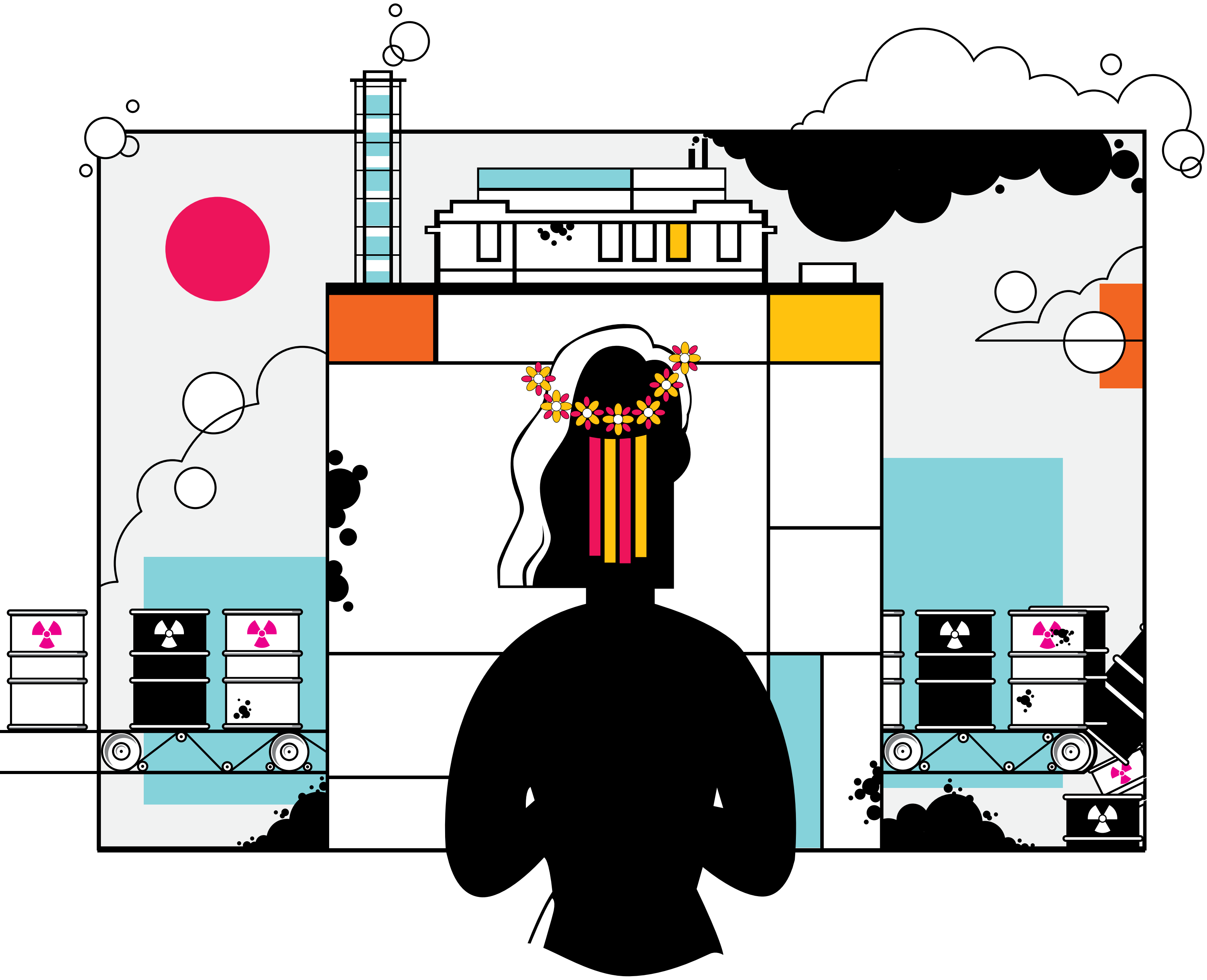

Too much to handle

Radioactive waste management

in the post nuclear accident country Ukraine

Kyiv, 2017

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Radioactive waste management in the post nuclear accident country Ukraine

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Abstract
In 1986, Ukraine experienced a major nuclear accident at the Chornobyl nuclear power plant (NPP); over three decades later, this event continues to define Ukraine's waste management situation. Today, radioactive waste at the Chornobyl NPP site and surrounding exclusion zone constitutes over 98% of total solid radioactive waste. Spent nuclear fuel is excluded from this figure as it has special legal status and is not considered to be radioactive waste. Following Ukraine's independence from the Soviet Union, its institutional system to manage nuclear waste problems has continually changed and has not reached the state of clear responsibilities and distribution of roles between various institutions. However, the need for this clarity is recognized by experts and proposals have been made to centralise the management system. EU and IAEA funding enables research on the waste management system most suitable for Ukraine, including deep geological disposal (DGD), regulatory system improvements and physical infrastructure. Adaptation of the Ukrainian standards and practices to the European standards will be accelerated in view of the EU-Ukraine Association Agreement. Because of the ongoing military conflict with Russia, Ukraine lost control over its research reactor in Sebastopol and nuclear waste collection center in Donetsk.

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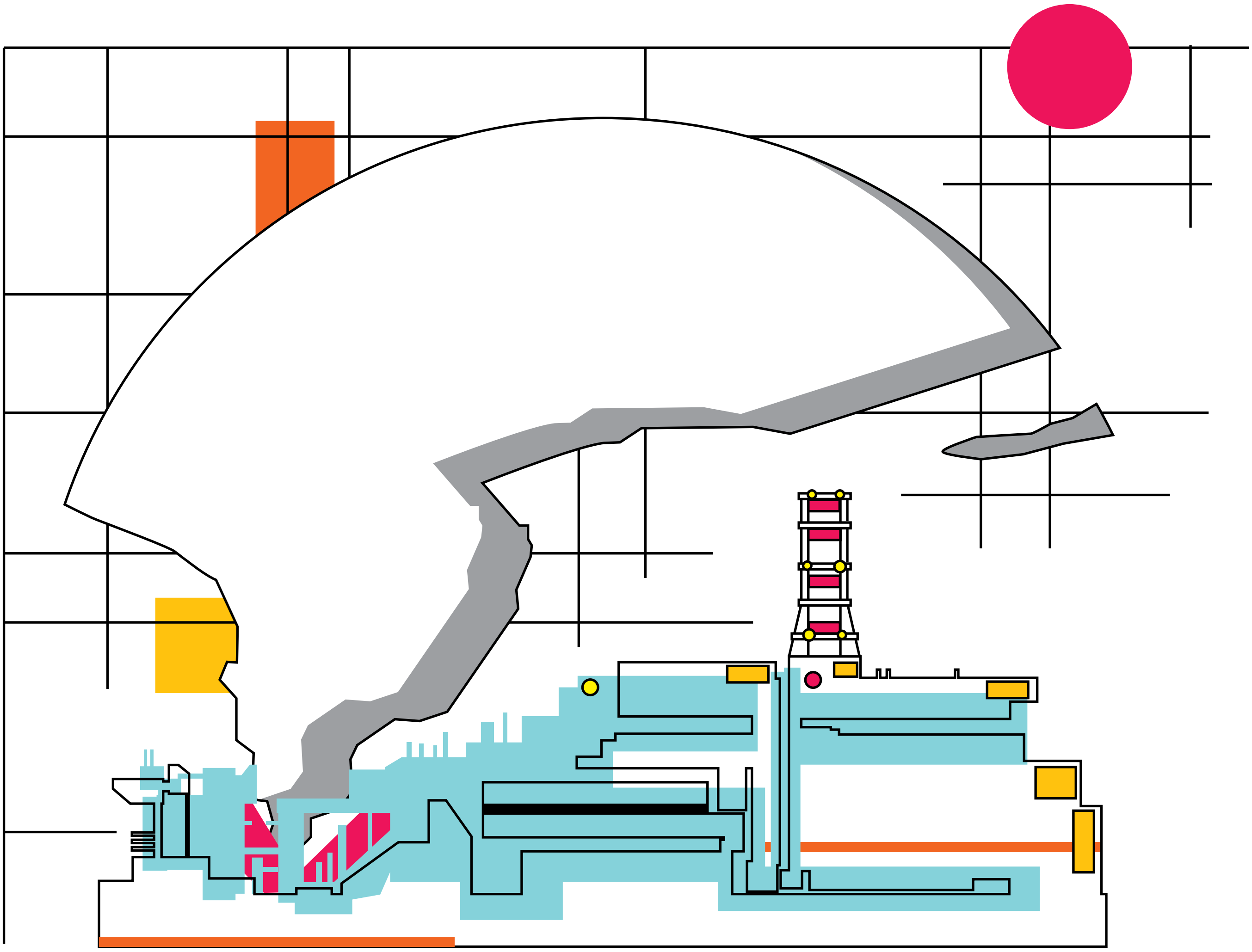
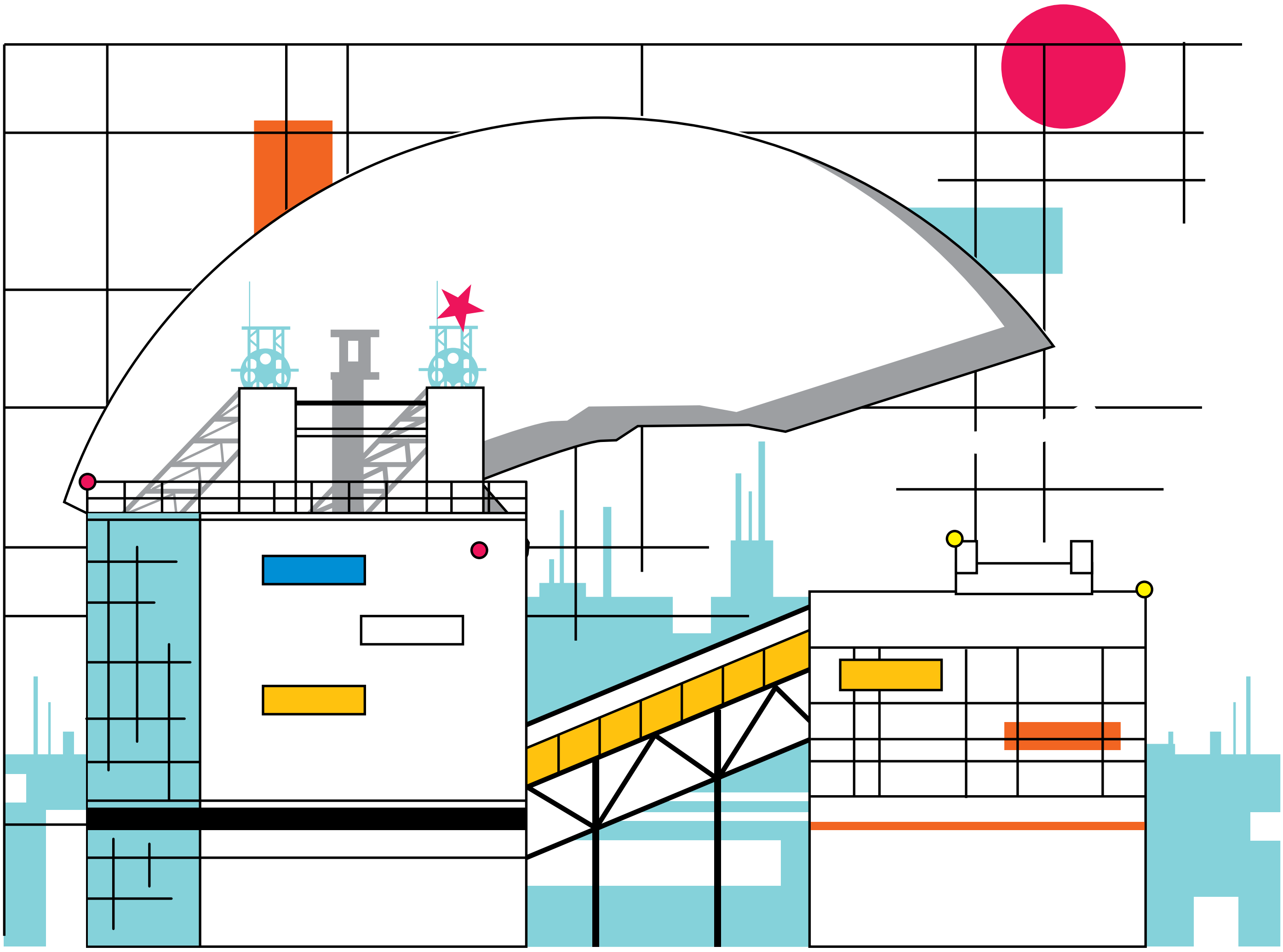


1. Introduction

Ukraine's 1986 Chornobyl nuclear accident led to the biggest release of radioactive materials from a destroyed nuclear reactor in history. Ever since, dealing with radioactive waste from the reactor's destruction has been the primary concern of the Ukrainian state and has garnered attention and financial support from the international community. Solving this problem required the nuclear industry to learn from its mistakes in attempting to put the waste under some level of control.

