Enhancement of the physical protection of waste storages – a step to maintain the nuclear security regime in Ukraine

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Abstract:
Radioactive wastes are unavoidable by-products in the use of nuclear materials and other radioactive sources and concurrently pose the threat to radiation safety. Ukraine has an advanced infrastructure of nuclear power engineering and is attaching great importance to nuclear security and particularly physical protection of not only nuclear facilities and nuclear materials but radioactive wastes as well. Furthermore, Ukraine has unique practices of ensuring nuclear safety and security of radioactive wastes and fuel-containing materials generated after the accident at Chornobyl NPP and during its decommissioning. To this end, the continuous improvement of physical protection systems for storages of radioactive wastes of industrial, medical and scientific origin, Chornobyl facilities containing radioactive materials, including the Shelter, takes place in our country. Such activities in synergy with nuclear and radiation safety measures are of great significance for implementation and maintenance of nuclear security regime in Ukraine. This paper is dedicated to activities on modernization of physical protection systems for radioactive wastes and some other radioactive materials and concise review of nuclear security regime status in Ukraine.

1 INTRODUCTION

Radioactive wastes are unavoidable by-products of nuclear power production and use of nuclear technologies, mining and processing of uranium ore and some other commodities, use of radioactive sources and materials in industry, medicine, scientific research etc. Now in Ukraine there are four nuclear power plants in operation and one under decommissioning, two nuclear research reactors, some new nuclear facilities under construction, including new power reactors and fuel processing plant, three uranium ore mines and ore-dressing plant under renovation. Each of these facilities, not to mention the Chornobyl zone and Shelter, is a high-capacity source of various activities and generate radioactive wastes. Besides, there are storages of radioactive wastes generated by entities beyond the nuclear fuel cycle or after the Chornobyl or other radiation accidents, mortuaries of dismantling the former military objects, mine dumps and tailing repositories.

All of the above-mentioned objects pose a potential danger to radiation safety of the population and environment through ionizing radiation and radioactive contamination, especially if the radiation protection requirements are not met and the wastes are treated thoughtlessly and without due care. Radiation accidents involving radioactive wastes are often caused by carelessness, disregard and unintentional violations. But taking into account huge amounts of radioactive material stored in one place, high activity concentration and long life of some radioisotopes, radioactive wastes may be extremely dangerous under malicious offences. Theft of some assets in radioactive waste that are attractive for the perpetrator would result in radiation exposure or contamination. Spread of radioactivity through sabotage of facilities where radioactive wastes are reprocessed/stored could contaminate large territories and menace the health and well-being of population.

Prevention, detection and response to such malicious acts against nuclear and other radioactive materials and associated facilities are the objectives of nuclear security. Having a well-developed nuclear energy infrastructure, Ukraine attends greatly to its nuclear security. Physical protection of radioactive wastes, like that of nuclear facilities and nuclear materials, is always the matter of great concern. Ukraine was among the initiators of development and acceptance of the Amendment to Convention on the Physical Protection of Nuclear Material and ratified it in 2008. Implementation of fundamental principles of physical protection of nuclear material and nuclear facilities set forth in the Amendment gave a powerful incentive to modernization of physical protection systems for radioactive waste facilities. This work is devoted to examination of modernization measures and their impact on the nuclear security status in Ukraine.

2 HANDLING OF RADIOACTIVE WASTES IN UKRAINE

2.1 Legislation framework for handling radioactive wastes

The issues of management, safety and security of radioactive wastes are considered in a number of Ukrainian laws [14]:
- On Nuclear Energy Use and Radiation Safety;
- On Radioactive Waste Management;
- On Physical Protection of Nuclear Facilities, Nuclear Materials, Radioactive Waste, Other Radioactive Sources;
- On Human Protection against Ionizing Radiation;
- On Protection of Population and Environment against Man-Induced and Natural Emergencies;

and a series of regulatory acts approved mainly by the Ministry of Health or Nuclear Regulatory Authority. These documents establish classifications of radioactive wastes, requirements on their collection and isolation from the biosphere.

