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INPRO Assessment of the Planned Nuclear Energy System of Belarus

A report of the International Project on Innovative Nuclear Reactors and Fuel Cycles (INPRO)

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International Atomic Energy Agency

INPRO ASSESSMENT OF THE PLANNED NUCLEAR ENERGY SYSTEM OF BELARUS

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INPRO ASSESSMENT OF THE PLANNED NUCLEAR ENERGY SYSTEM OF BELARUS

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Innovative Nuclear Reactors and Fuel Cycles (INPRO)

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FOREWORD

The International Project on Innovative Nuclear Reactors and Fuel Cycles (INPRO) was started in 2001 on the basis of IAEA General Conference resolution GC(44)/RES/21. INPRO activities have since been continuously endorsed by IAEA General Conference resolutions and by the General Assembly of the United Nations.

The objectives of INPRO are to help ensure that nuclear energy is available to contribute, in a sustainable manner, to the goal of meeting the energy needs of the 21st century, and to bring together technology holders and users so that they can jointly consider the international and national actions required for ensuring sustainability of nuclear energy through innovations in technology and/or institutional arrangements.

To fulfill these objectives, INPRO has developed a set of basic principles, user requirements and criteria, and an assessment method which, taken together, comprise the INPRO methodology for the evaluation of the long term sustainability of innovative nuclear energy systems. The INPRO methodology is documented in IAEA-TECDOC-1575 Rev.1, comprising an overview volume and eight additional volumes covering economics, institutional measures (infrastructure), waste management, proliferation resistance, physical protection, environment (impact of stressors and availability of resources), safety of reactors, and safety of nuclear fuel cycle facilities.

This publication is the final report of an assessment of the planned nuclear energy system of Belarus using the INPRO methodology. The assessment was performed in 2009–2011 by Belarusian experts in a strategic partnership with the Russian Federation and with support from the IAEA's INPRO Group.

The IAEA officer responsible for this publication was A. Korinny of the Division of Nuclear Power.

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SUMMARY

The INPRO methodology as documented in *IAEA-TECDOC-1575 Rev.1* (*INPRO Manual*) was used by Belarus experts to assess the long term sustainability of the planned nuclear energy system in Belarus. The planned system consists of an AES-2006 nuclear power plant and associated waste management facilities. Nuclear fuel is planned to be purchased from abroad and spent fuel is planned to be returned to the supplier.

The assessment was performed in all INPRO methodology areas, i.e. in economics, infrastructure, waste management, proliferation resistance, physical protection, environment and safety. The results of the assessment are presented in the following report.

An *economic* comparison of several options of power plants confirmed the competitiveness of nuclear power in Belarus. Taking strategic considerations into account — such as security of supply by diversification of energy sources — the Belarus Government has confirmed sufficient economic attractiveness for an investment in the nuclear power project in comparison with alternative energy projects. Evaluation of the risk associated with an investment in nuclear power produced the following results. There is strong Government commitment to nuclear power, which is an important prerequisite for a successful nuclear power programme. Sufficient robustness of economic results — especially for levelized unit electricity cost — for the planned nuclear technology AES-2006 has been clearly demonstrated. Currently, only the level of maturity (licensing status, experience with construction schedule) of the planned nuclear power plant AES-2006 is responsible for a certain risk level. The assessment revealed a lack of operational experience for this reactor design, but the plant is licensed and currently under construction in the country of origin; because of the extensive experience of the designer of AES-2006, very satisfactory operational behaviour of this plant is expected. Thus, it is concluded that the planned nuclear power programme in Belarus is in general agreement with the economic requirements of the INPRO methodology.

The evaluation of the *legal and institutional infrastructure* in Belarus revealed that it is well established. Some minor corrections of the text of the nuclear law [1] are recommended, such as adding definitions of terms used in the law and defining more precisely the functions of the regulatory body. Regulatory authorities of Belarus are independent of the operator of the future nuclear power plant. Nevertheless the conditions should be considered to enhance the autonomy of the body created to provide the functions of state regulation and licensing in the area of safe use of nuclear energy, ionizing radiation and the safety of radioactive waste (Department of Nuclear and Radiation Safety of the Ministry for Emergency Situations - Gosatomnadzor). The evaluation of the existing *industrial and economic infrastructure* and its planned development in Belarus confirmed, in general, the readiness of this part of the national infrastructure. The existing national industry is found ready to support the installation of nuclear power plants and no substantial financial investment is expected for upgrading national industries. An independent Government investigation is recommended in order to demonstrate the economic benefits of the planned nuclear power programme to society and define the size of the planned nuclear fuel cycle facilities. The evaluation of *public acceptance and political support* confirmed that adequate measures of public information had been taken by the Government. Development of nuclear power has strong Government support. Development of a policy of public information on the operation of the nuclear power plant is recommended. The evaluation of *human resources* needed for development of nuclear power revealed that practically all necessary activities are being implemented in Belarus.

Nevertheless, a problem may be the planned salary level at nuclear installations, which should be the same as in neighboring countries to avoid emigration of trained skilled professionals.

The INPRO methodology for *waste management* specifies waste minimization at the source, protection of humans and the environment against radiation exposure, avoidance of undue burdens on future generations, and optimization of the waste management system. All requirements on waste management directly related to design and operation of the nuclear power plant are fulfilled by the AES-2006 design. However, as the development of the waste management system for treatment of the radioactive waste outside the nuclear power plant is ongoing in Belarus, for the assessment of this part of the waste management system insufficient data were available at the time the report was written. The missing information should be recorded and the assessment finalized.

The obligations of the State with regard to the establishment of a legal framework dealing with *non-proliferation* have been met by Belarus. The ratification of the additional protocol to the existing comprehensive safeguards agreement is ongoing. The attractiveness of technology used in the nuclear energy system of Belarus for a weapons programme is very low, as no enrichment or reprocessing plant is planned to be built in the country. The nuclear material used in the planned nuclear power plant AES-2006 is not attractive for such a programme also due to its form, quantity and quality. The design of the AES-2006 ensures great difficulty to misuse the plant for proliferation and a high detectability of any activity to divert nuclear material for such a purpose. Although no results of a detailed acquisition and diversion path analysis were available for assessment, a significant number of robust barriers could be identified in the AES-2006 design against diversion of nuclear material. The status of activities regarding implementation of the safeguards agreement for the planned nuclear power plant AES-2006, i.e. the establishment of a facility attachment, is on schedule. The verification process will start before the nuclear fuel is delivered to the plant. The planned national nuclear fuel cycle facilities regarding proliferation resistance should also be assessed, especially the interim dry storage facility for spent fuel.

A comprehensive legal framework for *physical protection* of nuclear installations is established in Belarus and is currently being developed further to cover aspects of the nuclear facilities of the planned nuclear energy system, especially the nuclear power plant. The legal framework includes the necessary regulations and regulatory bodies dealing with physical protection. Physical protection is fully integrated into the design of the AES-2006 plant and is based on long-term experience with earlier types of this design (VVER family). Due to the early stage of the nuclear power programme, sufficient information was not yet available to the assessor on some specific aspects of physical protection defined in the INPRO methodology, e.g. security culture, insider adversaries, and contingency plans. It is expected that this information will become available in due time, enabling completion of the assessment.

There are two kinds of *environmental* effects caused by a nuclear energy system. The first effect is the generation of stressors that could have an adverse impact on the area surrounding nuclear facilities; the second one is the depletion of non-renewable resources that are needed for construction and operation of the nuclear installations. The results of an environmental impact study show that all impacts by stressors from the AES-2006 plant are clearly within national regulatory limits. The assessment of necessary non-renewable resources needed for construction and operation of the nuclear energy system of Belarus revealed that sufficient resources are available for the service life time of the AES-2006 plant.

Within the AES-2006 reactor design, the *safety* concept of defence in depth has clearly been enhanced. For the assessment of the independence of defence-in-depth levels and of the application of a human response model, not enough data were available to the assessor. The

AES-2006 design has incorporated increased emphasis on inherently safe characteristics and passive systems in its safety approach. The radiation exposure to workers in the AES-2006 reactor is well below the regulatory limits. Insufficient data were available to the assessor to compare the radiation risk in an AES-2006 plant with the risk in non- nuclear power plants. Intensive R&D activities have been performed to ensure reliable behaviour of all new engineered features in the AES-2006 design, such as the use of additional passive systems for prevention and mitigation of severe accidents.

The nuclear energy system assessment confirmed, in general, the long term sustainability of the planned nuclear energy system of Belarus. In some areas of the INPRO methodology — due to the early stage of development of the nuclear programme — not all necessary information was available to the assessor. This should be collected in the future and the assessment finalized.

1. INTRODUCTION

1.1. GENERAL INFORMATION ON BELARUS

Belarus is located in the eastern part of Europe. In the west it borders Poland, in the north-west Lithuania, in the north Latvia, in the north-east and east Russia, in the South Ukraine. The territory of Belarus is crossed by several European transport corridors providing the shortest communication routes from the central and eastern regions of the Russian Federation to western European countries, and between the Baltic and the Black seas.

The territory of Belarus is 207 600 square kilometers. The longest distance, 650 km, is from west to east, and 560 km from north to south. By the size of its territory, Belarus occupies the thirteenth place among the European countries and the sixth among the Commonwealth of Independent States (CIS) countries (following Russia, Kazakhstan, Ukraine, Uzbekistan and Turkmenistan).

The topography of Belarus features predominantly low hilly land with an average altitude of 160 m above sea level, while the highest point is only 345 m above sea level. The flatland nature of its surface creates favourable conditions for the expansion of human settlements, agricultural development of the territory, construction of industries, transport and service lines, and development of tourism and recreational services.

Agricultural land occupies 45% of the territory, including 30% of tillage. There are 0.9 hectares of cultivated land, including 0.6 hectares of tillage, per capita in Belarus.

Forests account for 36% of the country's territory. There are 0.7 hectares of woods and 111 m^3 of timber per capita here, which is almost twice as high as the average European level. The trees growing in Belarus mostly belong to valuable species. Pine occupies 52.9%, fir 10.5%, oak and other hard-leaved species 3.8%, birch 18.1%, aspen 2.3%, alder 9.6% of the forest-covered area. However, the species composition of the woods is far from optimal. Considering the fertility of the forest soils, the area under hard-leaved species could be expanded two-fold. The forest potential in Belarus is rather high; the annual increment of timber reserves is 25 million cubic meters, while the actual timber production is 10–11 million cubic meters per year. The area with mature woods is steadily growing. The forest, apart from being a source of timber, performs numerous ecological functions (such as water protection, water regulation, soil protection, assimilation functions), and also sanitation, recreation and health-building functions. Belarusian forests play an important biospheric role and make a considerable contribution to the ecological stabilization of central and eastern Europe.

1.1.1. Natural resources

About 30 kinds of mineral raw material can be found in Belarus (more than 4000 deposits and fields). The most significant are potassium salts; their reserves occupy one of the leading places in Europe. The reserves of rock-salt are also notable. The prospected industrial reserves of these minerals in the Mozyr, Davydov and Starobin deposits exceed 22 billion tons.

The country is rich in rock products, such as granites, dolomites and dolomite limestone, marl, chalk, fusible and refractory clay, loam, sand and gravel. There is raw material for the production of natural paints (e.g. marsh iron ore, ochre, glauconite).

The availability of high quality water resources stimulates the construction of sanatorium and resort complexes and the development of companies trading and exporting mineral curative and table water. In recent years, more than 63 springs have been discovered with a potential supply of 155 572 m^3 per day.

Belarus possesses sufficiently strong raw material reserves for the production of construction material. However, there is a deficit of high-grade glass-making sand and clay.

Peat fields are widely spread in Belarus, although — due to intensive exploitation — the peat fields as production sources have largely been exhausted. The total geological reserves are estimated at 4.4 billion tons. Sapropels are an important natural raw fertilizer; their estimated reserves are three billion cubic meters. A comprehensive utilization of peat and sapropel resources is important.

The reserves of oil are not large and oil is extracted in small quantities. Deposits of brown coal have been found in Belarus. However, its low caloric value and high ash content preclude its utilization in energy production in the near future. Briquetted brown coal (possibly, with peat) can be used only as household fuel or as raw material for producing wax and plant growth stimulants.

The Belarusian territory is promising in terms of ferrous and non-ferrous metal. Geological exploration in search for amber, titanium and rare-earth metal deposits is under way.

The existing mineral resources fully provide for the future needs of potassium and rock salt, lime and cement, refractory and ceramic clays, construction sand, gravel and facing stone.

It must be noted that the mining resources in Belarus are still insufficiently investigated. The new economic situation and the emergence of sophisticated technologies call for a revaluation of the deposits and reserves of mineral resources in the Republic, and a more efficient utilization of all components of the resources mined.

1.1.2. Climate

The climate of Belarus is moderately continental with mild and humid winter, warm summer and wet autumn. The mean temperature in January is from – 4 °C in the south-west to – 8 °C in the north-east of the country; that of July is + 17 to + 19 °C. The annual precipitation is 550–650 mm in lowland areas and 650–750 mm in flatland and elevated areas. The average vegetation period is 184–208 days. The climatic conditions in Belarus are favourable for growing staple grain crops, vegetables, fruit trees and bushes which are common for moderate climate zones of east Europe, especially for cultivating potatoes, flax, annual grass and fodder root crops.

There are more than 20 000 rivers and streams in Belarus with the total length of 91 000 km, and about 11 000 lakes, including 470 lakes with the area exceeding 0.5 km^2 each. Naroch is the largest lake in Belarus (79.2 km^2, the deepest point about 25 m). More than half of the water resources belong to the Black Sea basin, the rest belongs to the Baltic Sea basin. The Pripyat, Dnieper, Nieman, Berezina and Zapadnaya Dvina rivers, and also the Dnieper-Bug canal are important for river navigation.

More than 145 artificial lakes have been created in Belarus. The most important is the Viliya Reservoir (75 km^2) that gives birth to the Viliya–Minsk system of canals along which water from the Viliya river is directed to Minsk, the Republic's capital.

The renewable resources of surface and underground fresh water in the country are sufficient for meeting the present and future needs: the river water resources constitute 57.9 km^3/a. The total volume of water accumulated in lakes is estimated at 6–7 km^3, the volume of artificial reservoirs is 3.1 km^3. The average water intake for the household and industrial purposes does not exceed 5–7% of annually renewable water reserves.

1.1.3. Territorial division

Belarus consists of six oblasts which include 118 administrative districts and the city of Minsk. There are 104 towns and 108 settlements with the status of a town.

Regional differentiation is not high in Belarus, although the oblasts differ in their level of socioeconomic development and the structure of their economy. The main socioeconomic, natural geography and ecological features include:

- A higher level of industrial development in the eastern regions and, therefore, a high level of production and consumption of energy and material;
- The presence of major chemical and petrochemical complexes in Vitebsk, Grodno, Gomel, Minsk and Mogilev oblasts, which are a severe burden on the environment;
- A high concentration of industrial production in the capital and major cities;
- Differences between oblasts in the level of agricultural production connected with soil, climatic, ecological and other local characteristic features, and with differences in the location of main branches of agricultural specialization;
- Main concentration of social infrastructure complexes in Minsk, oblast centres and other towns.

The city of Minsk is situated in the central part of Belarus and is the national capital and the centre of the oblast and district with the same name. Minsk is granted a special status. It is the largest political, economic, scientific and cultural centre of the Republic. The population is 1 885 100. The territory is 255.8 km^2. Administratively, it is divided into nine districts and has one city council with jurisdiction over some villages and urbanized settlement. With about 300 industrial enterprises, Minsk has the largest industrial production in Belarus — more than 22% of the country's industrial output. The city of Minsk exceeds the other regions in the output of machine engineering, electric energy, non-ferrous metallurgy, medical and printing industries. The prevalence of machine engineering industries — producing more than half the city's industrial products — is a characteristic feature of the capital. There are such major enterprises as BelavtoMAZ, Minsk Tractor Works, Minsk Engine Works, and Atlant. Electric energy, and the food industry also has a high share. The industrial complex of the city possesses a high export potential: at a number of companies up to 80% of output is exported.

1.1.4. Population

The size of the resident population of Belarus amounted to 9 465 200 people as of the beginning of 2012. Over 24% of the urban population resides in the Belarusian capital.

Belarus is a comparatively densely populated country. Average population density is 46 persons per sq km. The territory of Belarus is inhabited rather uniformly, most densely in central regions.

The sex/age structure of the population is as follows: males account for 45.7% and females for 54.3%. Dynamics of size of population in Belarus during 1990–2011 are given in Table 1.

TABLE 1. DYNAMICS OF SIZE OF POPULATION IN BELARUS

	1990	**2000**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**
Number of resident population, thousands.	10190	9990	9800	9751	9714	9690	9514	9500	9481

Belarus is a polyethnic and polyconfessional State in which over 130 nationalities (comprising just under 20% of the total population) reside with Belarusians (81.2%).

1.1.5. State institutions

The President of Belarus is the head of State, guarantor of the *Constitution* and civil rights. The President takes measures to maintain the sovereignty of the Republic, its national security and territorial integrity, and provides political and economic stability, succession and cooperation of State bodies, and is a mediator between them.

In accordance with the *Constitution*, the President issues edicts and decrees that have binding force on the whole territory of Belarus. In cases stipulated by the *Constitution*, the President issues decrees with the force of law. Directly or through special bodies he provides for the execution of decrees and edicts.

The Parliament, i.e. the National Assembly, is the representative and legislative body of the Republic. The Parliament consists of two chambers, the Chamber of Representatives and the Council of the Republic. The *Constitution* defines the composition and the procedure of forming the chambers. The Chamber of Representatives consists of 110 deputies elected on the basis of universal, free, equal and direct suffrage, by secret ballot. The Council of the Republic is the chamber of territorial representation. In each region and in the city of Minsk, eight members of the Council of the Republic are elected at sittings of deputies by secret ballot. A further eight members are appointed by the President. Each Chamber elects its own Chairman and vice-chairmen who run the sittings and manage the internal regulations.

In conformance with the *Constitution*, the Chamber of Representatives is entitled to hear the reports of the Prime Minister on the Government's programmes of activities, give a vote of no confidence to the Government, and consider the issue of confidence to the Government upon the request of the Prime Minister. The Chamber of Representatives appoints elections of the President and accepts the dismissal of the President.

The Council of the Republic may cancel the decisions of local councils of deputies which run contrary to the national legislation, and takes decisions on dissolution of a local council in cases of systematic or gross violations of the legislation and in other cases stipulated by the law.

The *Constitution* establishes the right of the Council of the Republic to consider the decrees of the President on introducing the State of emergency, martial law, total or partial mobilization, and must take an appropriate decision within three days after their submission.

The Parliament takes a decision on the President's dismissal.

The term of office of the Parliament is four years and may be extended only in event of war.

Local government and self-government is exercised through local councils of deputies, executive and management bodies, bodies of territorial public self-management, local referenda and meetings.

The local councils of deputies are representative bodies of State power in the respective territorial administrative units and the main bodies of self-management.

The *Constitution* establishes the exclusive competence of local councils of deputies for approval of programmes of economic and social development, local budgets and report on their execution, imposition of local taxes and duties in conformance with the law, determination, in conformance with the law, of the procedure of managing communal property, and the conduct of local referenda.

The local councils of deputies are elected by citizens of the respective territorial administrative units for four years.

In conformance with the *Fundamental Law*, heads of the local executive and management bodies are appointed and dismissed by the President or in the order established by him, and approved by the respective local councils of deputies.

The *Constitution of Belarus* establishes a binding force of the decisions of local councils of deputies, and of executive and management bodies on their respective territory, taken within their frame of competence, which is one of the guarantees of their efficient work.

1.1.6. Economy

The Belarusian economy has experienced steady and sizable growth since 1996. Following an estimated decline of close to 40% during 1992–95, gross domestic product (GDP) growth resumed in 1996. During 1996–2004, the GDP grew by 77.4%, at 6.6% on average per annum. Rates of GDP growth in 2005–2010 fluctuated between 7.0% and 10.2% (except in 2009, Table 2) according to the data of the National Statistics Committee of Belarus [2, 3].

TABLE 2. BELARUS: BASIC MACROECONOMIC INDICATORS, 1995–2010

	1995	**2000**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**
GDP, bln. BRB	121403	9134*	65067	79267	97165	129791	137442	162964
GDP, % in relation to previous year, const. prices	89.6	105.8	109.4	110.0	107.0	110.2	100.2	107.6
GDP structure,%:								
Industry	27.6		28.4	27.6				26.8
Agriculture	15.1		7.9	7.5				7.5
Construction	5.4		6.9	7.9				11
Transport & communication	12.2		9.5	9.2				9.5
Trade & catering	7.6		9.4	10.3				11.1
Net Taxes	9.7		14	14.2				12.8
Other	22.4		23.9	23.3				21.3

*Taking the currency adjustment into account, divide by 1000

Economic growth in Belarus has been rather broad-based. It has been driven primarily by improvements in labour productivity and increases in both energy efficiency and capacity utilization. Fiscal and external adjustments have been significant and have helped to improve the macroeconomic conditions for growth. In contrast to some other CIS countries, where growth and exports remain concentrated in the extracting sectors with limited employment opportunities, the growth structure in Belarus has been much more beneficial for labour. Growth in labour-intensive sectors, backed by Government wage and income policies, has helped to ensure that the benefits from recent growth have been fairly broadly shared by the population. Poverty rates have declined substantially, while inequality has remained stable and moderate. The poverty headcount ratio (national definition) fell from 38.6% of the population in 1996 and 46.7% in 1999 to 17.8% in 2004, while inequality, which was moderate by regional standards during the entire period of economic growth, decreased further after 2001. This decline in poverty is, however, in line with a broader trend in poverty reduction that took place recently in the transition economies. This remarkable achievement is the result of a unique constellation of factors — rapid ‘catch-up’ growth in CIS accompanied by reductions in inequality in some countries.

Before 2001, in terms of economic growth, Belarus outperformed both the central eastern European and Baltic States (CEEBS) and the CIS but during the second period (2001–04), the CIS as a group had a stronger performance than Belarus and the difference in growth rates between Belarus and the CEEBS decreased. In addition, Belarus' relatively strong debt and trade indicators in the late 1990s should be treated with caution: the use of the official exchange rate at the time of the multiple exchange rate system distorted the data. The application of the alternative exchange rate revealed that during the first period of growth, Belarus had much more serious problems with its balance of payments than is usually recognized. In 1998, the current account deficit amounted to almost 16% of the GDP, while the official figures show only 7%. However, both measures show a strong post-1999 recovery in all main indicators of external vulnerability, indicating a strong external adjustment.

The macroeconomic performance during the years of economic growth has been rather mixed. Belarus has managed to maintain moderate budget deficits and debt levels. However, such indicators as inflation, foreign direct investment inflow and the current account balance were weak. Inflation in Belarus, which is being reduced substantially, remained significantly higher during both periods than in other transition economies, including neighbouring countries. The current account position is still precarious, given the low level of reserves, the inability to attract a sizable amount of direct foreign investment, and the limited access to international financing.

Overall, the Belarusian economy has a number of features that make it quite different from its neighbours in both the CIS and the CEEBS. These features include:

- The dominance of traditional firms (State-owned or partially privatized) in production and exports;
- The high degree of Government intervention in state enterprise operations, including the preservation of some elements of central government planning of output, wages, and employment;
- The high level of the tax burden and the major budget redistribution of funds aimed at supporting traditional firms and employment;
- Quite substantial dependence on trade with the Russian Federation along with the slow pace of geographic diversification of exports.

The pattern of changes in the structure of the nominal GDP by sector in Belarus is similar to that in other transition economies but the magnitude of these changes is somewhat different. As in other transition economies, especially those considered as over-industrialized, the share of services in GDP structure increased. The reduction in the share of agriculture has also been in line with the developments in other CEEBS. At the same time, the increase in the share of services is relatively moderate. Moreover, in 2000–2006 these trends were reversed — the share of industry actually increased while the share of services declined. However, changes in the nominal GDP structure are not the most informative in the environment of changing relative prices.

1.2. PRIMARY ENERGY SUPPLIES

In the past several years, Belarus has demonstrated considerable growth in its economy. The GDP of the country more than doubled from 2000 to 2010.

However, domestic fuel use during the same period was very moderate. Belarus remained highly dependent on its single foreign fuel supplier – the Russian Federation.

Belarus remained one of very few countries in the world which notably increased the share of natural gas in the national energy mix in the given period without having its own reserves of this energy resource. For example, the share of natural gas used for electricity generation is one of the highest in the world and equals 95–96%. At the same time, underground storage does not meet modern requirements for energy security (25% of total annual resource consumption).

All these facts jeopardize the efforts of the Belarusian government to sustain successes achieved lately and to create a strong economic basis for further national development.

To address these challenges, reduce energy dependence and lessen the national economy's vulnerability to energy price shocks in the future a comprehensive energy policy is required.

1.2.1. Primary energy sources

Imported crude oil and natural gas are the main sources of primary energy for Belarus. The history of these kinds of primary energy is given in Table 3.

TABLE 3. IMPORTED CRUDE OIL AND NATURAL GAS

	2000	**2005**	**2006**	**2007**	**2008**	**2009**
Crude oil, mill. tonnes	11.9	19.2	20.9	20.0	21.5	21.5
Natural gas, bill. m^3	17.1	20.1	20.8	20.6	21.1	17.6

1.2.1.1. Domestic energy resources

To decrease the share of imported energy sources, it is planned to increase the use of domestic and renewable energy resources. In 2020 domestic resources and renewables will amount to 6.7 million tce.

Biomass

Wood and residues of wood processing are the most important source of domestic fuel in Belarus. At present, biomass reserves in forests of the country are estimated to be 1.43 billion m^3. Territory of the country covered by forests is 9.3 million hectares.

Belarus has considerable potential to increase biomass use for energy purposes. It is supposed to increase the use of wood to 11 million m^3 (3.1 million tce) per year by 2020.

Peat

Belarus has one of the largest reserves of peat in Europe. More than 9000 deposits of economically justifiable peat extraction have been found there. Their total area is 2.54 million hectares, and peat reserves there are estimated to be 5.65 billion t. Geological reserves of peat in Belarus amount to 4 billion t. Reserves of peat available for energy use are estimated at 100–130 million t.

At present, most of peat produced in Belarus is consumed by housing and utilities as fuel for small boilers, which is the main restriction for its wider use.

Further growth of peat use as a fuel will be possible if new small combined heat and power plants or centralized district heating plants designed especially for its use are built in Belarus.

For this purpose, it is expected to increase peat for energy production by 1.5 million tce by 2020. To achieve this goal, the development of new peat deposits will be necessary with due consideration given to environmental issues.

Lignite

In 2003, the available reserves of lignite in Belarus were estimated to be 151.6 million t. Lignite found in Belarus has the following characteristics:

- Humidity — 56–60%;
- Ash content — 17–23%;
- Sulphur content — 0.6%
- Calorific value — 1500–70 kcal/kg

Dried lignite can be used for briquettes, manufactured jointly with peat as a fuel for hot water boilers. Subject to thermochemical processes, lignite can be used as raw material for liquid fuel or other products.

The largest deposits of lignite in Belarus are located at Zhitkovichi. Its reserves allow to extract annually 2 million t of lignite (0.46 million tce). After completion of feasibility studies, it is planned to develop this deposit and its annual production will reach 0.2 million tce by 2020.

Oil shale

Forecast, reserves of oil shale in Belarus are estimated at 11 billion t. Reserves of the Luban and Turov deposits available for extraction are expected to be around 3 billion t. Oil shale in Belarus is characterized by low calorific value (1000–1510 kcal/kg), and high ash (61–82%) and sulphur content (2.6%) that makes its use for direct combustion impossible. The alternative way to involve oil shale in use in Belarus is to subject it to high-cost thermochemical processes; however, that is not economically feasible at present.

1.2.1.2. Renewable energy resources

Hydroelectricity

The theoretical potential of hydro resources for electricity generation in Belarus is estimated at 850 MW. However, only 529 MW is technically available. Economically feasible potential for hydroelectricity in Belarus is 250 MW.