The Chornobyl exclusion zone defines Ukraine's waste strategy. The absence of a local population and that most of the country's nuclear waste is located in this area makes it suitable as a final disposal site (storage on the ground and a future deep geological disposal (DGD). The final disposal of the nuclear waste is regarded from a very long perspective. Ukrainian nuclear experts argue that there are richer and more advanced countries that perform research on strategies for final nuclear waste disposal, and thus Ukraine simply needs to wait for the time when best practices are defined.

Ukraine has traditionally sent its spent nuclear fuel to Russia for reprocessing. However, ever-growing costs led to the decision to build its own capacities that will allow for nuclear waste storage in the country for a period of 50 to 100 years. The Association agreement with the European Union means adaptations of the Ukrainian legislation to the relevant EU and Euratom Directives. This might require Ukraine to accelerate its decision making process on numerous aspects of nuclear waste and spent nuclear fuel management to meet EU Directives requirements (see legal framework section).



2. Nuclear waste disposal in Ukraine

2.1. Historical background

The Ukrainian nuclear industry originates from uranium mining development in the late 1940s as the USSR was developing its military nuclear program. VostGOK plant (abbreviation for 'Eastern ore processing plant') was established in 1951 and produced the first Uranium concentrate in 1959. Various facilities built as elements of the common USSR nuclear industry appeared in Ukrainian cities at Soviet times and continue to function today. The Turboatom company produced first turbines for the test nuclear reactors in 1956 and became the main facility to provide turbines for the nuclear power plants built by the USSR.

The construction of the first reactor in Soviet Ukraine, the Chornobyl Nuclear Power Plant, was started in 1970 and completed in 1977. By the time the Soviet Union collapsed in 1991, Ukraine had 15 operating nuclear reactors and 3 more in advanced stages of construction. There are 15 reactors in operation in Ukraine today.

The Chornobyl accident on April 26, 1986 which destroyed reactor number 4 has had a great impact not only on the global nuclear industry, but also on the destiny of USSR. In the moment of proclaimed transformation of Soviet society towards more openness, massive popular antinuclear movement have raised, mixing with the Ukrainian movement for independence. Mikhail Gorbachev, then the President of USSR, suggested that the accident "was perhaps the real cause of the collapse of the Soviet Union five years later" (Gorbachev 2006).

Still as a part of the USSR, the Ukrainian Parliament introduced a moratorium on construction of new nuclear reactors. This moratorium was subsequently abolished in 1993 as nuclear power was seen as a basis for energy independence. Ukraine had an ambition to develop a full nuclear cycle that would allow it to produce nuclear fuel domestically. Nuclear was seen as a solution for energy sector problems, as Ukraine received nuclear fuel for free in exchange of passing its nuclear weapons to Russia (following the Budapest Memorandum on Security Assurances). (Trofymovych 2016: 280).

Today, Ukraine's nuclear sector continues to depend on Russia, using Russian TVEL (nuclear fuel producer) as primary source for fresh nuclear fuel and continuing to send much of its spent nuclear fuel to Russia for reprocessing. The Ukrainian state, with support from Western governments and in cooperation with Westinghouse, has taken steps to limit this dependence by bringing in alternative fuel and building spent fuel storage facilities within Ukraine. However, the country is far from achieving independence in the nuclear sector.

Major accidents like Chornobyl as well as the overall safety and image of the Ukrainian nuclear industry were of major concern for governments and the nuclear industry in Europe and the USA. Various programs backed by financial support of the EU and USA were implemented following Ukrainian independence. EU technical assistance programs like Tacis (which has received €170 million in funding since 2007 from the Instrument for Nuclear Safety Cooperation) were given unusual rights to invest in industrial equipment, in contrast to their historic role as advisors. The European Commission has supported numerous projects to develop Ukrainian nuclear safety and waste management systems.

Management of the infrastructure and waste in the Chornobyl exclusion zone and development of the new shelter above the destroyed reactor became a truly international effort. Various projects financed by international donors and managed by the European Bank for Reconstruction and Development (EBRD) allowed implementation of massive projects as New Safe Confinement, which Ukraine would have a had difficult time implementing by itself. The various failures in this process (as the failure to build proper Spent Nuclear Fuel Storage by Areva, see section 2.4.2), however, have demonstrated how unprepared the nuclear industry is to deal with the challenges brought by accidents of Chornobyl scale.

Ukraine has leveraged the Chornobyl accident for its broader nuclear ambitions, communicating that it would not close operating Chornobyl reactors until it received funding from the G7 and EC governments for two new reactors: Khmelnitsky 2 and Rivne 4. After the long saga of the Khmelnitsky and Rivne reactors' (known as K2R4) project appraisal, the last operating unit (no. 3) at Chornobyl was shut down in December 2000. New Soviet design rectors were completed in 2004 with financial support from the EBRD and Euroatom. Conditions of the loans included that Ukraine develop an effective nuclear safety system.

External technical and financial support as well as Ukraine's active participation in relevant international treaties continue to improve the nuclear waste management system and regulatory framework. However, since the majority of nuclear waste originated from the Chornobyl accident, international practice is not fully applied. Critically, the state rather than the nuclear operator company is financially responsible.

Russian military intervention in Eastern Ukraine and Crimea has further complicated the situation. Ukrainian authorities have lost control over the storage of the nuclear waste in Donetsk and its research nuclear reactor in Sebastopol, although they remain responsible for nuclear safety at these sites. Most concerningly, the warfare involves heavy artillery and missiles just 200km away from the biggest European nuclear power plant at Zaporizhzhya and its dry spent nuclear fuel storage.

2.2. The national inventory

2.2.1. Categorization

Ukrainian legislation defines radioactive waste as radioactive materials created by human activity that cannot be further used (The Parliament of Ukraine 1995). Spent nuclear fuel does not formally fall into this category and the nuclear industry and the government believe that SNF contains valuable elements as uranium and plutonium that might be used in the future. However, different methods to categorize waste are used for different purposes. Besides, introduction of new categorizations of waste were done without cancelation of previous ones.

The Ministry of Health defines five different approaches to classifying radioactive waste in its *Main Sanitary rules of the Radiation Safety in Ukraine* (Ministry of Health 2005): aggregate state, types, groups, categories and kinds.

- Approach 1 – state of matter. Here waste is categorized by aggregate state into solid and liquid waste.
- Approach 2 – "types" - based on period of radioactivity. Short-lived RAW should have a potential radiation dose rate below 1mSv/year after 300 years from the moment of disposal. Consequently, monitoring of such a disposal site can be stopped or simplified. Such waste can be disposed at the near-surface facilities. Long-lived RAW will have a potential radiation dose above 50 mSv/year and should be stored in deep geological formations.
- Approach 3 – "groups" - RAW is also classified by the 'exemption level' as shown in Table 1.
- Approach 4 – "categories" – There are three categories of RAW based on specific activity range in kBq/kg: low level waste, intermediate level waste and high level waste. See details at Table 2.
- Approach 5 – "kinds" – classifies waste based on the half-life of the radionuclides in the waste as following:
  - Short-lived includes radionuclides with half-life of no more than 10 years;
  - Middle-lived includes radionuclides with a half-life between 10 and 100 years; and
  - Long-lived includes radionuclides with a half-life over 100 years.

  Short-lived RAW are further split into sub-categories referring to radionuclides with half-lives measured in days, weeks or years.

Table 1 RAW classified by the 'exemption level'

RAW group	Solid RAW	Exemption level kBq/kg
1	Transuranic alpha-emitting radionuclides	0.1
2	Alpha-emitting radionuclides	1.0
3	Beta- and Gamma- emitting radionuclides (Except those in the group 4)	10
4	3H, 14C, 36Cl, 45Ca, 53Mn, 55Fe, 59Ni, 63Ni, 93mNb, 99Tc, 109Cd, 135Cs, 147Pm, 151Sm, 171Tm, 204Tl	100

Source: Ministry of Health 2005

Table 2 Solid and liquid RAW categories based on specific activity

RAW Category		Solid RAW specific activity range, kBq/kg				Liquid RAW specific activity as a multiplier PC_B^{ingest}
		Alpha- emitting radionuclides		Beta- and Gamma- emitting radionuclides		
		Group 1	Group 2	Group 3	Group 4	
1	Low level waste	$>10^{-1}$ $<10^{1}$	$>10^{0}$ $<10^{2}$	$>10^{1}$ $<10^{3}$	$>10^{2}$ $<10^{4}$	>1 $<10^{2}$
2	Intermediate level was	$\geq10^{1}$ $<10^{5}$	$\geq10^{2}$ $<10^{6}$	$\geq10^{3}$ $<10^{7}$	$\geq10^{4}$ $<10^{8}$	$\geq10^{2}$ $<10^{6}$
3	High level waste	$\geq10^{5}$	$\geq10^{6}$	$\geq10^{7}$	$\geq10^{8}$	$\geq10^{6}$

Source: Ministry of Health 2005

Additionally, the Ministry of Health regulation enables classification by the technologies that lead to the creation of RAWs as well as accidental sources. Beyond these very different approaches to RAW categorization from the Ministry of Health, there are even more categories defined by other legal provisions. This circumstance creates confusion and makes it difficult for various actors to come to shared conclusions on appropriate waste management strategies.

Because of this situation, the EU Instrument for Nuclear Safety Cooperation project (U4.01/08-C) has been working in Ukraine to help update radioactive waste classification for disposal purposes. The suggested classification divides radioactive waste into classes to meet the requirements for disposal in four types of repositories: surface repository (landfill-type facilities with limited regulatory control); near-surface repository with a system of engineered barriers; underground repository located at intermediate depths; and DGD. The authors of the proposed system argue that moving to this classification system will make waste management cheaper, enabling simpler storage for low-level waste.

In this regard, system developers suggest to divide radioactive waste into the following classes: non-radioactive waste; natural radioactive materials (NORM); very low-level waste (VLLW); low-level waste (LLW); intermediate-level waste (ILW); high-level waste (HLW); and spent radiation sources (SRS). The updated classification is expected to provide considerable efficiency as radioactive waste is classified according to optimum disposal method and types of repositories. Draft legislation has been developed for adoption by Ukraine's parliament (Proskura 2014); however, the law remains absent from the parliament database.

2.2.2. RAW accounting

The fifth State Inventory of RAW was carried out in 2013. There are state registers of radiation sources and of radioactive waste, which exchange information in the process of this inventory. For example, 719 spent radioactive sources (SRS) were transferred to the Radon facilities in 2014 as RAW and 241 user stored 3715 SRS in 2014. There were 11,784 radioactive sealed sources in the register at the end of 2014 (State Nuclear Regulatory Inspectorate of Ukraine 2015a).

The most comprehensive overview of the radioactive waste stored and managed in Ukraine is available in English in the *National reports on Compliance with the Obligations under the Joint Convention on the Safety of Spent Fuel Management and on the Safety of Radioactive Waste Management*. The last of these reports was published by the State Nuclear Regulatory Inspectorate of Ukraine in 2008. Results of the fifth State Inventory of RAW cannot be found online.

The 2009 Radioactive Waste Management Strategy of Ukraine stated that 27 m^3 of solid and 35.1 m^3 of liquid radioactive waste is produced for every 1 bn kWh of nuclear electricity, which equates to 370 m^3 of solid and 480 m^3 of liquid waste per year. Collectively, Ukrainian solid waste storage sites were at 30-70% capacity and liquid waste storages at 21-76% capacity. The nearly full storages of the high-concentration salt solution at NPP sites was pointed out as a particularly important problem (Cabinet of Ministers of Ukraine 2009).