2.2 Generation and aspects of radioactive wastes

Depending on the activities that resulted in generation of radioactive wastes, they may be wastes of [15]:
nuclear fuel cycle:
- -nuclear power plants (including plants under decommissioning);
- -uranium mining and processing plants;

production and use of radionuclides beyond the nuclear fuel cycle:
- -industry;
- -medicine;
- -science research programs;

decontamination of facilities and territories contaminated by accidents including the Chornobyl disaster:
- -Shelter (destroyed unit 4 of Chornobyl NPP);
- -decontamination enterprises, storages and disposal facilities, places of uncontrollable concentration of wastes in the Chornobyl zone;

functioning, dismantling and decontamination of military objects.
Radioactive wastes include solutions, materials, products, biological objects containing radioactive materials, not intended for further use. Radioactive wastes also include spent radiation sources, spent nuclear fuel and technologically-enhanced natural sources.

The conditions in which wastes are generated influence their morphology:
liquid radioactive wastes: homogeneous combustible or incombustible and heterogeneous;
solid radioactive wastes: combustible or incombustible.
Depending on time during which wastes remain potentially hazardous, they are divided into long-lived and short-lived.

Table 1 – Nomenclature of radioactive wastes in Ukraine [15]

Manufacturing processes	Liquid wastes	Solid wastes
1. Nuclear fuel cycle enterprises: 1.1 Uranium ore mining and processing	Mining waters Mother waters	Mining scrap Uranium processing and leaching tailings
1.2 Uranium processing and production of fuel assemblies	Mother waters and industrial waters	Wastes of consumption Wastes of fuel processing
1.3 Energy and heat production at nuclear power plants	Industrial waters Circuit waters Decontaminating solution Regenerators Pulps	Filters Equipment Outwear Insulation materials First-circuit equipment
1.4 Decommissioning of facilities, dismantling of blocks and structures	Waters of bathing and delousing Industrial waters Circuit waters Decontaminating solution Regenerators Pulps	Outwear Personal protective gear Equipment Control equipment Insulation materials Construction waste Coating First-circuit equipment and parts of reactor vessel
2. Rehabilitation of territories contaminated after operation or accidents 2.1 Contaminated territories after Chornobyl accident 2.2 Shelter	Waters and slimes of cooling and clearing pools. Contaminated ground waters Waters of storage pools Contaminated underground waters Hydroxide pulps of storage pools	Contaminated soil Solid radioactive wastes from decontamination of storages
3. Industrial enterprises, research centers and medical institutions, specialized enterprises for waste handling	Industrial waters of laboratories	Outwear Personal protective gear Organic radioactive wastes Spent radiation sources

2.3 Storage of radioactive wastes

2.3.1 Storage of spent fuel

In spent fuel, which is unloaded from the reactor as fission isotopes are burned out and poses the main source of artificial technogenous radionuclides, fission products and transuranium elements (Np-237, Pu-238, 239, 240, 241, Am-241, 243, Cm-242, 244). They pose the main hazard to nuclear and radiation safety and continue to release heat after unloading from the reactor. So spent fuel is primarily stored in cooling pools and is transferred for dry storage after proper cooling.

In Ukraine there is currently the only one dry storage facility for spent fuel. It is situation at Zaporizhzhya NPP and is intended for spent fuel of only this plant. Spent fuel of other NPPs is transported to Russia in line with contract on fresh fuel supply.
The governmental decision is made for construction of a new dry storage facility for spent fuel (DSF-2) on the site of Chornobyl NPP.

