmental and scientific information on energy topics, including nuclear energy. The organization is a member of the Public Council at the State Nuclear Regulatory Inspectorate of Ukraine.

7. Ukrainian Greens Association NGO see their mission as preventing the deterioration of the environmental situation in Ukraine, raising environmental awareness, participation in national ecological policy-making, ensuring radiation safety, implementing energy- and resource-saving technologies and achieving other environmental goals. The list of activities contains a permanent heading "Radiation Safety". The content of this section covers various events, news, actions, reports on governmental and NGOs’ actions. A visitor is offered detailed information about all the issues currently on the nuclear energy agenda. The organization is an active member of the Public Council at the State Nuclear Regulatory Inspectorate of Ukraine.

13.7. Conclusions

1. There is no broad public movement in Ukraine against the development of nuclear energy. Nevertheless, a number of environmental NGOs, both national and regional, are active participants in the process for nuclear-free development of the energy sector in Ukraine. Today, the main form of participation of the environmental community in the process of anti-nuclear policy-making is via the
participation of environmental NGOs in the activities of the Public Councils at the Ministry of Ecology and Natural Resources, the Ministry of Energy and Coal Industry, and the State Nuclear Regulatory Inspectorate. At the regional level, this is participation in Public Councils at Regional State Administrations.

2. The environmental NGOs should improve their performance and boost the number of their supporters, volunteers and members.

The environmental NGOs of Ukraine lack expert, organizational, informational and financial resources to empower them so that they may improve their performance. In the current context, they are most likely to receive real resources only from international institutions. At the same time, it should be understood that the performance of non-governmental organizations and their impact on the population will depend on whether their activities are connected with the realities of Ukraine today and in the near future.
Conclusions

The conclusions set forth here are based on the information of the experts who prepared this report. In addition, the conclusion outlines the main positions of Bellona on the issues considered in this report.

Following the collapse of the Soviet Union, Ukraine inherited four operating nuclear power plants with fifteen reactors, as well as the Chernobyl nuclear power plant with its many problems. Also remaining on the territory of Ukraine was a part of uranium production, several enterprises that operated under the Soviet nuclear industry, and a system of nuclear industry management and regulation that requires structural and personnel restructuring.

This restructuring process occurred against the backdrop of a weak economy and the revolutionary political processes that have periodically arisen in the country. The economic and political situation in Ukraine, on the one hand, did nothing to contribute to the effective development of the nuclear industry, but on the other hand, it allowed the preservation of nuclear energy potential, which helps the country survive despite problems in the fuel and energy complex, which were especially aggravanted after the events of 2014.

Today we must go further. Ukraine, at least for the next few decades, intends to preserve its nuclear energy potential. To this end and proceeding from the current situation, the government, business sector and the public of Ukraine will have to address several priority issues in order that they not become problems in the near future:

1. The issue of ensuring nuclear power plant operating safety

Of the fifteen reactor units in service in Ukraine, six units have received engineering lifetime extensions. The rest will approach this deadline in the next three to five years. Despite the fact that extending the operational periods of nuclear power units is an international practice and takes place in all countries using nuclear energy, Bellona believes that the old is always unreliable and vulnerable when compared to the to the new. Therefore, we should devote a great deal of attention to lifetime extensions for the main elements of nuclear reactors, safety systems, and systems and elements of nuclear units that are important for safety.

A significant role should be played by scientific and technological diagnostics, as well as by the supervisory and control apparatus of the nuclear regulator. The safe operation of reactors that have received extensions will largely depend on the results of that work. We should perhaps also avail ourselves of the experience of international institutions that have technologically and financially supported projects to extend reactor resources in various countries, including those in Eastern Europe.

From the point of view of political and economic expediency it is necessary to treat with care the question of replacing nuclear fuel in Russian designed nuclear reactors with the modified fuel designed by Westinghouse. However, Bellona's position is that security issues should remain the primary ones. The time for experimenting on nuclear reactors ended on April 26, 1986. The transition to Westinghouse fuel will continue over the course of several more years, therefore, despite any external and internal circumstances for the nuclear power plants of Ukraine, the main task will be to ensure the safety of the transition to this new design of fuel.