Table 3 Types of radioactive waste and the ways to handle it in Ukraine

Type of Liability	Long Term Management Policy	Funding of Liability	Current Practice/ Facilities	Planned Facilities
Spent fuel	Decision deferred	Funds set aside during operation	Reprocessing abroad and interim long-term storage	Interim Storage Facility -2 at ChNPP; centralized Interim Storage Facility; deep geologic repository
Nuclear fuel cycle waste	Treatment complexes at each NPP; final disposal at a centralized repository (*Vektor site*)	National RAW Fund (fees collected from electricity tariff)	On site storage, treatment at the NPP RAW complexes; Liquid Radioactive Waste Treatment Plant for ChNPP	Treatment complexes for all operating NPPs completion, Industrial Complex for Solid Radioactive Waste Management for ChNPP completion;
Application waste	Final disposal at centralized repository, (*Vektor site*)	National RAW Fund (fees paid by waste producers)	Storage and limited treatment at Radon facilities	Centralized processing and disposal facility, (*Vektor site*)
Decommissioning liabilities	ChNPP – plans in place, operating NPPs – strategy in place	Decommissioning Fund (fees collected from electricity tariff) ChNPP – state budget	ChNPP – final shutdown and conservation stage	
Disused sealed sources	Historic and orphan sources – centralized repository; new – return to producers/ centralized repository	National RAW Fund (fees paid by waste producers); state budget for legacy	Storage at Radon facilities	Centralized processing and long-term storage (Vektor site); deep geologic repository

Source: State Nuclear Regulatory Inspectorate of Ukraine 2015a

Estimates for the total amount of solid RAW and liquid RAW in Ukraine are 2,960,000 m^3 and 42,340 m^3, respectively. The distribution of nuclear waste at various sites is as follows:

Table 4 Share of Solid Radioactive Waste in Ukraine by location

Location	Share of all Solid Waste (%)
Exclusion zone (Temporary waste Localization Sites)	72.4
Shelter over Destroyed Chornobyl 4 unit	20.2
Radioactive Materials Storages	5.8
Chornobyl NPP site	0,1
Nuclear Power Plants	1,3
"Radon" Waste Storages	0.2

Source: Gramotkin 2016[1]

Table 5 Share of Liquid Radioactive Waste in Ukraine by location

	Share of all Liquid Waste (%)
Chornobyl Nuclear Power Plant	47.2
Other Nuclear Power Plants	43.9
"Shelter"	5.9
"Radon" Waste Storages	1.9
Research Nuclear Reactors	1.1

Source: Gramotkin 2016[1]

The estimated amount of the radioactive waste stored at Chornobyl NPP storages is 21,000 m^3 of liquid radioactive waste and 2,500 m^3 of solid radioactive waste. Another 500 m^3 of liquid RAW and 225,000 m^3 of solid RAW will be produced at the process of Chornobyl NPP decommissioning (Gramotkin 2016)1.

2.2.3. RAW at Nuclear Power Plants

The National Nuclear Energy Generating Company, Energoatom, implemented the "Comprehensive Program for Radioactive Waste Management" in 2012-2016. As a result of this program, there is ongoing construction of RAW Treatment Plants NPP sites in order to minimize RAW and prepare for disposal or long-term storage in the centralized near-surface disposal facilities at the Vektor site, once it is built (State Nuclear Regulatory Inspectorate of Ukraine 2015a: 20).

Energoatom NPPs produce on average 27 m^3 SRAW and 35m^3 LRAW per 1 bn kWt·h of electricity produced. The lack of space at the temporary storage sites becomes a problem in view of plans to extend the lifetime of the reactors. The situation is made even more difficult by the presence of liquid radioactive waste: according to current legislation, it is not suitable for disposal and there are no facilities to solidify this waste (Kondratiev 2016: 41).

Chornobyl NPP has three reactors that continued to operate after the accident at unit 4 in 1986. The last one was shut down in 2000. Activities to decommission units 1, 2 and 3 of the plant are ongoing. High-level RAW are collected in special containers (KTZV-0.2) and are held in temporary storage organized at the building originally used to store fresh nuclear fuel. Low and medium level waste is sent directly to Buriakivka storage (Kondratiev 2016). In the process of decommissioning the Chornobyl site, 0.03 m^3 (0,012 t) of solid radioactive waste was accumulated in 2014. Overall 3,783 m^3 of high-level and long-live RAW is stored there with a cumulative activity of 8.59 TBq (State Nuclear Regulatory Inspectorate of Ukraine 2015b).

1 The author of the document is not confirmed. The document is not published and was obtained by email. Figures correspond well to other sources.

At the Chornobyl site, there is an Industrial Complex for Solid Radioactive Waste Management (ICSRM) constructed by RWE NUKEM GmbH with the European Commission support, as well as a Liquid Radioactive Waste Treatment Plant (LRWTP) built with EBRD support. The European Commission has also financed construction of the Long-Length Waste Cutting Facility at Chornobyl NPP (LICF Project). All of the facilities were completed in recent years.

2.2.4. RAW at destroyed Chornobyl reactor

2006 estimates suggested that there are 400,000 to 1,740,000 m^3 of RAW located in the Object Shelter (OS) (also known as the 'Sarcophagus') at the site of the destroyed Chornobyl NPP unit 4. High level of radiation and destruction caused by the explosion makes it difficult to have precise estimates. At the beginning of 2005, their total activity was known to be about 4.1×10^{17} Bq.

Over 10% of the total amount of the OS RAW is high level waste (HLW), a significant amount of which is concrete, metal structures and equipment and other materials from the reactor. Over 2,800 t of HLW are fuel content materials (FCM), including lava-like FCM, fragments of the reactor active zone, reactor graphite and fuel dust.

At the OS, there is constant accumulation of atmospheric water, condensate and liquids of technological origin. Liquid RAW (LRW) has arisen from the interaction of water with radioactive materials. Annually, up to 900 m^3 of LRW are pumped from the accessible OS rooms and transported to the onsite treatment and storage system for LRW. In process of OS operation, including transformation of the OS into an environmentally safe system (OS stabilization stage), considerable amounts of solid RAW have arisen and have been disposed of at the Buryakivka Radioactive Waste Disposal Site (RWDS) (Ministry of Ukraine of Emergencies and Affairs of population protection from the consequences of Chornobyl Catastrophe 2006).

Radionuclide and chemical composition of LRW depends on its location. Water inside the OS is characterized with presence of Cs134, Cs137, Sr90, Pu239-240 and Am241 as well as organic and membrane-forming compounds (State Nuclear Regulatory Committee of Ukraine 2008b).

According to the state register of radioactive waste in 2007, the following radioactive waste is located inside the OS and at its site:

Table 6 Radioactive waste is located inside the OS and at its site

№	Type of RAW; (location)	Physical state	Category of activity	Volume, m^3	General activity, TBq	Nuclide composition%
1.	Solid radwaste[1], located inside Shelter and at Shelter industrial site, occurred as a result of accident and works on elimination of accident consequences	Fresh and spent fuel assemblies, lava-like FCM, dust, metal equipment, construction -and-assembly elements, etc.	Intermediate and high-level	530,400 – 1,737,400	740,000 (20 MCi)	Mix of radionuclides (uranium, caesium, strontium, cobalt, transuranium elements – plutonium, americium and others)
2.	After-accident waste[2] located inside Shelter	Liquid RAW	Intermediate and low-level	2,500 – 3,000[2]	12,4 (335 Ci)	Mix of radionuclides: uranium, caesium, strontium, plutonium and others.

Notes by SNRCU: 1. Data in table is approximate and based on the results of research.
2. Amount of liquid waste changes every year depending on atmospheric precipitation that fall inside Shelter (State Nuclear Regulatory Committee of Ukraine 2008b: 93).

A major international effort to make the Chornobyl accident site as safe as possible, the Shelter Implementation Plan (SIP), was implemented in 1997 and managed by the EBRD with financial support from the USA, European Commission and various national governments.

The SIP effort was first focused on developing proper monitor systems inside of the Object Shelter, developing surrounding infrastructure and then stabilising the sarcophagus to manage the risk of an accidental collapse. One of the walls was stabilised with steel structures to take some of the weight off the roof.

In November 2016, a milestone in the completion of the extraordinary New Safe Confinement (NSC) was achieved when an arch-shaped structure weighing 36,000 tonnes and standing 108 meters tall was moved from the construction site over the SO. The structure includes massive cranes and is designed in a way that allows for disassembly of the old sarcophagus and further retrieval of the nuclear waste inside the destroyed reactor.

NSC construction started in 2010. The cost of the NSC now stays at €1,504 million (€1,424 million plus €80 million of unexpected costs), according to the Ukrainian Accounting Chamber. It is designed to be in operation for 100 years.

Overall costs of the Shelter Implementation Plan are expected to amount to €2.1 billion; the plan is to be completed by 2017. It is funded by contributions from more than 40 countries and organisations.

2.2.5. RAW at the Chornobyl exclusion zone

The Chornobyl accident created a great amount of RAW that requires very special attention. Dealing with the nuclear waste storage systems created right in a rush after the accident further complicates the situation, as these systems do not meet current nuclear safety requirements. Hundreds of thousands of cubic meters of radioactive waste are stored at more than 600 interim radioactive waste locations and under the Chornobyl Shelter. A significant share of this waste is considered long-lived radioactive waste (State Nuclear Regulatory Inspectorate of Ukraine 2015a). Buryakivka, Pidlisny and Chornobyl NPP Stage III are major sites of radioactive waste disposal in Chornobyl exclusion zone.

Buryakivka RWDS has been in operation since 1987. Buryakivka RWDS is composed of 30 near-surface storage modules (trenches) for RAW disposal. The main engineering barrier which provides for radionuclide storage is a special clay protective layer, 1 meter thick. Since the Buryakivka RWDS began operation, approximately 1,330.5 thousand tons (665.25 thousand m^3) of Chornobyl origin RAW were located in the trenches with total capacity 2.53 E15 Bq (as of the late 2012).

Pidlisny RDWS and Chornobyl NPP Stage III RDWS were constructed during the years following the Chornobyl accident. These facilities contained the most dangerous high-activity and long-lived emergency RAW. According to the State Nuclear Regulatory Inspectorate, in future, all RAW will be removed and re-disposed of in geological storage facilities. Before beginning construction of these geological storage facilities, the safety of existing facilities is to be maintained and improved. Accordingly, activities to protect waste disposal sites from degradation and support necessary localizing functions of the engineering barriers of these storage facilities, as well as to create additional barriers and to improve monitoring systems, were carried out in 2012 (State Nuclear Regulatory Inspectorate of Ukraine 2013).

As most of Ukraine's nuclear waste is located in the Chornobyl exclusion zone, where there is also an availability of nuclear infrastructure and small local population, this zone was chosen to host all of the country's RAW. The Vektor complex at the edge of the 30-km zone is supposed to accumulate all of the waste from various facilities. The design of the complex envisions storage of the 533,644 m^3 of RAW. The first stage of the complex development envisions two facilities and supporting infrastructure with a total volume of 19,200 m^3. Construction started in 2000 and was stopped in 2010 due to lack of funding. Thus, some of the elements constructed at the beginning of this process have started to deteriorate (State Nuclear Regulatory Inspectorate of Ukraine 2016: 66).

2.2.6. RAW from non-NPP sources

Non-NPP Radioactive waste is systemically managed via the Radon facilities which are situated at six locations across the country. There were 539,728 ionizing radiation sources with total 2,86E+16 Bq and 5864 m^3 of RAW, totalling 7,28E+15 BQ at the Radon sites in 2014 (State Nuclear Regulatory Inspectorate of Ukraine 2015b: 50). In light of the outdated standards at these storage sites there is a plan eventually to move the waste to the centralised storage at the Vektor complex. First, however, approval is required for the operational and technical approaches to extract the waste from existing wells at Radon sites, as these sites were not designed for waste retrieval. Funding and possible personnel exposure to radiation during extraction operation are the key limiting factors to handle this task.

In 2014, there were 14 cases of unexpected radioactive materials identification – in most cases radioactive sources found in the scrap-metal brought to metallurgy plants (State Nuclear Regulatory Inspectorate of Ukraine 2015b: 47).

Ukraine has over a dozen uranium tailing sites created by the mining and enrichment industry. Some, like Balka Scherbakivska, are operational, while others are closed. There was no proper management of the sites following the collapse of the Soviet Union, and thus the nearby population continues to be at risk. Various programs to manage the risk of radioactive pollution were designed by state bodies, but often lack funding for implementation. According to the Radiation Safety Standards of Ukraine, waste from the uranium mining industry is not considered RAW.

There are four RAW disposal sites remaining from the former activities of the USSR Army. These are maintained by the Ministry of Defence and State Border Guard Service of Ukraine (State Nuclear Regulatory Inspectorate of Ukraine 2014: 31).

2.3. Spent Fuel

2.3.1. Chornobyl reactors

There is spent nuclear fuel stored in 21,284 spent fuel assemblies (SFA) at the site of Chornobyl NPP. There is no fresh nuclear fuel at the Chornobyl site. The majority of SFAs (21,231.5)[2] is stored in the cooling pool of the Wet Spent Fuel Storage Facility (ISF-1), which was commissioned in 1986. There remaining 52.5 SFAs (which are damaged) are stored in the cooling pools of unit 1 and 2 of Chornobyl NPP (ChNPP) (State Nuclear Regulatory Inspectorate of Ukraine 2015b). The State Specialized Enterprise Chornobyl NPP is in charge of Chornobyl SNF.