Currently (2012), the total installed capacity of hydroelectric power plants is about 32 MW. The strategic goal of Belarus with regard to hydroelectricity is to construct new plants, and reconstruct and recover old hydroelectric power plants (HPPs). According to these plans, total installed capacity of HPPs will reach 120 MW in 2015.

For estimation of the economic feasibility of constructing hydro cascades on such rivers as the Sozh, Pripyat, and Dniepr, more detailed investigation is needed.

In the near future attention should be focused on the use of small hydro units with installed capacity from 50 to 5000 kW each. The use of small hydro generators of capsule design is more advantageous due to lower scheduled outages for maintenance.

Geothermal energy

The most favourable conditions for geothermal potential use in Belarus are in Pripyat and Podlyassk-Belostok cavities where extracted heat resource potential reaches 5–6 tce per m^2. To exploit this reserve, a complex of special geological studies is required in order to determine the exact sites for well drilling and development of special technologies for geothermal energy use taking into account high mineralization of this heat source.

Wind energy

According to the meteorological data available, approximately 1840 sites for wind turbine installation are to be found in Belarus. On 1 January 2005, the total installed capacity of wind turbines in Belarus was 0.85 MW, and their annual electricity generation made up 0.4 tce. Currently, in 2012, total installed capacity of wind turbines in Belarus is about 3 MW. The scale of wind electricity is subject to annual correction taking into account possible changes of fossil fuel costs.

Use of wind energy in remote rural areas, farms and greenhouses for electricity generation, heating and water pumping is considered to be the most feasible option for Belarus due to the low average wind speed in the country.

Biogas

Potential for biogas use in Belarus is estimated to be 160 000 tce per year. At present, three pilot biogas projects are completed in Belarus. However, an integrated approach with regard to biogas technologies is needed to make them competitive with traditional ones. Results achieved show that, for biogas projects, it is necessary to take not only costs of electricity and heat generated into account but also environmental effects.

Solar energy

According to meteorological surveys, average solar radiation in Belarus is 243 kcal/m^{2}day, equal to 2.8 kWh/m^{2}day. Providing the efficiency of energy transformation is 0.3, the average potential for solar energy production is 0.3 kWh/m^{2}day.

Possible ways to use solar energy in Belarus are agricultural and domestic applications, mainly for water heating purposes. Potential for use of solar energy in Belarus could amount to 5000 tce.

Solid waste

Total energy reserves possible from solid waste use are estimated to be around 470 000 tce. Providing that the efficiency of the process of transformation of waste into gas equals 30%, total available reserves of this source are 100–120 thousand tce. When considering use of solid waste as an option, it is necessary to take into account its large reserves in all the large cities in Belarus as well as possible environmental effects related to waste use.

Fast growing biomass and agricultural waste

Fast growing biomass of trees and bushes can be used as a fuel or a source of raw material for solid of liquid fuel production. Possible crops of fast growing biomass from one hectare in Belarus may exceed 10 t, i.e. equal to approximately 4 tce per year. If special growing technologies are used, productivity of such plantations can be 2–3 times higher. According to the data of special research, potential of this kind of energy resource in 2020 will reach 350 000 tce.

Agricultural waste also makes up a considerable reserve as energy resource. Total available potential of this alternative fuel in Belarus is estimated at 1.46 million tce per year. Agricultural waste is thought to be widely used as fuel for small heating plants and individual heating systems in rural areas.

By 2020, potential of this energy resource use is estimated at 140–200 thousand tce.

Biodiesel and bioethanol

Belarus has good prospects for the wide use of biodiesel and bioethanol as alternative automobile fuel. Rapeseed, soybean and sugar beet are considered to be the best crops for this liquid fuel production. Biodiesel and bioethanol can be used as additives to traditional fuel or in pure form as main fuel. Total available reserves of these fuel sources are about one million tce, taking into account existing and projected crop productivity and their main use for the food industry.

Should the necessary investment for the industry be available, the volume of biodiesel and bioethanol production could be 110 000 tce in 2020.

For launching bioethanol production in the country, large-scale modernization of existing sugar been processing industry is required. Biodiesel production will be organized at plants for the food industry operating at present.

Secondary energy resources

According to estimates made, the potential volume of secondary fuel energy resources available in Belarus is about 580 000 tce per year, including methane-hydrogen for ethylene production — 162 000 tce, X-oils — 14 500 tce, black liquor — 9200 tce, flax scotch — 36 900 tce, and fuel oil residues — 2400 tce. Efficiency of the secondary energy resources in technology and boilers varies from 70 to almost 100%.

At present, these reserves are partially in use. The most considerable project realized in this field is the utilization of lignin produced at Rechitsa hydrolysis factory for the generation of heat energy.

The use of secondary energy resources at refineries operated in Belarus is expected to increase notably. For example, the volume of oil coke produced at Novopolotsk refinery Naftan as a by-product will be up to 4 000 000 tce in 2015–2020. This energy resource can be used as fuel for heat and electricity generation and may be consumed by either Naftan or power plants and also the construction material manufacturing industry. It is expected to use appropriate technology at Naftan and Novopolotsk CHP.

Belarus also has great potential for use of waste heat resources. Their use in 2006 reached 4.9 million Gcal and the volume of their utilization in 2010 was about 5.9 million Gcal.

Enterprises of chemical and petrochemical industry have the largest reserves for waste heat use (about 96.5% of total reserves available).

Capital investments needed for that purpose will be about 70–80 million USD by 2015. Providing necessary investment is forthcoming, the volume of high-temperature waste heat use will increase by 200 000 tce and of medium- and low-temperature waste-heat by 60 000 tce.

The largest reserves for use of this energy resource are concentrated at the following factories:

- JSC Grodno Azot — production of ammonia fertilizers;
- JSC Gomel Chemical Plant — production of sulphuric acid;
- Naftan refinery — oil processing, including waste heat of hydrogen production;
- Mozyr refinery

The targeted volumes of waste heat utilization can be achieved only if scheduled volumes of oil processing and mineral fertilizer production are guaranteed.

The use of waste heat by factories owned by the Ministry of Industry of Belarus was about 5 925 000 tce in 2010.

1.2.2. Diversification of primary energy supplies to Belarus

At present, Belarus receives all oil and natural gas consumed from a single supplier — the Russian Federation. Such a structure of routes of primary energy transportation makes the economy of Belarus highly vulnerable to energy price changes and supply interruptions in case of damage to oil and gas transportation pipelines or political conflicts, for example.

However, the number of possible economically feasible alternatives of primary energy resource supplies to the country is very limited.

Taking into account the locations of existing and prospective gas and oil fields in the world and also the political relations between Belarus and other countries, it is worth examining the effectiveness of organization of energy resource supplies from Azerbaijan, Venezuela, Iran, and Kazakhstan.

Preliminary feasibility studies of energy supplies from these countries have already been conducted and detailed examination of economic effectiveness of these projects is necessary to make the final decision.

The most important alternative routes of primary energy supply to Belarus are for:

- Natural gas — Kazakhstan, Turkmenistan and Uzbekistan;
- Oil — Azerbaijan, Kazakhstan, Iran, Iraq and Venezuela;
- Coal — Kazakhstan, Poland and Ukraine.

1.3. ENERGY SECTOR

1.3.1. General data

The total installed capacity of all power plants in Belarus in 2010 was about 9.1 GW, of which 8266.5 MW of thermal capacity plants belong to the national utility Belenergo. The total length of the electricity grid was 238 800 km, and the total length of heat transmission pipelines was 5.100 km.

In 2010, the overall consumption of electricity in Belarus was 37.46 billion kWh. Electricity generation by the national power plants amounted to 34.5 billion kWh, of which 32.5 billion kWh were generated by Belenergo power plants. Electricity import in 2010 was 2.97 billion kWh.

Heat generation by power plants and district heating plants belonging to Belenergo in 2010 totalled 36.72 million Gcal. Electricity in transmission and distribution grid and heat energy losses made up about 11% and 10%, respectively.

Total fuel consumption of Belenergo generation facilities in 2006 was 1 3984 900 tce, of which 13 161 500 tce was natural gas (94.1% of overall fuel consumption), 799 900 tce — fuel oil (5.7%) and 23 500 tce. — other types of fuel (0.2%).

1.3.2. Main options for modernization

The current five-year power sector modernization programme takes the physical state of heat and electricity generation equipment, existing and prospective electricity and heat load profiles, and tendencies of fuel prices into account, and aims to achieve the least-cost regime of operation of energy objects in the country.

Installation of new, efficient combined-cycle generation equipment in power plants operated at present in Belarus is considered the strategic way to improve the efficiency of electricity and heat generation of Belenergo facilities.

Other strategic ways aiming to increase the efficiency of operating generation equipment at thermal power plants are:

- Replacement of turbine blades;
- Dismantling of worn-out units and installation of new more efficient units on existing bases;
- Installation of modern generating unit automation control systems;
- Modernization of existing heating plants with installation of steam and gas turbines;
- Replacement of burners.

During 2012-2015 it is planned to continue modernization of the largest power plants in the country — Lukoml and Bereza condensing power plants. These power plants have been in service for more than 35 years, which considerably exceeds their assigned plant life (27 years) and makes their further operation inefficient.

In some cities in Belarus, construction of small combined heat and power (CHP) plants which use domestic fuel resources (primarily wood chips and peat) will be completed in 2012–2015. For instance, a new biomass-firing boiler is to be commissioned in Zhodino CHP plant (60 t/h), a small CHP facility with electrical capacity of 2.7 MW will be built in Pruzhany.

Construction of hydroelectric power plants is considered one of the most important ways to reduce dependency of Belarus from the import of fossil fuels from the Russian Federation and to reduce greenhouse gases emissions.

An additional possibility is to use domestic, renewable and secondary energy resources in the power generating facilities. The total volume of these energy resources used by Belenergo for electricity and heat generation was about 274 500 tce in 2010.

Newly built units are expected to be provided with modern technologies for solid fuel combustion (e. g. fluidized bed technologies), highly efficient systems of ash removal and exhaust gases catalytic reduction.

1.3.3. Energy supply

1.3.3.1. Natural gas supply and distribution system

At present, all natural gas consumed in Belarus is supplied from the Russian Federation via a well-developed gas transmission pipeline network. The total length of large-size pipelines in Belarus exceeds 7000 km and of the distribution pipelines is about 28 000 km.

Nominal transit capacity of the main pipeline passing through the territory of Belarus Torzhok-Ivatsevichi is 51 billion m^3 of gas per year, and the length of the Belarusian part of the Yamal-Europe pipeline is 575 km and its annual capacity equals 33 billion m^3 of gas.

Distribution and delivery of natural gas to final consumers in Belarus is performed by Beltransgas which operates:

- More than 6.9 km of large-size pipelines;
- Eight compressor stations with installed electrical capacity of gas compressors equaled 729.7 MW;
- Two underground gas storage facilities, including Osipovichi gas storage with a nominal capacity of 0.36 billion m^3 of gas and Pribugskoe gas storage with a capacity of 1.35 billion m^3 of gas;
- 218 gas distribution stations with a nominal capacity of 93.4 billion m^3 of gas (in 2002, supplies of gas were only 17.6 billion m^3);
- 24 gas filling stations and other facilities.

The majority of gas distribution stations are located in Brest (46), Grodno (34) and Minsk (52) regions while other regions of the country receive a more moderate level of gasification due to the remote location from large-size gas transmission pipelines.

In general, the existing system of gas supply can be characterized by a rather low capacity utilization rate of about 20%. This is a legacy of the central planning and design policy of Soviet times when Belarus had low natural gas prices.

In spite of the fact that a considerable overcapacity in the transmission and distribution network exists, the organization of economically feasible gas supply of some regions of Belarus is a challenge because of the lack of necessary pipe-lines.

Development of gas transmission and distribution network is considered one of the key components of the national energy strategy.

Annually, 1350 km of gas transmission and distribution pipelines are built in Belarus. The forecast length of this gas supply network for 2015 is 38 000 km and for 2020 43 000 km.

The existing gas supply network well maintained. Pipelines that have been operating for 15-25 years account for 15% of the total length, while those operating for 5-15 and less than 5 years account for 47% and 26% respectively. Existing pipeline system provides good basis for reliable gas supply of consumers in Belarus.

Until 2020, priority will be given to the construction of new distribution gas pipelines from existing gas distribution stations to large fuel consumers, primary energy intensive industrial enterprises and dwelling areas.

The gasification of 35 medium and small cities and is expected to be completed and a gas supply infrastructure put into operation for more than 200 000 households by 2020, which will require more than US $140 million.

Two possible scenarios are considered when analysing prospects of the gas supply system development in Belarus.

According to the *pessimistic scenario*, limited national and foreign financial capabilities may be the main restriction for the further development of the national gas supply network. In this case, the main priority will be given to the construction of new gas supply networks from existing gas distribution stations and reconstruction of gas distribution facilities operated more than 40 years. That will retain considerably switching to natural gas use of some territories, primarily small rural areas and also of dwelling areas.

The *optimistic scenario*, implies more active participation in the gas network development by both private and State institutions. For this, an active development of the gas supply system in Vitebsk, Gomel, Brest and Minsk regions is forecast. Enhancement of existing piping systems along with the implementation of intensive maintenance and repair programmes for operating facilities and improvement in industrial energy efficiency are expected.

However, comprehensive assessment of possible alternatives regarding more active domestic fuel use as an integral part of the planning and development process of the national gas supply system should be taken into consideration due to energy security concerns and continuously increasing natural gas prices.

1.3.3.2. Liquefied petroleum gas supply system

Liquefied petroleum gas (LPG) consumption in Belarus has demonstrated a constant decline recently primarily because of its active substitution by natural gas in the housing and utility sector. About 60% of the existing demand for LPG is covered by domestic production, and rest of it is supplied by Russia.

In the forecast period, further decline of LPG consumption is expected.

The use of LPG is economically feasible to meet energy demands of sparsely populated rural areas where construction of natural gas distribution pipelines is not an effective option.

However, possibly LPG use by the transport sector will double. Should the necessary infrastructure be provided, it is possible to considerably increase the use of this energy resource due to its lower demand in housing and utility. The preliminary amount of investment needed would be about US $14.5 million for the construction of new filling stations and the acquisition of special transport and storage tanks.

1.3.3.3. Oil supply system

At present, Belarus receives all its oil from the Russian Federation via a system of pipelines: Unecha-Polotsk with a transit capacity of 29 million tons of crude per year, Unecha-Mozyr (80 million t per year) and Surgut-Polotsk (40 million t per year). The existing pipeline capacity in Belarus is sufficient to meet both the domestic oil demand and a large part of the oil demand of other European countries.

1.4. ELECTRICITY AND HEAT

1.4.1. Electricity

Electricity production and consumption in Belarus during 1995–2008 are presented in Table 4 as electricity balance [2].

TABLE 4. ELECTRICITY BALANCE OF BELARUS IN 1995–2008, BLN KW·H

	1995	2000	2001	2002	2003	2004	2005	2006	2007	2008
Electricity produced total	24.9	26.1	25.1	26.5	26.6	31.2	31.0	31.8	31.8	35.0
- by thermal PP	24.898	26.074	25.033	26.427	26.599	31.176	30.924	31.484	31.518	35.008
- by hydro PP	0.020	0.027	0.030	0.028	0.028	0.034	0.036	0.035	0.035	0.039
Electricity imported	10.1	10.0	11.0	10.0	10.8	8.0	9.1	10.1	9.4	7.1
Electricity consumed total	32.1	33.3	33.4	33.0	33.4	34.5	35.0	36.2	36.2	36.9
- by industry and construction	13.8	16.0	16.1	15.4	15.7	16.7	17.0	17.7	17.9	18.3
- by agriculture	4.8	3.9	3.7	3.5	3.3	3.2	3.2	3.4	3.3	3.4
- by transport	1.8	1.9	2.0	2.2	2.2	2.1	2.1	2.0	1.8	1.8
- by other branches	8.1	8.1	8.1	8.5	8.8	8.9	9.1	9.1	9.5	9.7
Losses of electricity in grid	3.6	3.4	3.5	3.4	3.4	3.6	3.6	3.8	3.7	3.7
Electricity exported	2.9	2.8	2.7	3.5	4.0	4.7	5.1	5.8	5.1	5.2

Electricity consumption in Belarus during 2000–2008 grew by 10.8% and in 2008 was 36.9 billion kWh. The most considerable contribution to this growth was made by industry (2.3 bln kWh, or 14% growth) and housing and utilities sector (1.6 bln kWh, or 20% growth). The most intensive growth of electricity consumption took place in 2006.

During 2006, a tendency of more active growth of electricity consumption was monitored. For instance, electricity consumption increased by 4.6% while for the previous year growth was only about 1.5%. Primary fuel consumption in 2006 rose by 6.4% compared to 3% growth in 2005. About 95% of electricity consumed in the country in 2008 was provided by domestic generation facilities, which was almost 17% higher than in 2000. Thus, electricity net import sank almost fourfold during this period.

1.4.2. Heat energy

Heat energy balance during 1995–2008 is presented in Table 5. A tendency of overall heat demand decrease is shown by the data in this table. There are tendencies of a decrease in heat production by boilers and an increase by exhaust heat utilization equipment. Heat consumption is characterized by a weak but stable tendency of a heat demand decrease by household and utility consumers. The tendency of heat loss increasing in pipelines reversed during the 2007–2008 period.

TABLE 5. BALANCE OF HEAT IN BELARUS IN 1995–2008, MILLION GCAL

	1995	2000	2001	2002	2003	2004	2005	2006	2007	2008
Heat generation total	72.7	69.1	73.7	71.3	72.7	72.7	73.5	74.4	69.7	67.5
- by power plants	29.3	28.1	29.6	29.1	30.2	31.6	32.4	32.9	31.5	32.0
- by boilers	41	38.1	41.4	39.5	39.4	37.5	36.6	36.7	33.1	30.0
- by exhaust heat utilization equipment	2.2	2.8	2.6	2.6	3.0	3.5	4.4	4.7	5.0	5.5
- by other equipment	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.0
Heat consumption total	72.7	69.1	73.7	71.3	72.7	72.7	73.5	74.4	69.7	67.5
- for industrial purposes	49.1	40.8	41.7	39.5	40.2	41.3	42.7	43.2	41.1	40.3
- for oil and oil condensate processing		2.5	2.7	3.0	3.0	3.3	3.4	3.7	4.4	4.3
- fertilizer production		2.2	2.4	2.4	2.5	2.7	2.7	2.7	3.1	2.9
- chemical fibre production		1.6	1.5	1.4	1.5	1.4	1.4	1.3	1.4	1.3
- tar and plastics production		2.7	2.7	2.5	2.6	2.5	2.6	2.7	2.8	2.7
Heat delivered to household and utilities	20.3	23.6	26.8	26.5	26.7	25.3	24.4	24.5	22.3	21.0
Heat losses	3.3	4.7	5.2	5.3	5.8	6.1	6.4	6.7	6.3	6.2

1.5. ELECTRIC POWER SYSTEM EXPANSION OPTIMIZATION

Optimization of the electric power system structure has to be an essential part of measures for sustainable development — not only of the energy sector but also the overall economy of a country. Results of research devoted to this problem and carried out at the JINPR-SOSNY of the National Academy of Science (NAS) of Belarus [4] are briefly described below. The WASP IV code was used as an instrument for optimization [5].

The following are the results of recent studies on the optimum electricity source structure made in 2012 (forthcoming for publication). These studies are based mainly on the approach presented in [4]. There are following improvements compared to [4]:

- Recent data on the characteristics of candidate units on natural gas and coal are used for expansion of the power system [6];
- For nuclear units, real data on capital expenditure and cost of nuclear fuel are used from the contractual agreement for the construction of a nuclear power plant (NPP) in Belarus between the Russian Federation and Belarus [7];
- Starting from 2012, the growth rate of nuclear fuel prices is taken as the same as for natural gas.

It should be noted that the data used for the candidate of units on natural gas and coal are from 2009 and are likely to provide a more optimistic view of the traditional energy technologies, since they do not take into account the possible escalation of prices for these technologies by 2012.

Input data for the study included long time electricity demand and system peak power forecasts, prognoses for fuel prices and characteristics of existing and alternative power plants, and schedules for decommissioning and commissioning units regarding the programme of modernization of energy system. New cogeneration power plants were not considered as candidates for expansion of the system because of difficulties with their presentation in the framework of WASP methodology. However, some were estimated from WASP calculations.

The lower forecast of electricity consumption (extrapolated historical data) was used compared to the one previously used from [8]. It is shown in Figure 1. According to the needs of the electricity system, peak power was also less than in [4] and is shown in Figure 2.

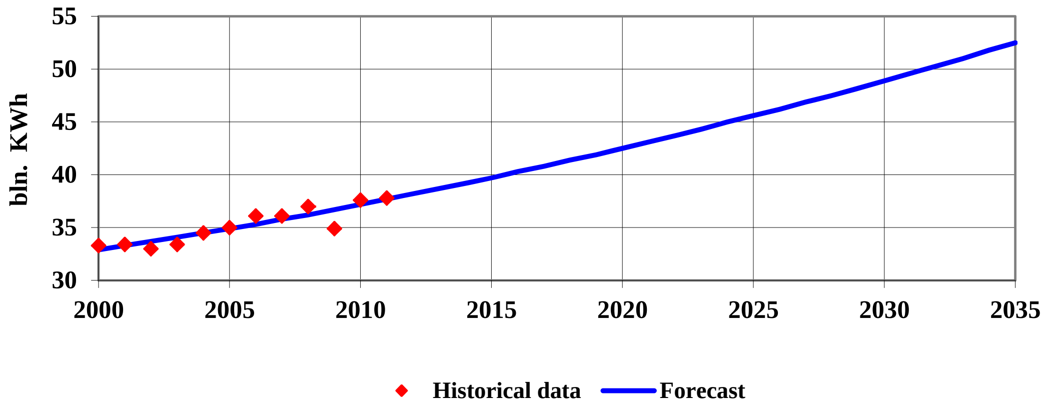

FIG. 1. Electricity demand forecast.

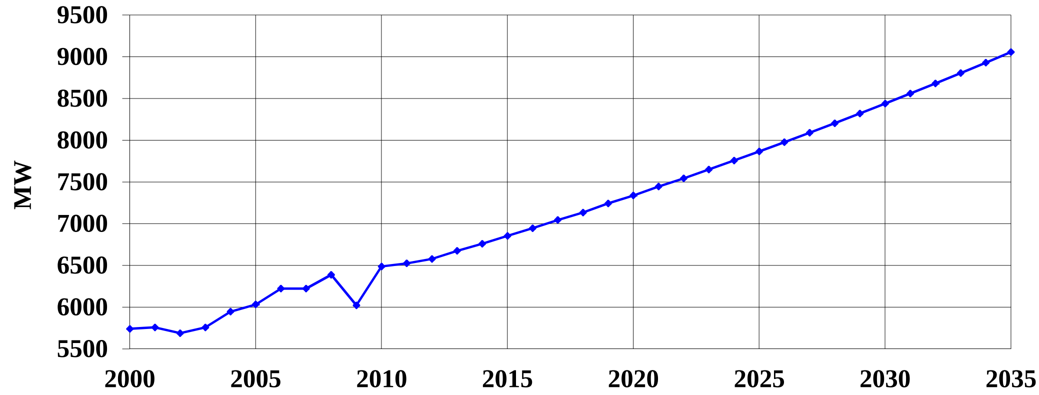

FIG. 2. Peak power forecast.

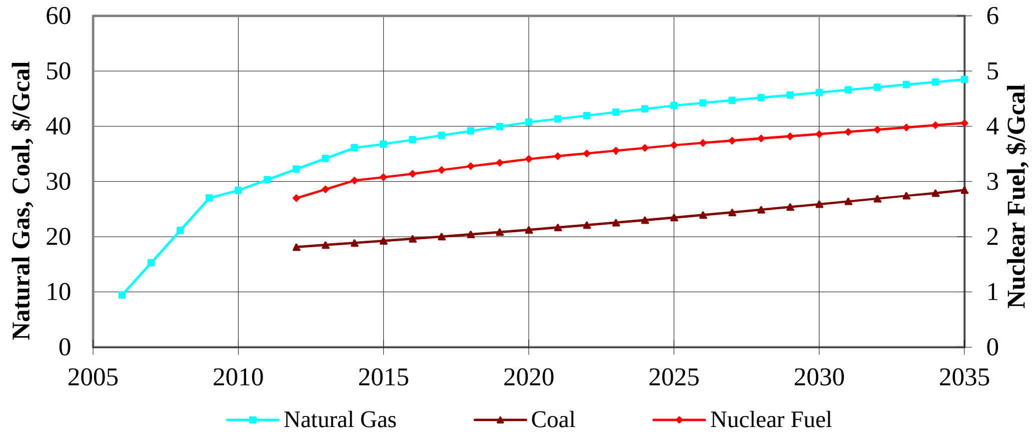

FIG. 3. Fuel price prognosis.

The natural gas price prognoses used and shown in Figure 3 were performed using information from [9]. The price of coal in 2012 was adopted on the information from [10]. The price of coal growth rate was assumed to be 2% per year. For nuclear fuel, as mentioned above, the cost is taken from the contractual agreement between the Russian Federation and Belarus for the construction of an NPP in Belarus [7], and the growth rate taken as the same as for natural gas.

The deficit in the energy system capacity as a result of power source decommissioning and increasing peak power is shown in Figure 4. A 20% reserve of system capacity is taken into account.

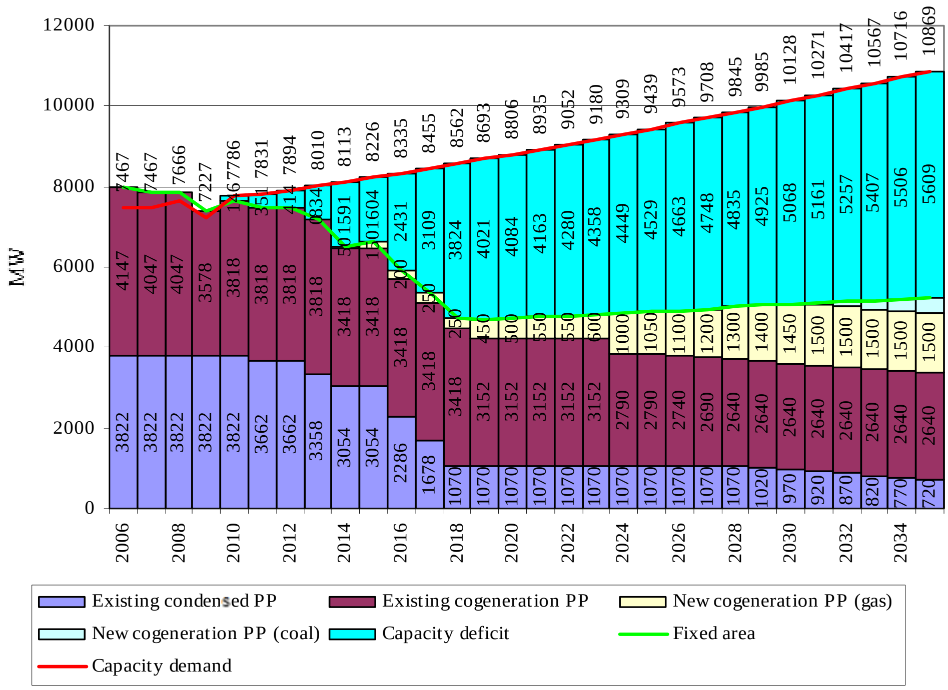

FIG. 4. Deficit of energy system capacity.

Figure 4 shows a gradually retiring from service of energy sources of the existing power system, and newly introduced heat and power for coal and gas. Expansion and reconstruction of cogeneration power plants was estimated regarding of heat demand from WASP calculations. Taking these into account, it can be seen from Figure 4 that optimizing the deficit volume is about 1600 MW in 2015, 4000 MW in 2020, 4500 MW in 2025, 5000 MW in 2030 and 5600 MW in 2035. Characteristics of existing power plants in the Belarus energy system were derived from data provided by experts of BELNIPIENERGOPROM [11].