The decommissioning of nuclear reactors is a difficult and costly process. According to economists, the decommissioning of a nuclear power plant is about 60% of the capital expenditure for its construction. The withdrawal of nuclear reactor under emergency circumstances can be called a special process, as it requires separate decisions on technology, security and, as a rule, demands additional financing. The process of decommissioning the Chernobyl nuclear power plant, currently underway in Ukraine, has made significant progress, but several major tasks from this process are still ahead.

This is due first of all to the completion of the Shelter and the establishment of a new arc type safety shelter, as well as the construction of storage facilities for spent nuclear fuel and high-level radioactive waste, which should enter service in 2018. It is necessary to implement a long-term program for the maximum possible rehabilitation of Chernobyl’s exclusion and compulsory resettlement zones.

As for existing nuclear power plants that will be decommissioned before 2055, Bellona believes that it is here necessary to focus on the creation of a monetary fund, the development of a concept, programs and technologies for decommissioning, which takes account the experience of countries that have already carried out this process safely (for example, Lithuania, Germany, and so on.).
In solving the above problems, international cooperation plays an important role – a role which in Bellona’s opinion, should not only continue, but also grow until the Chernobyl nuclear power plant is completely decommissioned and the concerned territories rehabilitated.

2. The issue of spent nuclear fuel handling

In Ukraine, about 6,000 tons of nuclear fuel has accumulated, and which is mainly stored in wet-type storage facilities, with the exception of 1,350 tons that are stored in the dry-storage facility at the Zaporozhia NPP.

At the moment, part of the fuel from VVER-1000 reactors operating at Ukrainian nuclear power plants continues to be exported for storage and subsequent reprocessing in Russia. However, Ukraine’s energy strategy with regard to SNF management calls for the implementation of a so-called deferred solution, which provides long-term storage in excess of 50 years for fuel in its own storage facilities, with a subsequent determination of future prospects. To do this, it will be necessary to implement construction of a centralized dry-storage facility for SNF in the Chernobyl zone, something that is under discussion today. For Ukraine, addressing the issue of handling spent nuclear fuel is primarily a matter of financial resources. The cost of building a centralized storage facility is about $1.5 billion. Obviously, without international assistance, it will not be easy to solve this issue.

Bellona’s position relative to the treatment of spent nuclear fuel is that, firstly, spent fuel must be stored in the country in which it was created. This reduces the risks of transboundary SNF transportation and forces countries that wish to use nuclear energy to bear a fair share of the economic, environmental and social risks. In addition, Bellona believes that the reprocessing of spent nuclear fuel by technologies in use today is potentially dangerous to the public and causes damage to the environment. This damage largely exceeds the benefits that can be derived from extracting potential valuable energy resource as a result of the reprocessing.

3. The issue of radioactive waste handling

Ukraine ranks second in Europe in terms of the accumulated radioactive waste of various levels. Experts have concluded that the country’s system of radioactive waste management requires development and improvement. In particular, the issue of choosing a site for deep geological disposal of highly active long-lived radioactive waste has not at the moment been resolved. This is major important issue, as by 2018 Ukraine will likely begin receiving from Mayak in Russia high-level vitrified waste formed as a result of reprocessing spent fuel from VVER-440 reactors at the Rivne NPP. This is not just a question of security, but also of economics, as violation of agreements can entail penalties. According to experts, the Ukrainian State Fund for Radioactive Waste Management does not work efficiently, which results in lacking support for the infrastructure for radwaste management, which then leads to a decrease in the quality of the waste storage facilities, and hence the level of radiation safety.

The effectiveness of the functioning of the Ukrainian state system for radioactive waste management in the long term remains an open question. By the existing system, there is no end link in the chain of radioactive waste management - repositories (unlimited time). For the purposes of safe conditions for all classes of radioactive waste within them under the conditions of monitoring their condition for the entire period of their hazardousness.