The life-time of ISF-1 is until 2025, following an earlier decision by the nuclear regulator. A new dry type storage facility (ISF-2) is under construction at the ChNPP site in order to provide for safe long-term storage of all spent nuclear fuel. This construction is sponsored by the international community as a part of safe Chornobyl plant decommissioning efforts. It was originally planned to be completed in 2004. The construction was started by French company Areva, but the contract was cancelled as the storage technology was shown to be inadequate for the Chornobyl SNF. Construction was subsequently taken over by the US company Holtec and is currently at a late stage of completion.

2.3.2. Research reactors

Spent fuel from the WWR-M research reactor of NASU INR (Kyiv) is stored in a SF storage facility at the research reactor itself. There has been no decision made on its future. The Ministry of Education and Science is responsible for the management of this SNF. The research reactor IR-100 at the Sebastopol Nuclear Energy and Industry Insti-

2 Some spent fuel assemblies are broken, thus 0,5 of SFA

tute (Sebastopol) has no SF – based on the definition of spent fuel in the Joint Convention (State Nuclear Regulatory Committee of Ukraine 2008b: 13).

Following the Russia's annexation of Crimea, the Ukrainian nuclear regulator has lost contact with the management of the Sebastopol Nuclear Energy and Industry Institute and invalidated its licence for reactor operation (State Nuclear Regulatory Inspectorate of Ukraine 2015b: 10).

2.3.3. Operating commercial reactors

Ukraine has arrangements with the Russian Federation for spent fuel from Khmelnitsky, Rivne and South Ukraine NPPs. The spent fuel is transported to the Mayak facility at Chelyabinsk oblast of the Russian Federation. The WWER-440 fuel (from the units 1 and 2 of Rivne NPPs) is reprocessed there, while WWER-1000 fuel is stored. Mayak is expected to finalise the WWER-1000 reprocessing process development and will start WWER-1000 fuel reprocessing in 2017. The contract for the processing of Ukrainian WWER-440 fuel suggests that Ukraine should start receiving radioactive waste accumulated from reprocessing in 2018.

The high radioactive waste created from reprocessing in Russia should come back to Ukraine. However, the storage for the disposal of this waste is not yet constructed. The government plan is to build an appropriate facility at the Vektor complex.

To reduce the cost associated with SNF management, a dry storage facility was built at Zaporizhzhya NPP. The feasibility study done by Energoatom and approved by the Cabinet of Ministers of Ukraine in 2009 showed the economic viability of storing SNF in Ukraine, rather then sending it to the Russian Federation. Building a single centralised storage site was chosen as the most efficient approach (State Nuclear Regulatory Inspectorate of Ukraine 2015b: 39). The decision has been criticised by environmental NGOs which suggest that storage systems should be built at NPP sites and transferred to the site of final disposal once it is ready.

2.3.4. Alternative Westinghouse fuel

Almost all of the fuel used by the Ukrainian NPPs is produced by the Russian TVEL manufacturer. Since late 1990s, Ukraine has cooperated with the Westinghouse company to become an alternative producer of nuclear fuel for WWER reactors. So far, the fuel produced at the Westinghouse factory in Sweden has been tested at the South Ukraine NPP and the tests have recently been extended to include the Zaporizhzhya NPP.

We can expect that the handling of spent Westinghouse fuel should not be different from that produced by TVEL. However, this fuel will not be sent to Russia for reprocessing and instead needs to be stored in Ukraine. There is the dry storage at Zaporizhzhya NPP. But for the South Ukraine NPP, fuel should stay on site until the Centralised Dry Storage is commissioned in the Chornobyl Exclusion Zone and the spent fuel of all Ukrainian NPPs (but Zaporizhzhya) is transported there.

2.4. The (interim) storage sites

2.4.1. Radioactive waste at NPPs

Nuclear power plants in Ukraine manage and store their radioactive waste at their sites. The key deficiency of the current practice is the absence of facilities to prepare radioactive waste for long-term storage or disposal. It is expected that this waste will be transported to the centralised Vektor storage once it is fully operational.

Most of the solid radioactive waste is generated at NPPs during maintenance, repair and modernisation work. About 80% of solid waste is rags, insulation materials, metal and concrete pieces of the equipment and buildings. Liquid waste is made up of the trapped water coming from the leakage of the primary circuit, cooling pool, discharges from the deactivation rooms and test laboratories, etc. Still bottoms that are formed in the process of evaporation of radioactive waters, as well as sorbents and molten salt formed by further evaporation process are also considered to be liquid waste.

Solid waste is sorted primarily based on the dose rate and stored at the temporary storage on site, both in bulk and in 200 litters steel barrels. There were no plans to use installations of the deep evaporation of liquid waste at the time of the NPP's design, so there is no dedicated storage for salt fusion cake. This is instead housed at solid waste storages.

The lack of space at the temporary RAW storage systems becomes a problem in view of the plans to extend lifetime of the reactors. The situation is further compounded by the challenges of the liquid radioactive waste: it is not suitable for disposal (according to current legislation) and there are no facilities to solidify it.

Energoatom is implementing a program to build facilities for solid radioactive waste management at the power plants. Such complexes are in late-stage construction at Zaporizhzhya and Rivne power plants. Construction of solid waste treatment facilities at Khmelnitsky plant is about to start. There is no final decision to build such a facility at the South Ukraine NPP (Kondratiev 2016).

All NPPs have systems for liquid radioactive waste storage. LRW is stored in stainless steel containers with an alarm system to detect leakages. The containers are stored in concrete spaces covered with the stainless steel sheets. NPPs have evaporation facilities with different levels of efficiency each.

Solid wastes are sorted according to gamma radiation intensity and are transported to the temporary storage units on site. Some NPPs have facilities to reduce the volume of waste by compacting with pressure (ZNPP and SUNPP) or incineration (ZNPP). The storage units are concrete buildings divided into different sections by waste type. There are fire alarm and automatic firefighting systems as well as filtered ventilation systems (State Enterprise 'National Nuclear Energy Generating Company 'Energoatom'' 2014: 12).

2.4.2. Spent Nuclear Fuel

Currently Ukraine has two facilities for the temporary storage of SNF: Intermediate Spent Fuel Storage (ISF) 1 (wet) at the Chornobyl NPP and ISF (dry) at the Zaporizhzhya NPP. There are two more storage facilities under construction: ISF-2 (dry) at the Chornobyl NPP and Centralised ISF for the fuel of the WWER reactors at multiple Ukrainian NPPs. While the first is about to start operations, the second is still a greenfield project.

ISF (dry) at Zaporizhzhya NPP (only for SNF generated at Zaporizhzhya) – in operation

Zaporizhzhya NPP was the first to reach the end of available space at the spent fuel pools on site. The resulting Dry Type Spent Fuel Storage Facility project was started in 1996 and first stage of the storage was completed in 2001, with capacity for 100 ventilated storage casks. The second stage was completed in 2011. The storage facility is designed to fit 380 casks with 9,000 fuel assemblies inside. There were 124 casks on site as of January 1, 2015.

The storage facility was designed by the US company Duke Engineering & Services. The cask includes 24 fuel assemblies that spent five years at the spent fuel pool and have low energy production (below 1 kWh) (State Nuclear Regulatory Inspectorate of Ukraine 2015b: 38).

ISF-1 (wet) at Chornobyl NPP – in operation

The Chornobyl SNF of the RBMK type was supposed to stay in the cooling pools next to reactors for no less than 1.5 years and then stored in the wet SNF storage. There are 21,284 fuel assemblies at Chornobyl NPP site as of January 1, 2015. There are 52.5 damaged SFAs in the pools of the reactors 1 (32) and 2 (20.5) and 21,231.5 undamaged SFAs in the ISF-1.

Chornobyl NPP State Enterprise is responsible for implementing the action plan to improve safety of ISF-1. ISF-1 was supposed to be free of fuel and closed in 2016, but will need to operate longer as the replacement (ISF-2) was not commissioned in time. The life-time of ISF-1 will end in 2025, based on the safety reassessment conducted in 2011 (State Nuclear Regulatory Inspectorate of Ukraine 2015b: 42).

ISF-2 (dry) at Chornobyl NPP - under construction

The contract to build new spent fuel storage for the Chornobyl NPP fuel was signed by Ukrainian government with Framatome (now Areva) in 1999. The spent nuclear fuel from Chornobyl's no. 1, 2 and 3 reactors was to be stored there for at least 100 years. It was expected that facility will be ready by the year 2005. The project was a part of the special fund managed by the European Bank for Reconstruction and Development (EBRD). However, in 2004, it became clear that Areva's technical solution was not suitable for the Chornobyl reactors' fuel and construction was stopped. Areva had to pay a fine.

Areva's contract was taken over by Holtec International in September 2007. The new facility would retain the concrete structures built by Vinci and Bouygues, as well as some equipment. Work at the site only resumed in October 2014, 14 years after its start and 11 years after the shutdown of the construction managed by Areva. The total cost of the storage facility has about quadrupled in the meantime. Today, total costs are tentatively estimated at more than €300 million.

The design of ISF-2 suggests that the fuel assemblies will be divided into two parts. Each part will be placed in special cartridge. Then, each of the 186 cartridges will be put into hermetic steel containers with helium. These containers will be stored in concrete storage modules, where they can stay for 100 years. The design allows for extraction of the containers, to see if they are still hermetically sealed, and repacking if necessary (State Nuclear Regulatory Inspectorate of Ukraine 2015b: 43).

CSFSF (dry) for the SF from Khmelnytska, Rivne and South Ukraine NPPs – site is selected, designing is ongoing

The Centralized Spent Fuel Storage Facility (CSFSF) is designed to have capacity for 12,500 SFA of WWER-1000 and 4,000 SFA of WWER-440 type and to operate for 100 years. The decision to locate central storage in the Chornobyl Exclusion Zone is spelled out in the law 4384-VI approved on February 9, 2012 by the Parliament of Ukraine.

The Cabinet of Ministers approved the process for allocating 45.2 hectares of land between the relocated villages of Stara Krasnytsia, Buriakivka, Chystogalivka and Stechanka of Kyiv oblast to Energoatom to build the storage and connecting railroad (State Nuclear Regulatory Inspectorate of Ukraine 2015b: 40).

In 2014, Energoatom was assigned to operate CSFSF. In that same year, the State Agency of Ukraine for the Exclusion Zone Management obtained a special permit for preparatory works on CSFSF construction.

The current contract with Holtec International requires the company to supply the specified process equipment to store 2,511 SFA of WWER-1000 and 1,105 SFA of WWER-440, supply spent fuel handling and storage technology and implement other activities to support the establishment of the CSFSF. In 2015, the operator (NNEGC Energoatom) with the support from IAEA experts, developed the "Plan for Equipment Infrastructure Requirements for the Spent Fuel Transfer Process in Ukraine: NPPs to CSFSF" (State Nuclear Regulatory Inspectorate of Ukraine 2015a: 42).

2.5. The waste management strategy (with current waste disposal plan/concept)

Implementation of state strategy in the area of radioactive waste management is performed in accordance with the Strategy on Radioactive Waste Management in Ukraine (up to 2060), the National Environmental Program on Radioactive Waste Management and the National Program on Chornobyl NPP decommissioning and Shelter Transformation into an Environmentally Safe System.

The strategy includes organizational and technical measures directed at the management of so-called "post Chornobyl" waste, localized in the Exclusion Zone at the ChNPP site. In the Exclusion Zone at the ChNPP site and at the site of Vektor Complex, a number of new facilities for RAW management are being constructed: for removal of RAW from existing temporary storage facilities; sorting, processing and conditioning of RAW; new facilities for RAW storage; and near surface storage facilities for conditioned RAW (State Nuclear Regulatory Inspectorate of Ukraine 2013).

The strategy is designed for 50 years. This is the time needed to develop an entire infrastructure for radioactive waste storage and mitigate the long-term nature of radioactive waste threats.

The strategy will be implemented in three stages. The first stage (10 years) includes:
- Developing a proper legal base,
- Developing a national institution to manage waste disposal,
- Development and introduction of the financing mechanisms,
- Creation of new and modernization of the existing facilities for processing, conditioning and packaging of radioactive waste in accordance to the requirements for the waste to be stored and disposed,
- Development of the containers and vehicle fleets to transport the waste,
- Designing, construction and operation of the storage systems for short-term low- and medium- level waste, as well as storage systems for high level and long-term low- and medium level waste,
- Identification of a site to dispose high level and long-lived low- and medium level waste in deep geological formations.