TABLE 6. CHARACTERISTICS OF CANDIDATES FOR EXPANSION OF ELECTRICITY SYSTEM [6, 7]

Utility	Instal. capacity, MW	Heat rate, kkal/KW·h		Forced outages, %	Planned outages, d/a	O&M cost		Capital cost, $/kW	Constr. period, a	Lifetime, a
		Min. load	Average increm. load			Fixed, $/kW	Variable, $/MW·h			
Condensed (steam-gas)	395	1859	1550	0.82	28	0.9	1.53	1100	3	30
Condensed (coal)	660	2335	1946	0.8	35	1.84	4.95	1844	4	30
Gas turbine	111	3000	2646	0.55	28	1.27	2.84	745	1	30
NPP	1170	2520	2100	4.5	57	4.81	6.59	3715	6	50

The technologies considered as ‘candidates’ for electricity system expansion to make up the electric power deficit shown in Figure 4 were:

- Condensed power plant using natural gas (steam-gas technology);
- Condensed power plant using coal fuel;
- Gas-turbine power plant;
- NPP 1170 MW capacity.

The characteristics of these candidates are presented in Table 6.

In this study, the base year for discounting of costs is 2012 and the discount rate values 10%. The calculations show that the gas-nuclear scenario is optimal for the development of power generation source structure in Belarus. In this scenario, the first and second NPPs of 1170 MW installed capacity each are introduced in 2018 and 2020. 2028 is optimal for the introduction of a third nuclear unit of the same capacity. Coal units do not fall in the best scenario because of the high capital costs. Although the cost of coal is less than the cost of natural gas, it is not low enough (due to high component of delivery) to compensate for the large capital investments.

The optimized electricity system structure for the gas-nuclear scenario is shown in Figure 5. Energy planning results has demonstrated the cost-effectiveness of few more nuclear units which could be introduction after 2025. However the decision on the introduction of these NPP has not been made yet and the assessment displayed in this report is focused on two NPP units.

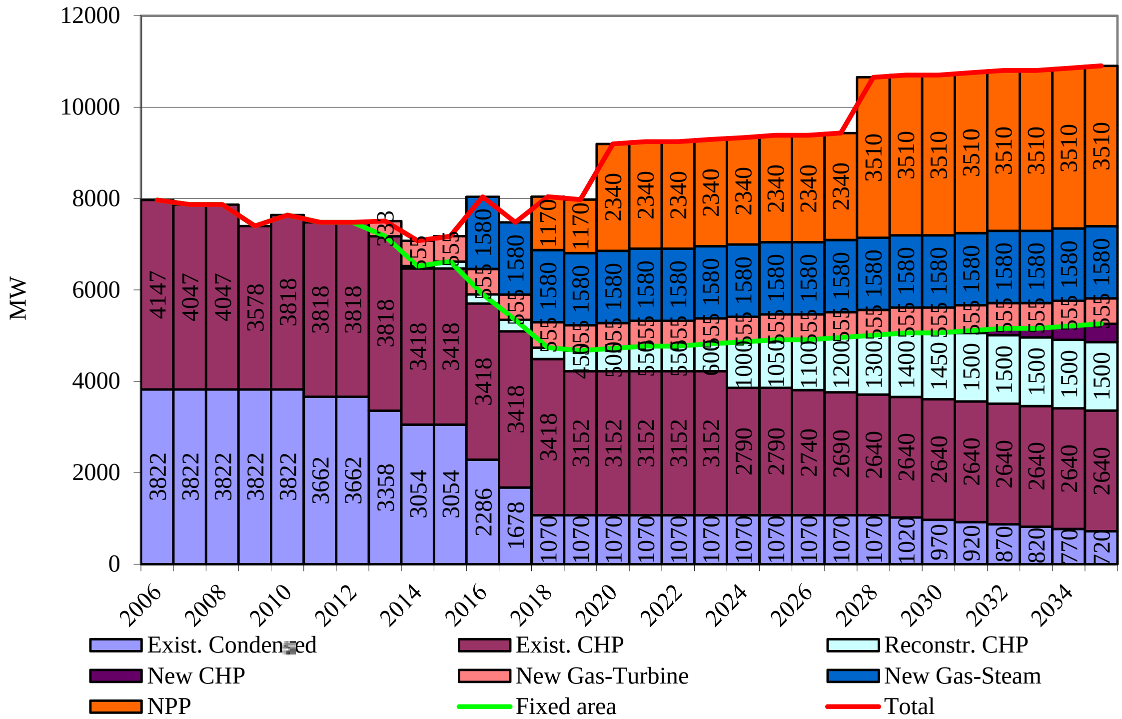

FIG. 5. Structure of electricity system for nuclear scenario.

The advantage of nuclear scenario is seen also from the comparison of electricity production costs for the scenarios considered. In spite of higher cost in the construction period of nuclear units, the overall cost of electricity production for the nuclear scenario is lower than for the scenario with fossil fuel.

Accordingly, nuclear power generation is considered one of the most promising electricity generation technologies at present. In spite of the serious concerns that arose after the accident at Chernobyl NPP in 1986, the nuclear option proved its competitiveness in comparison with such traditional technologies as fossil fuel-based or hydro generation. More than 120 nuclear power units have been put into operation in the world since the Chernobyl catastrophe. Today nuclear technology accounts for 16% of the world’s electricity generation, being thus one of the most widespread sources of energy for society.

Such contemporary challenges as global climate change, high dependence on primary energy resources, notable growth in fossil fuels costs and their limited reserves are the main reasons nuclear power development.

Belarus considers implementation of its own nuclear programme one of the key elements of the national long-term energy strategy. High dependence on the import of primary energy, limited economically feasible alternatives for energy supply and high burdens imposed on the national economy by constantly growing fossil fuel costs were the main factors that were taken into consideration to make an appropriate decision.

According to the preliminary calculations, construction of the first 2000 MW Belarusian NPP by 2020 will allow a reduction of annual consumption of fossil fuel (primarily natural gas) for electricity generation by more than five million tce. Nuclear energy will notably change the structure of primary energy consumption in the country, making it more diversified. Nuclear fuel costs were considered another important advantage of a national nuclear programme. It is expected to cover the base load electricity generation and thus decrease the use of much more expensive natural gas for this purpose. The strategic goal is to achieve a share of nuclear power generation in Belarus of 27–29% by 2020.

Construction of the first NPP in Belarus can be considered an important project aimed to fulfil the Republic’s commitments under the *Kyoto Protocol* and will allow greenhouse emissions to be reduced by 7–10 million tons per year.

The criteria taken into consideration when determining the effectiveness of NPP construction and possible integration into the national power system were:

- High investment needs for NPP construction;
- Technical difficulties related to NPP operation during the night with low electricity demand;
- Limited load following capability of nuclear units;
- Long NPP life that requires long-term optimization (up to 2060) of the Belarusian utility if a nuclear energy programme is launched.

1.6. NUCLEAR ENERGY SYSTEM TO BE ASSESSED

The scenario of introducing nuclear energy in Belarus to be assessed is illustrated in Table 7. Complementary to the schedule in the table, one should take into account the possibility of introducing a third nuclear unit after 2020, and units with the same capacity together with the start of decommissioning of units 1 and 2.

The scheme for the nuclear energy system (NES) to be assessed is shown in Figure 6.

Not shown in Figure 6 are the disposal facilities for final storage of operational radioactive waste from the NPP that will also be considered in the NESA.

The current NESA focuses on the domestic facilities and evaluates the non-domestic facilities depending on the availability of data. Also, the assessors intend to perform an assessment of nuclear facilities placed abroad in a comprehensive full-scope NESA, i.e. in the same depth and detail as for domestic facilities.

TABLE 7. SCENARIO: FIRST TWO NUCLEAR UNITS AND DRY SPENT NUCLEAR FUEL STORAGE FACILITY

Year	**Unit 1*** 1170 MW(e) VVER AES-2006	**Unit 2*** 1170 MW(e) VVER AES-2006	**Dry Storage of Spent Fuel** (Transportable containers)
2012	Start of construction		
2014		Start of construction	
2018	Commissioning		
2020		Commissioning	
2022			Start of construction
2027			Commissioning
2078	Start of decommissioning		
2080		Start of decommissioning	
2088	End of decommissioning		
2090		End of decommissioning	
2125			Decommissioning

* Remark: introduction of same capacity units is considered together with the start of decommissioning of units 1 and 2

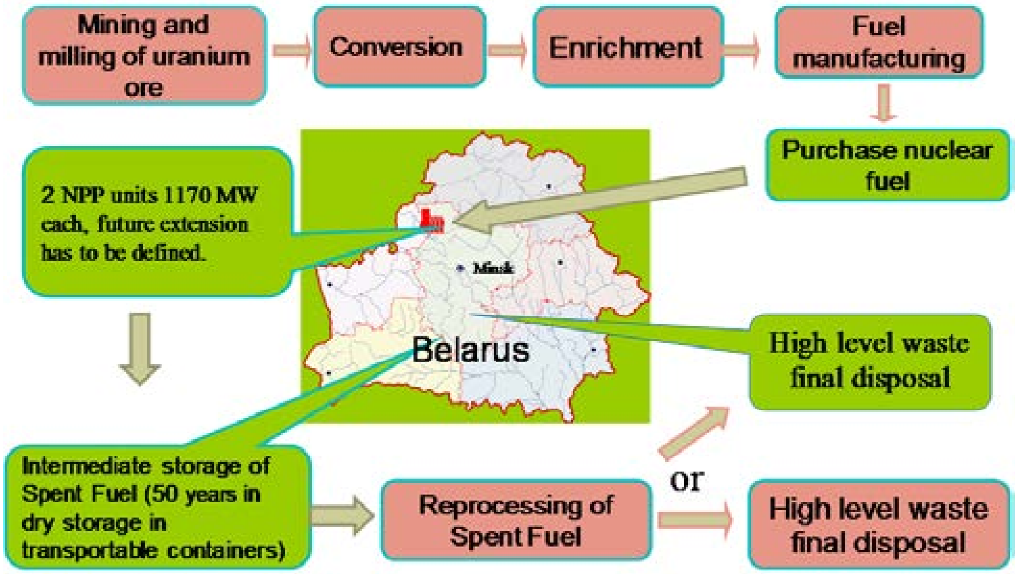

FIG. 6. Nuclear energy system of Belarus to be assessed (processes in green cells are to be located inside of Belarus territory, in red – outside).

This assessment started end of 2009 with a collection of necessary input data and was completed in the end of 2011 by production of a draft report. During this period Belarus made significant progress in the implementation of its national nuclear energy programme. Information comprised in this report was maintained "up-to-date" by the assessors during the whole assessment period to the extent possible.

However, several important actions were performed in the second half of 2012 which are not considered in this report:

In July 2012, Belarus signed a construction contract with the Russian Federation for two AES-2006 units covering fuel supply, take-back of spent fuel, training and other services.

In October 2012, the IAEA delivered the final report from an IAEA Integrated Nuclear Infrastructure Review (INIR) mission to Belarus. This mission report made 16 general recommendations, and 22 specific recommendations. It concluded that Belarus has made important progress in its development of infrastructure for a nuclear power programme and that Belarus is on its way to being well-prepared with its infrastructure to support the construction of a NPP. To support the INIR mission the draft report on nuclear energy system assessment (current NESA report) was made available to the INIR mission participants in advance.

In December 2012, Belarus has approved a draft intergovernmental agreement on cooperation in the area of nuclear safety with the Russian Federation.

Finally, a few national documents referred in this report were updated or replaced late in 2012 and early in 2013.

These important actions are to be taken into account while analyzing the results of the assessment of the nuclear energy system of Belarus mainly in the INPRO methodology areas of Infrastructure, Waste Management, Safety and Economics. For example, the assessor stated in several areas – mainly safety and waste management – that he had difficulties to gather necessary information for the assessment. This missing information will be available in the future based on the contractual agreements with the supplier.

At the moment of the report drafting lessons to be learned from Fukushima Daiichi accident in March 2011 were still under discussion. Many of the lessons relevant topics are covered in this report, e.g. regulatory body independence issues, reactor cooling systems including passive systems, seismic issues etc. However a detailed analysis of the implementation of the lessons learned from Fukushima could not be performed within a few months after the accident.

2. ECONOMICS

In this section, firstly, several important economic parameters are calculated and, secondly, these parameters are then used as input for an assessment of the economics of the Belarus nuclear power project according to the INPRO methodology (as documented in Volume 2 of *IAEA-TECDOC-1575 Rev.1*, the *INPRO Manual*) in the context of the planned NES in Belarus.

2.1. CALCULATION OF ECONOMIC PARAMETERS

2.1.1. Definition of input data

Input data for a calculation of the main economic parameters are shown in Table 8 for three selected types of power plants that are available in Belarus as future energy sources: two nuclear reactors of the type AES-2006 (VVER-1000) and, as alternative energy sources, four coal fired plants and five gas fired plants. All three power plant types have approximately the same power output. The main sources of these input data are [6] for fossil fuel power plants and the *Contract agreement between the Russian Federation and Belarus for the construction of NPP in Belarus* [7] as shown in the notes below Table 8. Unmarked data are suggestions by the authors.

TABLE 8. INPUT DATA FOR ECONOMIC CALCULATION

№	Parameters	Units	Power plants		
			NPP	**Coal**	**Natural gas**
1	Net electric power output	kW(e)	2 × 1170[1]	4 × 660[2]	6 × 400[2]
2	Construction time	a	6[1]	4[2]	3[2]
3	Plant lifetime	a	50[1]	30[2]	30[2]
4	Average load factor	-	0.9[1]	0.85[2]	0.85[2]
5	Decommissioning cost	mills/kW·h	1	-	-
6	Overnight cost	$/kW(e)	4700[3]	1175[2]	755[2]
7	Normalized capital investment schedule (share per year)	-	0.020 0.146 0.220 0.244 0.217 0.153	0.15[2] 0.3 0.3 0.25	0.3[2] 0.5 0.2
8	Real discount rate	1/a	0.1	0.1	0.1
9	Price per unit of electricity sold	mills/kW·h	125	125	125
10	Market income	M$/a	3600	3600	3600
11	Market share	-	1	1	1
12	Profit margin	-	0.12	0.12	0.12
13	Growth time	a	6	4	3
14	Adjusting coefficient	-	2.4	2.4	2.4
15	Fixed O&M cost	$/kW(e)	57.7	22.0[2]	10.8[2]
16	Variable O&M cost	mills/kW·h	6.6	5.0[2]	1.53[2]
17	Fuel price	$/GJ	-	6.14[5]	8.97

TABLE 8. INPUT DATA FOR ECONOMIC CALCULATION (CONTINUED)

№ п/п	Parameters	Units	Power plants		
			NPP	Coal	Natural gas
18	Real fuel price annual escalation rate	-	-	0.02	0.02
19	Nuclear fuel backend cost	$/kg	500[4]	-	-
20	Spent nuclear fuel average burnup	MW·d/kg	55.5[1]	-	-
21	Net thermal efficiency of plant	-	0.352[1]	0.442[2]	0.555[2]
22	Reactor first core average power density	kW/kg	43.5[4]	-	-
23	Natural U purchase cost	$/kg U	130[4]	-	-
24	U conversion cost	$/kg U	10[4]	-	-
25	U enrichment cost	$/kg U	163[4]	-	-
26	Nuclear fuel fabrication cost	$/kg U	240[4]	-	-
27	Number of stages at frontend of fuel cycle	-	4	-	-
28	Time from U purchase till fuel loading	a	-1.5	-	-
29	Time from U conversion till fuel loading	a	-1	-	-
30	Time from U enrichment till fuel loading	a	-0.75	-	-
31	Time from fuel fabrication till loading	a	-0.5	-	-
32	Losses at U purchase	-	0	-	-
33	Losses at U conversion	-	0.005	-	-
34	Losses at U enrichment	-	0	-	-
35	Losses at fuel fabrication	-	0.01	-	-
36	First core lowest ^{235}U concentration	-	0.02[4]	-	-
37	First core medium ^{235}U concentration	-	0.028[4]	-	-
38	Refuelling fuel ^{235}U concentration	-	0.0479[4]	-	-
39	Natural ^{235}U concentration	-	0.00711	-	-
40	Enrichment tails ^{235}U conc.	-	0.0025	-	-

[1] - input from Ref. [13]
[2] - input from Ref. [6]
[3] - input from Ref. [7]
[4] - input from Ref. [12]
[5] - input from Ref. [10]

As shown in section 1, a gas turbine power plant (GTPP) was also considered as a candidate for the extension of the power system. However, the financial performance of GTPPs is significantly lower than that of the other candidates and is not considered in this section.

2.1.2. Results of economic analysis

Calculations were carried out using the input data defined in Table 8 and a tool of the NESA support package called NEST (NESA economic support tool), which has been provided by IAEA/INPRO group to Belarus.

As proposed in Annex A of Volume 2 of *IAEA-TECDOC-1575* (*INPRO Manual for Economics*), for the three types of plant to be compared in Belarus, the following economic parameters were calculated (Table 9): Levelized unit electricity costs, internal rate of return, return of investment, total investment volume and investment limit.

TABLE 9. RESULTS OF ECONOMIC PARAMETER CALCULATIONS

Indicators	**Unit**	**Abbreviation**	**Value**
Levelized unit electricity cost			
- NPP AES-2006	cent/kW·h	C_N	8.03
- Coal PP	cent/kW·h	C_{A1}	9.56
- Natural gas PP	cent/kW·h	C_{A2}	8.79
Internal rate of return			
- NPP AES-2006	-	IRR_N	0.159
- Coal PP	-	IRR_{A1}	0.216
- Natural gas PP	-	IRR_{A2}	0.602
Return of investment			
- NPP AES-2006	-	ROI_N	0.223
- Coal PP	-	ROI_{A1}	0.200
- Natural gas PP	-	ROI_{A2}	0.131
Investment volume/limit			
- NPP AES-2006	10^9 $	INV_N	11 610/2592
- Coal PP	10^9 $	INV_{A1}	5724/2592
- Natural gas PP	10^9 $	INV_{A2}	1979/2592

The *levelized unit electricity cost* LUEC consists of three factors, the capital costs, the operation and maintenance costs (O&M), and the fuel costs. LUEC is equivalent to the price of electricity that would have to be paid by consumers to repay exactly all costs for capital, O&M and for fuel supply with a proper discount rate (and without considering profits).

Internal rate of return (IRR) is equivalent to a discount rate that makes the net present value of all cash flows of a particular project equal to zero. The higher a project's IRR, the more attractive it is to undertake the project.

Return on investment (ROI) is frequently derived as the "return" (incremental gain) from an action divided by the cost of that action. Again the higher the ROI the more attractive is the project.

Investment volume is the total investment needed for a project up to the time of commissioning including contingency and owner's costs. *Investment limit* is the maximum investment a private company can afford taking into account the (private) market conditions the company is working in.

According to Ref. [14], in the Russian Federation the cost advantage of nuclear against fossil power is even more significant: electricity produced with coal and gas is almost twice as expensive as that generated by an NPP of AES-2006 design.

To confirm the robustness of the calculated levelized unit electricity costs of the selected NPP, *robustness indexes* were also calculated as specified by the INPRO methodology for economics by simultaneous variation of input parameters of the nuclear and gas power plant such as plant lifetime, average load factor, overnight capital cost, delay of construction, fuel costs, and gas price escalation rate together with nuclear backend cost and fuel burnup (see Table 10).

TABLE 10. ROBUSTNESS INDEX OF LEVELIZED NUCLEAR ELECTRICITY COSTS

Name of perturbed parameter	Perturbation of NPP data	Perturbation of gas PP data	Abbreviation	Robustness index
Plant lifetime	-5%	+5%	$RI_{lifetime}$	1.095
Average load factor	-5%	+5%	RI_{Lf}	1.051
Overnight cost	+5%	-5%	RI_{CI}	1.059
Construction schedule delay	1 year	-1 year	RI_{sch}	1.092
Fuel cost	+5% (nat U cost)	-5% (gas price)	RI_{Ucost}	1.054
Nuclear backend cost	+10%	-10% (gas price escalation rate)	RI_{BEcost}	1.056
Nuclear fuel burnup	-5%	+5% (Net PP thermal efficiency)	RI_{burnup}	1.095

According to the INPRO methodology, a robustness index of greater than 1.0 indicates sufficient robustness of the economic analysis results, which means that all perturbations studied in Table 10 above show acceptable results.

2.2. ASSESSMENT OF ECONOMICS OF BELARUS NUCLEAR ENERGY SYSTEM

Using the results of the economic analyses above, the following economic assessment was performed applying the INPRO methodology as documented in Volume 2 of the report *IAEA-TECDOC-1575 Rev.1* (*Guidance for the Application of an Assessment Methodology for Innovative Nuclear Energy Systems*; *INPRO Manual*, published November 2008).

The **basic principle** of the INPRO methodology area of economics reads: *Energy and related products and services from innovative NESs shall be affordable and available.*

Affordable means that the electricity costs produced by an NPP must be competitive against other available energy sources in the country, and *available* means that investment in nuclear power must be sufficiently attractive and the risk acceptable.

To check whether the goal of this basic principle is met by the selected NES, INPRO has defined four user requirements that are evaluated below.

2.2.1. User requirement UR1 — cost of energy.

User requirement UR1: *The cost of energy from innovative NESs, taking all relevant costs and credits into account, C_N, should be competitive with that of alternative energy sources, C_A, that are available for a given application in the same time frame and geographic region.*

INPRO has defined one criterion CR1.1 (cost competitiveness) that simply repeats what user requirement UR1 asked for: It states that the costs of nuclear energy C_N (also called Indicator IN1.1) should be cheaper than the costs of an alternative energy source C_A (called Indicator IN1.2) available in the country multiplied by a factor k:

$$C_N < k \cdot C_A$$

The factor k in criterion CR1.1 is usually taken as 1. A factor k greater than 1 can be used to justify higher costs of nuclear electricity (compared to alternative energy sources) on the basis of strategic considerations such as an increase of security of supply by diversion of energy sources.

The INPRO methodology recommends using the common approach of the LUEC for determination of energy costs. This approach enables to compare very different energy sources such as nuclear and gas fired plants.

Calculated values of the LUEC for the three selected types of power plants in Belarus were presented in Table 9: the LUEC of nuclear power C_N is equal to 8.03 cent/kWh for an NPP with AES-2006 reactors and the LUEC for alternative energy sources C_A are 9.56 cent/kWh for a coal fired power plant and 8.79 cent/kWh for a power plant using natural gas as fuel.

Thus, electricity produced by nuclear power is cost competitive against gas and coal fired plant electricity in Belarus under the boundary conditions defined.

Final assessment of user requirement UR1 cost of energy

The advantage of nuclear energy against technology using gas fuel and coal provides the basis to confirm the satisfaction of criterion CR1.1 and, thus, the satisfaction of user requirement UR1 in relation to natural gas and coal, i.e. under the defined boundary conditions (input data in Table 8) nuclear power for electricity generation is cost competitive in Belarus against gas and coal. Criterion CR1.1 can be considered as satisfied.

2.2.2. User requirement UR2 — ability to finance

User requirement UR2: *The total investment required to design, construct and commission innovative NESs, including interest during construction, should be such that the necessary investment funds can be raised.*

INPRO has developed two criteria for user requirement UR2. Criterion CR2.1 (figures of merit) requires that the investment in an NPP be attractive to an investor compared to an investment in alternative energy sources. Criterion CR2.2 (total investment) defines the maximum investment — based on market conditions — that a private utility can make.

2.2.2.1. Criterion CR2.1 — financial figures of merit

Criterion CR2.1 states that financial figures of merit for an investment in nuclear power should be at least comparable to or more attractive than those for an investment in alternative energy projects.

INPRO recommends using the internal rate of return (IRR) and the return of investment (ROI) as financial figures of merit. Thus, criterion CR2.1 requires that the IRR and ROI of a nuclear project should be comparable or better than the figures of merit for alternative energy projects.

As shown in Table 9 above, the IRR for an investment in an NPP in Belarus is 0.158, i.e. it is smaller than for power plants with fossil fuel (0.216 for coal and 0.414 for gas). This value of IRR is caused by the significantly higher capital investment for an NPP. It means that energy projects related to fossil fuel are more attractive for private investor than an NPP. Nevertheless, the value of the IRR for an NPP is high enough for the Government to accept the nuclear project, taking into account again strategic considerations such as increased security of supply by diversification of energy sources.

The ROI for a nuclear project (0.223) shows an advantage over projects with coal fuel (0.200, see Table 9) and gas-fired PP (0.090) plants.

Assessment

Criterion 2.1 is partially fulfilled, i.e. investment in the planned nuclear project is better only by criteria ROI compared to investment in gas and coal energy sources. On other criteria, nuclear technology loses to both alternative technologies. However IRR 0.158 for nuclear technology is high enough to be attractive for introduction in Belarus.

2.2.2.2. Criterion CR2.2— availability of total investment

Criterion CR2.2 states that the total investment needed for a nuclear project should be available to a (private) investor in the country. The value of needed capital for the planned nuclear project in Belarus, as shown in Table 9, is higher than the calculated investment limit. This means that the national utility on its own would not be capable of raising the needed capital by itself, but would need a Government loan.

Assessment

The Belarusian Government is known to ensure the availability of capital through a line of credit from the Russian Federation. Criterion CR2.2, consequently, has been satisfied.

2.2.2.3. Final assessment of user requirement UR2 — ability to finance nuclear power programme

As not both criteria of UR2 are satisfied, it could be stated that user requirement UR2 is partially satisfied, i.e. the planned nuclear power project is not a sufficiently attractive investment for the government of Belarus from all points of view.

2.2.3. User requirement UR3 — investment risk

User requirement UR3: *The risk of investment in innovative NESs should be acceptable to investors taking into account the risk of investment in other energy projects.*

Satisfaction of this user requirement UR3 is verified by evaluation of criteria CR3.1 (maturity of design), CR3.2 (construction schedule), CR3.3 (robustness) and CR3.4 (political environment).

2.2.3.1. Criterion CR3.1 — maturity of design

To limit the risk of investment in nuclear power, criterion CR3.1 requires an adequate status of the licensing process, depending on the experience of the country that intends to install an NPP. In the case that the first few NPPs are to be deployed in a country — as in Belarus, intending to install the latest VVER1000 design called AES-2006 as its first NPP — CR3.1 states that nuclear plants of the same basic design should have been constructed and operated in the country of the supplier. At the time the assessment was performed, AES-2006 was licensed in its country of origin and construction projects were ongoing with an AES-2006 type of reactor.

However, the absence of operational experience with NPPs of AES-2006 design in the supplier country (Russian Federation) leads to the conclusion that criterion CR3.1 is currently not yet completely satisfied. The assessor acknowledges that other novel pressurized water reactor (PWR) designs, e.g. EPR, APR-1400 and AP-1000, do not have operational experience in the supplier countries yet, either.

2.2.3.2. Criterion CR3.2 — construction schedule

To limit the investment risk, criterion CR3.2 requires evidence that the construction schedule (of the nuclear plant type to be installed) considered in the economic analysis has been met in previous construction projects for the same basic design.

As construction of AES-2006 reactors is currently not yet completed, CR3.2 is not fully satisfied (for the same reason as CR3.1), i.e. the absence of experience with construction schedules and operation of this plant type in the supplier country. The assessor acknowledges that also other available novel PWR reactors do not currently have enough experience with construction schedules and operation.

2.2.3.3. Criterion CR3.3 — robustness

Criterion CR3.3 (robustness) is satisfied if the economic robustness index RI (as defined in Annex A of Volume 2 of *IAEA-TECDOC-1575 Rev.1*) for selected major input parameters of the planned NES is greater than 1.0. As shown in Table 10, all calculated robustness indexes satisfy this condition within a rather high range of perturbed parameters.

Thus, criterion CR3.3 is fully satisfied.

2.2.3.4. Criterion CR3.4 — political environment

Criterion CR3.4 stipulates long-term commitment of the national political environment to nuclear power to reduce risk of investment. The Decree [15] of the President of Belarus on the introduction of two nuclear energy units, first in 2016 and second in 2018, confirms the favourable political climate for installation of NPPs in Belarus.