The Bellona position with respect to radioactive waste management is that the following approaches and principles should be observed:

- The producer of radioactive waste pays. That is, those enterprises and organizations that generate radioactive waste pay for all stages of handling them (temporary storage, transportation, burial, monitoring for the entire period of their hazardousness, as well as all costs associated with the liquidation of emergencies and the negative impact of radioactive waste on the environment).
- Liquid radioactive waste should not be introduced into natural or open water reservoirs or pumped into underground geological formations.
- The maximum amount of radioactive waste must be conditioned in order to reduce its hazard and volume.
- Radioactive waste at the final stage of its handling should be placed at disposal sites (unlimited time) that correspond with best available technologies. The technology of placement must meet the "principle of reversibility", that is, when situation the radioactive waste, it should be possible to withdraw it if necessary (force majeure, availability of new technologies for neutralization, etc.).

Additionally, Bellona supports the principle of a single and independent operator responsible for the disposal of radioactive waste, the operation of disposal facilities and the safety of radioactive waste located at these points (as per the example of SKB Sweden Andra, France).
4. The place and role of the nuclear regulator in the state

There is concern and worry about the place and role of the nuclear regulator in the government structure of Ukraine. Under conditions of energy instability, the nuclear regulator should be one of the main guarantors of the fact that nuclear power engineering operates in a safe manner.

Bellona’s position is that the state nuclear regulator must be truly independent of the companies and departments that are responsible for the operation of nuclear facilities. This structure should fully and without exception have the authority to designate, license, control and compel within its supervisory powers and responsibilities. The regulator should act as a guarantor to the public and the leadership of the country that the activities of all structures and officials of the nuclear industry are carried out in accordance with international and national safety regulations and rules.

5. Issues of public participation and control over the activities of the nuclear industry

Bellona, as an environmental organization, devotes more attention to the development of the civil society environmental movement in countries that use nuclear energy. We believe that the public should actively participate in the processes of developing and adopting decisions that relate to the safety of the nuclear industry. Bellona believes that today the civil society organizations of Ukraine do not have sufficient potential and resources to interact at an expert and informational level with companies, enterprises and organizations that represent the nuclear industry and implement projects that ensure the safety of nuclear technologies.

Conclusions

In the current realities and in view of the prospects for the next few decades, Ukraine's nuclear sector will remain the main sources of electricity in the country. At the same time, almost all of the country's nuclear power plants will approach the point of closure. Therefore, it will be necessary to make decisions on the choice of prospective sources of electricity. Given the development of new renewable and clean energy, these choices may not favor nuclear technology. Based on the review of experts presented in this report, it follows that the construction of new nuclear power plants and their subsequent operation would require huge resources from the country. It is already clear that the price of nuclear electricity, when accounting for the total costs -- ranging from uranium mining to decommissioning of nuclear power plants -- are too high. Ukraine does not need military nuclear technology, which is a major reason that large states do not abandon their own nuclear energy programs. What decisions will be made and when depends on Ukraine's leadership and society. But it is now necessary to focus on one of the main issues - ensuring the safety of the entire nuclear industry located in Ukraine. To do this, it is necessary to define the fine points of dangerous spots within the Ukrainian nuclear complex and correctly prioritize projects aimed at improving safety.
Chronology of Events in the Explosion at ChNPP Unit 4 on 26 April 1986
(from archives of the Chernobyl NPP)

Shutdown of ChNPP unit 4 for routine maintenance was planned for 25 April 1986. It was
decided to take this opportunity to perform a series
of tests. One of the tests was intended to check the
design mode in which turbine generator inertia
was used to feed reactor systems in the event of
loss of off-site power supply.

The tests were to be conducted at 700 MW, but
it dropped to 30 MW because of operator errors
in the power decrease process. It was decided
not to raise the power to planned 700 MW but to
increase it only to 200 MW. With rapid decrease
in power and further work at 30–200 MW, Xenon-135
poisoning of the reactor core intensified. In order
to raise power, a part of the control rods was
drawn from the core.

After 200 MW was reached, two additional
pumps were connected to serve as generator
loads in the experiment. The amount of water flow
trough the core exceeded the allowed value for
some time. At that instant, the operators had to
further raise the control rods to maintain power.
In this case, the operational reactivity margin was
lower than allowed, but the reactor staff did not
know about it.

The experiment began at 1:23:04 on 26 April
1986. At that time, there were no signals to indicate
that the reactor was in abnormal or unstable state.
As idle rpms of the pumping equipment connected
to the "running-down" generator decreased and
the void coefficient of reactivity was positive,
power began to increase (positive reactivity was
introduced), but the control system prevented this.