2.3.2 Shelter

In a result of accident at unit 4 of Chornobyl NPP, a significant amount of radioactive materials was spread. But the major part of radioactive products left in the local zone – in the destroyed unit and surrounding territory. For temporary confinement of radioactive materials, a concrete structure called the Shelter was built over the power unit. Decontamination measures were provided on the site, including the collection of core fragments, removal of the upper soil layer and placement of concrete, macadam and sand to form a technogenous layer. In such a way, certain amount of wastes was buried directly on the site. In the framework of NPP decommissioning and Shelter transformation into an environmentally safe system, it is planned to construct a reprocessing plant for liquid wastes and industrial complex for solid waste management. This complex will include underground storage of V=55000 m^3 for final disposal of intermediate- and low-level wastes. The construction of new safe containment was started to ensure radiation safety of the Shelter and further dismantling of the old structure and retrieval of radioactive materials. The structure will be 85 m high and will fully cover the Shelter.

a) b)

Fig.1. Ensuring safety of Chornobyl NPP unit 4: a) Shelter; b) construction of new safe confinement

2.3.3 Radwaste facilities in Chornobyl zone

2.3.3.1 “Buryakivka” disposal site

The site is intended for intermediate- and low-level wastes. It has dimensions 1200x700 m and consists of 30 ditches of V=25000 m^3 each. Besides, metallic wastes (contaminated carriages) are temporarily placed on the site.

2.3.3.2 “ChNPP Stage 2” disposal site

The site is intended for intermediate- and low-level wastes and is located near the cooling racks of unfinished stage of Chornobyl NPP. It consists of a concrete box of dimensions

145x45x5 m and has two side ditches. Radwaste in storage is located in average 18000 metallic containers, covered by a layer of sand.

2.3.3.3 “Pidlisnyi” disposal site

This is the only site in Ukraine intended for high-level wastes. It is placed nearby unit 4 of ChNPP and consists of two concrete boxes of dimensions 55x26x8 m. The 22000 m^3 high-active wastes resulting from the Chornobyl accident are placed on the site. The site is currently in long-term storage.

All of the three above disposal sites are now parts of the State Centralized Enterprise for Radioactive Waste Management. Moreover, in Chornobyl zone, there are near 680 ditches and a series of radwaste temporary confinement plants. They are also under control of the above enterprise.

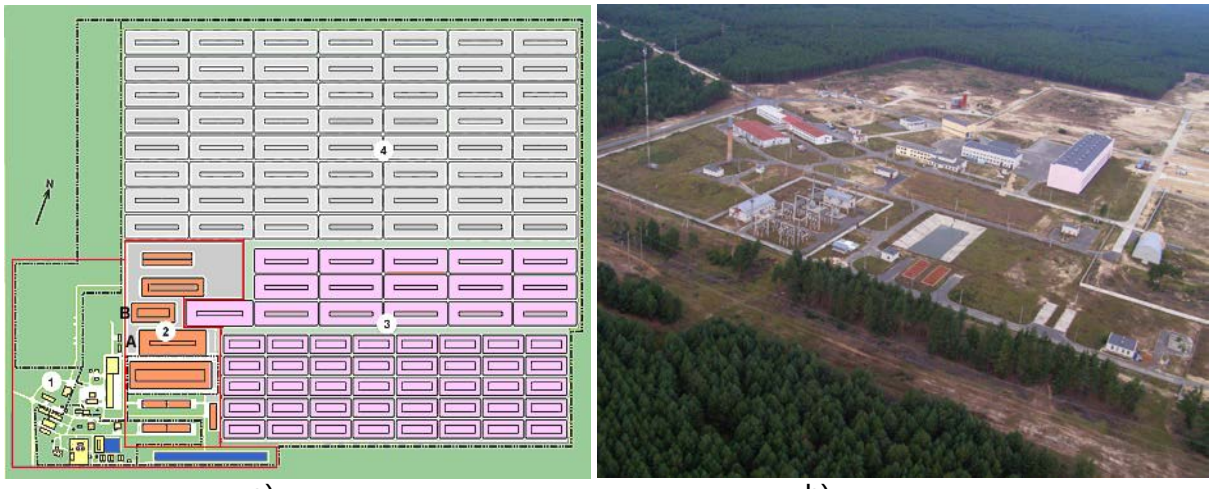
2.3.4 Storing radwaste at “Radon” enterprises

2.3.4.1 Special interregional enterprises

Six interregional enterprises (Kyiv, Kharkiv, Lviv, Odesa, Donetsk and Dnipropetrovsk) were established in 1959-1961 for collection and disposal of radwastes from entities not belonging to nuclear fuel cycle – industrial, medical and scientific. All of them are constructed in compliance with standard design and include near-surface concrete structures for solid wastes, biological wastes and spent radiation sources. The enterprises are consolidated in disposal centers located mainly in the countryside.