Thus, criterion CR3.4 can be considered as satisfied.

2.2.3.5. Final assessment of user requirement UR3 — investment risk

This user requirement states that the investment risk into nuclear power should be acceptable in comparison to other available energy projects.

Two factors clearly reduce the risk of investment in nuclear power in Belarus: There is a strong commitment from the Government of Belarus to nuclear power and the economic evaluation demonstrated sufficient robustness of its positive results regarding cost competitiveness.

However, it was found that the overall risk for an investment in nuclear power is rather high because criteria related to the maturity (status of licensing, experience with construction schedule) of the chosen nuclear plant design, AES-2006, are currently not yet completely satisfied, as there is no operational experience of that plant type available (although it is licensed and being constructed in the country of origin). Taking the vast experience of the designer of AES-2006 into account, a very satisfactory operational behaviour of the plant is to be expected.

Taking all aspects into account, it is concluded that user requirement UR3 is currently partially satisfied (but expected to be fully met soon).

Note: User requirement UR4 (flexibility) is not considered in this study, because it is not concretized enough in the existing documentation (*IAEA-TECDOC-1575 Rev.1, INPRO Manual*) of the INPRO methodology.

2.3. SUMMARY AND CONCLUSION OF ASSESSMENT OF ECONOMICS

The LUEC of the planned NPP AES-2006 is lower than for gas and coal energy sources available in the country. Approximately 9% cost advantage of nuclear power confirms that nuclear power used for generating electricity is cost competitive against gas based energy in Belarus.

Taking strategic considerations into account — such as security of supply by diversification of energy sources — for the Government, sufficient attractiveness for an investment in the nuclear power project has been confirmed via the high enough internal rate of return.

Evaluation of the risk associated with an investment in nuclear power in Belarus produced the following mixed results: There is a strong commitment by the Government to nuclear power, which is an important prerequisite for a successful nuclear power programme. Sufficient robustness of economic results — especially for levelized unit electricity cost — for the planned nuclear technology of AES-2006 has been clearly demonstrated. Currently, only the level of maturity (licensing status, experience with construction schedule) of the planned NPP AES-2006 is responsible for a certain risk level. The assessment revealed a lack of operational experience for this reactor design, but the plant is licensed and currently under construction in the country of origin. Moreover, because of the long experience of the designer of AES-2006, very satisfying operational behaviour of this plant is expected.

Thus, it is concluded that the planned nuclear power programme in Belarus is in partial agreement with the economic requirements of the INPRO methodology.

3. INFRASTRUCTURE

3.1. INTRODUCTION

In the INPRO methodology area of infrastructure (Volume 3 of *IAEA-TECDOC-1575 Rev.1*) one basic principle is defined:

Infrastructure basic principle: *Regional and international arrangements shall provide options that enable any country, that so wishes to adopt, maintain or enlarge an innovative NES for the supply of energy and related products, without making an excessive investment in national infrastructure.*

This basic principle defines the goal that the effort for establishment (and maintenance) of a nuclear infrastructure should be reduced by development of regional or international arrangements. An example of such an arrangement could be an international fuel cycle centre, e.g. for enrichment of uranium or for disposal of high level waste.

To meet the goal of this basic principle, four user requirements have been developed in INPRO, UR1–UR4. Additionally, for each issue addressed by the user requirements, options are presented in the INPRO methodology that, if realized, would reduce the effort for establishment and maintenance of a nuclear infrastructure. The four user requirements are used to evaluate the nuclear infrastructure in Belarus as follows.

3.2. USER REQUIREMENT UR1 — LEGAL AND INSTITUTIONAL INFRASTRUCTURE

User requirement UR1: *Prior to deployment of an innovative NES installation, the legal framework should be established to cover the issues of nuclear liability, safety and radiation protection, environmental protection, control of operation, waste management and decommissioning, security and non-proliferation.*

In the assessment of the legal infrastructure below it is assumed that the laws of Belarus and decrees of the President of the Republic have the same legal status.

Fulfilment of UR1 is checked by evaluation of two criteria, CR1.1 and CR1.2. Each criterion has one indicator and one acceptance limit.

3.2.1. Criterion CR1.1 — legal aspects

Indicator IN1.1: *Status of legal (nuclear) framework.*

Acceptance limit AL1.1: *Legal framework has been established in accordance with international standards.*

To enable the assessment of criterion CR1.1, INPRO has defined several evaluation parameters for IN1.1, namely: EP1.1.1, EP1.1.2, EP1.1.3, and EP1.1.4.

3.2.1.1. EP1.1.1 — scope of nuclear legislation

Acceptability of EP1.1.1: *the scope of the national nuclear legislation is adequate if all areas (issues) listed below are covered*:

1) Regulatory body and its functions, such as authorization, inspection and enforcement;
2) Radiation protection;
3) Protection of environment, if not covered by other State laws;
4) Safety of nuclear installations covering such areas as emergency preparedness and response, use of radiation sources and of radioactive material, transport of nuclear and

radioactive material, radioactive waste management and spent fuel management, and mining and milling (if there are such activities in the country);

5) Nuclear liability and coverage;

6) Export and import control of nuclear material;

7) Safeguards of nuclear material to ensure non-proliferation;

8) Security and physical protection of nuclear material and nuclear facilities.

The Belarus nuclear legislation was evaluated with regard to all the issues listed above as follows.

Evaluation of regulatory body and its functions (issue No.1)

The evaluation of the first issue of the evaluation parameter EP1.1.1 came to the following conclusion:

The first paragraph of Article 7 of the nuclear law [1] establishes a system of governmental bodies which regulate the use of nuclear energy:

"*The Ministry for Emergency Situations of Belarus, the Ministry of Natural Resources and Environmental Protection of Belarus, the Ministry of Health of Belarus, Ministry of Internal Affairs of Belarus, Committee for State Security of Belarus (hereinafter - the public authorities on regulation of the safe use of nuclear energy) are authorized as National governmental bodies, engaged in State regulation of safe use of nuclear energy, unless otherwise is established by the President of Belarus*".

In accordance with section 126 of the decree [16], licence activities for atomic energy are carried out by the Ministry for Emergency Situations of the Republic.

Thus, the first issue is covered by national nuclear legislation.

Evaluation of radiation protection (issue No.2)

Evaluation of the second issue of the evaluation parameter EP1.1.1 produced the following result:

The nuclear law [17] “defines the framework of legal regulation in the field of radiation safety, and is aimed at creating conditions that ensure the protection of life and health from the harmful effects of ionizing radiation”.

Thus, the second issue is covered by national legislation.

Evaluation of environmental protection (issue No.3)

Environmental protection is defined by the law [18]. Thus, the third issue is covered by national legislation.

Evaluation of safety of nuclear installations (issue No.4)

In accordance with Article 32 of the law [1] "*The operating organization shall develop and implement measures to maintain and enhance the safety of nuclear installations and (or) storage facility, create the appropriate services exercising control over security, provide information about the security status of these objects to the State authorities to regulate the safe use of nuclear energy that they have set terms*.”

In accordance with Article 7 the Ministry for Emergency Situations of Belarus "*carries out State supervision in the field of nuclear and radiation safety, as well as for the physical protection of nuclear facilities*" within its competence.

Emergency preparedness and response are the responsibilities of the operating organization, defined by Chapter 7 of the Law [1].

Finding: The law does not fully present the issues to ensure the safe handling of radioactive waste and spent fuel.

Thus, the forth issue is partially covered by national legislation.

Evaluation of nuclear liability and coverage (issue No.5)

Liability and its limits for damage resulting from activities associated with the use of atomic energy are established by Chapter 9 of the law [1].

Thus, the fifth issue is covered by national legislation.

Evaluation of export and import control of nuclear material (issue No.6)

Export and import control of nuclear material is carried out in accordance with the following national legislation:

- *Law on export control* [19];
- *Decree on the restrictions and limits on the transfer of goods across the border* [20];
- *Resolution of Council of Ministers on the issues of transfer of goods across the border* [21].

Thus, the sixth issue is covered by national legislation.

Evaluation of safeguards of nuclear material (issue No.7)

Chapter 3, art.12 of the law [1] states that nuclear material in Belarus is subject to accountancy and control by a corresponding State System. The State system of accountancy and control of nuclear material (SSAC) is to be organized by the government of Belarus.

Chapter 2, art.7 of the law [1] states that the regulatory body is responsible for the performance of the SSAC in Belarus.

Evaluation of security and physical protection (issue No.8)

In accordance with Article 3 of the law [1]:

"*Protection of NPPs is carried out by the internal troops in accordance with the Law [22] on the internal troops of the Ministry of Internal Affairs".*

The law further states:

"*Physical protection of nuclear facilities is provided by operating organizations and State administration bodies within their competence*".

"*State supervision of physical protection of nuclear facilities is carried out by authorized government agencies on the basis of regulation of the safe use of nuclear energy prescribed by the Government of Belarus".*

"Operation is forbidden of a nuclear facility and of storage of nuclear material, as well as carrying out of any work using nuclear materials or treatment of spent nuclear materials and (or) operational radioactive waste, in any form and in any stage, if necessary measures to fulfil requirements to ensure their physical protection are not taken".

Thus, issue No.8 is covered by national legislation.

3.2.1.2. Evaluation parameter EP1.1.2 — adequacy of nuclear law

Acceptability of EP1.1.2: *the national nuclear law is deemed adequate if the following six questions (section 3.2.3.2 in Volume 3 of IAEA-TECDOC-1575 Rev.1) can be answered positively*:

1) Does the current legislation make it clear that public health, safety, security and the environment are overriding considerations in the use of nuclear techniques and material?
2) Are there major gaps or overlaps in the legal structure regarding the treatment of nuclear related activities or material, both those currently being conducted or used and those that can reasonably be expected?
3) Have the most important terms used in the legislation been given clear and consistent definitions in the statutory documents? Does the use of different terms and definitions, or a failure to define certain terms, produce confusion about how nuclear related activities are to be regulated?
4) Are the institutional responsibilities for regulating nuclear related activities clear and consistent, permitting efficient regulation without delays and bureaucratic conflicts?
5) Does the present regulatory system involve unnecessary financial or administrative burdens on regulated entities or regulatory agencies that could be reduced in order to improve efficiency?
6) Does the present system fully comply with the State's international legal obligations and reflect international best practice, as described in safety standards documents [23] promulgated by the IAEA or other relevant multinational bodies?

These six questions were answered after evaluating the existing nuclear legislation of Belarus as follows

Evaluation of question No.1

The existence of the following laws of Belarus allows us to answer the first question affirmatively:

- *Law on Environmental Protection* [18];
- *Law on the Sanitary-Epidemiological Welfare of the Population* [24];
- *Law on Radiation Safety* [17].

Thus, current national legislation in Belarus makes it clear that public health, safety, security and the environment are overriding considerations in the use of nuclear techniques and material.

Evaluation of question No.2

The confirmed presence of the (mentioned-above) bodies of State administration and regulatory activities in atomic energy in Belarus allows us to answer the second question of the evaluation parameter EP1.1.2 affirmatively.

Regulatory body for nuclear and radiation safety (Promatomnadzor) was established in Belarus in the beginning of the 1990s.

By Decree [15] on measures for the installation of an NPP, the Department of Nuclear and Radiation Safety (Gosatomnadzor) was established as the successor of Promatomnadzor and a structural unit of the Ministry for Emergency Situations of Belarus with special functions. By the same decree the Directorate for NPP Installation was created within the Ministry of Energy to perform the functions of the customer on the implementation of preparatory and survey work on the construction of nuclear power plant.

Decree [25] created the Nuclear Energy Department of Ministry of Energy of the Republic; Decree on the Department was approved.

Authority of the last three bodies is established by regulations, annexed to the relevant Presidential Decree.

Finding: Ministry for Emergency Situations is a nuclear regulatory body of Belarus since it fulfills key regulatory functions, e.g. licensing, has necessary administrative and financial autonomy. However Ministry for Emergency Situations performs several other than regulatory functions in the area of nuclear energy.

Gosatomnadzor is a structural unit of the Ministry for Emergency Situations. While it has own legal status and extensive regulatory functions in the field of nuclear energy Gosatomnadzor administratively and financially reports to the Ministry for Emergency Situations. Perhaps the decision to grant full autonomy and a full set of regulatory functions to Gosatomnadzor could become an alternative approach, possibly more effective, than the existing system of government and regulation of the use of nuclear energy.

Evaluation of question No.3

There are several findings regarding this question:

- There is no definition in the law [1] of ionizing radiation and ionizing radiation source, although, these terms are used in several articles of the law;
- Ionizing emission sources are not included in nuclear facilities, although, the text of the law says clear that they are such sources;
- The first paragraph of Art.6 of the law [1] contradicts the last paragraph of Art. 7. The Ministry for Emergency Situations of Belarus is mentioned in these articles as an organ of State management and as an organ of State regulation on the safe use of nuclear energy. However, the last paragraph of Art.7 declares the independence of regulatory bodies from management bodies;
- Some safety specific terms in the law [1] are not defined according to *IAEA Safety Glossary* [26], e.g. definition of the term *nuclear safety*.

Evaluation of question No.4

Article 4-8 of Chapter 2 of the law [1] defines the sharing of power and functions in nuclear energy use between the:

- President of Belarus;
- Government of Belarus;
- Organs of State management;
- Organs of State management engaged in governmental regulation;
- Local regulatory and self-regulatory bodies.

In Article 6 the powers of organs of State management are divided between:

- The Ministry of Energy;

- The Ministry for Emergency Situations;
- Other national authorities and organizations authorized by the President.

The State regulatory bodies are listed in Article 7:

- Ministry for Emergency Situations;
- Ministry of Natural Resources and Environment;
- Ministry of Health;
- Ministry of Internal Affairs;
- Committee for State Security.

Finding: Only the regulatory functions of the Ministry for Emergency Situations are clarified. Regulatory functions of the Ministry of Natural Resources and Environment, the Ministry of Health, the Ministry of Internal Affairs, and the Committee for State Security have not identified and separated.

Evaluation of question No.5

Gosatomnadzor is a structural unit of the Ministry for Emergency Situations and financed from the state budget. Number of staff of Gosatomnadzor is determined by law. These give reason to believe that the present regulatory system does not involve unnecessary financial or administrative burdens on regulated entities or regulatory agencies and its activity is effective enough.

Evaluation of question No.6

On the basis of the analysis above, it can be concluded that the legislative framework and system of management and regulatory bodies of Belarus for atomic energy are generally satisfactory and conform with international practice.

Summary of findings regarding EP1.1.2 (adequacy of national nuclear legislation): The national law [1] *On the use of atomic energy* needs further improvements in terms of completeness and correctness of definitions and a clear division of responsibilities between the relevant bodies of regulation in the area of nuclear energy.

3.2.1.3. EP1.1.3 — international legal arrangements

Acceptability of EP1.1.3: *the national legal framework is adequate if relevant international arrangements are signed and ratified and incorporated into national nuclear legislation.*

INPRO methodology recommends that a State sign and ratify at least the following international instruments:

1) *Convention on Nuclear Safety*;
2) *International Nuclear Liability Convention*;
3) *Convention on Early Notification of a Nuclear Accident*;
4) *Convention on Assistance in the Case of a Nuclear Accident or Radiological Emergency*;
5) *Joint Convention on the Safety of Spent Fuel Management and on the Safety of Radioactive Waste Management*;
6) *Treaty on the Non-Proliferation of Nuclear Weapons* (*NPT*) (and associated safeguards agreements);
7) *Convention on Physical Protection of Nuclear Material and Nuclear Facilities*;

8) *International Convention for the Suppression of Acts of Nuclear Terrorism.*

The status of the above mentioned international legal agreements was checked. Data for the entry into force of these agreements in Belarus are cited below in Table 11:

TABLE 11. INTERNATIONAL AGREEMENTS

Name of agreement	Came into force
1. *Convention on Nuclear Safety*	27.01.1999
2. *International Nuclear Liability Convention*	09.05.1998
3. *Convention on Early Notification of a Nuclear Accident*	26.02.1987
4. *Convention on Assistance in the Case of a Nuclear Accident or Radiological Emergency*	26.02.1987
5. *Joint Convention on the Safety of Spent Fuel Management and on the Safety of Radioactive Waste Management*	24.02.2003
6. *Treaty on the Non-Proliferation of Nuclear Weapons*	27.07.1993
7. *Agreement between Belarus and the IAEA on the Admission of Safeguards according to the NPT*	02.08.1995
8. *Convention on Physical Protection of Nuclear Material and Nuclear Facilities*	14.06.1993
9. *International Convention for the Suppression of Acts of Nuclear Terrorism* The Law of Belarus *On ratification of the International Convention for the Suppression of Acts of Nuclear Terrorism*	20.10.2006 (the date of signing)

In addition to agreements listed above, recommended by INPRO, Belarus is party to the following international legal agreements:

- The *Convention on the Trans-boundary Effects of Industrial Accidents*, 23.09.2003.
- *Agreement on the Ecological Security in the CIS Member States*. Resolution of the Inter-parliamentary Assembly of CIS on 06.13.2000.
- *Agreement between the Council of Ministers of Belarus and the Government of the Russian Federation on the mutual recognition of State licenses for construction activities* issued by the licensing centers of Belarus and the Russian Federation, 08.12.1994.
- *Agreement on interstate examination of construction projects of the CIS Member States' mutual interest*. It was signed by the Council of CIS Heads of Government on 01.13.1999.
- The *Convention on Long-range Trans-boundary Air Pollution*. Ratified 03.16.1983.

Thus, the completeness can be confirmed of international legal agreements signed by Belarus and incorporated into national nuclear legislation. Evaluation parameter EP1.1.3 is completely fulfilled.

3.2.1.4. EP1.1.4 — completeness and adequacy of regulations and guidelines

Acceptability of EP1.1.4: *national nuclear regulations and guidelines are considered complete and adequate if they are consistent with and take into account all aspects of international standards.*

As part of the legal framework, the third and fourth level of the legal requirements, consisting of regulations and guidelines, has to be established (the first two levels are constitution and statute).

To create these additional levels for nuclear safety documents, INPRO recommends the national regulatory body to take international safety standards into account (e.g. [27–29]). Similar international standards are being prepared for the security regime [30, 31].

Section 1.5.10 of Ref. [23] discusses approaches to the application of standards and guidelines of international organizations or other States in national legal framework of Belarus.

The shortlist of recently introduced regulatory documents is given in Table 12. The shortlist of regulations to be developed currently is presented in Table 13. Full list of regulations to be introduced before NPP startup comprises 234 items.

TABLE 12. RULES AND REGULATIONS OF BELARUS FOR NUCLEAR ENERGY

Title of document	Developed	Cleared	Approved	Registered
Safety rules for storage and transportation of nuclear fuel at nuclear power facilities	NAS Belarus	Ministry of Justice	Ministry for Emergency Situations	Decree No72, 30 Dec 2006
Siting of NPPs. Guidelines on development and content of justification of NPPs ecology safety	NAS Belarus	Ministry of Architecture And Construction	Ministry of Natural Resources and Environmental Protection; Ministry for Emergency Situations	TCP 099-2007 (02120/02300), dated December 25, 2007
Siting of NPPs. Main demands to the structure and range of investigations while selecting the location and site for NPP	NAS Belarus	Ministry of Energy; Ministry of Natural Resources and Environmental Protection.	Ministry of Architecture and Construction; Ministry for Emergency Situations	TCP 098-2007 (02250/02300), dated December 25, 2007
Siting of NPPs. The main criteria and requirements for safety	NAS Belarus	Ministry of Energy; Ministry of Architecture and Construction	Ministry for Emergency Situations	TCP 097-2007 (02300), dated December 29, 2007
Siting of NPPs. Procedure for development of general quality assurance programme for NPP	NAS Belarus	Ministry of Natural Resources and Environmental Protection	Ministry of Energy; Ministry of Architecture and Construction; Ministry for Emergency Situations	TCP 101-2007 (02230/02250/02300), dated December 25, 2007
Siting of NPPs. Procedure for development of quality assurance programme while selecting the site for NPP.	NAS Belarus	Ministry of Natural Resources and Environmental Protection	Ministry of Energy; Ministry of Architecture and Construction; Ministry for Emergency Situations	TCP 102-2007 (02230/02250/02300), dated December 25, 2007
General provision for NPPs safety guaranteeing	NAS Belarus	Ministry of Energy	Ministry for Emergency Situations	TCP170-2009 (02300), dated May 1, 2009
Nuclear Safety Regulations for reactor facilities of NPPs	NAS Belarus	Ministry of Energy	Ministry for Emergency Situations	TCP171-2009 (02300), dated May 1, 2009
Requirements for the content of the safety analysis report for NPPs with VVER reactor		Department of Nuclear and Radiation Safety of Ministry for Emergency Situations; Ministry of Energy	Ministry for Emergency Situations	TCP294-2010 (02300), dated April 1, 2011

TABLE 12. RULES AND REGULATIONS OF BELARUS FOR NUCLEAR ENERGY (CONTINUED)

Title of document	Developed	Cleared	Approved	Registered
General provisions to ensure safety of nuclear power stations	NAS Belarus	Ministry of Energy	Ministry for Emergency Situations	Decree No14, dated February 17, 2009
Regulations on the Physical Protection of nuclear facilities	Ministry of energy; NAS Belarus	Ministry for Emergency Situations; Ministry of Internal Affairs; KGB; Ministry of Justice; Ministry of Energy; Ministry of Transport and Communications	Council of Ministers of Belarus	Decree No1385, dated 27 Sept 2010
Safety in handling radioactive waste. General Provisions	NAS Belarus	Department of Nuclear and Radiation Safety of Ministry for Emergency Situations; Ministry of Natural Resources and Environmental Protection	Ministry of Energy	Decree No47, 28 Sept 2010
Rules for design and operation of the localizing of security systems of NPPs	NAS Belarus	Ministry of Energy	Ministry for Emergency Situations	Decree No48, 12 Oct 2010
Hygienic requirements for design and operation of NPPs	Ministry of Health, NAS Belarus,	Ministry for Emergency Situations; Ministry of Natural Resources and Environmental Protection; Ministry of Architecture and Construction	Ministry of Health	Resolution No. 39, dated March 31, 2010
Regulations on the order of examination of documents justifying nuclear and radiation safety of nuclear installations, radiation sources and storage	NAS Belarus	Ministry of Energy, Ministry for Emergency Situations,	Ministry for Emergency Situations	Resolution No.58, dated Oct. 30, 2010
Nuclear safety regulations subcritical stands	NAS Belarus	Ministry of Justice	Ministry for Emergency Situations	Decree No72, 30 Dec 2006
Nuclear safety regulations critical stands	NAS Belarus	Ministry of Justice	Ministry for Emergency Situations	Decree No72, 30 Dec 2006
Rules for the safety of research reactors	NAS Belarus	Ministry of Justice	Ministry for Emergency Situations	Decree No72, 30 Dec 2006
Safety rules for storage and transportation of nuclear fuel for storage and management of spent nuclear fuel	NAS Belarus	Ministry of Justice	Ministry for Emergency Situations	Decree No72, 30 Dec 2006
Rules of construction and safe operation of the actuators reactivity	NAS Belarus	Ministry of Justice	Ministry for Emergency Situations	Decree No72, 30 Dec 2006

TABLE 13. SHORTLIST OF REGULATIONS TO BE DEVELOPED IN BELARUS FOR NUCLEAR ENERGY

Title of document	Developed	Cleared	Approved
Requirements for the quality assurance programme during of construction of NPP	NAS Belarus	Ministry of Natural Resources and Environmental Protection, Ministry of Architecture and Construction	Ministry of Energy; Ministry for Emergency Situations
Requirements for the quality assurance programme for the design of NPPs	NAS Belarus	Ministry of energy, Ministry of Natural Resources and Environmental Protection, Ministry for Emergency Situations	Ministry of Architecture and Construction
Requirements to write a report on environmental impact assessment for NPP environmental impact assessment (EIA)	NAS Belarus	Ministry of Architecture and Construction, Ministry of Health	Ministry of Energy, Ministry of Natural Resources and Environmental Protection, Ministry for Emergency Situations
Acceptance of the completed construction of the reactors	NAS Belarus	Ministry of Natural Resources and Environmental Protection; Ministry of **A**rchitecture and Construction; Ministry for Emergency Situations; Ministry of Industry	Ministry of Energy
The account of natural and anthropogenic impacts on nuclear and radiation hazardous objects	NAS Belarus	Ministry for Emergency Situations	Ministry of Energy, Ministry of Natural Resources and Environmental Protection
The main provisions for the selection, training, admission to work and control of the operation staff of NPPs	NAS Belarus	Ministry for Emergency Situations	Ministry of Energy
Design Guidelines for justification of investment in building a nuclear power station and the procedure for siting NPP	NAS Belarus	Ministry for Emergency Situations; Ministry of Natural Resources and Environmental Protection; Ministry of Architecture and Construction	Ministry of Energy
Regulations on the general requirements for physical protection of nuclear facilities	Ministry of energy; NAS Belarus	Ministry for Emergency Situations, Ministry of Internal Affairs; KGB; Ministry of Energy; Ministry of Architecture and Construction	Council of ministers of Belarus
Basic safety and security rules of nuclear material transportation	NAS Belarus	Department of Nuclear and Radiation Safety of Ministry for Emergency Situations; KGB; Ministry of Energy; Ministry of Justice; Ministry of Transport and Communications	Ministry for Emergency Situations
Basic rules of safety and physical protection of nuclear material in transit	NAS Belarus	Ministry of Energy; Ministry of Defense; State Border Committee; Ministry of Justice	Ministry for Emergency Situations; KGB; Ministry of Internal Affairs

TABLE 13. SHORTLIST OF REGULATIONS TO BE DEVELOPED IN BELARUS FOR NUCLEAR ENERGY (CONTINUED)

Title of document	Developed	Cleared	Approved
Reporting requirements documentation for physical protection, control and accounting of nuclear material to the public authority	NAS Belarus	Ministry for Emergency Situations	NAS Belarus
The structure of the SSAC	NAS Belarus	Ministry for Emergency Situations; KGB; Ministry of Internal Affairs; Ministry of Finance; Ministry of Justice; Ministry of Energy	Council of Ministers of Belarus
The basic rules of accounting and control of nuclear material"	NAS Belarus	Department of Nuclear and Radiation Safety of Ministry for Emergency Situations; KGB; Ministry of Energy	Ministry for Emergency Situations
A typical instructions for registration and control of nuclear material at the research facility, critical and subcritical stands	NAS Belarus	Ministry for Emergency Situations; KGB	NAS Belarus
The procedure for determining the level of PP NF, NM, RW	NAS Belarus	KGB; Ministry of Internal Affairs; Ministry of Energy	Ministry for Emergency Situations
The organization of private security services NDO	NAS Belarus	KGB; Ministry of Energy	Ministry of Internal Affairs
System PP NM and NF. Instructions for organization of designee	NAS Belarus	Ministry of Energy	Ministry for Emergency Situations
Sanitary Rules for Radiation Safety personnel and the public for transportation of radioactive material (substances).	Ministry of health; NAS Belarus	Department of Nuclear and Radiation Safety of Ministry for Emergency Situations; Ministry of energy; NCRS; Ministry of Natural Resources and Environmental Protection.	Ministry of Health
Safety regulations for transportation of radioactive substances	NAS Belarus	Department of Nuclear and Radiation Safety of Ministry for Emergency Situations; Ministry of Energy; Ministry of Natural Resources and Environmental Protection.	Ministry for Emergency Situations
The collection, processing, storage and conditioning of liquid radioactive waste. Security requirements	NAS Belarus	Department of Nuclear and Radiation Safety of Ministry for Emergency Situations; Ministry of Energy; Ministry of Natural Resources and Environmental Protection.	Ministry for Emergency Situations
The collection, processing, storage and conditioning of solid radioactive waste. Security requirements	NAS Belarus	Department of Nuclear and Radiation Safety of Ministry for Emergency Situations; Ministry of Energy; Ministry of Natural Resources and Environmental Protection.	Ministry for Emergency Situations
Management of gaseous radioactive waste. Security requirements	NAS Belarus	Department of Nuclear and Radiation Safety of Ministry for Emergency Situations; Ministry of Energy, Ministry of Natural Resources and Environmental Protection.	Ministry for Emergency Situations

TABLE 13. SHORTLIST OF REGULATIONS TO BE DEVELOPED IN BELARUS FOR NUCLEAR ENERGY (CONTINUED)

Title of document	Developed	Cleared	Approved
Standards of design of fire protection facilities	Ministry for Emergency Situations	NAS Belarus; Ministry of Energy	Ministry for Emergency Situations
Warning systems and evacuation of people during fires in buildings	Ministry for Emergency Situations	NAS Belarus; Ministry of Energy	Ministry for Emergency Situations
Fire protection of nuclear plants. Standards of design	Ministry for Emergency Situations	NAS Belarus; Ministry of Energy	Ministry for Emergency Situations

The regulations developed and planned within the programme of scientific support of NPP construction by Belarus institutions cover:

- Siting;
- Design and operation;
- Safety;
- Safety of storage and transportation of nuclear fuel;
- Safety of research reactors and assemblies;
- Requirements to the report on justification of NPP safety with VVER-type reactor;
- Design and operation of actuating mechanisms for controlling the reactivity.
- Accounting and control of nuclear material and organization of nuclear material balance areas in particular (safeguards);
- Organization of the security tasks;
- Radioactive waste management;
- Analysis of the vulnerability of nuclear facilities;
- Terms of supply of imported equipment, products and components of nuclear facilities, radiation sources and storage;
- Licensing of nuclear and radiation safety;
- Certification of equipment, products and technologies for nuclear facilities, radiation sources and storage;
- Industry rules of nuclear safety for the use, processing, storage and transportation of nuclear (dangerous) fissile material;
- The order for testing of managers, engineers and technical workers regarding their knowledge of rules, norms and instructions on safety in nuclear power;
- Physical protection;
- Requirements for quality assurance programmes;
- Requirements for documents;
- Fuel management;
- Fire protection;

- Environmental protection.