The second stage (30 years) includes:
- Completing work to clean up dangerous storage of radioactive waste of Chornobyl origin, as well as dangerous storages of waste from the state corporation UkrDO 'Radon' and national defence programs,
- Exclusion, conditioning and transfer for the ultimate disposal of the operational radioactive waste from NPP storage units as well as the waste generated from NPP (including Chornobyl NPP),
- Disposal of all short-lived low and medium level waste,
- Storage of the high level and long-lived low- and middle- level waste,
- Design, construction and commissioning of the storage system for high level and long-lived low- and middle- level waste,
- Design of the technologies, equipment and work to extract radioactive waste from the Chornobyl unit 4 OS.

The third stage (10 years) includes:
- Operation of the equipment to condition and pack radioactive waste of all types and categories,
- Transportation to the storage units for disposal,
- Operation of the storage units to dispose radioactive waste of all types and categories,
- Finalising works to dispose radioactive waste created in the process of the Chornobyl NPP decommissioning and turning the OS into an environmentally safe site,
- Conducting activities to rehabilitate radioactively polluted areas.

(Cabinet of Ministers of Ukraine 2009)

The main aspects of the RW management system development are as follows:
- On-site treatment of the NPP RW to the condition when it can be disposed of or stored for a long time,
- Collection, conditioning, temporary storage, transportation of RW created by medicine, science, industry at the specialized regional enterprise of the State Company UkrDO Radon,
- Centralized disposal of the low- middle level short-lived RW and long term storage of the long-lived and high-level RW of all origins at the storage units of the Vektor complex,
- Disposal of the long-lived and high-level RW in geological storage systems,
- Creation of the national RW Management Organization,
- Providing sustainable and sufficient financing of RW management activities,
- Development of the legal base and international cooperation.

(Datsenko 2015)

2.5.1. Vektor facility

The strategy for nuclear waste management is based on the idea of having one centralized storage for different types of waste at the Vektor complex. Different onsite facilities will handle radioactive waste from Chornobyl NPP and the Exclusion zone as well as from sealed radioactive sources:

- Centralized near-surface disposal facilities for solid RAW:
  - An engineered near-surface disposal facility for solid radioactive waste at the Vektor Site is in operation
  - Two near-surface disposal facilities (SRW-1 and SRW-2) are under construction
  - Management infrastructure is established
- A Centralized Long-Term Storage Facility for Spent Sources (CLTSF) is under construction
- A special facility is being designed for long-term storage of vitrified high-level RAW to be returned after reprocessing of SF from NPPs
- A facility for long-term storage of long-lived RAW is being designed
- A facility for long-term storage of high-level RAW from Object Shelter is being designed

(State Nuclear Regulatory Inspectorate of Ukraine 2015a: 12)

Constructions of all facilities at Vektor are constantly delayed because of the lack of funding. For example, the infrastructure for glassification of the waste to be returned from Russia was supposed to be completed in 2010 (Energoatom letter to Chornobyl trade unions). Five storage units corresponding with the second phase were supposed to be completed by 2012.

2.5.2. Spent Nuclear Fuel

Ukraine has not made a decision on the final management of SNF beyond long-term storage. Thus, Ukraine has a delayed decision strategy. Additionally, there is no clear unified plan for SNF management by the state. The "Spent nuclear fuel management and centralised storage design, location and construction" law only deals with fuel from the WWER reactors and states that it will be managed by Chornobyl NPP SSE along with the separate storage of spent fuel storage from the Chornobyl reactors. However, the construction of the Centralised Dry Storage is managed by Energoatom.

While there is a special fund for radioactive waste management, there is no such fund for spent nuclear fuel. Rather, the expectation is that the nuclear operator is in control of the situation and will solve problems as part of the operational costs.

Final Disposal Plan

The process to identify the site for deep geological disposal (DGD) in Ukraine started in 1993. From1996 to 2003, a screening of possible sites across Ukraine was conducted. In 2000-2006, complex research on two of the preferred sites was implemented as along with research into the conceptual design of the geological disposal and RAW isolation technologies.

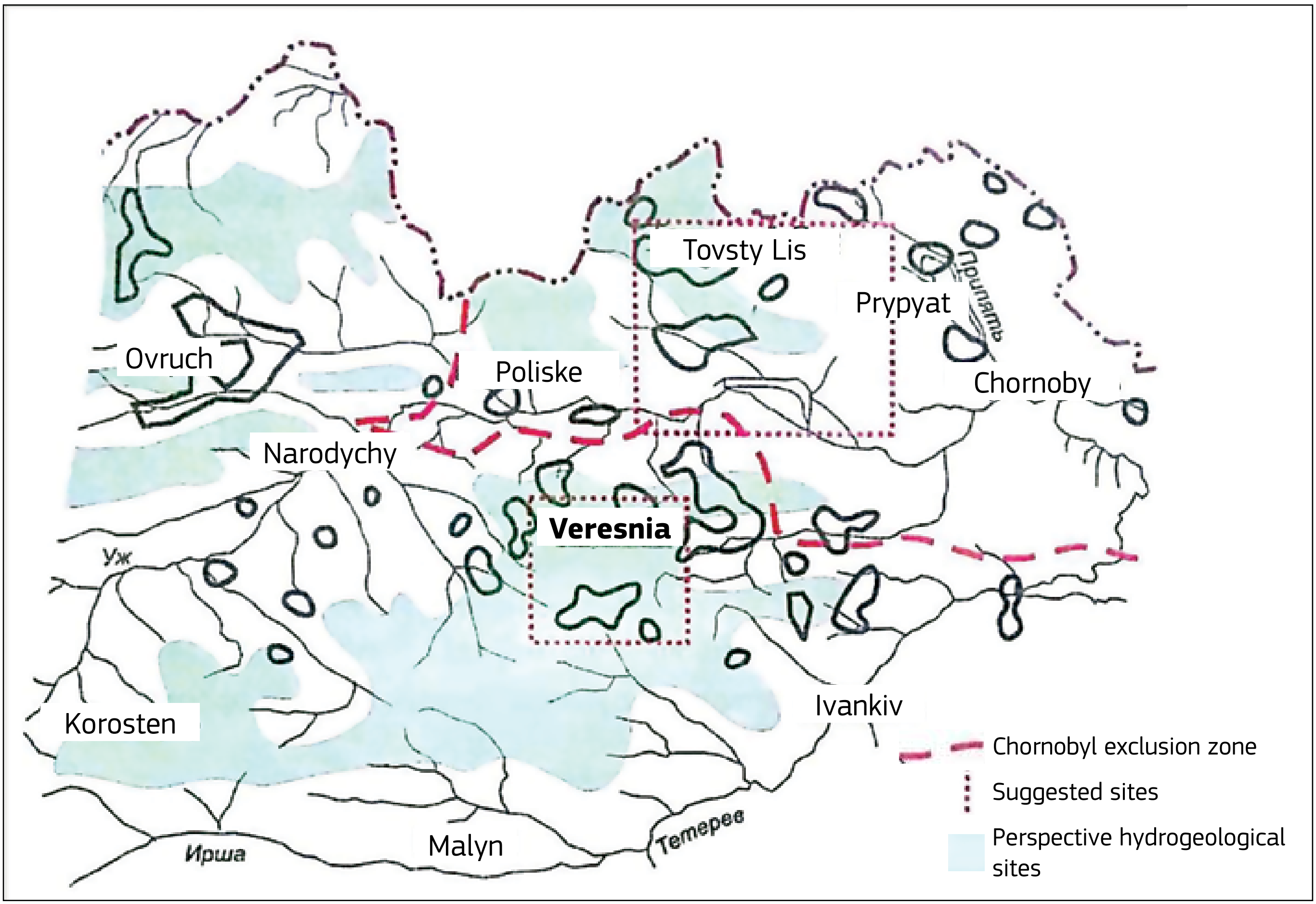
Designers of the DGD assume that it will be a place for SNF storage as well as classified RAW. There is also an assumption that Ukraine will be building new nuclear power plants until 2030 as described by the Energy Strategy of Ukraine (now outdated, as new versions of the strategy cancelled proposals to construct 20 new reactors by 2030) (Shybetskyi 2011).

Preliminary investigations have shortlisted sites for a DGD for high- and intermediate-level wastes, including all those arising from Chornobyl decommissioning and clean-up. It is assumed that approximately 59,000 m^3 of long-lived waste must be disposed of in the geological repository. With 95% of the total volume of long-lived waste stored at the Chornobyl Exclusion Zone, there was dedicated research to use this area for final disposal.

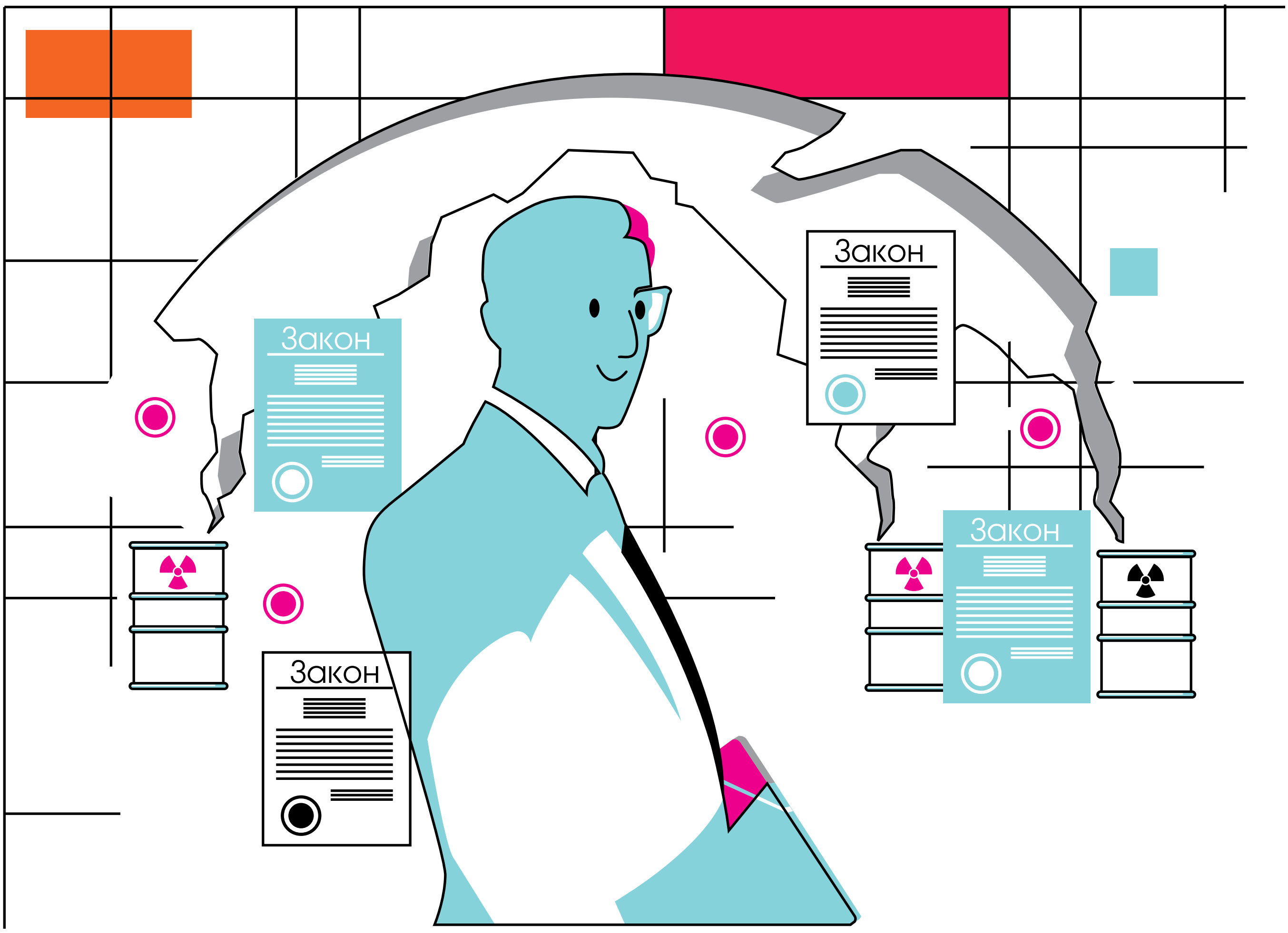
Most of this research has been conducted within the framework of international technical assistance projects with the aim of providing scientific grounds for the future decision-making.

Based on geological and geophysical investigations conducted in 2001-2003, two areas within the Ukrainian Shield were selected for deep boreholes: Veresnia and Tovsty Lis (see Figure 1).

Figure 1 Suggested geological disposal sites based on hydrogeological and geodynamic characteristics.



Source: Shestopalov 2006: 231



3. The legal and institutional framework

3.1. The legal framework

Ukrainian legislation in the field of radioactive waste management attempts to mirror the developments in international rules and best practices. A number of laws were developed as a part of the technical assistance provided by the European Union. The need to implement these provisions is consequently challenge for the regulator. In one case, there is even a typographical mistake in the figures that defines the category of the waste made into a law.