2.3.4.2 “Vector” site

The “Vector” site is located in the Chornobyl zone and includes four repositories and one near-surface disposal facility intended for solid wasted, especially for bulky scrap. The site will also include a processing plant for compaction, cementation and conditioning of radwaste.



a) b)

Fig.2. “Vector” site: a) general plan of processing and disposal center; b) overview of “Vector” territory

3 ESTABLISHING AND MAINTAINING OF NUCLEAR SECURITY REGIME IN UKRAINE

Ukraine was among the initiators of amending the CPPNM [1] and undersigned the Amendment to the Convention on the Physical Protection of Nuclear Material [2] in 2005. Ratification of the above Amendment by the dedicated law [10] of Ukraine in 2008 was the most important step in physical protection improvement. This law and associated, specially amended law "On Physical Protection of Nuclear Facilities, Nuclear Materials, Radioactive Wastes and Other Radioactive Sources" [7] implemented not only 12 fundamental principles of physical protection but also identified concepts new for Ukraine such as nuclear security, physical protection regime, design basis threat etc.

3.1 State physical protection system and physical protection regime

The objective of a state's nuclear security regime is to protect persons, property, society and environment from harmful nuclear security events [3,5]. The nuclear security regime covers nuclear material and other radioactive material and associated facilities and activities. Thus the regime should also cover radioactive wastes and their storage, conditioning and reprocessing plants.

The first steps in establishing nuclear security regime in Ukraine were taken in 2009, after ratification of the Amendment to CPPNM [2], by establishment of a state physical protection system and identification of physical protection regime in the Law on physical protection 7[]. The state physical protection system consists of the state authorities maintaining, managing and regulating the physical protection regime, and covers all the entities acting in nuclear energy sphere. Physical protection regime in Ukrainian legislation involves a procedure established for ensuring the physical protection [10].

The state physical protection system is based on the design basis threat (DBT) [7,10]. DBT is defined by state authorities and approved by the President of Ukraine. First DBT in Ukraine was enacted in 2011 and then revised in 2012. In the process of development or revising of DBT, intelligence services join state authorities – participants of the state physical protection system.

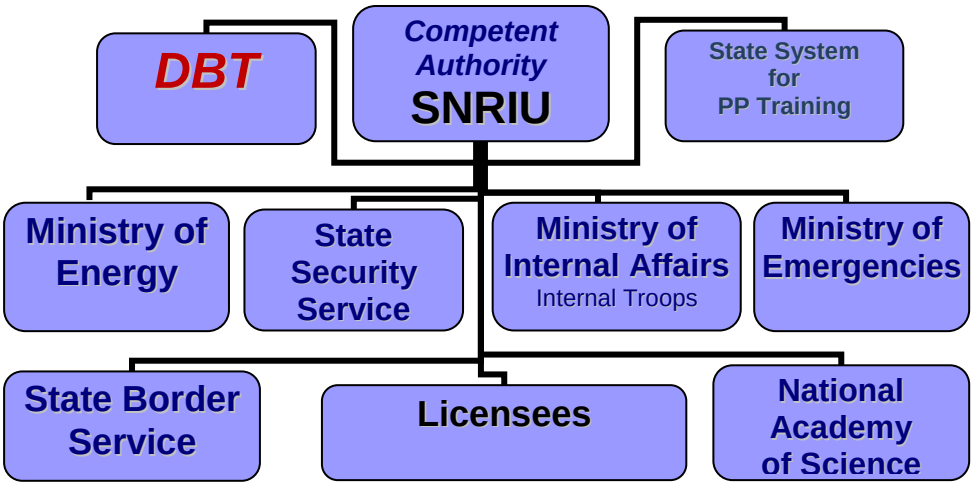


Fig.3. Interaction scheme of State Physical Protection System in Ukraine

3.2 Defining threats and risks for radioactive wastes

DBT embraces all the objects of nuclear sphere in Ukraine including radioactive wastes and associated facilities. Based on state DBT, all operators and other licensees define and approve the design basis threats of their facilities. This is provided by the State Enterprise "Radon", Chornobyl NPP, facilities in construction and all other entities handling radioactive wastes mentioned above.