Thus, in Belarus the legal framework for atomic energy is already partially developed and there is a concrete programme for developing the additional necessary regulations. This allows us to conclude that EP1.1.4 has been fulfilled.

Final evaluation of criterion CR1.1 (legal aspects)

The national legal framework necessary for a nuclear power programme is established in Belarus according to international standards.

Missing parts of nuclear regulation are clearly identified and are under development (with support from SOSNY) with the goal that they will be available before startup of the planned NPPs.

In particular it was found that the national nuclear law [1] needs some improvements in wording, such as correction and additional definition of terms, and a clear distinction of responsibilities of the relevant Government bodies involved in nuclear regulation (further discussed in the evaluation of CR1.2).

As a follow-up action it is recommended that the wording of the nuclear law [1] be updated as defined.

3.2.2. Criterion CR1.2 — institutions

Indicator IN1.2: *Status of State organizations with responsibilities for safety and radiation protection, protection of environment, control of operation, waste management and decommissioning, security (physical protection) and non-proliferation.*

Acceptance limit AL1.2: *the defined State organizations should be established, in accordance with international standards.*

Criterion CR1.2 is checked using five evaluation parameters, EP1.2.1–EP1.2.5:

3.2.2.1. EP1.2.1 — independence of regulatory bodies

Acceptability of EP1.2.1: *a regulatory body is deemed sufficient independent if its human resources and its competence and capability are adequate to make and maintain positions, independent of the owners/operators of nuclear facilities, and if it is free of undue pressure from interested parties — commercial or political.*

An important attribute of a regulatory body is its independence from interference in its regulatory functions from operators of nuclear facilities or organizations that are promoting nuclear power. The basis for its independence should be set out in the nuclear legislation.

As discussed before (Subsection 3.2.1.2, EP1.1.2, adequacy of nuclear law), regulation of the activities on safety of nuclear energy use in Belarus is carried out by a governmental system. In Article 7 of the law [1], the independence of this system is defined:

"*The public authorities to regulate the safe use of nuclear energy, in terms of exercising their powers related to government regulation of safety, holding control and State oversight of the use of atomic energy, are independent from national government bodies and other governmental organizations engaged in public management in (promotion of) the use of nuclear energy*".

Finding: However, this declaration must be supported by the foundation of organizational and financial independence of regulatory activities. Under the current regulatory system the regulatory activities in the field of nuclear energy are only part of the activities of the Ministry for Emergency Situations.

A possible scheme for full financial independence of regulatory activities would be the separation of Gosatomnadzor into an independent organization, empowering it with all the powers and functions of a regulatory body and giving it financial independence by allocating to it a separate budget line.

The law [1] and other legislation on the use of nuclear energy have no articles relating to other aspects of independence of regulatory activities: technical and managerial competence, the availability of adequate human resources, effective leadership, and reporting mechanisms.

Thus, the acceptability of EP1.2.1 (independence of the regulatory body) is considered not to be completely satisfied.

3.2.2.2. EP1.2.2 — general functions of regulatory body

Acceptability of EP1.2.2: *A regulatory body is deemed adequate if it performs all the functions listed below:*

- Establishment of regulatory standards, codes and criteria, and guidelines for the design, construction, operation and decommissioning of nuclear facilities, including the safe and secure management of radioactive waste generated;
- Review and evaluation of licensing documents, such as the physical protection plan, safety analysis and environmental reports of nuclear facilities;
- Authorization of construction, operation, and decommissioning of a nuclear facility and the conduct of activities by a licensee, by, e.g. issuing licences, registration;
- Performance of inspections, reviews, audits and enforcement activities to ensure compliance with established rules and regulations;
- Provision of information about safety and security aspects of facilities and activities to the to the public, the media, and interested parties;
- Coordination with other regulatory bodies.

Functions of the Ministry for Emergency Situations as a key regulatory body and other Government agencies (not specified), which regulate the use of nuclear energy, are set out in Article 7 of the law [1].

The main functions of Gosatomnadzor are listed in Chapter 3 of the *Regulations for the Department of Nuclear and Radiation Safety of the Ministry for Emergency Situations of Belarus*, introduced by [15].

In both documents, the regulatory functions could be set out more clearly, and basic functions that are absent include:

- Development, approval and dissemination of regulations and guidelines upon which regulatory actions based;
- Review and evaluation of safety documents both before the issuance of licenses and authorizations, and periodically during operation.

Additional evaluation of legal documents provided the following results: Article 10 of the law [1] states that “*licensing of the use of nuclear energy is to be carried out in conformity with the legislation on licensing*”. Such a legislative act is the provision on licensing certain types of activities, approved by Decree [16]. In accordance with section 126 of Chapter 13 of this provision, the licensing of activities for nuclear energy and ionizing radiation sources is carried out by the Ministry for Emergency Situations. In paragraph 5 of Annex 1 of this provision, the services and activities subject to licensing in the use of nuclear energy and ionizing radiation are listed in full.

Thus, the acceptability of evaluation parameter EP1.2.2 has been met.

3.2.2.3. EP1.2.3 — review of safety regime

Acceptability of EP1.2.3: *a review of the safety regime has been made by a competent authority with positive results.*

In 2010, Gosatomnadzor in Belarus applied an updated IAEA tool SARCoN (Systematic Assessment of Regulatory Competence Needs). The SARCoN guidelines are intended to help analyse the training and development needs of regulatory bodies in Member States [32].

Finding: The authors of this study have no information about a review of the national safety regime by an independent authority. Results of the self-assessment using the SARCoN tool are not available to the assessor.

This evaluation parameter is not met due to a lack of information.

3.2.2.4. EP1.2.4 — review of emergency preparedness regime

Acceptability of EP1.2.4: *A review of the emergency preparedness measures has been carried out either by a competent independent national authority or by government auditor or by a competent international institution, such as the IAEA, with positive results.*

In 2008 two IAEA advisory missions on notification procedures and information exchange in case of radiation emergency and on further upgrading of emergency notification system were conducted in Belarus.

In 2010, upon request from Belarus Government, an EPREV (emergency preparedness and review) mission assessed the national system of emergency preparedness for nuclear and radiation accidents. The main conclusion of the IAEA expert group was that Belarus has a reliable system of emergency preparedness and response, but which needs to be reviewed in connection with the plans to build an NPP in Belarus. The mission also gave recommendations for further improvement of the existing system of preparedness and emergency response in accordance with international requirements and standards [33].

EP1.2.4 has been met if the IAEA recommendations have been followed.

3.2.2.5. EP1.2.5 — review of physical protection regime

Acceptability of EP1.2.5: *a review of the physical protection regime has been carried out by a competent organization and the results of such review are positive*.

From 31 August till 11 September 2009 an IAEA IPPAS mission was held in Belarus in order to examine the current status of the State system of physical protection of nuclear material and nuclear facilities, to compare it with internationally recognized practices and to assess compliance with international guidelines. Also a specific assessment was performed to ensure the physical protection of JIPNR-SOSNY NAS Belarus.

According to information available to the authors of this study, the IPPAS team concluded that the physical protection regime was in a satisfactory condition at both the State level and at JIPNR-SOSNY NAS.

Thus, acceptability of evaluation parameter EP1.2.5 has been confirmed.

Final assessment of criterion CR1.2 — institutions

A majority of the evaluation parameters of criterion CR1.2 were not completely met, i.e. EP1.1.1 (independence of regulator), EP1.2.2 (functions of regulator body), EP1.2.3 (review of safety regime), and EP1.2.4 (review of emergency preparedness regime).

Thus, criterion CR1.2 has not been completely met.

3.2.3. Final assessment of UR1 — legal and institutional infrastructure

Most the existing legal and institutional infrastructure of Belarus was found to be adequate.

To bring the nuclear legislation of Belarus completely in compliance with the requirements of user requirement UR1 of the INPRO methodology, the recommended follow-up actions are to:

- Provide legislatively for real financial independence of regulatory activities on the use of nuclear energy. A possible scheme would be the separation of Gosatomnadzor from the Ministry for Emergency Situations into an independent organization, to empower it with all the powers and functions of a regulatory body and to give it financial independence by allocating a separate budget line.
- Perform a review by competent authorities of the safety regime for atomic energy**.**
- Define the functions of the regulatory body or bodies more clearly in the law [1] and, in particular, to introduce such functions into the law as:
  - (a) development, approval and distribution of regulations and guidelines upon which regulatory actions are based;
  - (b) review and assessment of safety documents before the issuance of licences and authorizations, and periodically during operation.

3.3. USER REQUIREMENT UR2 — INDUSTRIAL AND ECONOMIC INFRASTRUCTURE

User requirement UR2: *The industrial and economic infrastructure of a country planning to install a nuclear energy system (NES) installation should be adequate to support the project throughout the complete lifetime of the nuclear power programme, including planning, construction, operation, decommissioning, and related waste management activities.*

To check the fulfilment of UR2, INPRO has developed five criteria, CR2.1–CR2.5. These criteria will be used to evaluate the industrial and economic infrastructure in Belarus as follows.

3.3.1. Criterion CR2.1 — financing

Indicator IN2.1: *availability of credit lines.*

Acceptance limit AL2.1: *credit lines available in Belarus are sufficient for realization of planned nuclear power programme.*

Criterion CR2.1 is checked using two evaluation parameters, EP2.1.1 and EP2.1.2.

3.3.1.1. EP2.1.1 — financing of industrial infrastructure

Acceptability of EP2.1.1: *necessary financing for (planned) buildup of national industry — defined by a cost-benefit analysis or equivalent study — is available in the country.*

There is no plan to build up an additional national industrial infrastructure in the foreseen future, and the financing of the present one will be secured by its own capital resources and, if needed, by external credit or special State programmes.

Thus, EP2.1.1 has been met.

3.3.1.2. EP2.1.2 — financing of governmental infrastructure

Acceptability of EP2.1.2: *necessary governmental financing is confirmed by an analysis of budget resources.*

The budget item 'fuel and energy costs' includes an item for financing activities related to the installation of an NPP.

Thus, EP2.1.2 has been met.

Final assessment of CR2.1 financing

The above evaluation shows that necessary credit lines are available, thus criterion CR2.1 has been completely fulfilled.

3.3.2. Criterion CR2.2 — energy market

Indicator IN2.2: *Demand for and price of energy products.*

Acceptance limit AL2.2: *Adequate demand and price (of electricity) to enable a satisfactory financial return.*

Ref. [34] comprises a detailed analysis of the national energy market and a guarantee of satisfactory financial return confirmed by the calculations.

Thus, adequate demand for electricity and sufficient price is confirmed in Belarus, i.e. CR2.2 has been met.

3.3.3. Criterion CR2.3 — size of nuclear installations

Indicator IN2.3: *Size of installation.*

Acceptance limit AL2.3: *size of nuclear facilities matches national needs.*

The optimum size (power output) of an NPP in Belarus was defined by energy system planning (see section 1.5 of this report, 'electric power system expansion optimization', for details).

For criterion CR2.3, INPRO developed two additional evaluation parameters, EP2.3.1 and EP2.3.2.

3.3.3.1. EP2.3.1 — energy system expansion plan

Acceptability of EP2.3.1: *results of an energy system expansion plan (defining the role of nuclear energy) have been performed with adequate means.*

Ref. [34] presented a plan to expand the energy system in Belarus, and also data on the development of neighboring countries in order to determine the possible volume of electricity imports. Additional information is presented in section 1.5 of this report.

Thus, evaluation parameter EP2.3.1 has been met.

3.3.3.2. EP2.3.2 — size of nuclear fuel cycle facilities (other than NPP)

Acceptability of EP2.3.2: *size of nuclear fuel cycle facilities has been determined by means of adequate studies.*

Currently, construction of only a temporary storage facility of spent fuel is foreseen in Belarus. It is possibly (depending on the conditions of the contract for the construction of NPPs) that a geological disposal for high level waste from reprocessing is to be built in the future.

Finding: sizes of these facilities are not defined yet.

Final assessment of criterion CR2.3

Size (power output) of the NPPs was defined on the basis of a comprehensive energy system planning study.

However, the size of planned nuclear fuel cycle facilities in the country is not yet defined. It is recommended as a follow-up action that the size of the planned nuclear fuel cycle facilities be defined.

Thus, CR2.3 has been partially met.

3.3.4. Criterion CR2.4 — national support structure

Indicator IN2.4*: availability of infrastructure to support nuclear owner/operator.*

Acceptance limit AL2.4: *Availability of domestic or foreign support infrastructure needed by the operator*.

For criterion CR2.4, INPRO developed two evaluation parameters, EP2.4.1 and EP2.4.2.

3.3.4.1. EP2.4.1 — review of existing capabilities of industry

Acceptability of EP2.4.1: *a survey of the existing capabilities of national industry to support the owner/operator of nuclear installations has been performed.*

As part of the State scientific-technical programme *Nuclear-physics technology for the national economy of Belarus*, section 17 contains an analysis of the availability and sufficiency of industrial capacities for construction, of raw material and of the scientific basis in Belarus for installation of NPPs.

Thus, evaluation parameter EP2.4.1 has been met.

3.3.4.2. EP2.4.2 — plan for national participation

Acceptability of EP2.4.2: *plan for participation of national industry in nuclear power programme has been established.*

A plan of participation of national industry in the NPP installation is currently being prepared and is based on the analysis of availability and sufficiency of the industrial capacity for construction, of raw material and of the scientific basis of Belarus in installing an NPP (see also evaluation of EP2.4.1).

Thus, evaluation parameter EP2.4.2 has been met.

Final assessment of criterion CR2.4 — national support structure

As both evaluation parameters have been met, it was confirmed that the necessary support infrastructure was available in the country, i.e. criterion CR2.4 had been met.

3.3.5. Criterion CR2.5 — added value

Indicator IN2.5: *Full added value of proposed nuclear installation (AVNI).*

Acceptance limit AL2.5: *AVNI should be greater than national infrastructure investment necessary to support nuclear installation.*

INPRO developed for criterion CR2.5 two evaluation parameters, EP2.5.1 and EP2.5.2.

3.3.5.1. EP2.5.1 — cost-benefit analysis for buildup of national industry

Acceptability of EP2.5.1: *a cost-benefit analysis regarding necessary investments has been performed by national industry to be involved in the nuclear power programme with a positive result.*

Introduction of nuclear power in Belarus does not foresee the creation of a full-scale national industrial base for the development of nuclear energy, but only selected participation of local industry. The main nuclear equipment will be supplied by one of the countries possessing (developing) nuclear power technologies, for example by Russia. Thus, no significant investment by national industry is foreseen in Belarus. Additionally, it is reasonable to assume that any investment in national industry related to NPP installation will be considerably lower than the investment in the planned NPP units.

Finding: No information about a cost benefit study for a buildup of national industry to be involved in a nuclear power programme was available to the authors of this study.

Assuming that the necessary investment in national industry build-up in Belarus is negligible, it can be concluded that EP2.1.2 is not relevant.

3.3.5.2. EP2.5.2 — study to define benefits of nuclear programme to society

Acceptability of EP2.5.2: *a governmental study to define benefits of the planned nuclear power programme to society has been performed with a positive result.*

Finding: The authors of this study have no information about governmental expertise regarding potential benefit to society of the planned nuclear programme.

However, it follows from the discussion above that the existing industrial infrastructure and its forecast fulfil all requirements for support of the owner and operator of the planned NPPs and that it does not require considerable financial investment.

Final assessment of criterion CR2.5 — added value

Criterion CR2.5 has not been met due to lack of available information on benefits of the nuclear power programme to society. It is recommended that such a study be initiated.

3.3.6. Final assessment of UR2 — economic and industrial infrastructure

This user requirement stipulates that economic conditions in the country should be adequate and that sufficient support should be provided by national industry to of nuclear facility operators.

Economic conditions have been confirmed via criterion CR2.1 (national capability to finance), and CR2.2 (national energy market). For assessment of CR2.3 (size of nuclear facilities) not sufficient data are available.

A sufficient national support structure has been confirmed via CR2.4 (support structure), but for assessment of CR2.5 (added value of nuclear power programme) sufficient data are not available. Thus, user requirement UR2 has not been completely fulfilled.

Recommended follow-up actions are to:

- Perform additional independent governmental research to demonstrate the benefits of the planned nuclear power programme to society.
- Define the size of the planned nuclear fuel cycle facilities.

3.4. USER REQUIREMENT UR3 — POLITICAL SUPPORT AND PUBLIC ACCEPTANCE OF NUCLEAR POWER

User requirement UR3: *Adequate measures should be taken to achieve public acceptance of a planned NES installations to enable a government policy commitment to support the deployment of NES to be made and then sustained*.

INPRO has developed four criteria, CR3.1–CR3.4, for this user requirement.

3.4.1. Criterion CR3.1 — information

Indicator IN3.1: *Information on nuclear power programme provided to public*.

Acceptance limit AL3.1: *Scope and level of information is sufficient according to the best international practice.*

Belarus is guided by the *Aarhus Convention* for carrying out public information and awareness-raising activities. A comprehensive report [35] was prepared on the preconstruction environmental assessment of the planned NPP.

A summary of the environmental impact assessment regarding the planned NPP installation was prepared by the State enterprise BELNIPIENERGOPROM together with the Directorate for NPP Construction of the Ministry of Energy. This information was published on the official websites of the Ministry of Nature, the Ministry of Energy and the Directorate for Nuclear Power Plant Construction (minpriroda.by/en; www.dsae.by).

The following activities with regard to public information have been performed by Belarus in accordance with international practice:

- Stage No.1: Notification to the public on taking the decision on NPP construction, including a preliminary assessment and terms of reference for implementation of a comprehensive environmental impact assessment (EIA);
- Stage No.2: Performing research on environmental impact and preparation of preliminary version of EIA.
- Receipt of comments and notes from the public is in progress.
- Public consultations took place in Ostrovetskiy district on 9 November 2009.
- In compliance with the United Nations Economic Commission for Europe's *Convention on Environmental Impact Assessment in a Transboundary Context* (Espoo, February 25 1991), which Belarus ratified on 10 November 2005, the Ministry of Natural Resources and Environmental Protection submitted brief information on the EIA for planned construction and NPP operation in Belarus to concerned countries — Austria, Lithuania, Latvia, Poland and Ukraine. In the framework of this process, a discussion of the preliminary report on environmental impact assessment took place in Vilnius, Riga and Kiev on 2, 23 and 31 March 2010 respectively.
- Official consultations and public consultations on the report on the EIA of the Belarusian NPP took place with Austria in Vienna on 10–11 May 2010 and with Poland in Warsaw on 25 May 2010.
- To prepare the general contract on Belarusian NPP construction between Belarus and Russia, the British company AMEC was chosen as an international consultant. The Director of the Directorate for the NPP construction reported on this activity to journalists on 10 March 2010.

Considering the activities presented above, it can be concluded that Belarus has taken significant effort to inform the public at home and abroad about the planned nuclear power programme.

INPRO has developed five evaluation parameters, EP3.1.1 to EP3.1.5, for criterion CR3.1.

3.4.1.1. EP3.1.1 — national energy policy

Acceptability of EP3.1.1: *adequate national energy policy is available to the public.*

Activities related to the possibility and feasibility of NPP installation in Belarus were begun in accordance with Directive [36]. Item 1.3.1 of this Directive — Assignments of Head of the State on (draft) development of concept to achieve increased security and independence of energy supply in Belarus — considers:

- Intensification of activities related to NPP construction, thermal power stations based on coal, hydropower stations of small and medium capacity, mini thermal power stations and also production of biofuel, wind energy installations, complexes of biogas, and installations which supply energy using municipal waste.
- A concept of security of energy supply in Belarus approved by the Decree [37], which justifies nuclear power development to increase both national energy security and fuel diversity.
- A Decree [15] on measures related to NPP construction, which considers:
  - (a) the establishment of a regulatory and oversight body for radiation safety — Department for Nuclear and Radiation Safety of the Ministry for Emergency Situations, which is responsible for organization and implementation of public administration for nuclear and radiation safety.
  - (b) the State Nuclear Plant Construction Directorate, established in accordance with the Decree of the President of the Republic to implement customer functions of NPP construction. The Directorate is subordinated to the Ministry of Energy.
  - (c) the State scientific research and design enterprise BELNIIENERGOPROM, which reports to the Ministry of Energy as the general designer for coordination for construction document development related to NPP construction in Belarus.
  - (d) the State Joint Institute for Power and Nuclear Research, SOSNY, NAS of Belarus, as the organization carrying out scientific support of NPP construction.

In November 2007, the Council of Ministers made a decision [38] on financing of the preliminary activities regarding NPP installation. The decision to start an implementation of the nuclear programme was taken on 15 January 2008 at the meeting of the Security Council of Belarus.

The Decree of the President on the establishment of the Department of Nuclear Power in the Ministry of Energy [25] and the *Law on the Use of Atomic Energy* [1] were issued in July 2008.

A plan for activities of authorities on implementation of the law [1] considering amendment of existing acts and development of new ones to adjust them in accordance with the adopted law was developed and approved by the First Deputy of Prime Minister on 22 September 2008.

A Belarusian delegation headed by the Deputy Minister of Health (Chief State Sanitary Officer of the Republic) took part in a meeting and negotiations with the Federal Agency for Protection of Consumers and Human Welfare of the Russian Federation (Rospotrebnadzor) in particular with the Head of the Federal Agency (Chief State Sanitary Officer of Russia). During the negotiations, an agreement was reached on practical assistance in establishing a system of State sanitary (health) inspections taking into account NPP construction, on information exchange and on new legislative and methodological documents of the Russian Federation and Belarus related to issues of sanitary (health) and epidemic welfare.

Technical codes of the established practice defining the requirements for site selection of NPP construction and basic provisions on NPP safety assurance were implemented. Thus, necessary conditions to carry out preliminary work to be done prior to NPP construction, were established in Belarus.

Preparation of NPP construction in Belarus is held in close cooperation with the IAEA, with which technical cooperation is successfully developing.

The strategy of energy supply in Belarus considers an improvement of the fuel and energy balance plan, taking into account the necessity of replacement of the currently used monopolistic fuel type — natural gas. Decrease of its portion in the fuel and energy balance plan is considered through the increased use of coal, nuclear power and other domestic energy resources. (25 April 2009 Interview of Minister of Energy for Journal FERST).

Thus, a national energy policy exists in Belarus and was communicated to the public, i.e. EP3.1.1 has been met.

3.4.1.2. EP3.1.2 — informing the public about benefits of nuclear energy

Acceptability of EP3.1.2: *Results of public surveys show that the benefits of nuclear energy have been understood by the public.*

Ministry of Energy coordinates and organizes information activities on NPP installation.

In Belarus much attention is paid to the public attitude towards nuclear power development. Outreach activities are aimed at fostering a positive public attitude towards nuclear power. A plan for the organization of informational and promotional activities was approved. In accordance with this plan, the opinion of population related to nuclear power development in the country is being studied on a regular basis.

Activities regarding public outreach and awareness-raising are carried out by the Department on Nuclear Power and Directorate for NPP construction in the Ministry of Energy, in the framework of Measure 9 *Implementation of informational and analytical support of nuclear power development in Belarus* of the State Programme on the nuclear power development scientific support [39].

An information centre was established for outreach and awareness-raising work with different population groups: students, workers, public organizations, mass-media and authorities on the topic of nuclear power and NPP construction. The main goal of this information centre is to inform the public about nuclear power and its facilities, about the nature of nuclear power, and principles of NPP operation. Group visits to the information centre are arranged by appointment. (Business hours – 08:30 17:00 Lunch break 13:00 – 13:30; Days off: Saturday, Sunday; address: Grodnensky district, Ostrovets, 3, Oktybrskaya str.; Phone: (01591) 23708)

A centre for nuclear power development, RATEN, has been established in the the Press House of the Ministry of Information. Public relations activities are carried out (briefings, roundtables, seminars) on different aspects of NPP construction: Bulletins on nuclear power are issued regularly; world news about nuclear power is reviewed; booklets for children are provided and a special activity for children is carried out.

Since 2005, the Institute of Social Science (BISS) of the NAS has been carrying out sociological monitoring regarding attitudes in Belarus regarding possible types of power development, including nuclear power. Research has confirmed that there is a clear trend in public opinion showing an increase of support for nuclear power development.

In 2005, on the question ‘Should Belarus have and develop nuclear energy?’, the following answers were received from the public: *yes* — 25.8%, *no* — 46.7%, *have not thought about it* — 25%. It is obvious that nuclear power is still associated with the threats and risks caused by the Chernobyl disaster.

A similar national survey conducted in December 2007–January 2008 demonstrated that the ‘Chernobyl syndrome’ has been gradually overcome. So at this time, 54.8% of respondents answered positively to the question ‘Should Belarus have and develop nuclear energy?’, and only 23% responded negatively.

The indirect support of nuclear power in Belarus is illustrated by answers to a number of other questions. For example, 41.6% of respondents believe that the Republic cannot ensure its energy security without nuclear power, and 58.6% consider the option of using nuclear fuel for energy development in Belarus as very promising. 48.2% agree that nuclear plant construction will increase the competitiveness of domestic products (because nuclear power is cheaper). 64.3% of respondents believe that constructing a nuclear power station will improve the situation in the energy sector of the country, a little or substantially.

The question: ‘Subject to which of these conditions you would have supported the idea of building an NPP in the country?’ was answered by 48%: ‘The most modern and safest reactors should be used’. This point of view is fully consistent with Government policy on nuclear energy development.

During 2009–2010, the Institute of Sociology of NAS of Belarus conducted regular surveys of public opinion on NPP construction in Belarus. 2000 respondents of different ages, social groups in different regions of Belarus were interviewed. The results were released in September 2010. Preliminary results show a positive trend.

In addition, questions on the construction of NPPs were raised in the BISS study jointly with the Novak laboratory: ‘The social consequences of the global financial crisis,’ conducted in spring 2010. The study was conducted with a representative sample of 1571 people in all regions of Belarus. Starting with the question “How respondents relate to the plans for the construction of NPP”, the Belarusian society is divided almost in half. Strong opponents of NPP construction are somewhat more numerous than strong supporters but, overall, supporters prevail over opponents with a difference of less than 3% (see Table 14).