In 2015, the regulator presented the concept of legal base improvement in order to match the hybrid of Soviet strict regulations with the Western approach, in which some of the provisions are recommendations.[3]

Different aspects of waste management are covered by a number of Ukrainian laws:

- On the Use of Nuclear Energy and Radiation Safety;
- On Radioactive Waste Management;
- On Protection of Human Against Impact of Ionizing Radiation;
- On Decision Making Procedure for Sitting, Design, Construction of Nuclear Facilities and Objects for Radioactive Waste Management of State Importance;

3 Selected Ukrainian regulations on nuclear waste are available in English at: http://www.snrc.gov.ua/nuclear/en/doccatalog/list?currDir=119835

- On Physical Protection of Nuclear Facilities, Nuclear Materials, Radioactive Waste and Other Sources of Ionizing Radiation; and
- On Permissive Activity in the Area of Nuclear Energy Use.

RAW management is further defined in norms, regulations and standards of nuclear and radiation safety:
- Radioactive waste management. Requirements to the radioactive waste management until their disposal. General provisions;
- Radioactive waste management. Radioactive waste disposal in near surface storages.
- General radiation safety requirements;
- General provisions of safe disposal of radioactive waste in geological repositories;
- General provisions of NPP safety.

(State Nuclear Regulatory Committee of Ukraine 2008b)

The Law on the Use of Nuclear Energy and Radiation Safety (1995) is the key legislation of the sector. It defines the decision-making process regarding the location, construction and decommissioning of RAW management facilities, among other things. The law references 1) *the probability of an ionising radiation impact*, 2) *the number of people that are effected* and 3) *the individual doses should be the lowest practically achievable* as guiding principles in this decision-making process.

The Law on Radioactive Waste Management (1995) further defines the principles of state policy:
- Prioritize the health and safety of people and environment from radioactive impacts (in accordance with state norms of the radiation safety);
- Minimize the level of waste production (as is practically achievable);
- Avoid uncontrolled accumulation of radioactive waste;
- Involve the local communities and authorities in decision making; and
- Clearly state the responsibilities of the involved parties for safe RAW management.

The law defines that the state´s radioactive waste management fund should cover the cost of radioactive waste management.

In 2009, the "On the National Program for the Chornobyl NPP Decommissioning and Transformation of the Shelter Object into an Ecologically Safe System" Law replaced previously active Comprehensive Program.

There are additionally programs and strategies which specify steps to be completed by the state in the field of RAW management. These include:
- National Ecological Program of Radioactive Waste Management approved by Law of Ukraine № 516-VI, 17 Sept 2008
- Radioactive Waste Management Strategy in Ukraine approved by the Order of Government № 990-p, 19 August 2009
- State Program for Safe Storage of Disused High-Level Sources approved by the Order of Government № 1092, 3 August 2006

The Radioactive Waste Management Strategy of Ukraine envisions preparations regarding the decision on the DGD as well as:
- To develop and approve terms of references for the geological storage (GS);
- Conduct research on the selected GS sites, develop technology to store the radioactive waste and technology to build the storage;
- Design and conduct safety analysis of the storage; and
- Build, license and commission geological storage (including construction of the underground research lab as a pilot section of the storage).

(Cabinet of Ministers of Ukraine 2009)

In 2012, the parliament passed a law dedicated to the creation of the centralised storage facility. The law states that the centralised storage will be part of the Special Enterprise Chornobyl NPP. It specifies that the storage should have capacity for 16,259 nuclear fuel assemblies. These will contain fuel from the Ukrainian NPPs and specifically the WWER-440 and WWER-1000 reactors. It requires the company to allocate 10% of the storage costs to the development of the social infrastructure in the nearby city of Slavutych as well as Ivankiv and Polissya rayons of Kyiv oblast.

International agreements
Ukraine is a party of two international agreements under IAEA, where it takes active part and implements its provisions. These agreements are
- The Joint Convention on the Safety of Radioactive Waste Management, and
- the Safety of Spent Fuel Management and the Convention on Nuclear Safety.

EU Association agreement
Following signing of the EU-Ukraine Association agreement, the government has developed an action plan to implement the association agreement.

The action plan lists the following relevant Directives for implementation[4]:
- Council Directive 2013/59/EURATOM of December 5, 2013, defining basic safety standards for protection against the dangers arising from exposure to ionizing radiation and repealing Directives 89/618/Euratom, 90/641/ Euratom, 96/29/ Euratom, 97/43/ Euratom, and 2003/122/ Euratom;
- Council Directive 2006/117/Euratom of November 20, 2006 on the supervision and control of shipments of radioactive waste and spent fuel; and
- Council Directive 2014/87/Euratom of August 7, 2014, amending Directive 2009/71/Euratom and establishing a Community framework for the nuclear safety of nuclear installations.

The State Nuclear Regulator Inspectorate created an interagency working group to implement provisions of the Directives.

3.2. The institutional framework

In accordance with Ukrainian law, the **State Nuclear Regulatory Inspectorate of Ukraine** implements functions of the national regulatory body on nuclear and radiation safety. It sets safety criteria, requirements and conditions in nuclear energy use (normative documents, standards), grants permits and licenses to carry out activity in this area (licensing), and exercises state supervision for observance of legislation, norms, rules and standards of nuclear and radiation safety (supervision).

Responsibility for the management of WWER reactors' SNF is assigned to the nuclear operator **Energatom** and the **Ministry of Energy and Coal**. Responsibility for the management of Chornobyl (RBMK) reactors' SNF is assigned to the **Special State Enterprise Chornobyl NPP** and the **Ministry of Environment and Natural Resource**. SNF from the **research reactors** is stored on sites and is the responsibility of the **Ministry of Education and Science**.

In 2010, the Ministry of Emergencies (no longer in existence) created a single national utility responsible for long term storage and disposal of RAW called the **Specialised State Enterprise Central utility to manage radioactive waste** (SSE CEMRW) a main utility of the **Ukrainian State Corporation Radon** (USC Radon). USC Radon specializes in scientific and technical research, design engineering, technical and project documentation and production of special equipment and devices. It also specializes in the design, construction, exploitation and technical and radiation monitoring of existing storage points for radioactive waste at all stages, including those located in the Chornobyl Exclusion Zone. USC Radon includes 6 regional centres to collect radioactive waste from medical, scientific and other facilities, as well as operates the utility that handles radioactive waste at uranium mines.

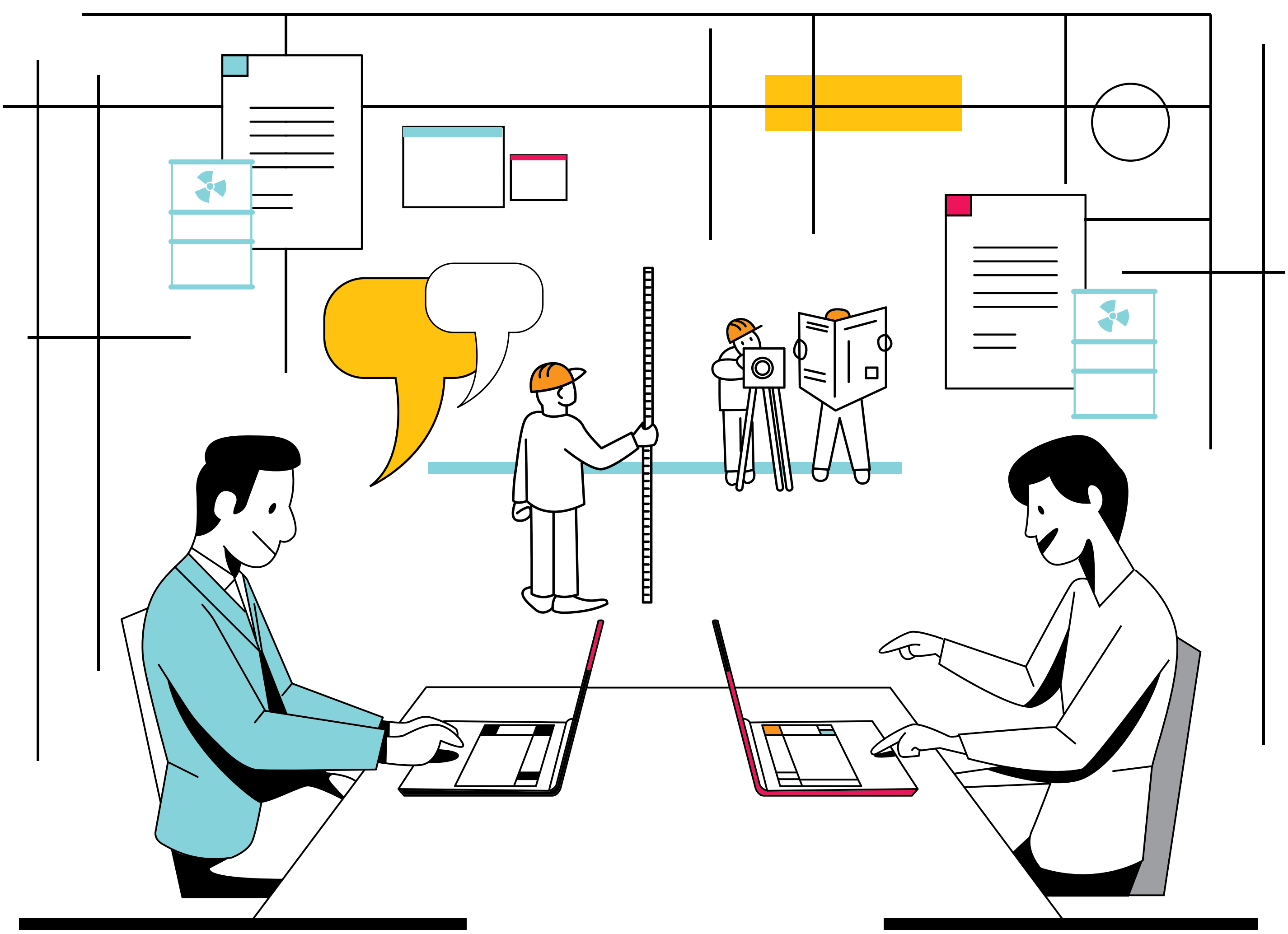
The State Exclusion Zone Agency (SEZA) is currently responsible for the long-term storage and disposal of radioactive waste and thus SSE CEMRW; this agency reports to the **Ministry of Environment and Natural Resources**. However, the **Ministry of Energy and Coal** is responsible for preliminary treatment of the waste produced by NPPs with the exception of Chornobyl NPP.

4 For details, see: http://goo.gl/Lexqfa

More specifically, the State Exclusion Zone Agency is responsible for:

- State management of RAW long-term storage and disposal, including disposal of the radioactive waste at existing storage units and the development of a DGD;
- the State Fund to Manage Radioactive Waste, development of a method to use the funds and sponsorship of the statewide environmental program on the radioactive waste management;
- ensuring state registry of radioactive waste and its storage systems, state inventory, also on radioactive materials managed by other state agencies;
- organizing activities to identify, create and support stable functioning of the system for physical protection of RAW, as well as the safety of collection, transportation, processing, storage and disposal stages;
- implementing archival of documentation that defines the utilities which manage RAW, control of warning signs and fences of the utilities with RAW etc.;
- making decisions on the closure (conservation) of RAW storage units following approval of the State Nuclear Regulatory Inspectorate;
- ensuring development of the study plans and experts study programs on RAW management; and
- organizing training, retraining and advanced skills development for personnel in the field of radioactive waste.

(Cabinet of Ministers of Ukraine 2014)



4. Siting procedures

The Ukrainian law "On Decision Making Procedure for Siting, Design, Construction of Nuclear Facilities and Radioactive Waste Management Objects of National Importance" was introduced in 2005. It is the key document that defines the decision-making process in siting nuclear waste storage and final disposal sites.

4.1. Procedures and criteria for site selection

According to the aforementioned law, the government of Ukraine is responsible for proposing a specific law on siting any individual nuclear facility of national importance; this law is subject to approval by the parliament.

The state nuclear regulator adopted requirements and procedures for the selection of the nuclear waste sites in 2008 (State Nuclear Regulatory Comittee 2008a). It is up to the nuclear operator to plan and implement activities for the waste facility siting. An environmental impact assessment (EIA) is required for the preselected sites.

Investigations of alternative sites are also required. The procedures set a rather lengthy list of requirements for the sites, including geological, hydrological, geochemical, anthropogenic, sociological and other conditions. Site preference depends on the ability to provide maximum isolation and safety and consideration of socio-economic factors. The procedures emphasize a conservative approach to this site criteria assessment.