At 1:23:40, the operator pressed the scram
button. The exact cause of this operator’s action
is unknown; it is believed that this was done in
response to the rapid increase in power. Anatoly
Dyatlov, deputy chief engineer on plant, who was
in the control room of unit 4 at the time of
the accident, states in his book that it was envisaged
earlier in instructions and done in the regular (but
not emergency) mode for shutting the reactor down
with the beginning of turbine "run-down" test after
the rods of the automatic power controller reached
the core bottom [1]. The reactor control systems
did not record any power increase until scram was
actuated.

The control and emergency rods began to
move downwards into the reactor core, but after
a few seconds, reactor thermal power jumped to
an unknown high value (all power readings were
off scale). Two explosions occurred with intervals
of several seconds and destroyed the reactor.
There are no accurate data on the sequence
of processes that caused the explosion. It is
generally acknowledged that initially there was an
uncontrolled increase in reactor power, which
resulted in the destruction of several fuel rods.
This damaged the fuel channels in which these fuel
rods were located. Several damaged channels fell
into the reactor space and caused a sharp jump
in pressure and raised the upper reactor plate
through which all the fuel channels passed. This
led to massive destruction of the channels, boiling
throughout the entire core volume and steam
release. This led to the first (steam) explosion [2, 3].

Regarding the further accident progression and
the nature of the second explosion that destroyed
the reactor, there are no objective registered data,
only hypotheses can be made. According to one of
them, it was a chemical explosion; i.e. explosion
of hydrogen generated in the reactor at high
temperature as a result of the steam–zirconium
reaction and a number of other processes.

According to another hypothesis, this was an
explosion of nuclear nature, a thermal explosion
of the reactor caused by power increase on fast
neutrons resulting from complete dewatering
of the core. A high positive vapor coefficient of
reactivity makes this version quite probable [4].

Finally, there is a version that the second
explosion is also a steam explosion, i.e., continuation
of the first one. According to this version, all the
destruction was caused by the steam flow that
threw a significant portion of graphite and fuel
from the reactor. Pyrotechnic effects as "fireworks"
of flying hot fragment observed by eyewitnesses
were the result of "steam–zirconium and other
chemical exothermic reactions" [2].

Therefore, if the main, most significant,
dominant source of energy was a chain nuclear
fission reaction, the explosion must be regarded as
nuclear by its physical nature, though a very low-
power one (compared to explosions of the smallest
nuclear weapons). On these grounds, a posteriori
model rather than a hypothetical version can
be suggested according to experimental studies
of unit 4 after the accident (such as raise of the
reactor from the cavity, dehydration and explosion
of the core – nuclear explosion by energy source –
in the air, but within the central hall [4].

First, this model of accident development
at ChNPP unit 4 on 26 April 1986 appears to be
the most consistent, as it allows for a coherent
explanation for the condition of civil structures,
reactor equipment and nuclear fuel after the accident. Moreover, it also allows one to explain some features of the spatial distribution of radioactive fallouts. A whole analysis without the proposed model provided too wide spread of estimates, and biological effects of such fallouts [4].

Second, recognizing that the core explosion of about 100-250 t TNT (trinitrotoluene explosive blast equivalent) occurred in the air above the reactor shaft and gave rise to high temperatures because of its nuclear nature and some part of the core materials dispersed and some part evaporated. This model does not give grounds for assumptions that 97% of nuclear fuel returned back to the reactor cavity and sub-reactor premises*

Indeed, there was no more than 9-13% of nuclear fuel from the volumes preliminarily loaded into the reactor core in the solidified fuel-containing melts found in premises under the reactor. Given gas cavities and equipment components contained in the melts, this estimate may further decrease, possibly up to 4-6%, but this does not have fundamental significance [4].

In the years after the accident, it was declared that 97% of fuel remained in ChNPP unit 4, but it was never found there. At the same time, after analyzing the condition of equipment and civil structures of the destroyed reactor, one can conclude that the proposed "nuclear" model agrees well with the assessment of release carried out on 24 June 1986 in Chernobyl by leading experts of the USSR Ministry of Medium-Scale Machine-Building. According to this assessment there are 15-25% of fragmented nuclides and fuel outside the industrial site, about 25% on its territory, about 5% in the gas cavities and possibly 10-30% in the reactor cavity.