TABLE 14. SPRING 2010 SURVEY RESULTS: HOW DO YOU FEEL ABOUT THE FACT THAT IN THE NEAREST FUTURE BELARUS PLANS TO BUILD AN NPP?

Answers	**%**
Completely positive	14.2
Rather positive	26.5
Rather negative	21.5
Completely negative	16.4
Know nothing about it	7.5
Difficult to answer	13.9

The supporters and opponents of nuclear power have a specific gender profile. Men are almost twice as likely than women to accept the idea of building an NPP with full enthusiasm and, taking into account those with a rather positive attitude towards nuclear power, the ratio is 50% male to 33% female.

The distribution of supporters and opponents of NPP construction, taking into account their residence, refutes the claim that the number of supporters increased due to mass media brainwashing of the population and supports the assumption that the Government has found rational arguments for its position. In particular, dominance of supporters over opponents is very impressive among the citizens of Minsk (53% to 37%), while at the rural population is dominated by opponents (34% to 37%). Belarus experts deem that the information gap in relation to nuclear power is most evident among the residents of small towns.

Nuclear power is mostly supported by executives, managers, workers, private entrepreneurs, law enforcement officials and the unemployed. Least likely to support nuclear power are retirees, students, civil servants and budget/finance workers.

The State-run media have been conducting an active educational campaign in the press and electronic media in order to convince the citizens of Belarus that there are no problems in connection with new technologies or security standards, and that there is a high level of international cooperation in the installation of nuclear power.

The supporters of a nuclear power are middle class people, and mostly from socially active groups. Some of the groups (workers, entrepreneurs) are convinced in the economic benefits of nuclear power. Intimidation of these groups by the risk of nuclear accident apparently expired.

As for the opponents of nuclear power, they are mainly part of a primarily socially passive or State-controlled group, and a mobilization of these groups is very unlikely to happen.

On the basis of the information presented above, it is concluded that a great effort is being undertaken by Belarus to inform the public about the benefits of nuclear power. Public opinion is surveyed regularly to confirm that the public has understood the benefits of nuclear power.

Thus, EP3.1.2 has been met.

3.4.1.3. EP3.1.3 — information on operation of nuclear facilities

Acceptability of EP3.1.3: *a policy (by the owner/operator of nuclear facilities) on public communication is in place and its effectiveness has been demonstrated by surveys.*

As there is no facility of the planned NES of Belarus currently in operation yet, this evaluation parameter cannot be assessed.

Finding: A policy on keeping the public informed on the operation of nuclear facilities should be developed before the startup of the NPP.

3.4.1.4. EP3.1.4 — addressing public concerns regarding nuclear installations

Acceptability of EP3.1.4: *a communication programme exists that addresses issues of risk of nuclear power.*

The following official statement by the government confirms that the issues of risk are fully taken into account in the Belarus nuclear power programme: *"I guarantee that we will choose such the option of building NPPs where the risks are minimized and environmental protection is fully ensured,"* said the President of Belarus in his annual address to the Belarusian people and the parliament on 29 April 2008.

The public information programme described in section 3.4.1.2 includes addressing concerns raised by the public regarding nuclear power.

Thus, EP3.1.4 has been met.

3.4.1.5. EP3.1.5 — use of communication experts for public information

Acceptability of EP3.1.5: *communication experts are used in formulating and executing communication plans.*

This evaluation parameter was not assessed directly in this study. However, it can be assumed that the Ministry of Energy — which is responsible for public information on nuclear power — is using communication experts.

Thus, EP3.1.5 has been met.

Final assessment of criterion CR3.1 — public information

All evaluation parameters of CR3.1 have been met completely with the exception of EP3.1.4, which recommends that a policy of the owner/operator of nuclear facilities be developed before the startup of the NPP.

Thus, criterion CR3.1 has been met, assuming the communication policy of the owner/operator will be available before the NPP starts up.

3.4.2. Criterion CR3.2 — participation of public

Indicator IN3.2: *Participation of the public in the decision making process (to foster public acceptance).*

Acceptance limit AL3.2: *Public participation in decision process is sufficient according to national requirements.*

For criterion CR3.2, INPRO has developed two evaluation parameters, EP3.2.1 and EP3.2.2.

3.4.2.1. EP3.2.1 — appropriateness

Acceptability of EP3.2.1: *The participation process is deemed appropriate if four issues are covered: public access to information resources, identification of tasks in which the public is involved, structuring of decision-making process, and cost effectiveness of public participation.*

This evaluation parameter was not assessed in the study.

3.4.2.2. EP3.2.2 — acceptability of participation

Acceptability of EP3.2.2: *The participation process is deemed appropriate if the following four issues are dealt with: sample representative, independence of the participation process, early involvement, and influence of results on policy.*

The evaluation parameter was not assessed in this study.

Final assessment of criterion CR3.2 — participation of public

Criterion CR3.2 was not assessed in this study.

3.4.3. Criterion CR3.3 — public acceptance

Indicator IN3.3: *public acceptance of nuclear energy*

Acceptance limit AL3.3: *public acceptance is sufficient to ensure there is negligible political risk to policy support for nuclear power.*

For criterion CR3.3, INPRO has developed three evaluation parameters, namely EP3.3.1 to EP3.3.3.

3.4.3.1. EP3.3.1 — regular surveys

Acceptability of EP3.3.1: *public polling is performed on a regular basis, commensurate with the circumstances.*

According to the results of reports submitted to the assessor [40] it follows, that the survey of public opinion is carried out on an ongoing basis.

TABLE 15. DISTRIBUTION OF RESPONSES TO THE QUESTION: 'WHAT IS YOUR ATTITUDE TO THE NPP BUILDING NEAR THE TOWN YOU ARE LIVING IN?' BY REGION (IN % OF RESPONDENTS)

Responses	Total		
	2005	2006	2008
1. Comfortable	8.6	7.3	12.2
2. Agree if it guarantees security of property and a State system of insurance for the people living near the NPP	34.3	35.4	41.1
3. Take part in the various protests against this construction	32.7	32.2	16.0
4. Try to leave this territory	17.0	18.9	23.9
5. Other	7.3	7.0	5.7

A survey of public opinion is also discussed in section 3.4.1.2 (EP3.1.2, information of public on benefits of nuclear power).

Thus, EP3.3.1 has been met.

3.4.3.2. EP3.3.2 — survey adequacy

Acceptability of EP3.3.2: *surveys are adequate if they are performed by certified professionals with use of licensed instrument.*

The surveys on public acceptance of nuclear power in Belarus are carried out by the Agency for Political Analysis (BISS) together with the survey laboratory NovAK. Results of these surveys are documented in reports called *the social consequences of the global financial crisis*, based on a survey conducted in spring 2010, and *Nuclear power plants — and what do people think?* in *News of the Day*, by BISS.

Thus, the surveys are performed by professionals, i.e. EP3.3.2 has been met.

3.4.3.3. EP3.3.3 — survey result acceptability

Acceptability of EP3.3.3: *survey results are acceptable if they indicate that a majority of the public supports the nuclear power programme with a stable positive trend.*

From Tables 14 and 15 it is clear that, at the moment, more than 50% (part 1 and part 2) agree with the installation of nuclear power and a positive trend is observed.

Thus, EP3.3.3 has been met.

Final assessment of criterion CR3.3 — public acceptance

CR3.3 has been met completely as have all assessed evaluation parameters.

3.4.4. Criterion CR3.4 — political environment

Indicator IN3.4: *government policy*

Acceptance limit AL3.4: *policy is supportive of nuclear energy*

In recent years, clear Government support of NPP construction in Belarus can be seen. For example, it is stated in the resolution [41] that in order to develop nuclear power in Belarus, the Security Council of Belarus acts:

"to carry out the construction of an NPP in Belarus with a total electrical capacity of 2000 MW, with the commissioning of the first energy unit in 2016 and the second in 2018".

Other examples of Government support are discussed in sections 3.4.1 and 3.4.2 above.

Thus, criterion CR3.4 has been met.

3.4.5. Final assessment of user requirement UR3 — political support and public acceptance

The evaluation above shows that development of nuclear power in Belarus has strong support from the Government.

Public acceptance was low at the initial stage of the programme but this was due to the lack of information about modern NPPs and the influence of the 'Chernobyl syndrome'. Recently, public acceptance has been growing.

It is recommended that in time, a policy of public information on the operation of the NPP by the future owner/operator be developed.

Thus, user requirement UR3 has been met, assuming that a policy for public information of NPP operation will be available in time.

3.5. USER REQUIREMENT UR4 — HUMAN RESOURCES

User requirement UR4: *The necessary human resources should be available to enable all responsible parties involved in a nuclear power programme to achieve safe, secure and economical operation of the NES installations during their lifetime. The owners/operators should have enough knowledge of the NES to be intelligent customers and should keep a stable worker of competent and trained staff.*

INPRO has developed two criteria for this user requirement, CR4.1 and CR4.2.

3.5.1. Criterion CR4.1 — availability of human resources

Indicator IN4.1: *availability of human resources*

Acceptance limit AL4.1: *human resources are sufficient according to international experience.*

For criterion CR4.1, INPRO has developed three evaluation parameters, namely EP4.1.1, EP4.1.2, and EP4.1.3.

3.5.1.1. EP4.1.1 — educational and training system in nuclear power projects

Acceptability of EP4.1.1: *a (qualitative) adequate educational system exists (is planned).*

In Belarus, the *National Training Programme* [42], and the *Programme of Scientific Support* [39] were developed and adopted. In February 2008, a mission by the IAEA was conducted in Belarus on staff training for future NPPs. The decision to create a national training system for nuclear power was taken.

Specialists for NPPs are currently trained in the leading universities of the country: the Belarusian National Technical University provides staff training for construction in the energy sector; the Belarusian State University Physics Department teaches specialists for NPPs; and the Belarusian State University of Informatics and Radioelectronics prepares personnel to work in the management system and security of nuclear power stations. In the long term, national educational establishments will provide new special courses to educate nuclear power specialists.

In order to meet the needs of the State for highly qualified nuclear personnel, the government set up a special State Committee. This organization should arrange and coordinate the development of legal and financial support for all types of training of personnel needed in a nuclear power programme. In addition, its major task is to coordinate the training programme for nuclear power with the concerned governmental bodies, universities, scientific institutes of the NAS, and with international and foreign organizations engaged in training specialists in the sphere of nuclear power.

Thus, an adequate educational system exists and is planned to be enlarged in the future, i.e. EP4.1.1 has been met.

3.5.1.2. EP4.1.2 — attractiveness of nuclear power sector

Acceptability of EP4.1.2: *there are (are planned) attractive workplaces, comparable to those in other high-tech countries.*

In the available data taken for the calculation of economic parameters, wages at the nuclear power station were found to be comparable with the average wages in Belarus for workers of the same qualifications. Also, a sensitivity analysis on wages was performed. With an increase in absolute value of wages up to 400% to 7.7 million rubles (US $2500), production cost will increase by 23.1%, while the share of wages in the production cost structure will increase from 7.7% to 25%. However, a competitive advantage (electricity production cost) of NPPs is still maintained compared to non-nuclear power stations. In the publications [43, 44], it was announced that the wages of workers with the same skills in Western Europe are about US $6000 and in the Russian Federation wages are also at this level.

Thus, wages in Belarus for nuclear power related jobs are not competitive with similar jobs outside the country, i.e. EP4.1.2 has not been met.

3.5.1.3. EP4.1.3 — capacity to accept additional load of nuclear power programme

Acceptability of EP4.1.3: *human resources needed for the nuclear programme are available without adverse impact on other industrial activities of comparable value to the country.*

Taking into account the specificity of an NPP, the issue of recruitment and training of personnel for NPPs needs to be addressed from the first day onwards after the decision to build the power plant is taken:

- In 2008, students started to take courses relevant to nuclear power in the four metropolitan universities;
- There are ongoing activities to invite nuclear specialists with experience in operating NPPs;
- There is a screening programme of Belarusian energy specialists to retrain them for the most important positions at the NPP.
- The number of workers at NPPs depends on the project and is expected to be about 2000 people. During peak demand, it is expected that approximately 10 000 employees will be used to build the power plant and associated infrastructure.

As discussed above, activities in Belarus started early enough to recruit and retrain nuclear power specialists so that no adverse impact on other industrial activities is expected.

Thus, EP4.1.3 has been met.

Final assessment of criterion CR4.1

Criterion CR4.1 has been only partially met. An adequate educational system is in place, but the structure of wages for nuclear facilities seems to be too low.

It is recommended that the structure of wages at nuclear facilities be reconsidered to ensure that human resources are not lost to competitive establishments outside the country.

3.5.2. Criterion CR4.2 — safety and security culture

Indicator IN4.2: *Attitude to safety and security in nuclear organizations.*

Acceptance limit AL4.2: *a safety and security culture prevails in all nuclear organizations confirmed by periodic safety and security reviews.*

Following an initiative of the State Belaya Rus association, a roundtable meeting was held on 21 April 2010 on the prospects of nuclear energy in Belarus. Several parties participated in the discussion: representatives from the Ministry of Energy, the Ministry of Natural Resources and Environment; Belnipienergoprom employees, developers of the Belarusian nuclear power station project, the Ministry of Education, and representatives from the leading universities of the country and the Ostrovetsky district community.

Delegates from the general office (directorate) DSAE to this round table drew the meeting’s attention to the need to develop a safety culture in organizations dealing with nuclear power: *“Formation of a safety culture means training of each person, involved in nuclear energy to achieve such a mindset, that s/he — in the performance of duties — , will be simply unable to do any, even the smallest, step to the detriment of safety. Development and implementation of the concept of a safety culture needs efforts from ‘top down’, i.e. a visible impact by leadership, as well as from ‘bottom up’, i.e. from the staff. For the successful implementation of a safety culture, it is necessary to ensure both effective cooperation and awareness at all levels, which primarily depend on an atmosphere of trust in an organization. Technical specialists, human factor specialists, operational personnel and management should work together to develop common understanding, despite the differences in their functions. This is a characteristic of a strong safety culture itself".*

Necessary support to build up the culture of nuclear (and radiation) safety in all nuclear power related organizations is provided by the Government. It is expected that — once the organizations for operating the NPP are established — periodic reviews of the safety culture will be performed by competent institutions such as the IAEA.

According to the information available to the assessor, no review of the safety and security culture has taken place until now.

Thus, criterion CR4.2 has not yet been met.

3.5.3. Final assessment of user requirement UR4 — human resources

The evaluation above shows that in Belarus all activities to achieve and maintain the necessary human resources for a nuclear power project are being implemented.

Nevertheless, a problem may be the currently planned salary level at nuclear power installations, which is too low and should be set at the same level as in neighboring countries to keep trained skilled professionals of Belarus from going abroad. Also no information was available to the assessor whether security and safety culture has been reviewed.

3.6. SUMMARY AND CONCLUSIONS OF ASSESSMENT OF BELARUS' INFRASTRUCTURE

The evaluation – using the INPRO methodology – presented above allows us to make the following conclusions on infrastructure readiness for the development of nuclear power in Belarus.

The evaluation of the *legal and institutional infrastructure* in Belarus revealed that it was well established. Some minor corrections of the text of the nuclear law [1] are recommended, such as adding definitions of terms used in the law and defining more precisely the functions of the regulatory body. It is also recommended that full financial independence of the licensing authority be considered.

The evaluation of the existing *industrial and economic infrastructure* and its planned development in Belarus confirmed, in general the readiness of this part of the national infrastructure. The existing national industry is found ready to support the installation of NPPs and no substantial financial investment is expected for upgrading national industries. An independent government investigation is recommended in order to demonstrate the economic benefits of the planned nuclear power programme to society and define the size of the planned nuclear fuel cycle facilities.

The evaluation of *public acceptance and political support* confirmed that adequate measures of public information are taken by the Government, which strongly supports the development of nuclear power. In time, a policy of public information should be developed on the operation of the NPP.

The evaluation of *human resources* needed for development of nuclear power revealed that practically all necessary activities are being implemented in Belarus. Nevertheless, a problem may be the planned salary level at nuclear installations, which should be the same as in neighbouring countries to avoid trained skilled professionals being enticed to better paid jobs abroad.

4. WASTE MANAGEMENT

In this section, an assessment of the selected NES of Belarus in the area of waste management is performed.

4.1. INTRODUCTION

Generally, *radioactive waste* is defined as material that contains radionuclides with a defined concentration or activity exceeding acceptance levels established by regulatory bodies, and for which no further use is considered.

Radioactive waste is generated at all stages of a complete nuclear fuel cycle, i.e. during:

- Mining and milling, raw material separation;
- Uranium conversion;
- Uranium isotope enrichment;
- Fuel fabrication;
- Reactor operation;
- Fuel reprocessing;
- Spent fuel management;
- Waste processing;
- Decommissioning.

However, Belarus expects to perform only a few nuclear activities (see also section 1.6, NES of Belarus to be assessed) with a generation of radioactive waste within the country, namely:

- Reactor operation;
- Storage of spent fuel;
- Treatment and storage of radioactive waste produced during operation of nuclear facilities;
- Decommissioning of nuclear facilities.

4.1.1. Overview on existing waste management facilities in Belarus

The currently existing storage facilities for radioactive waste in Belarus are briefly described below, from Ref. [45].

Existing radioactive waste storage facilities in Belarus

A radioactive waste storage facility called EKORES is located two km outside Minsk. It is a typical near surface RADON-type facility[1], and was commissioned in 1963 to accept waste from a research reactor of the Academy of Science of Belarus. It currently provides the storage of a wide range of radioactive waste produced in medicine, industry and research in Belarus.

At present, this site contains:

- Two closed old repositories (in operation 1963–1979)
- Two new generation near-surface repositories intended for solid waste and sealed radioactive sources;
- Storage for sealed radioactive sources;

[1] RADON is a company based in Moscow.

- Special (contaminated) laundry (100 kg per shift).

The two old repositories are rectangular reservoirs with 225 m^3 volume each, with walls and floor constructed as a concrete monolith and with a covering of precast concrete slabs. Their design dimensions are 5×15 m, and their depth is 3 m. During the final conservation process, the upper surface was covered with hot bitumen and, after that, with layers of asphalt (0.03 m) and soil (1.2 m).

The two new generation repositories (constructed in 1977) have an above-ground floor with a precast metal frame (design dimensions are 12×30 m) and an underground floor (830 m^3) consisting of eight vaults (depth is more than 3 m and design dimensions are 6×6 m) made of a concrete monolith. The facilities are equipped with a suspension cat-crane with a lift capacity of 3.2 tons, which can remove one or two floor slabs and the waste packages can then be loaded into the vaults. The capacities of the new generation repositories are designed for loading solid waste with a specific activity and total annual activity not exceeding 3.7 MBq/kg and 7.4 TBq respectively. Currently, 6–10 tons of solid low and medium level waste annually comes to this EKORES facility. It is loaded into the vaults in the producer's package or container. Until recently, incoming waste has not been segregated. The content of the filled vaults represents a conglomerate of different material (e.g. plastic, glass, rag), contaminated with both short-lived and long-lived radionuclides. The planned length of operation for the new generation repositories is 20 years.

There are wells for disposal of sealed spent radiation sources equipped with an S-type pipe of 108 mm diameter for source loading. The depth of these wells is 6 m. The designed well capacity does not exceed 20kg-equivalent of radium of total activity in a single well without any time limitation for loading. The planned length of operation of the wells is also 20 years.

For managing spent sealed sources, those:

- Delivered in transport containers with the capability of bottom unloading are loaded into the wells through an S-type pipe;
- Delivered in containers not providing a capability for bottom unloading and some radiation devices with built-in protection (for example, gamma-radiography units) are stored in special vaults under a concrete slab together with their shielding;
- Containing radioactive isotopes such as plutonium or americium are collected in a separate container, which is stored in a special concrete vault.

In 2003 at the EKORES site, the RADON company carried out activities for conditioning spent sealed radioactive sources to be stored in a metallic matrix inside a well type repository. In the course of reconstruction work at the EKORES site, a new storage for sealed radioactive sources was constructed and commissioned in 2003.

There are seven wells for spent gamma sources and four wells for alpha and beta sources. They are considered an intermediate (long-term) storage facility with a technical capability to take out the sealed sources if it necessary to store them in another place. For this, the upper part of a well is movable and weighs less than 2 tons.

Existing disposal facilities for decontamination waste of Chernobyl origin (DFDW)[2]

Depending on the specific activity or surface contamination of decontamination waste and formation history, solid decontamination waste is disposed in a special disposal facility named DFDW.

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[2] Information in this subsection is not directly related to the planned NES of Belarus but it demonstrates an experience accrued in the country in the area of waste management.

There are three different types of engineering structures used in DFDW facilities:

DFDW-I is a special engineering structure intended for disposal of decontamination waste with a specific activity more than 10^5 Bq/kg caused by the nuclide ^{137}Cs. Isolation is ensured by use of special engineering barriers, hydrotechnical measures and a permanent system of radiation control. Currently, there is only one disposal facility of such a kind: KHATKI. It is located in the South of the Chernobyl zone several kilometers away from the border to Ukraine. It consists of nine trenches, equipped with concrete cells (3×3×3 m), where 3088 tons of radioactive material with a total activity of $74.5 \cdot 10^{10}$Bq (201488 Ci) were deposited in 1991.

DFDW-II is a near-surface engineering structure with a clay floor intended for disposal of decontamination waste with a specific ^{137}Cs activity from 10^3 Bq/kg to 10^5 Bq/kg. There are eight DFDW-II facilities in Belarus: four in the Mogilev Region, three in the Gomel Region, and one in the Brest Region.

DFDW-III facilities are formed as temporary units during mass decontamination of inhabited areas carried out by civil defence forces in the Gomel Region (1986–1989). The total number of DFDW-IIIs is 82. Almost all of them were created under (extreme) emergency conditions and, in general, equipped spontaneously without much design consideration in former pits, ravines, lowlands, and sometimes in specially dug trenches or on flat sites. Only three of them have floor protection in the form of a clay layer or plastic foil, and 11 of them have test bore holes for control of contamination of ground water.

Collection, transportation and disposal of waste originating from decontamination of land after the Chernobyl accident and also construction, maintenance and radiation control of DFDW is executed in the three Belarus regions (mentioned already above) by the waste management organization:

- POLESIE in the Gomel Region;
- RADON in the Mogilev Region;
- BRESOBLSELSTROI in the Brest region.

4.1.2. Safety of existing waste management facilities in Belarus

The text of this section is based on the information from the national reports on the joint convention on the safety of spent fuel management and on the safety of radioactive waste management (*Convention*) Ref. [33, 45].

General safety considerations of radioactive waste management

General Safety requirements: According to Article 12 of the Law [17] the operating organization must:

- Arrange and realize activities for ensuring radiation safety;
- Carry out systematic control of radiation at workplaces, rooms, sites, sanitary protection and surveillance zones, and radioactive discharge;
- Account for and control individual exposure doses of personnel;
- Conduct training and examination of managers and other workers;
- Organize medical examinations;
- Inform personnel about individual dose and dose rates at workplaces;
- Inform State authorities about emergences and breakdowns;
- Carry out of orders and decisions of State authorized authorities;
- Ensure human rights in radiation safety.

OSP-2002 states the necessity while managing radioactive material to ensure:

- The minimized irradiation of personnel;
- Highest automation and mechanization of operations;
- The lowest discharge of radioactive material into the environment;
- Safe operation of processing equipment.

These and other requirements followed from the Contracting Parties commitments according to Section 3 of the *Convention* are defined by the new national *Sanitary Regulations of Radioactive Waste Management* which came into force in 2005.

The obligations according to the *Convention* which are not reflected in prior legislation are assigned in the Law [1] and new version of the Law [17].

Safety of existing facilities

The major task is to ensure radiation safety of the existing facilities and radioactive waste storage facilities, originated from practices in the past.

A reconstruction project aimed at the improvement of safety of the EKORES facility was approved. Construction work has already been carried out. Commissioning is planned for 2013.Completion of reconstruction of the radioactive waste repository of EKORES and its radiation and environmental safety is one of the priority directions of the planned activity in the area of radioactive waste. In the reconstruction project, according to the legislation and regulations the principles of radioactive waste management realized are:

- Preliminary sorting of radioactive waste according to SPORO-2005;
- Separate management of different waste classes;
- Conditioning of radioactive waste, including a passport[3] system;
- Separate storage of different waste classes;
- Architectural-building solution making to simplify decommissioning of installations.

It is planned that the methods indicated will be applied both for newly arriving waste and waste disposed in the closed old repositories. While implementing the third reconstruction phase, waste from old disposal facilities will be, where possible, retrieved, identified, processed and put into conditioned forms suitable for long-term storage and transportation.

Disposal facilities for decontamination waste of Chernobyl origin[4]

In order to prevent unauthorized access and to ensure safety and security of waste, the fence and radiation hazard signs were installed around the perimeter of the disposal facility. Around the disposal facilities, a 500 m-radius sanitary protection zone was established where all activities that are not related to facility operation are restricted.

After DFDW-II and DFDW-III have been filled, the facilities will be covered with clay and loose earth a meter thick. The service organizations carry out annual activities to prevent the consequences of spring flooding. In DFDWs equipped with wells, the ground water level is monitored. Water samples are taken to monitor radionuclide migration to ground water.

Radiation monitoring and surveillance of all operating and closed DFDWs are conducted according to a programme of radiation monitoring and surveillance. This programme defines

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[3] Detailed information on the passport system will be provided in section 4.4.1.1 dealing with Criterion CR3.1.1.

[4] Information in this subsection is not directly related to the planned NES of Belarus but it demonstrates an experience accrued in the country in the area of waste management.

objects, parameters & frequency of control, control points, equipment and responsible persons.

For DFDW-I and DFDW-II, the parameters of radiation control established are:

- Dose rate at control points;
- Specific activity of ^{137}Cs, ^{90}Sr in water samples from control wells at least twice a year;
- Ground water level in control wells.

At operating DFDWs, the control of dose rate is conducted:

- Every day, during activities in places with most probable decontamination waste carryover (roads, places of waste unloading);
- At five permanent control points outside the disposal area and within a fenced area, in accordance with the monitoring scheme, not less than once a month in the period of disposal work.

At DFDW-III, the dose rate is measured at the control points. The number of control points for DFDW-III supervision depending on square is given in table 16.

TABLE 16. NUMBER OF CONTROL POINTS FOR DFDW-III SUPERVISION DEPENDING ON SQUARE

DFDW-III square, hectares	Number of control points
up to 0.01	1
0.01–0.10	4
0.11–0.50	8
0.51–1.00	15
1.01–2.00	25
2.01 and more	30

DFDW supervision includes control of technical state which is conducted at the same time as radiation control, and also after floods, heavy rain, and hurricane winds. The visual inspection of technical equipment is conducted to examine a fence, upper protective layer, radiation hazard signs and roads.

Assessment of safety of existing facilities

In accordance with Article 11 of the *Law on Radiation Safety of the Public*, safety assessment of the existing facilities is currently ongoing, using the parameters:

- Characteristic of radioactive contamination of the environment;
- Analysis of measures on radiation safety and compliance of norms, rules and sanitary guidelines;
- Probability of radiation emergencies and their estimated scale;
- Level of preparedness for efficient elimination of emergencies and their consequences;
- Analysis of radiation dose which certain groups of population were exposed to from all sources of ionizing radiation;
- Number of people exposed to beyond the defined level of dose.

Assessment results are annually registered in the radiation-sanitary certificate of the facility, which is the main document confirming its safety for personnel, population and the environment. On the basis of the radiation-sanitary certificate, regulatory bodies take the decision to issue, prolong, suspend operation or withdraw the license (permission) to carry out relevant operations while managing radioactive waste.

Planned activities to improve safety in existing facilities

As is obvious from the above sections, the implementation by Belarus of its commitments under the *Convention* has been carried out so far in conjunction with the development of a general legal and regulatory base for providing radiation safety. In the legislation important elements stipulated by the *Convention* have been established, such as:

- The licensing system;
- Prohibition to operate a facility without a license;
- A system of institutional and regulatory control;
- Documentation and accountability;
- A system of ensuring the execution of the regulatory provisions;
- Ensuring the preparation of emergency action plans.