For the purpose of reducing the risks of malicious acts, structured risk management is followed. Concerning the radioactive wastes, the main risks are:
- theft or other unlawful acquisition for subsequent sale when the offender does not intend to apply materials by himself;
- theft or other unlawful acquisition for production of a radiological dispersal device – so-called dirty bomb;
- risk of sabotage at facilities directly.

Mostly all the attempts of theft of radioactive wastes are involving contaminated equipment made of nonferrous metals. Theft of some assets situated in radioactive wastes and attractive for the perpetrator would result in radiation exposure of the perpetrator and people around or even in contamination of some premises. Taking into account that spent radiation sources are stored amongst other wastes, the acquisition of highly active sources for production of a dirty bomb is also possible. Spread of radioactivity through sabotage of facilities where radioactive wastes are reprocessed/stored or use of the dirty bomb could contaminate large territories and menace the health and well-being of population.

a) b)

Fig.4. Primary targets of unlawful acquisition of radioactive wastes in Ukraine: a) radioactive contaminated metal scrap, especially nonferrous; b) spent sealed radioactive sources

To prevent these risks and threats and ensure nuclear security of radioactive wastes, the physical protection systems of storage, conditioning and reprocessing plants and other associated facilities is established and maintained. To ensure the robustness, compliance with the regulatory requirements and adequacy to up-to-date threats, physical protection systems should be periodically evaluated and upgraded. The vulnerability of facilities and the effectiveness of physical protection systems are evaluated by operators and other licensees based on the respective design basis threats. The results of these evaluations are crucial in assessment of physical protection system status and making decision on its modernization or reconstruction.

3.3 Synergy of nuclear and radiation safety and nuclear security

To ensure the effectiveness of safety and security measures, it is not sufficient to exclude the negative mutual influence. The objective is to ensure that the synergy of safety and security outweighs the ordinary sum of functioning of each element. They should mutually increase the effect of measures completed in every sphere.

For example, combined use of physical barriers or simultaneous application of the defense-in-depth principle in physical protection and radiation protection in designing a radwaste facility should not only provide economical result but also improve safety and security of wastes.

The synergy approach for ensuring nuclear and radiation safety and nuclear security is now followed in all new designs of nuclear facilities in Ukraine.

3.4 Physical protection of radioactive wastes during transport

During transportation the radioactive wastes are mostly vulnerable, especially for the acts of sabotage. So for each case of transportation, a special physical protection system is developed and established. It operates only for the period of conveyance till delivery to the last consignee. The level of physical protection measures depends on type, activity and amount of transferred radioactive material.

Requirements of physical protection are complied with during domestic as well as international transportations. Ukraine has not a closed fuel production cycle. Therefore, it has to import fresh nuclear fuel and remove the spent one. These transportations are performed with Russia by land and, as experiment, by sea with some other countries. Moreover, after some time the wastes resulting from reprocessing of spent fuel should be returned from Russia. These transportations are performed with Russia by land and, as experiment, by sea with some other countries. According to international agreements of Ukraine and the Working Plan of Washington Nuclear Security Summit of 2010, highly enriched fuel and other highly enriched nuclear materials were removed from Ukraine to Russia. The removal was performed by air.