Another assessment was carried out by A. N. Rumyantsev to determine the amounts of nuclear fuel remaining in the Shelter above destroyed ChNPP unit 4 using the so-called limited knowledge method, which is also known as quantile uncertainty assessment [10]. The results of calculations according to this method indicate that the weight of remaining fuel can be assessed with a mathematical expectation of 110 tons and from 61 to 177 tons within the 90% confidence interval. This mathematical expectation assessment exceeds the results of estimates provided in [9] by more than three times, which are even below the 90% confidence interval (61 tons). Since access to the lava fuel-containing materials remains limited because of high levels of radiation, it is impossible to analyze all zones where fuel-containing materials are located and, hence, this difference is quite understandable.

Uranium dioxide with a weight of 110 tons has a volume of about 11 m³. Its melt with sand and other structural materials (steel) may have a specific density in a range of 3-5 g/cm³ with an average density of 4 g/cm³. This melt may have a volume of about 30 m³. This volume is unevenly distributed over a large area of sub-reactor premises, which virtually eliminates the possibility to perform representative measurements in the near future. Therefore, in the opinion of A. N. Rumyantsev, the above estimates of the remaining fuel weight should be used as the basis in management of radioactive waste and spent nuclear fuel in Shelter-2 [11].

REFERENCES FOR ANNEX

7. V. M. Fedulenko. Briefly about the causes and progression of the accident at ChNPP unit 4. Draft articles for Nuclear Energy journal, April 2006 (article was not published).

* There were about 180 tons of fuel in the reactor core with a total radioactivity of about 10 billion Ci. According to data published in the report for the IAEA in August 1986, the amount of radionuclides thrown outside the reactor was estimated at 3.5% of the total amount of radionuclides in the reactor at the time of the accident [5, 6]. The error in assessment of radionuclide releases (daily and integral over the first 10 days after the accident ≈50 million Ci) was estimated at ± 50%. The combustion of zirconium and graphite in the reactor initiated by energy release of the remaining fuel and free air access actually lasted about 10 days. All this time, part of the fuel as finely dispersed fragments could release out of the reactor with a stream of hot air. All fuel that did not have time to release from the reactor continued to heat up and began to form a melt (lava-like fuel-containing materials) with sand and other materials that were thrown into the reactor cavity from helicopters. These lava-like materials flowed from the reactor to sub-reactor premises so that the reactor cavity itself was virtually empty [7]. The assessments of radionuclide contamination on the territories of Ukraine, Belarus and Russia adjacent to ChNPP carried out in 1987 using a newly developed database with experimental information and various data processing methods show that the total releases of heavy fuel radionuclides could exceed the previous estimates [8]. Later studies showed that about 30 tons of nuclear fuel remained in the Shelter after the accident [9].
Annex 2 to Section 7

Structural Units of Ukrainian Regulator

1. Nuclear Installation Safety Directorate
2. Radioactive Waste Management Safety Department
3. Radiation Safety Department
4. Nuclear Security and Safeguards Department
5. Legal Department
6. Economy, Finance and Accounting Department
7. Personnel Division
8. International Cooperation and European Integration Division
9. Division for Documentation Provision and Control and Interaction with Regional Bodies
10. Organizational Activity and Management Support Sector
11. Information-Analytical Support and Public Relations Sector
12. Corruption Prevention and Combating and Internal Audit Sector
13. Administrative and Service Support Sector
14. Clearance and Restrictions Sector
15. North-Western State Nuclear and Radiation Safety Inspectorate
16. Western State Nuclear and Radiation Safety Inspectorate
17. Southern State Nuclear and Radiation Safety Inspectorate
18. South-Eastern State Nuclear and Radiation Safety Inspectorate
19. Central State Nuclear and Radiation Safety Inspectorate
20. Eastern State Nuclear and Radiation Safety Inspectorate
21. State Nuclear Regulatory Inspectorate at Zaporizhzhya NPP
22. State Nuclear Regulatory Inspectorate at South Ukraine NPP
23. State Nuclear Regulatory Inspectorate at Rivne NPP
24. State Nuclear Regulatory Inspectorate at Khmelnitsky NPP
25. State Nuclear Regulatory Inspectorate at Chornobyl NPP
## Annex to Section 10