Resolution of the Ministry for Emergency Situations [46] elaborates the points relevant to radiation safety and associated with articles 13-17, 23 and 26 of the *Convention*.

These measures are set forth in the Law [1] and also in changes and additions to the Law [17] and in developing the corresponding regulations.

The fulfillment of the obligations of Belarus under the *Convention* has been coordinated with the development of legislation, regulation and infrastructure for radiation safety. The following steps were implemented and are planned to be improved further:

- Licensing system;
- System of prevention of an unauthorized facility operation;
- System of regulatory supervision;
- System of documentation and reporting;
- System of maintenance of performance of existing regulating provisions and license conditions;
- Support of development of emergency plans, etc.

The priority directions of the planned activity in the area of radioactive waste management include:

- Further development of regulations in compliance with the requirements of the national law and international agreements and recommendations;
- Completion of reconstruction of the radioactive waste repository of EKORES and its radiation and environmental safety;
- Ensuring long-term safety of repositories of radioactive sources in the places of former location of the Soviet Union military troops.

At present activities to be realized for the design of a national radioactive waste storage facility include:

- Carrying out investigation for layout and arrangement;
- Feasibility study for construction of new storage;
- Siting new storage.

Part of this work is the redevelopment of the strategy of radioactive waste management taking into account the construction of a national radioactive waste storage facility for operational waste and also waste from industrial, scientific and medical institutions.

In conclusion, it should be noted that the system of ensuring radioactive waste safety and safety management of the spent fuel in Belarus is being improved. Substantial efforts will be required, financial and other support from the Government and regulatory bodies of Belarus to ensure its development in compliance with the *Convention*'s provisions. International cooperation would favor this activity, and shared goals — to maintain a high level of radioactive waste management and spent fuel safety in the whole world — will be best reached efficiently with such cooperation.

In accordance with the principles for safe disposal of radioactive waste, predicted radiation exposure of future generations caused by radioactive waste disposal is not allowed to be higher than the acceptable radiation exposure of the current population established by the effective national law and regulations. Future generations must be protected against the harmful impact by radioactive waste to no lesser extent than the current generation.

The INPRO methodology for waste management as described in Volume 4 of Ref. [47] will be used to assess the planned Belarus NES (see section 1.6).

Evaluations of waste generation and treatment processes are based on information of the AES-2006 reactor design from the Saint-Petersburg Research and Design Institute ATOMENERGOPROEKT (JSC SPAEP). As defined in section 1.6 of this report, two AES-2006 reactors are considered to be installed as the first NPP in Belarus. Spent fuel storage facility and operational waste disposal facilities have been considered within this study since they potentially would be included into the nuclear energy system of Belarus.

4.2. FIRST BASIC PRINCIPLE BP1 — WASTE MINIMIZATION

The first INPRO **basic principle BP1** of Waste Management reads: *Generation of radioactive waste in an innovative NES shall be kept to the minimum practicable*.

INPRO has developed one user requirement UR1.1 that simply repeats the goal of the corresponding BP1 in a more detailed fashion.

4.2.1. User requirement UR1.1 — reduction of waste at source

User requirement UR1.1: *The innovative NES should be designed to minimize the generation of waste at all stages, with emphasis on waste containing long-lived toxic components that would be mobile in a repository environment.*

This user requirement states that the designer of nuclear facilities should minimize the generation of waste with long-lived toxic substances that would be mobile in a final depository, i.e. in the end state of this waste. Mobile toxic components are the main contributors to detrimental health effects on humans (e.g. dose) or the environment.

INPRO has developed two criteria, CR1.1 and CR1.2, to check whether this user requirement has been met.

4.2.1.1. Criterion CR1.1 — waste characteristics

Indicator IN1.1.1: *Technical indicators: alpha-emitters and other long-lived radionuclides per GW·a; total activity per GW·a; mass per GW·a; volume per GW·a; chemically toxic elements that would become part of the radioactive waste per GW·a.*

Acceptance limit AL1.1.1: *Technical indicators should be as low as reasonable practical, social and economic factors taken into account (ALARP).*

In the following, some background information on waste management of the AES-2006 reactor design is provided.

Two main types of waste are distinguished, namely:

- Spent (used) fuel;
- Operational waste.

Background information on spent fuel

According to the traditional approach inherited from the Soviet Union, the Russian Federation and Belarus assign spent fuel to a separate group of waste characterized by a high level of radioactivity, considerable heat generation and the long life-time of a whole range of its radionuclides.

Article 9 of the Intergovernmental agreement between Belarus and the Russian Federation on *Cooperation in Construction of an NPP on the territory of Belarus* signed on 15 March 2011 provides for supplies of fresh nuclear fuel by the Russian contractor throughout the whole NPP life cycle and spent fuel takeback. As the modalities for the return of spent fuel would be defined by a separate commercial contract, it is assumed that the parties would agree on whether high-level waste obtained after reprocessing spent nuclear fuel would be either returned to Belarus for the final disposal, or disposed of in the Russian Federation.

An important characteristic of radioactive waste is its radiotoxicity. Radiotoxicity of i-th nuclide in air or water is defined as the ratio of the specific activity A_i of the i-th nuclide to the allowable level of the specific activity of the i-th nuclide DA_i in air or water, as described in the regulation of Belarus: $RT_i = A_i / DA_i$.

Table 17 shows the dynamics (decrease) of radiotoxicity of fission products and actinides in air and water during extended storage of one ton of spent nuclear fuel of VVER-1000 reactors.

TABLE 17. DYNAMICS OF RADIOTOXICITY OF FISSION PRODUCTS AND ACTINIDES IN 1 TON OF SPENT NUCLEAR FUEL OF A VVER-1000 REACTOR WITH 4.4% ENRICHMENT OF ^{235}U [48]

Storage time, years	**Radiotoxicity**			
	In air, m^3(air)/t(FP or A)		**In water, kg(H_2O)/t(FP or A)**	
	fission products (FP)	**actinides (A)**	**fission products (FP)**	**actinides (A)**
1	$1.17 \cdot 10^{16}$	$1.24 \cdot 10^{17}$	$3.35 \cdot 10^{15}$	$5.3 \cdot 10^{14}$
3	$3.72 \cdot 10^{15}$	$1.17 \cdot 10^{17}$	$1.79 \cdot 10^{15}$	$5.1 \cdot 10^{14}$
10	$1.35 \cdot 10^{15}$	$1.14 \cdot 10^{17}$	$9.85 \cdot 10^{14}$	$5.0 \cdot 10^{14}$
30	$7.61 \cdot 10^{15}$	$1.07 \cdot 10^{17}$	$5.86 \cdot 10^{14}$	$4.7 \cdot 10^{14}$
100	$1.37 \cdot 10^{14}$	$8.73 \cdot 10^{16}$	$1.10 \cdot 10^{14}$	$3.7 \cdot 10^{14}$
300	$1.13 \cdot 10^{12}$	$5.92 \cdot 10^{16}$	$9.64 \cdot 10^{11}$	$2.5 \cdot 10^{14}$
1000	$3.0 \cdot 10^{10}$	$2.66 \cdot 10^{16}$	$4.77 \cdot 10^{9}$	$1.2 \cdot 10^{14}$
3000	$2.98 \cdot 10^{10}$	$1.14 \cdot 10^{16}$	$4.75 \cdot 10^{9}$	$5.0 \cdot 10^{13}$
10000	$2.93 \cdot 10^{10}$	$6.75 \cdot 10^{15}$	$4.69 \cdot 10^{9}$	$3.0 \cdot 10^{13}$
30000	$2.79 \cdot 10^{10}$	$2.53 \cdot 10^{15}$	$4.51 \cdot 10^{9}$	$1.0 \cdot 10^{13}$
100000	$2.36 \cdot 10^{10}$	$3.19 \cdot 10^{14}$	$3.98 \cdot 10^{9}$	$1.4 \cdot 10^{12}$
300000	$1.53 \cdot 10^{10}$	$2.0 \cdot 10^{13}$	$2.96 \cdot 10^{9}$	$8.74 \cdot 10^{10}$

It follows from Table 17 that the radiotoxicity of actinides in air exceeds by a factor of 10 to 80 the radiotoxicity of fission products at the beginning of storage and 1000-10 000 times after 100 years and more. During storage of less than 30 years, the radiotoxicity of fission products in water exceeds that of actinides but during further storage, the contribution of fission products quickly decreases and radiotoxicity of actinides becomes dominant as it decreases much more slowly.

The data demonstrated in Table 17 are related to the VVER-1000 design. However, this information gives a preliminary estimation of radiotoxicity of spent fuel to be produced in the Belarusian NPP with AES-2006 reactor. Later on these data may be adjusted upon a receipt of information relevant to the AES-2006 design.

Additionally, as a part of spent fuel management, radioactive waste management during transportation of spent fuel is necessary to be considered, first of all from the viewpoint of safety and the protection of human health and the environment and also from the viewpoint of necessary radiological control, decontamination of installations and vehicles, occurrence of emergency situations during transportation and the possible contingent generation of radioactive waste.

Transportation of spent fuel can also affect the environment. However, when all existing norms and regulations are observed, the expected impact will be negligible. The environment could be threatened during transportation only in accident or incident situations.

Background information on operational waste

Radioactive waste generated during reactor operation and storage of spent fuel in racks in the fuel pool and (secondary) radioactive waste produced during waste management constitute the second main waste stream called *operational radioactive waste*.

Operational radioactive waste is characterized by a wide variety of radioactive isotopes, such as:

- Global radionuclides consisting of fission products and nuclides generated by activation of some impurities in the coolant: ^{3}H, ^{14}C, ^{85}Kr, and ^{129}I.
- Fission products (including those produced by ternary fission) of nuclear fuel, penetrating into primary coolant through defects in fuel cladding produced during manufacturing or developed during operation.
- Steel corrosion and corrosion of other material of primary circuit (e.g. iron, nickel, manganese, cobalt, zirconium, niobium)
- Iodine and oxygen short-lived isotopes and also a range of long-lived radionuclides, including isotopes of chlorine, carbon and tritium, generated during activation of coolant elements and attached foreign material.

^{79}Se (half-life (HL) is 65 000 years), ^{93}Zr (HL $1.53 \cdot 10^{6}$ years), ^{99}Tc (HL $2.12 \cdot 10^{5}$ years), ^{107}Pd (HL $6.5 \cdot 10^{6}$ years), ^{126}Sn (HL $1.0 \cdot 10^{5}$ years), ^{129}I (HL $1.57 \cdot 10^{7}$ years), ^{135}Cs (HL $2.3 \cdot 10^{6}$ years) and ^{151}Sm (HL 87 years) are examples of ‘splinter’ radionuclides in operational radioactive waste, needing special management and disposal technology [49].

Long-lived fission products such as ^{63}Ni (HL is 91.6 years), ^{59}Ni (HL $7.5 \cdot 10^{4}$ years), ^{94}Nb (HL $2.03 \cdot 10^{4}$ years), ^{14}C (HL 5730 years), but also ^{137}Cs (HL 30 years), ^{90}Sr (HL 29.12 years) are major isotopes to be considered during shallow land burial of operational radioactive waste. ^{93}Zr is an isotope of both ‘splinter’ and corroding-activation origin. ^{60}Co, ^{51}Cr, ^{54}Mn, ^{59}Fe are also important during processing operational radioactive waste.

Most radioactive gaseous fission products are short lived and decay almost completely during their migration process or are caught in special adsorption systems. Exceptions are: ^{133}Xe, decaying only partly, and ^{85}Kr, quite long-lived.

During NPP operation some global radionuclides can accumulate in coolant purification systems and in ventilation ducts and then enter into the biosphere. The documentation of Russian NPP projects with VVERs — studied by the authors of this report — did not include information regarding distribution of global radionuclides between different waste streams.

Due to peculiarities of design and operation of VVER reactors, a large amount of liquid radioactive waste — about 30 000 to 40 000 m^3/GWa — is generated, most of which can cause problems during processing and disposal due to its complicated chemical and isotopic composition [50]. This liquid radioactive waste contains long-lived radionuclides that require separation from the environment for a long time; therefore, one of the most important goals of waste processing and conditioning is their maximum reduction before further disposal.

Liquid radioactive waste generated at an NPP differs significantly in its radiochemical composition and, therefore, its processing technology needs to be different too. Besides radionuclides, this radioactive waste can contain different organic compounds, sodium salts, sulphates, or fluorides.

Depending on salinity, liquid radioactive waste is divided into three groups, namely:

- Demineralized (water of NPP loops, pools, condensate and others);
- Diluted saline (water after cleaning, loop leakage);
- Considerably saliferous (laboratory, regeneration, deactivation water).

Regular operation of special water purification systems can lead to a generation of ion-exchange material that cannot be processed; this material is classified as wet radioactive waste. This group also includes used selective adsorbents of radionuclides.

Solid radioactive waste is usually generated during maintenance and scheduled prevention activities. A detailed assortment of this type of radioactive waste is shown from experience in an existing type of NPP.

Specific activity of long-lived radionuclides in operational waste taken out from a pool after up to 300 years cooling is given in Table 18.

TABLE 18. SPECIFIC ACTIVITY OF LONG-LIVED RADIONUCLIDES IN OPERATIONAL WASTE [51]

Radio-nuclide	**Decay rate, 1/s**	**Activity, Bq/kg**		
		5 year cooling	**100 year cooling**	**300 year cooling**
^{79}Se	$3.38 \cdot 10^{-13}$	0.371	0.370	0.370
^{90}Sr	$7.55 \cdot 10^{-10}$	$2.52\ 10^6$	$2.63\ 10^5$	$2.25 \cdot 10^3$
^{93}Zr	$1.44 \cdot 10^{-14}$	74.3	74.3	74.3
^{99}Tc	$1.03 \cdot 10^{-13}$	57	57	57
^{125}Sb	$7.93 \cdot 10^{-9}$	$1.094 \cdot 10^3$	0	0
^{135}Cs	$9.56 \cdot 10^{-15}$	1.301	1.301	1.301
^{137}Cs	$7.28 \cdot 10^{-10}$	$3.595 \cdot 10^6$	$4.05 \cdot 10^5$	$4.1\ 10^3$
^{144}Ce	$2.82 \cdot 10^{-8}$	$1.413 \cdot 10^5$	0	0
^{147}Pm	$8.97 \cdot 10^{-9}$	$1.50\ 10^5$	0	0
Total		$\mathbf{6.41 \cdot 10^6}$	$\mathbf{6.69 \cdot 10^5}$	$\mathbf{6.48 \cdot 10^3}$

Transfer of actinides to the primary coolant depends much on operational peculiarities of a nuclear reactor and on the physical properties of its nuclear fuel. Available design documents of the AES-2006 do not contain information about actinide content in the coolant and in radioactive waste. Rough estimation of actinide activity is $4.38 \cdot 10^3$ Bq/kg.

Almost all long-lived radionuclides contained in operational radioactive waste are ‘soft’ beta-emitters (^3H, ^{14}C, ^{59}Ni, ^{60}Co, ^{63}Ni, ^{90}Sr, ^{94}Nb, ^{137}Cs, ^{99}Tc, ^{129}I). Uranium isotopes ^{235}U, ^{238}U, and transuranic radionuclides ^{238}Pu, ^{239}Pu, ^{240}Pu, ^{242}Pu and ^{242}Cm are alpha-emitters.

In the following, the *technical indicators of criterion CR1.1.1* — cited at the beginning of this section — are quantified. The two types of radioactive waste considered are:

- Spent fuel;
- Operational waste.

Total activity of radioactive waste

At the moment of assessment the data on isotopic composition of AES-2006 spent fuel were not available to the assessors. Average concentrations of major isotopes in a fuel of selected reactor type (i.e. of a pressurised reactor, assuming that fuel rods diameters and enrichments are similar) depend primarily on a fuel burnup, water-uranium ratio and to some extent on the integrated burnable poison used. The fuel burnup and water-uranium ratio in large VVER reactors including AES-2006 are linked to the economic efficiency of reactor performance and competitiveness. They are expected to be similar to the PWR reactors of the same capacity and age. A burnable poison used in VVER reactors may differ from poisons used in western PWR (e.g. AP-1000) but this effect is limited by the relatively low share of fuel pins containing admixture of this poison (normally this share in VVER amounts up to 2-4%). Assessors deem that for the purpose of this study the activity of AES-2006 spent fuel may be approximately evaluated through the activity of typical PWR spent fuel.

Table 19 lists the main radionuclides and their activity in TBq in a *spent fuel* assembly (FA) from an AP1000 [52] after 90 years cooling time.

TABLE 19. RADIONUCLIDE ACTIVITIES FOR ONE SPENT FUEL ASSEMBLY FROM AP1000, TYPICAL PWR

Nuclide	**AP-1000 SF, TBq per FA**
^{14}C	$0.83 \cdot 10^{-1}$
^{36}Cl	$0.91 \cdot 10^{-3}$
^{59}Ni	$0.39 \cdot 10^{-1}$
^{79}Se	$0.27 \cdot 10^{-2}$
^{90}Sr	$0.29 \cdot 10^{3}$
^{99}Tc	0.48
^{126}Sn	$2.19 \cdot 10^{-2}$
^{129}I	$1.08 \cdot 10^{-3}$
^{135}Cs	$2.02 \cdot 10^{-2}$
^{137}Cs	$0.50 \cdot 10^{3}$
^{233}U	$1.29 \cdot 10^{-5}$
^{234}U	$0.43 \cdot 10^{-1}$
^{235}U	$1.84 \cdot 10^{-4}$
^{236}U	$0.81 \cdot 10^{-2}$
^{238}U	$0.61 \cdot 10^{-2}$
^{237}Np	$1.63 \cdot 10^{-2}$
^{238}Pu	$1.04 \cdot 10^{2}$
^{239}Pu	$0.76 \cdot 10^{1}$
^{240}Pu	$1.60 \cdot 10^{1}$
^{241}Pu	$0.51 \cdot 10^{2}$
^{242}Pu	$1.09 \cdot 10^{-1}$
^{241}Am	$1.23 \cdot 10^{2}$
^{242m}Am	0.47
^{243}Am	1.81

Total activity of spent fuel to be discharged annually from AES-2006 unit operating in equilibrium reloading regime is about 10^{20} Bq, i.e. $0.95 \cdot 10^{20}$ Bq/GW·a.

Total activity of operational radioactive waste is about $2 \cdot 10^{14}$ Bq/GW·a according to [53].

Mass of radioactive waste

After unloading from the reactor, spent fuel is placed into a spent fuel pool for more than three years; thereafter, it can be transported to a long-term storage or reprocessing facility. The design capacity of the spent fuel pool corresponds to the amount of spent fuel produced during ten years of reactor operation.

Designed annual flow of fuel is 23.7 t/GW·a; new fuel has enrichment up to 4.95% of ^{235}U, and spent fuel of about 0.8% [53].

In section 8 (assessment of safety) of this report it is demonstrated that maximum average burnup per fuel assembly in AES-2006 (V-491) was increased from 55MW·d/kgHM (in the VVER-1000 (V-320) design) up to 70 MW·d/kgHM. A higher burnup results in efficiency savings for the operator, i.e. for a similar quantity of electricity produced, the AES-2006 will create a smaller mass of spent fuel.

Preliminary calculations produced a value about 200 t/a for *operational radioactive waste*. However, it is supposed that liquid radioactive waste will be processed, solidified through cementation and conditioned.

Volume of radioactive waste

The volume of the spent fuel generated in one AES-2006 unit during its lifetime may be estimated as follows.

According to the design information, the service lifetime of reactor is 60 years, its load factor is assumed to be 0.9 and its thermal capacity is 3200 MW. Multiplying these values and switching from years to days, one can calculate that the total thermal energy to be produced by the reactor is 63 072 000 MW·d.

Average burnup of spent nuclear fuel will depend on the fuel management strategy selected in Belarus. The designer has provided several options of reactor cycle length and estimated that average burnup of the spent fuel in equilibrium reloading regime will amount to 55.8 MW·d/kgHM. Dividing total thermal energy produced by average burnup of spent fuel, one sees that the reactor will consume 1 130 323 kg of heavy metal, or 2410 fuel assemblies, bearing in mind that one bundle will contain approximately 469 kg of heavy metal. This amount should be added to the 121 fuel assemblies necessary to create the reactor’s first core (or, equivalently, to account the full core of reactor’s last cycle).

The total volume of the spent fuel assemblies to be stored or deposited (including the volume of steel and zirconium alloys, gaps between fuel rods, gaps within and outside the head and tail of the bundle) may be estimated as the volume of 2531 hexagonal prisms of corresponding size (4.5 m high, and with 0.235 m distance between opposite sides on horizontal cross-section). This rough estimation gives us 544.4 m^3 of spent fuel (in the form of fuel assemblies) that will be generated in the course of an AES-2006 reactor’s lifetime, i.e. approximately 0.024 m^3/GW·d.

A similar estimation for operating the VVER-1000 reactor yields 0.032 m^3/GW·d.

The volume of conditioned operational radioactive waste per power generating unit [50] is 100 m^3/a or ≈ 90 m^3/GW·a, taking solidification of liquid radioactive waste into account.

For disposal, solid and solidified radioactive waste is classified according to activity in three groups (Table 20).

Finally, decommissioning of an NPP must also be considered as a source of radioactive waste. The operation of a power-generating unit will be stopped when the designed service life time — equal to 60 years for an AES-2006 — of its principal equipment is reached (if it is not decided to prolong the lifetime). The process of removal from service is usually started approximately five years prior to the expiration of service of the power-generating unit.

TABLE 20 ANNUAL STREAMS OF OPERATIONAL RADIOACTIVE WASTE BASED ON AES-2006 DESIGN DATA

Group No	**Group of radioactive waste (RW)**	**Activity range, Ci/kg**	**Activity range, Bq/kg**	**Total volume of solid and solidified RW, m^3/a**	**Notes**
I	Low level waste	$2 \cdot 10^{-6}$ to $1 \cdot 10^{-4}$	$7.4 \cdot 10^{4}$ to $3.7 \cdot 10^{6}$	81.4	Including ion exchangers and saline fusion
II	Intermediate level waste	$1 \cdot 10^{-4}$ to 0.1	$3.7 \cdot 10^{6}$ to $3.7 \cdot 10^{9}$	18.1	Including case-hardened absorbents and case-hardened saline fusion
III	High level waste	More than 0.1	More than $3.7 \cdot 10^{9}$	0.5	-
Total waste				**100**	

Article [54] presents an estimation of mass and activity of radioactive waste that will be created at the decommissioning of an NPP with a new VVER reactor (either of V-491 or V-392M types) depending on the excerpt length after the final shutdown. Calculation results obtained using the computational code KATRIN. Detailed analysis is published in article [55] and demonstrated in Table 21.

TABLE 21. MASS OF RADIOACTIVE WASTE PRODUCED DURING AES-2006 DECOMMISSIONING

Waste	Period of delay, a					
	3	5	10	50	100	150
High level waste:						
Metal, t	236	236	236	236	106	106
Intermediate level waste:						
Metal, t	27	27	27	27	139	139
Serpentinite concrete, t	63	63	63	63	-	-
Concrete, t	146	115	85	-	-	-
Low level waste:						
Metal, t	-	-	-	-	18	18
Serpentinite concrete, t	-	-	-	-	63	63
Concrete, t	167	163	93	56	-	-
Total, t	639	604	504	382	326	326

This work demonstrated that:

- The majority of radioactive waste produced during NPP decommissioning contains long-lived radionuclides;
- All metallic components of AES-2006 are to be classified as radioactive waste for more than 150 years after the final reactor shutdown;
- Concrete components are to be classified as radioactive waste for more than 60 years after the final reactor shutdown.

It should be mentioned that according to the regulations of Belarus the Tables 20 and 21 should be supplemented by the data on a very low-level radioactive waste. This information is deemed to be obtained on the later stages of the nuclear power project.

An evaluation of volumes of operational radioactive waste created during decommissioning is available, as discussed below.

According to the information presented in Ref. [50], 3000 m^3 of boron-containing water will be subject to processing at a standard installation for evaporation, and the released boric acid (about 60 tons) is returned to further usage after special crystallization; residual radioactive waste is subject to disposal. Liquid radioactive waste is recycled into solid conditioned radioactive waste. The metal surface is Decontaminated using standard equipment for removal of surface layers. The liquid lubricant used for this process and other combustible waste is incinerated.

A large flow of radioactive waste is formed when the equipment of the primary coolant cleaning system, equipment of control systems**,** the incinerator of radioactive waste, and the radioactive waste recycling facility are demounted. The total volume of solid radioactive waste will reach roughly 200 m^3/unit a. The flow of secondary radioactive waste related to the decontamination activities during decommissioning of the NPP will be considerable. It is expected that the annual volume of such radioactive waste will be larger than the volume during normal service of the power-generating unit. Such volume of radioactive waste will reach approximately 150 m^3/a (solid radioactive waste). The duration of decommissioning activities of one power-generating unit is estimated to take four years. Therefore, when the power-generating unit is taken out of service, the total volume of solid radioactive waste will be 1400 m^3; high-level waste will be about 50 m^3. This waste needs to be managed after the NPP is no longer commissioned.

Chemically toxic elements in radioactive waste

Evaluations revealed that data on content of chemically toxic elements in radioactive waste were not available to the authors of this report. However, it is known that the chemical toxicity is the most dangerous factor in facilities for uranium refinery, conversion, enrichment and fuel fabrication and spent fuel reprocessing. Installation of such facilities is not planned in the NES of Belarus. Therefore, it is unlikely that chemical toxicity in radioactive nuclear waste will significantly influence its general properties.

Final assessment of criterion CR1.1.1 — characteristics of radioactive waste

This criterion requires that technical indicators, such as total activity, mass, and volume of waste of an NES should be kept ALARP.

There is no direct evidence available to the assessor — other than the increased burnup of nuclear fuel — that the designer of AES-2006 has applied the ALARP concept to the generation of radioactive waste. Also, it is not clear whether special emphasis has been placed on waste containing long-lived toxic components that would be mobile in a repository environment, as stipulated by the corresponding user requirement UR1.1.

Thus, criterion CR1.1.1 is deemed to be partially met.

4.2.1.2. Criterion CR1.1.2 — minimization study

Indicator IN1.1.2: *A waste minimization study has been performed, leading to a waste minimization strategy and plan for each component (facility) of the NES.*

Acceptance limit AL1.1.2: *The waste minimization study, strategies and plans are available.*

Most of the volume of generated radioactive waste consists of low and intermediate active waste. Therefore, most effort is spent on activities related to waste management of these categories. At present, most of processes and process steps related to low and intermediate waste management are considered to be well practiced and proven by substantial operational experience (Figure 7).