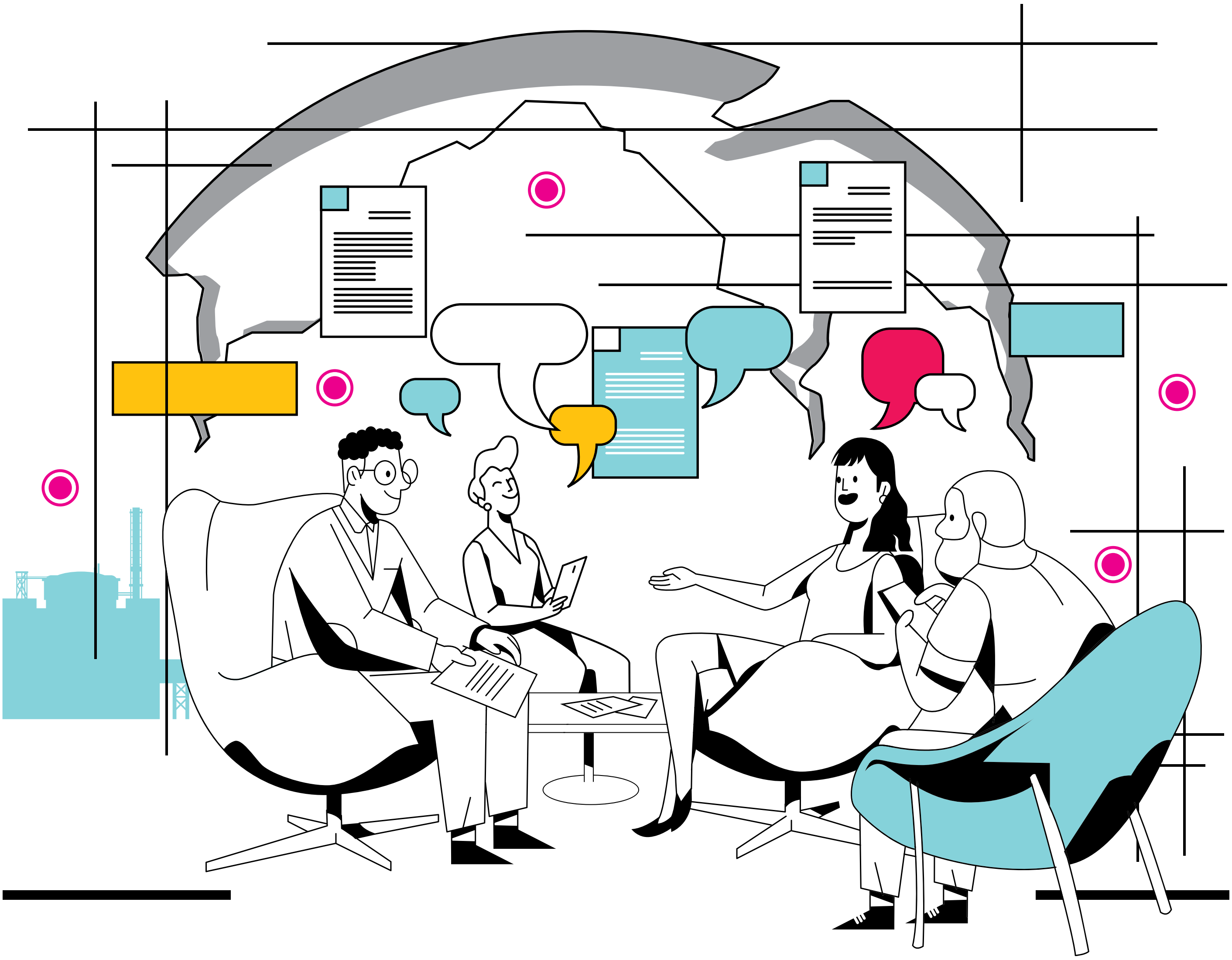
Also relevant in to site selection is the special decision of the nuclear regulator, “General Requirements on Radioactive Safety for the deep Geological Disposal Sites” (29.05.2007 #81). It is based on the requirements for any other nuclear waste site, but goes into more specific details. It also includes provisions for the elimination of the transboundary impacts and reducing the financial burden on future generations.

As stated previously, the Chornobyl Exclusion Zone is the top choice for the location of the new waste storage facilities. There are thus governmental decisions in place and work in progress to build the Vektor facility for radioactive waste and spent nuclear fuel storage. Most of the detailed research on options for final disposal in geological formation is also happening in the exclusion zone.

4.2. Compensation mechanisms and socio-economic impact

The “Law on the Use of Nuclear Energy and Radiological Safety” suggests that the volume of financing allocated to socio-economic development is determined for every site separately and is to be defined in the law that allows construction of the site. These costs are allocated in the construction budget and are disbursed as a reflection of the actual expenditures on a monthly basis to the local budgets. In the case of the centralised spent nuclear fuel storage, the allocation to social programs accounts to 10% of the project cost.

The local population has additional rights for being within the ‘observation zone’ of the RAW management utility, including specific social infrastructure like shelters and personal protection items (iodine tablets) in case of emergencies. The funds are to be allocated from the State Radioactive Waste Management Fund. The Cabinet of Ministers defines which local administrations are eligible for socio-economic compensation for the impacts of every particular utility.



5. Information and participation

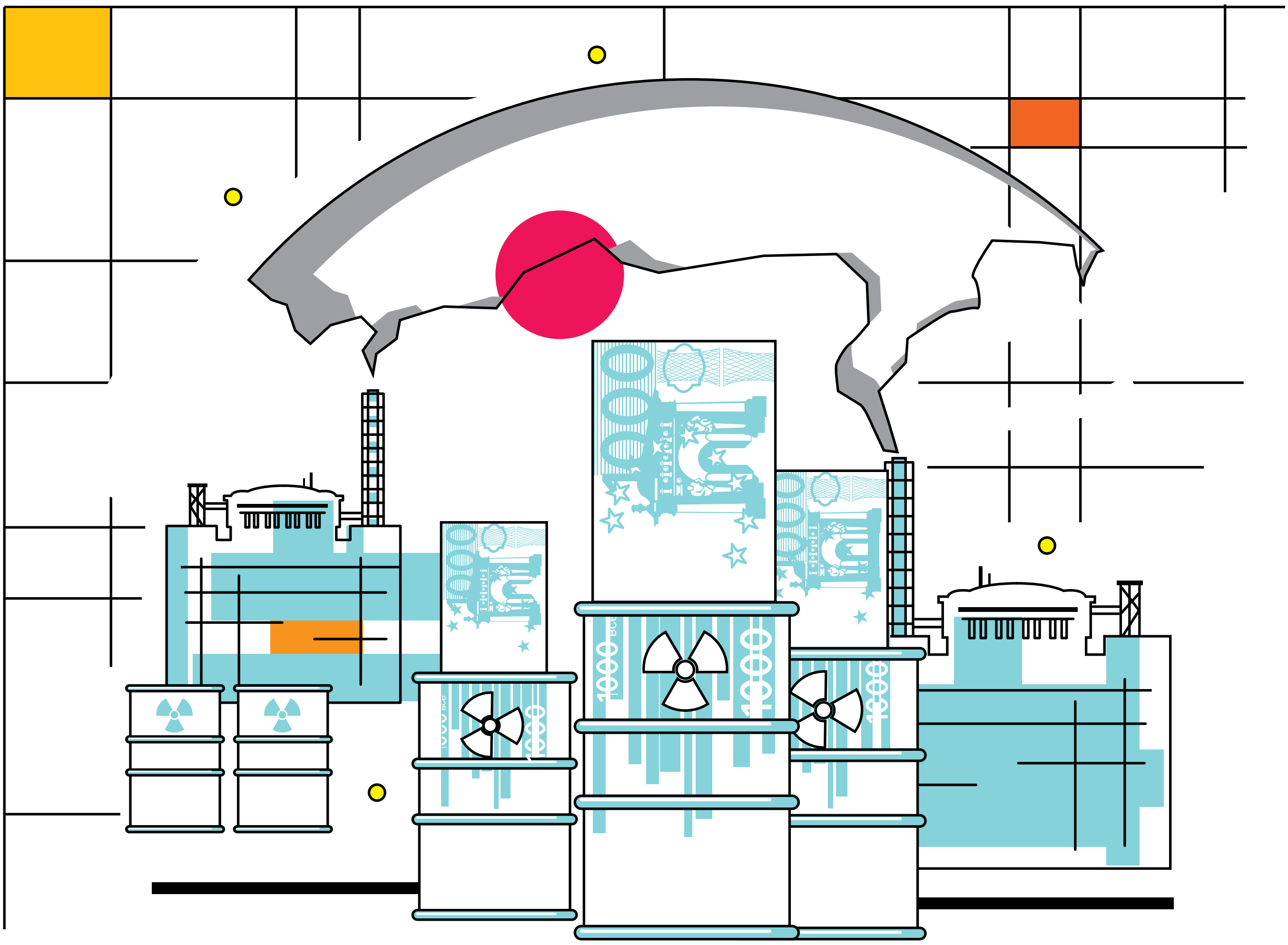
The parliament has to approve a law for the construction of any new facility that manages nuclear materials. It can only do so if the siting is approved by the local authorities. The local authorities 'accept the decision on agreement after conducting of local advisory questioning of citizens of Ukraine (advisory referendum) on this issue', according to the Ukraine law #2861-15 "On Decision Making Procedure for Sitting, Design, Construction of Nuclear Facilities and Radioactive Waste Management Objects of National Importance" from 2005.

The procedures for nuclear waste site selection require the nuclear regulator to provide the information necessary to conduct public hearings to local authorities (State Nuclear Regulatory Committee of Ukraine 2008c: 51).

A public consultation process organized by Energoatom in 2008 regarding the siting of the Centralised Spent Fuel Storage is the only instance where a consultation process was started. That year, Energoatom conducted public consultation process. There was one public hearing conducted at Slavutich, the satellite town of Chornobyl NPP on the other side of the Dnipro river. In the Ivankiv region, which borders the exclusion zone and the proposed site of the spent nuclear fuel storage the company limited its public engagement to the 'information round table', as it did in Kyiv.

Despite the requirement to have a public referendum on the siting of nuclear facilities, there is no evidence that it was ever held for the Centralised Spent Fuel Storage. Instead, the legislation was adjusted in 2009, removing the need for public consultation for the facilities located in the Chornobyl Exclusion Zone as they related to efforts to construct a Centralised Spent Fuel Storage facility. It is up to the state body responsible for the management of the exclusion zone to agree the construction there. The law to build a centralized SNF storage was approved by Parliament in 2012.

The existence of the Chornobyl Exclusion Zone gives the nuclear industry a significant opportunity to limit public consultation on waste management facilities. The absence of local population becomes an attractive factor, in addition to the presence of existing infrastructure for waste management and transport as well as proximity to the majority of Ukrainian nuclear waste. Locating the DGD in the exclusion zone will, most likely, not demand public consultation as well. Unfortunately, this also means further transformation of the exclusion zone into a nuclear waste dumpsite.



6. Costs and financing

The costs of nuclear waste management on the NPP sites are covered by Energoatom operational costs. Future costs of radioactive waste management are covered by the environmental tax accumulated in the RAW Management Fund. The state guarantees that it will manage the waste of the companies that have paid the tax.

In 2009, the State RAW Management Fund was created with the Law 17.09.2008 515-VI. The fund is a part of the state budget of Ukraine. It accumulates money collected through pollution fees assigned to RAW creation and temporary storage by its producers. The fund is managed by the State Exclusion Zone Agency. Since 2011, the amount and the method of payment to the fund is determined by the tax code (article 249 Section VIII).

The fund receives around UAH 600 million annually (€20 million at the exchange rate of March 2016). The nuclear operator Energoatom has transferred around UAH 3.1 billion (over €166 million) into the fund between 2009 and 2014. The exchange rate has changed from 10 UAH: 1 Euro in 2009 to 25 UAH: 1 Euro in 2014 (Energy and Coal Ministry of Ukraine 2015).

The use of the fund is defined by the Cabinet of Ministers Order (20.05.2009 #473). The order suggests that the fund be used for the implementation of the State Environmental Program on Radioactive Waste Management.

The 2010 budgetary law widens the scope of the fund's use and allowed for spending on other tasks. As a result, there is not enough money for the activities that the fund should finance – namely, radioactive waste management. In its letter to the Chornobyl United Trade Union Organization, Energoatom has stated that the program on waste management was financed at the level of 8-10%.