### List of Spent Fuel Management Facilities as of 01 July 2017

<table>
<thead>
<tr>
<th>Facility</th>
<th>Location</th>
<th>Purpose</th>
<th>Status</th>
</tr>
</thead>
<tbody>
<tr>
<td>Spent fuel pool of unit 1 at Zaporizhzhya NPP</td>
<td>ZNPP 71500, Energodar Zaporizhzhya Region</td>
<td>Temporary storage to reduce decay heat</td>
<td>In operation</td>
</tr>
<tr>
<td>Spent fuel pool of unit 2 at Zaporizhzhya NPP</td>
<td></td>
<td></td>
<td>In operation</td>
</tr>
<tr>
<td>Spent fuel pool of unit 3 at Zaporizhzhya NPP</td>
<td></td>
<td></td>
<td>In operation</td>
</tr>
<tr>
<td>Spent fuel pool of unit 4 at Zaporizhzhya NPP</td>
<td></td>
<td></td>
<td>In operation</td>
</tr>
<tr>
<td>Spent fuel pool of unit 5 at Zaporizhzhya NPP</td>
<td></td>
<td></td>
<td>In operation</td>
</tr>
<tr>
<td>Spent fuel pool of unit 6 at Zaporizhzhya NPP</td>
<td></td>
<td></td>
<td>In operation</td>
</tr>
<tr>
<td>Zaporizhzhya DSFSF, Stage 1</td>
<td></td>
<td>Interim storage of spent fuel</td>
<td>In operation since 2001</td>
</tr>
<tr>
<td>Zaporizhzhya DSFSF, Stage 2</td>
<td></td>
<td>Interim storage of spent fuel</td>
<td>In operation since 2012</td>
</tr>
<tr>
<td>Spent fuel pool of unit 1 at Khmelnitsky NPP</td>
<td>KHNPP 30100, Neteshin Khmelnitsky Region</td>
<td>Temporary storage to reduce decay heat</td>
<td>In operation</td>
</tr>
<tr>
<td>Spent fuel pool of unit 2 at Khmelnitsky NPP</td>
<td></td>
<td></td>
<td>In operation</td>
</tr>
<tr>
<td>Spent fuel pool of unit 1 at Rivne NPP</td>
<td>RNPP 34400, Varash, Rivne Region</td>
<td>Temporary storage to reduce decay heat</td>
<td>In operation</td>
</tr>
<tr>
<td>Spent fuel pool of unit 2 at Rivne NPP</td>
<td></td>
<td></td>
<td>In operation</td>
</tr>
<tr>
<td>Spent fuel pool of unit 3 at Rivne NPP</td>
<td></td>
<td></td>
<td>In operation</td>
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<tr>
<td>Spent fuel pool of unit 4 at Rivne NPP</td>
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<td>Spent fuel pool of unit 1 at South Ukraine NPP</td>
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<td>Spent fuel pool of unit 2 at South Ukraine NPP</td>
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<td>ISF-1 1 at Chornobyl NPP</td>
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<td>ISF-2 of Chornobyl NPP</td>
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<td>Long-term spent fuel storage (to 100 years)</td>
<td>Construction</td>
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<td>Spent fuel storage of the research reactor VVR-M, SFP-1</td>
<td>NRI 03680, Kyiv 47 Nauki Avenue</td>
<td>Temporary storage to reduce decay heat</td>
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<td>Spent fuel storage of the research reactor VVR-M, SFP-2</td>
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<td>Centralized spent fuel storage facility</td>
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## Inventory of Spent Fuel as of 01 July 2017

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<th>Material</th>
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<td>ZNPP Unit 1</td>
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</tbody>
</table>

* The amount of nuclear fuel loaded into IR-100 during commissioning is sufficient for its operation until lifetime expiration.
References

References to Section 1


References to Section 2


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4. Law of Ukraine "On mining and processing of uranium ores" № 645 dated November 19, 1997
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3. Law of Ukraine "National Target Ecological Program for Radioactive Waste Management".
12. Law of Ukraine "On Nuclear Energy Use and Radiation Safety".
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