Fig.5. Transportation of radioactive wastes requires physical protection measures as well as accountancy and control and radiation protection

4 ESTABLISHMENT AND MODERNIZATION OF PHYSICAL PROTECTION SYSTEMS FOR RADIOACTIVE WASTES

4.1 Defining the level of physical protection of radioactive wastes and associated facilities

The procedure for defining the level of physical protection of radioactive materials and associated facilities in Ukraine is approved by legislation [12]. PP level depends on category of material or facility, and requirements are established for areas of confinement and for physical protection systems respectively.

Table 2 – Requirements for levels of physical protection of radioactive wastes in Ukraine [16]

Objects and materials	Category	PP Level	Requirements
Solid wastes D>10^4µGr/h Liquid wastes A>10^6 PC_B^{ingest} Facilities for I cat. wastes	I RW	II	Confinement in protected area
Solid wastes D=10^2÷10^4µGr/h Liquid wastes A=10^2 PC_B^{ingest} ÷10^6 PC_B^{ingest} Facilities for II cat. Wastes	II RW	III	Confinement in area of controlled access
Solid wastes D=10^2÷10^4µGr/h Liquid wastes A=1 PC_B^{ingest} ÷10^2 PC_B^{ingest} Facilities for III cat. Wastes	III RW	IV	Protecting with prudent practice. Use of fences with intruder alarm
Spent nuclear fuel	II NM	II	Confinement in protected area
Spent high-level radiation sources (A>3,7 x 3,7 x 10^{13}Bq, lifetime≥5 years)	I RS	III	Confinement in area of controlled access
Spent high-level radiation sources (A>3,7 x 3,7 x 10^{13}Bq, lifetime≥5 years)	II RS	IV	Protecting with prudent practice. Use of fences with intruder alarm

4.2 Physical protection of spent fuel

As mentioned above, now spent fuel is kept on sites of nuclear power plants, mainly in wet storage (cooling pools), and after cooling is transferred to the fuel vendor to Russian Federation (see 3.4). The special dry storage facility for spent fuel is placed only at Zaporizhzhya NPP. Thereafter all spent fuel is subject to physical protection systems of NPPs and is secured in compliance with state regulations [13] and recommendations of IAEA [3].

Fig.6. Zaporizhzhya NPP – the only plant in Ukraine having dry storage for spent fuel

During last years, due to enactment of new design basic threat and new general requirements for physical protection systems and automatic systems of technical measures, the process of modernization of physical protection systems of NPPs started. It anticipated

renovation of alarm stations, installation of new surveillance and detection equipment and in some cases building of new physical barriers and other engineering means.

Now a new dry storage of spent fuel (DSF-2) is in construction on the site of Chornobyl NPP. It will include a facility for treatment of spent fuel before storage and a storage area for spent fuel. The plan developed for construction of DSF-2 takes into consideration the establishment of a comprehensive and robust physical protection system starting at the first stage of construction.

4.3 Modernization of physical protection system of Chornobyl NPP

The physical protection system of Chornobyl NPP was established simultaneously with construction of NPP in 1972. Of course during its operation and especially after the 1986 accident, it changed many times. Last changes in the perimeter of protected area were made in 2010-2011 due to changes of site configuration for construction of the new safe containment (see 2.3.2). Now modernization of system equipment is in process.

Fig. 7. Part of the perimeter of Shelter protected area with transport entrance gates and physical protection equipment

4.4 Modernization of physical protection systems of “Radon” interregional plants

Taking into consideration that physical protection systems of all six interregional plants were established at the beginning of 1960s, their renovation started in 2005. Now they are up-to-date, consistent and regulatory compliant automatized systems of disposal sites, with equipped perimeters of controlled areas and means of detection and surveillance of intruders.

a) b)

Fig.8 . Upgrade of physical protection systems of “Radon” interregional plants: a) entrance to Kharkiv disposal site; b) perimeter of Dnipropetrovsk disposal site

4.5 Ensuring physical protection of spent radiation sources

After disintegration of the Soviet Union, economy of Ukraine underwent significant changes. Some large enterprises utilizing radiation sources went bankrupt and cannot ensure safety and security of their facilities. So Ukraine, with international technical assistance, implemented program for removal and disposal of spent and other radiation sources. A list of such enterprises was developed and inventory of sources was carried out. For disposal of removed sources, the new facility was constructed in Dnipropetrovsk disposal site. To ensure the nuclear security of the disposal facility, the effectiveness and status of physical protection system were evaluated and the needed renovations were made. The average number of spent radiation sources disposed during these activities was near 4000 pieces.

a) b)

*Fig.*9 . Ensuring safety and security of spent sources: a) removal of sources under radiation and physical protection; b) facility for spent sources on Dnipropetrovsk disposal site.