International donors have paid for a number of RAW management utilities (the Liquid Radioactive Waste Treatment Plant and the Industrial Complex for Solid Radioactive Waste Management, just to mention a few) (Chornobyl NPP 2017). Industry specialists raise concerns over the absence of a single state policy, leading to duplicated facilities built at the sites of NPPs and at the centralised waste management facility.

Involvement of international donors is partly a result of the 1995 Memorandum of Understanding between G7 nations, the EU and Ukraine, which established international support to ensure timely and safe closure of the Chornobyl NPP (G-7 and Ukraine 1995).

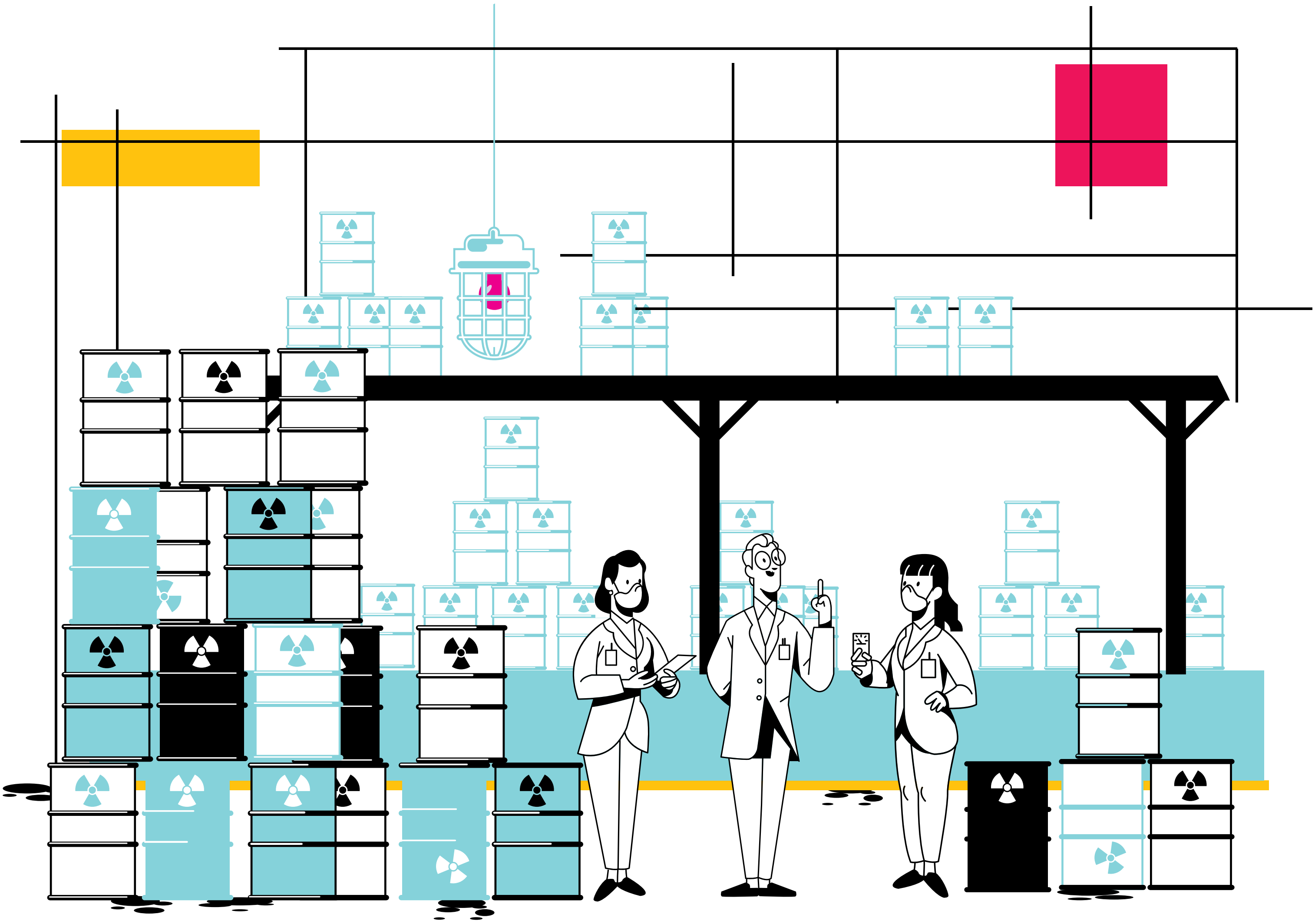
EBRD was asked to manage the Chornobyl-related funds as it had experience managing a Nuclear Safety Account (NSA) that operated to improve safety of the nuclear reactors in Eastern Europe. Its responsibility was extended to Ukraine in 1995. Since then, close to €2.5 billion has been received for EBRD-managed Chornobyl projects from 45 donors. The EBRD contributes €715 million of its own resources in support of the work to transform Chornobyl into an environmentally safe and secure site.

While EBRD positions its involvement as a tool to improve nuclear safety, some of its loans are seen by environmentalists as questionable, as it supports the Ukrainian nuclear industry's staying afloat. The most recent example of this is the EBRD €300 loan (backed by another €300 from Euratom) for the 'Nuclear Safety Upgrade Program'. This loan provides crucial funding to implement ongoing efforts to extend the lifetime of the Ukraine's ageing nuclear reactors (Holovko 2012).

Additionally, the EU has been providing various grants to improve radioactive waste management in Ukraine. As a part of the INSC U4.01/08-B project, EU experts have calculated that with the existing radioactive waste classification, the total cost of storing all waste in two types of storage systems would be UAH 750 billion (€25 billion). This estimate can be compared to the UAH 684.5 billion allocated as overall state budget expenses in 2016. It is clear that Ukraine will not be able to allocate sufficient funds to store all waste. The new system of radioactive waste classification proposed by EU mentioned project on waste classification, is expected to cut the cost by a factor of ten and be in accordance with international standards (State Exclusion Zone Agency 2016).

Ukraine has systematically attempted to cut costs on spent nuclear fuel reprocessing done by Russia. It initially built a SNF storage system at Zaporizhzhya NPP and is slowly moving forward with plans to build a centralized spent fuel storage for other NPPs. Although the costs for construction and maintenance of the storage facility is not published, according to Energoatom the operation of the storage allows Ukraine to save USD 40 million per year by not sending SNF to Russia for reprocessing (State Enterprise 'National Nuclear Energy Generating Company "Energoatom" 2006).

The Cabinet of Ministers' ordered to build a Centralised Spent Fuel Storage estimated UAH 1.59 billion (€160 million) for infrastructure construction and an annual maintenance cost of 3.67 billion UAH (€370 million) (Cabinet of Ministers of Ukraine 2009). According to the president of Energoatom, the cost of production and 100 years of operation for one cask amount to around USD 2.2 million, compared to USD 15 million cost of sending the same volume of SF to Russia for reprocessing (Ukrainian News Agency 2015).



7. Conclusions

The development of radioactive waste management in Ukraine has been impacted by the transition of the state management system in the post-Soviet era, the Chornobyl nuclear accident and the constant lack of funding. In the 1990s, the nuclear industry was too attractive for the bankrupt Ukrainian state to consider the future costs of nuclear waste. The nuclear industry was not obligated to repay capital investments (this was done by the collapsed USSR), it did not bear financial responsibility for the Chornobyl catastrophe and it received free nuclear fuel from Russia.

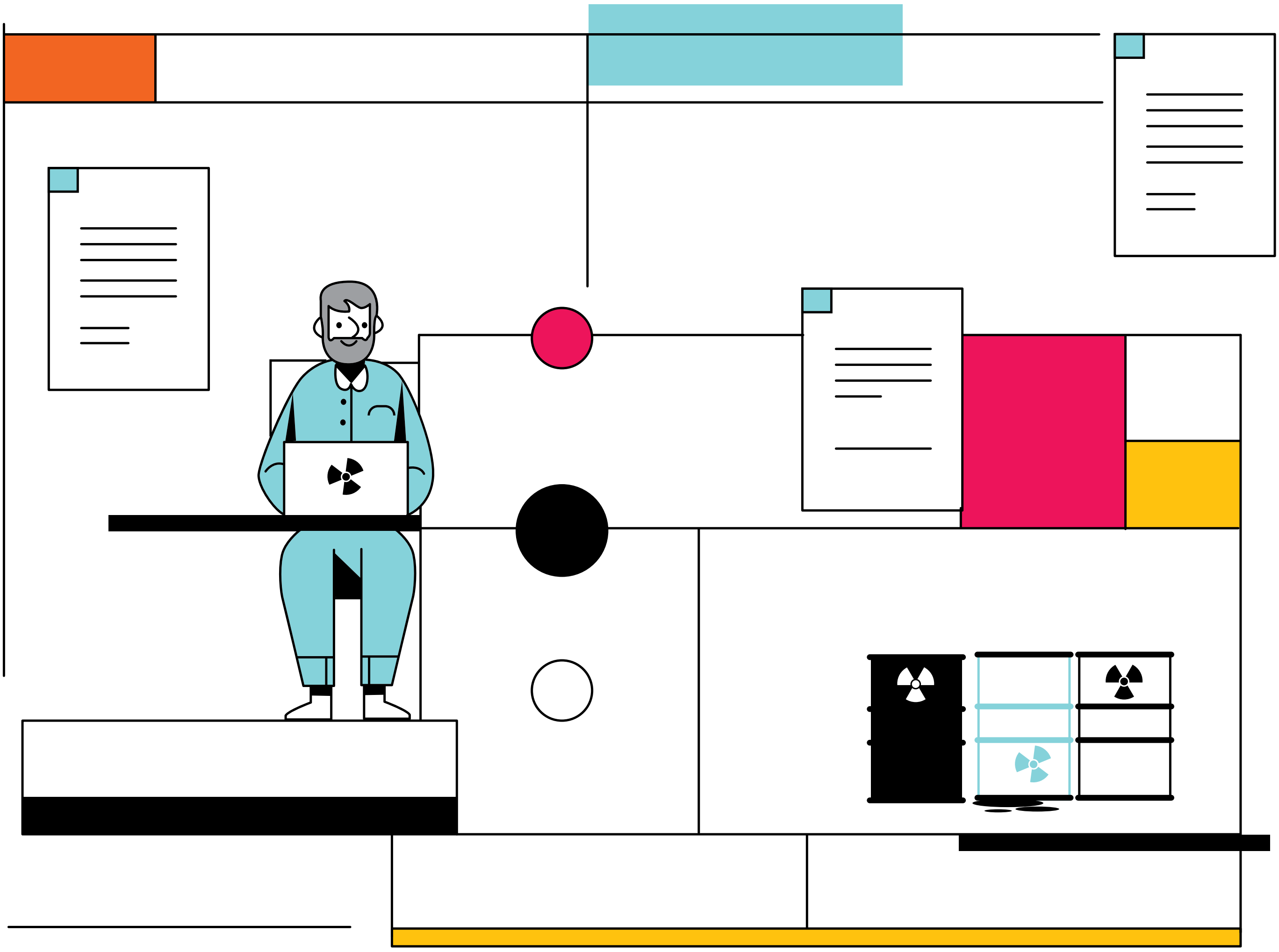
The scale and the cost of the Chornobyl nuclear waste problem overshadows the problems of the waste accumulated at Ukraine's additional 15 operating commercial reactors. It also complicates the governance of radioactive waste management.

At the same time, the Chornobyl exclusion zone has become extremely attractive for the development of the centralised nuclear waste and spent nuclear fuel management systems, as well as a final disposal site. With the absence of sizeable local population to consult, the presence existing infrastructure and trained personnel, and its proximity to the majority of the country's nuclear waste, the exclusion zone is seen as the ideal place to focus all operations. Thus, plans to construct a centralised spent nuclear fuel storage and ongoing research for a final deep geological disposal are ongoing.

The change of legislation in 2009 enabled construction of the new facilities in Chornobyl Exclusion Zone that are not related to the mitigation of Chornobyl nuclear accident, which were previously forbidden. Further changes removed requirements to consult with local populations for proposed facilities located in the exclusion zone, which are required for corresponding decisions elsewhere in the country.

Ukraine's waste management system suffers from the government's focus on solving day-to-day tasks rather than long-term objectives. This absence of strategy is particularly problematic for radioactive waste management. For example, it took just few years since its creation to undermine functioning of the Radioactive Waste Fund by widening the scope of activities it can finance and directing the funds accumulated to other purposes. As a result, activities envisioned by the State Waste Management Strategy are systematically delayed due to the lack of proper financing.

Nevertheless, Ukraine is progressing with the development of the legal, institutional and scientific structures to fulfil recommendations of the IAEA and adopt European best practices. Most of these activities are carried out with EU and IAEA financial support. Implementation of the provisions of the EU-Ukraine Association agreement is expected to drive the process further, as Ukraine will adjust its legal framework to relevant EU Directives.



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