4.5 Ensuring physical protection of uranium mining and processing wastes

In accordance with legislation, physical protection of uranium industry should be provided [11]. In Ukraine there are three uranium mines and uranium ore processing enterprises. The wastes of these processes are not of high activity but are in significant amounts and can contaminate large territories. To eliminate this threat, measures of physical protection for mines and tailing storages were provided during last years – fences along perimeters were built and security measures were taken.

a) b)

Fig.10 . Physical protection measures for wastes of uranium ore processing: a) polygon of Smolinska uranium mine; b) tailings storage near Dniprodzerzhinsk.

5 CONCLUSIONS

1. The presence of a substantial number of radioactive waste and other radioactive sources in Ukraine poses threats of malicious acts – sabotage, theft and dissemination of radioactive materials, which could result in inadmissible radiological consequences.
2. The threats are real and are taken into account at the State level as threats to national security.
3. The principal instrument of counteraction to these threats is nuclear security.
4. Modernization of physical protection systems for radioactive wastes and associated facilities and other physical protection measures reduce the threat and improve the nuclear security in Ukraine.

6 REFERENCES

1. Convention on the Physical Protection of Nuclear Material, INFCIRC/274, IAEA, Vienna (1980).
2. Amendment to the Convention on the Physical Protection of Nuclear Material, IAEA, Vienna (2005).
3. IAEA Nuclear Security Series No. 13. “Nuclear Security Recommendations on Physical Protection of Nuclear Material and Nuclear Facilities”, IAEA, Vienna (2011).
4. IAEA Nuclear Security Series No. 14. “Nuclear Security Recommendations on Radioactive Material and Associated Facilities”, IAEA, Vienna (2011).
5. IAEA Nuclear Security Series No. 20. “Objective and Essential Elements of a State’s Nuclear Security Regime”, IAEA, Vienna (2013).
6. The Law of Ukraine “On Nuclear Energy Use and Radiation Safety”.
7. The Law of Ukraine “On Physical Protection of Nuclear Facilities, Nuclear Materials, Radioactive Waste, Other Radioactive Sources”.
8. The Law of Ukraine “On Ratification of the Amendment to the Convention on the Physical Protection of Nuclear Material”.
9. The Law of Ukraine “On Radioactive Waste Management”.
10. “Procedure for Functioning of the State Physical Protection System”, approved by Resolution of the Cabinet of Ministers of Ukraine No. 1337 of 21 December 2011.
11. The Law of Ukraine “On Mining and Processing of Uranium Ore”.
12. "Procedure for Determining the Level of Physical Protection of Nuclear Installations, Nuclear Material, Radioactive Waste, Other Radioactive Sources Based on Their Categories”, approved by Resolution of the Cabinet of Ministers of Ukraine No. 625 of 26 April 2003.

13. “General Requirements for Physical Protection Systems of Nuclear Facilities and Nuclear Materials”, approved by Order of the State Nuclear Regulatory Committee of Ukraine No. 156 of 28 August 2008.
14. L. I. Gromok and A. A. Kretinin. ”Long-term Storage and Disposal of Spent Radiation Sources in Ukraine”, Kyiv (2001).
15. O. K. Avdeev and A. A. Kretinin. “Radioactive Waste in Ukraine: Status, Problems, Solutions”, Kyiv (2003).
16. O. K. Avdeev and A. A. Kretinin. “Storages of Radioactive Waste in Ukraine” Kyiv (2008).