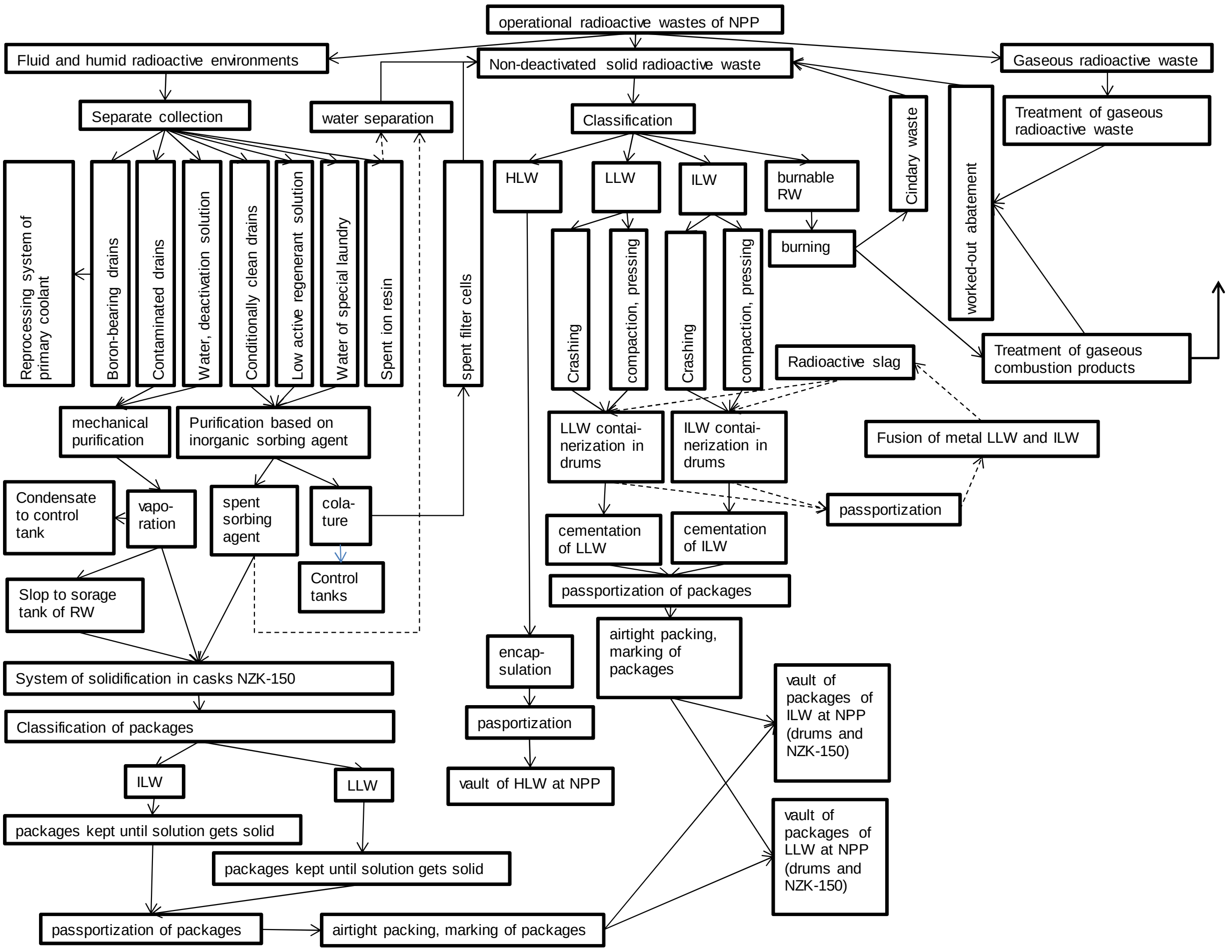

FIG. 7. General scheme of AES-2006 operational radioactive waste handling.

In compliance with INPRO recommendations, the methods for reduction of radioactive waste generation available in AES-2006 design are:

- Segregation of radioactive waste streams to avoid cross contamination and to increase share of radioactive waste for which controlled or free release options apply, and to reduce volume of radioactive waste, which is potentially dangerous in the long term;
- Recycling or reuse of material that would otherwise be radioactive waste;
- Design optimization to facilitate decommissioning and dismantlement of nuclear installations;
- Volume reduction of secondary radioactive waste.

Basic aspects in the radioactive waste minimization process considered in AES-2006 are:

- Separate collection and processing of radioactive waste depending on its chemical composition and activity;
- Localization (concentration) of basic radionuclides in minimum volume;
- Implementation of low-level waste technologies for treatment of liquid radioactive waste:

(a) application of technologies without reagents — avoidance of reclamation (reuse) of purification filters for salt in high activity water of primary coolant processing systems, of primary coolant purification systems, and of systems for water purification in the spent fuel pool and storage tank for borated water;

(b) spill and drains containing boron hydroxide to be included in the collection system of boron-bearing drains;

(c) consideration of purification of potentially non-radioactive or low active water by ion-selective an-organic absorbing agents in the processing system of water;

(d) application of low-waste decontamination methods and of special facilities and transportable modules;

- Assurance of high quality of delivered equipment and its operation to reduce unintended leakage.

Processing systems for liquid radioactive waste will be implemented considering the requirements for:

- Application of well-known technologies;
- Use of equipment the effectiveness of which is proven by operation in domestic and foreign nuclear facilities;
- Consideration of advanced technology application;
- During design of these systems, benefitting from the experience of designing, operation and upgrading of processing systems of liquid radioactive waste at Russian and foreign NPPs, for example:

(a) systems of ion-selective purification;

(b) new processing technologies for water of special laundry and wash houses;

(c) new decontamination technologies for work clothes, premises and equipment;

(d) technologies for deep decontamination of ion-selective resin;

(e) advanced developments related to solidification systems for liquid radioactive waste.

Management of all types of radioactive waste to ensure sufficient safety during its transportation and storage will be organized at all stages of the NPP life cycle. Radioactive waste management at the NPP site includes collection, processing, conditioning and temporary storage.

Research and development activities are carried out at JIPNR-SOSNY on:

- Methods of classification of radioactive waste generated during an NPP operation;
- Methods of radioactive waste processing and conditioning;
- Methods of storage of radioactive waste;
- Near-surface disposal of low and middle active waste radioactive waste.

Among the large quantity of radionuclides (more than 200 radioactive isotopes) generated during operation of an NPP, a list of radionuclides that are most important for radioactive waste classification, management and disposal was defined: ^{14}C, ^{59}Ni, ^{60}Co, ^{63}Ni, ^{90}Sr, ^{94}Nb, ^{99}Tc, ^{137}Cs, and ^{129}I, alpha-emitters and actinide elements ^{241}Pu, and ^{242}Cm [50].

Final assessment of criterion CR1.1.2 — minimization study of radioactive waste

This criterion states that a minimization study should be performed demonstrating that radioactive waste has been minimized by design and operational procedures.

In the strategic project for radioactive waste management in Belarus, requirements for designing the systems for solid and liquid operational radioactive waste and its processing have been developed and documented in the *Technical Code of Practice* for collecting, sorting, processing, storage and conditioning of radioactive waste — safety requirements. Key technological schemes for systems of operational radioactive waste management in the NPP were defined to reduce the volume of secondary radioactive waste in the systems of waste management. Technical decisions made are presented in reports on research and development, reports at conferences and in JIPNR-SOSNY publications (Refs [48–51, 56]).

Thus, at this stage of the nuclear power project in Belarus, there are studies available documenting research, strategies and plans on radioactive waste minimization, i.e. criterion CR1.1.2 has been met.

4.2.1.3. Final assessment of UR1.1 — reduction of waste at source

This user requirement stipulates the minimization of waste at the source with emphasis on long-lived toxic components that would be mobile in a repository environment.

It can be concluded that the designer of AES-2006 and the responsible institutions in Belarus have successfully made significant efforts — documented in studies — to minimize radioactive waste at the source, and to keep the generation of operational waste to the minimum practicable in their planned NES.

It is recommended further studies should concentrate on waste with long-lived toxic components that would be mobile in a repository environment because they are the main contributors to detrimental impact on humans and the environment from a depository.

Thus, user requirement UR1.1 has been partially met.

4.2.2. Final assessment of basic principle BP1 — waste minimization

This basic principle requires that generation of waste shall be kept to the minimum practicable.

Waste minimization in the national NES was intensively considered in the nuclear power project of Belarus. Thus, the goal of the first basic principle BP1 of waste management of the INPRO methodology has been met. Further studies are recommended to focus on waste with long-lived radioactive nuclides that would be mobile in a final repository.

4.3. BASIC PRINCIPLE BP2 — PROTECTION OF HUMAN HEALTH AND ENVIRONMENT

Basic principle BP2: *radioactive waste in an innovative NES shall be managed in such a way as to secure an acceptable level of protection for human health and the environment, regardless of the time and place at which impacts may occur.*

INPRO has developed two user requirements, UR2.1 and UR2.2, for BP2.

4.3.1. User requirement UR2.1 — protection of human health

User requirement UR2.1: *Exposure of humans to radiation and chemicals from innovative NES' waste management systems should be below currently accepted levels and protection of* *human health from exposure to radiation and chemically toxic substances should be optimized.*

INPRO has developed three criteria, CR2.1.1, CR2.1.2, and CR2.1.3 for this user requirement.

4.3.1.1. Criterion CR2.1.1 — public dose

Indicator IN2.1.1: *Estimated dose rate (from a waste management facility) to an individual of the critical group (in the population).*

Acceptance limit AL2.1.1: *Dose rate meets regulatory standards of Belarus*.

At the time this report was written information on the public dose from waste management facilities located outside of Belarus was not available to the assessor. Assessment of waste management facilities located within the NPP is covered in the INPRO methodology area of environment.

National regulatory standards [57, 58] define the acceptable dose limits of human exposure caused by ionizing radiation sources as:

- Effective *dose to the public* of 1 mSv in a year ,or 70 mSv over 70 years; in special circumstances, an effective dose of up to 5 mSv in a single year provided that the average dose over five consecutive years does not exceed 1 mSv per year;
- Effective *dose to workers* (in nuclear facilities) of 20 mSv in a year, or 1 Sv in a period of labour activity over 50 years; in special circumstances, an effective dose of up to 50 mSv in a single year provided that the average dose over five consecutive years does not exceed 20 mSv per year.

To keep the radiation *exposure of workers and public* as low as reasonably achievable (ALARA), economic and social factors being taken into account, national regulations require:

- Development and establishment of appropriate reference levels, taking into account the optimization and upgrading of protection and safety measures (article 17 of document [58], article 37, 215 of document [57]);
- Development of procedures and organizational arrangements for implementing relevant requirements of the regulations at local conditions, providing appropriate protective devices and monitoring equipment;
- Systematic control of radiation levels on workplaces, the territory of facility, in sanitary zone and zone of observation, and also control of discharges of radioactive material into the environment, which must not exceed the established limits;
- Control of and accounting for the radiation exposure of workers and the public on the basis of individual monitoring in accordance with the requirements of the unified State system of accounting for and control of individual exposure doses.

The effective dose to the public produced by radioactive waste at all stages of its management, including waste storage and disposal, must not exceed 10 μSv in a year (article 204 of [57]).

The reactor AES-2006 was designed with a strong concept of environmental protection stressing that during normal NPP operation population and environment must be absolutely protected against NPP radiation effects. Radiation effects can be significant only if normal operating mode is interrupted, i.e. if an accident happens. Design limits on dose to the public used in AES-2006 design, are presented in Table 22.

TABLE 22. AES-2006 DESIGN LIMITS OF RADIATION DOSE ON THE PUBLIC

Types of dose	Design limit, µSv/a
Upper limit of public dose at normal operation of NPP	100
Public dose after a beyond design basis accident (equivalent radiation dose of critical group at border of radiation protective zone):	
- the whole body	5 000
- separate organs for the first year after accident	50 000

Comparing the dose limits in Table 22 with Belarus' regulatory requirements presented above demonstrates that AES-2006 design clearly fulfils the relevant regulatory standards of Belarus.

According to the information presented in section 1.6 (and section 4.1), the NES of Belarus includes a storage facility for spent fuel, facilities for treatment (including storage) and disposal of operational waste and (optional) a final depository of high level waste from reprocessing of spent fuel (and final depositories for operational waste from the NPP).

Public dose from normal operation of (dry) storage of spent fuel and from a final depositary of spent fuel or high level waste (from reprocessing) is not expected to exceed public dose rates from the NPP (AES-2006 reactor) because at storage facilities spent fuel is usually sealed in hermetic containers. Modern types of such containers provide two protective barriers between fuel claddings and environment.

Finding: Concrete data on public dose from planned national waste management facilities during normal operation were not available to the authors of this report. Additionally, information on public dose due to accidents related to spent fuel storage was absent, e.g. consequences of accidents at a spent fuel storage facility and, in particular, release of radioactive material into the environment because of over packing of spent fuel into casks for transportation or storage.

Follow-up action: It is recommended that the missing data on waste management facilities be collected to complete the assessment.

Final assessment of criterion CR2.1.1 — public dose (from waste management facilities)

This criterion requires that dose rates to the public from waste management facilities meet national regulatory standards.

The AES-2006 reactor design clearly meets the relevant national standards (dose limits); the planned national facilities for final disposal or storage of radioactive waste are assumed to produce much less public dose than the nuclear reactor. However, no direct data on dose rates to the public were available to the assessor.

Thus, criterion CR2.1.1 has not been met and it is recommended that missing data be collected and the assessment completed.

4.3.1.2. Criterion CR2.1.2 — occupational dose

Indicator IN2.1.2: *Radiological exposure of workers (in waste management facilities).*

Acceptance limit AL2.1.2: *Exposure (occupational dose) meets regulatory standards of Belarus.*

Information on the radiotoxicity of fission products and actinides in the spent nuclear fuel is demonstrated in section 4.2.1.1.

At the time this report was written, information on the expected occupational dose from waste management facilities outside Belarus was not available to the authors.

As presented above, according to Belarus regulations [57, 58] effective dose for personnel should not exceed 20 mSv/a average for any five year period, but no more than 50 mSv per any year.

Waste management facilities located within the NPP are covered in the INPRO methodology area of safety of nuclear reactors.

Finding: Data on occupational dose in waste management facilities planned in Belarus were not available to the authors.

As an example for a different reactor design taken from [52], the maximum dose at 1 m from a transport container with four spent fuel assemblies from an AP-1000 reactor packed into a disposal canister after 90 years of cooling is 0.118 mSv/hr.

Follow-up action: It is recommended that the missing data be collected and the assessment completed.

Final assessment of criterion CR2.1.2 — occupational dose

Due to lack of data, this criterion could also not be assessed.

4.3.1.3. Criterion CR2.1.3 — occupational chemical toxins

Indicator IN2.1.3: *Estimated concentrations of chemical toxins in working areas (of waste management facilities).*

Acceptance limit AL2.1.3: *concentration of chemical toxins meets regulatory standards of Belarus.*

Finding: There is no specific data available to the authors to assess this criterion.

Follow-up action: It is recommended that the missing data be collected to complete assessment of this criterion.

Final assessment of criterion CR2.1.3 — occupational chemical toxins

Due to lack of data, this criterion could also not be assessed.

4.3.1.4. Final assessment of user requirement UR2.1 — protection of human health

This user requirement states that radiation exposure to humans inside and outside waste management facilities should be optimized.

Sufficient protection of human health at national waste management facilities can be expected to be fulfilled because of the high qualifications of the designer of these facilities. However, collection of additional detailed information on waste management facilities regarding human dose and completion of the assessment is required.

Thus, currently, due to lack of data this user requirement could not be assessed.

4.3.2. User requirement UR2.2 — protection of environment

User requirement UR2.2: *The cumulative releases of radionuclides and chemical toxins from waste management components of the NES should be optimized.*

INPRO has developed two criteria for this user requirement, CR2.2.1 and CR2.2.2.

4.3.2.1. Criterion 2.2.1 — release from waste management facilities

Indicator IN2.2.1: *Estimated releases of radionuclides and chemical toxins from waste management facilities.*

Acceptance limit AL2.2.1: *releases meet regulatory standards of Belarus.*

This criterion requires demonstration that releases from waste management facilities in Belarus meet national standards.

As indicated in sections 1.6 and 4.1, the NES of Belarus contains a storage facility for spent fuel, facilities for treatment and final depository of operational waste, and (optional) a final depository for high level waste (returned from the Russian Federation) from reprocessing spent fuel assemblies.

Quantity, activity and form of radioactive waste generated during the operation of the NPP AES-2006, was presented in section 4.2.1.1 (criterion CR1.1.1 – waste characteristics).

Data on releases of radioactive noble gases and aerosols from the Russian NPP (Novovoronezhskaya, Kolskaya, Rostovskaya) in 2005 are presented in Ref. [53]. These data confirm that all releases were below limits of annual allowable emissions and did not exceed values defined in Russian regulations [59]. Also, on a daily or monthly basis, no releases were observed above the values of the reference levels. Data on liquid releases from Russian NPPs in 2005 into the environment and ingression of radioactive nuclide into subsurface waters in relation to allowable releases are documented in the same source [53]. Practically, all values of radionuclide ingression are below the Russian regulatory limits.

Requirements of Belarus regulation [60] on radioactive releases are consistent with the regulation of the Russian Federation [59].

Estimation of maximum mean yearly concentration of radioactive noble gases near the considered NPP (about 1.5 km) shows that it is more than 100 times lower than regulatory limits.

During processing of solid radioactive waste, release of deleterious substances such as CO_2, NO_x, SO_2, HCl can occur, but the aggregated gross amount of these emissions is shown not exceed the allowable values [59].

The final task of radioactive waste management at the NPP site is to have solid conditioned waste placed in standard certified casks. Such form of waste will securely and safely solate radionuclides during normal and emergency conditions and prevent their release to environment.

In general, experience has shown that release of radionuclides and chemical toxins from a reactor does not exceed volumes defined by the regulatory standards.

Finding: No data were available to the authors about release of radionuclides and chemical toxins from planned national radioactive waste treatment, including storage and disposal facilities. However, it is expected that these facilities will be designed and constructed to meet the national regulatory requirements.

Follow-up action: it is recommended that data be collected on release of radioactive nuclides and chemical toxins from national waste treatment (including storage) and disposal facilities to complete the assessment.

Final assessment of criterion CR2.2.1 — release from waste management facilities

This criterion requires that estimated releases of radioactive nuclides and chemical toxins from waste management facilities meet national regulatory standards.

It is expected that the planned national waste management facilities will meet all national regulatory requirements. However, no relevant data were available to the assessor.

Thus, criterion CR2.2.1 has currently not been met and it is recommended the the missing data be collected and the assessment completed.

4.3.2.2. Criterion CR2.2.2 — release from all other components of NES

Indicator IN2.2.2: *Estimated releases of radionuclides and chemical toxins from all other components of the* ***NES****.*

Acceptance limit AL2.2.2: *releases meet regulatory standards.*

This criterion stats that, in addition to waste management facilities, all other nuclear facilities should demonstrate releases below national regulatory standards.

Releases from waste management facilities in Belarus have been assessed via criterion CR2.2.1. The only nuclear facility planned in Belarus which is not entirely a waste management facility is the NPP (AES-2006) itself. Releases of radionuclides and chemical toxins from the NPP are covered in the INPRO methodology on environment. Thus, all nuclear facilities inside Belarus have been covered.

At the time this report was written, no information on the releases of radionuclides and chemical toxins from nuclear fuel cycle facilities located outside Belarus was available to the authors. However some general observations on global releases can be made.

In the nuclear power project in Belarus different components (facilities) of the complete NES with potential radiological consequences will be under the jurisdiction of different States (Belarus, Russian Federation and Ukraine). In compliance with international good practice, radiological safety of one component (facility) of an NES should be considered in conjunction with all other components. Resultant impact of the total NES should be optimized. In general global radiation dose from radionuclides distributed in the world is also calculated for a complete fuel cycle.

The expected dose rate caused by atmospheric and liquid emissions was estimated according to radionuclide distribution models using averaged meteorological conditions for each stage of the nuclear fuel cycle. During time frames considered in the estimation of global radiation exposure caused by long-lived radionuclides, the world population is supposed to reach a steady-state value and considerable changes in its age structure will not happen. Nutrition and other population characteristics are also supposed to remain approximately constant.

Local and regional collective absorbed dose from global nuclear fuel cycle operations is estimated to be approximately 5.5 manSv/GW·a. In this value 0.5 manSv/GW·a are contributed by mining, fuel reprocessing and fabrication, 4 manSv/GW·a are contributed by reactor operation and 1 manSv/GW·a from fuel reprocessing. ^{14}C makes the main contribution to the dose during reactor operation 2.8 manSv/GW·a [61]. Most of the radiation dose arises during the first year after discharge into the air. Even if pessimistic assumptions about future radioactive releases are applied, predicted individual doses in 2025 will be extremely low (1.4 μSv/a, according to Ref. [62]).

Global collective absorbed dose from radionuclides by nuclear power is approximately estimated as 670 manSv/GW·a. ^{14}C produces the main contribution during tens of thousands of years (110 manSv/GW·a) and ^{129}I during tens of millions years (560manSv/GW·a) [63].

Final assessment of criterion CR2.2.2 — releases from all other components

This criterion requires that (in addition to waste management facilities) radioactive and chemically toxic releases of all other components of the NES in Belarus meet national regulatory standards.

All components of Belarus NES have been covered.

Only general information about releases of radionuclides from fuel cycle facilities located outside Belarus was available to the authors of this report to asses this criterion. It is recommended that the assessment be extended by including nuclear facilities outside Belarus.

Thus, CR2.2.2 has been partially met.

4.3.2.3. Final assessment of user requirement UR2.2 — protection of environment

This user requirement stipulates optimization of cumulative releases of radioactive nuclides and chemical toxins from waste management facilities.

No detailed information on releases of radionuclides and chemical toxins from the planned waste management facilities in Belarus was available to the authors of this report. However, it is expected that the national waste management facilities will meet all national regulatory requirements. Also, an evaluation regarding this issue of nuclear facilities outside Belarus could not be performed due to lack of data.

Thus, protection of the environment in and outside Belarus against a release of radionuclides could not be demonstrated completely, i.e. user requirement UR2.2 has not been completely met.

Work on this issue should continue and the necessary information should be collected.

4.3.3. Final assessment of basic principle BP2 — protection of human health and environment

An acceptable level of protection of human health and environment is expected to be secured for the management of radioactive waste in Belarus. However, for a detailed evaluation of the status of protection of human health and the environment inside and outside Belarus against a release of radionuclides, sufficient data were not available.

It is recommended that the missing information be collected to complete the assessment.

4.4. BASIC PRINCIPLE BP3 — BURDEN ON FUTURE GENERATIONS

Basic principle BP3: *Radioactive waste in an NES shall be managed in such a way that it will not impose undue burdens on future generations.*

INPRO has developed two user requirements for BP3 — UR3.1 and UR3.2.

4.4.1. User requirement UR3.1 — end state

User requirement UR3.1: *An achievable end state should be specified for each class of waste which provides permanent safety without further modification. The planned energy system should be such that the waste is brought to this end state as soon as reasonably practicable. The end state should be such that any release of hazardous material to the environment will be below that which is acceptable today.*

The state of radioactive waste that provides permanent passive safety, i.e. safety without a need for further human activities, is called the end state

There are five criteria, CR3.1.1–CR3.1.5, to check fulfillment of this user requirement UR3.1.

4.4.1.1. Criterion CR3.1.1 — technology for achieving end state

Indicator IN3.1.1: *Availability of technology (to reach end state for each radioactive waste of the NES)*

Acceptance limit AL3.1.1: *All required technology (to achieve the end state of all radioactive waste) is currently available or reasonably expected to be available on a schedule compatible with the schedule for introducing the proposed innovative fuel cycle.*

The technology to achieve an end state consists of:

- Treating/processing waste at the NPP (such as solidifying liquid waste);
- Waste packaging designed for transportation and to retain the radioactive material for a sufficient long time;
- Selecting a final (passively safe) repository in which the waste packages will be placed until the radioactive material has decayed to levels that meet the requirements for free release.

Two types of waste will be considered: spent nuclear fuel and operational radioactive waste produced in the NPP.

Technology for end state of spent fuel

In October 2011, Belarus has entered into a contractual agreement with the Russian Federation on the construction of nuclear power plant on the project AES-2006. The contract was signed on 18 July 2012. Nuclear fuel for the reactors will be potentially supplied from the Russian Federation. In this case, Belarus experts assume that the spent fuel assemblies — after storage in an away-from reactor storage facility in Belarus — would be returned to the Russian Federation for further processing, storage and final disposal in accordance with a tentative prior agreement with the Russian supplier.

As shown in section 1.6 (NES in Belarus), as an option a final depository is to be considered that will have to store and dispose of the waste from reprocessed spent fuel assemblies in the Russian Federation.

Thus, no end state technology is needed in Belarus for spent fuel other than, optionally, a disposal facility for reprocessing waste and, primarily, technologies for achieving the end state of operational waste.

No information was available to the assessor regarding a technology to construct a final depository for reprocessing waste returned from Russia.

Technology for processing NPP operational waste

The technologies to process operational radioactive waste at the planned NPP AES-2006 in Belarus are fully developed. They are described in detail in Ref. [45]. A short outline of the available technologies for treatment of operational radioactive waste is presented below.

Firstly, the *sources of operational waste* in the NPP are described, i.e. generation of gaseous, liquid and solid waste, and, secondly, *processing of this operational waste* is presented to prepare the waste for final disposal.

Sources of NPP operational waste

In the NPP, cleaning equipment for management of *gaseous radioactive operational waste* such as filters, absorbers, and bubblers are used to reduce discharge as much as possible of gaseous radioactive substances to the environment. This cleaning equipment is installed in the exhaust system for special ventilation of rooms where radioactive gases could be discharged into the air, and is also installed in systems designed to remove radioactive gases during normal operation.

There is a special system designed to limit — to an acceptable level — gaseous and aerosol releases into the atmosphere from vessels with radioactive liquid. This system consists of two identical and interchangeable lines, one is active and the second one is in reserve. The blown out releases containing come to a heat exchanger of the operable line, and then to an aerosol filter for drying after cooling. Dry gas is heated and directed to iodine filters where ions of iodine are trapped and vented in a ventilation stack afterwards.

Filter equipment in exhaust ventilation systems is designed to reduce activity in gaseous and aerosol emissions to the environment. The filter equipment in exhaust ventilation systems cleans the air of various groups of radioactive aerosols, and especially iodine, with effectiveness for aerosols — 99.99%, for elementary iodine — 99.9%, and for organic iodine compounds — 99%.

As a result of removal of radioactive gases by cleaning systems in the NPP, solid radioactive waste is formed such as filter elements, sorbent agents, elements of ventilation systems. The annual volume of such radioactive waste produced during normal operating conditions of the NPP is taken into account in the design of the waste management system.

The main sources of *liquid operational radioactive waste* are:

- Designed and non-designed leakage of a coolant from non-tight connectors, seals, and welded joints during washing and draining of equipment and piping; such leakage goes to a special closed system;
- Used liquid chemicals for decontamination and cleaning water;
- Purifying water from steam generators;
- Regeneration and cleaning water produced during the recovery process of exchange capacity of ion-exchange material in installations for processing of liquid radioactive medium;
- Condensate of turbines and heating steam from heaters;
- Water from special washhouses, shower cubicles, and sanitary sluices.

The operation of systems for coolant cleaning results in the formation of ion-exchange material that cannot be regenerated and becomes part of a waste type called wet radioactive waste. This type of waste also includes used selective adsorbents of radionuclides.

Processing of operational waste generated at NPP

Several waste management systems at the plant site are foreseen for further processing and storage of operational waste.

A system is planned for storing *liquid radioactive waste* for at least three months to reduce radioactivity due to decay of short-lived radionuclides. 90% of radioactivity of liquids is caused by removal of resins from filters and 5% by decontamination of equipment of the primary coolant system.

The main processes to be used for liquid waste treatment are:

- Separation of the solid phase;
- Chemical deposition (designed decontamination factor is 10 to 100, but could be >1000);
- Ion exchange, sorption (decontamination factor is 10 000);
- Evaporation (decontamination factor is 10 000–100 000).

The possibility of implementing new, more advanced technologies based on a membrane method of separation such as electrodialysis, reverse osmosis, and ultrafiltration are also considered in the nuclear power project of Belarus.

A system of conditioning and solidification of liquid radioactive waste is foreseen to solidify used ion-exchange resins and distillation residues by mixing them with cement and additive agents in a container to ensure further safe and secure transportation and storage. The system enables also a concentration of distillation residue. The medium-radioactive and low-activity ion-exchange resins are collected in special tanks for storage of liquid waste and processed at the installation for solidification. The planned waste management system enables processing medium-radioactive ion-exchange resins after a sorbent agent has been kept in the tanks for a certain period (no more than two months for decay of ^{131}I). Solidification of ion-exchange resins is performed in the same manner as the solidification of distillation residues. Finally, the compound of solidified waste in cement is packed up in concrete containers type NZK-150. These containers are designed for temporary storage of radioactive waste at the site of the NPP in a separate storage room and later for transportation to a final disposal site.

Conditioning of *low-activity and medium-active solid waste* is stipulated to be carried out by compaction. For this purpose, the technologies are applied are:

- Sorting and grinding of solid radioactive waste;
- Pressing of solid radioactive waste;
- Introducing a *passport system* for the waste to clearly identify physical, chemical and technological properties of the waste during several stages of treatment.

Large-volume solid low-activity waste is stored in a separate room where it is treated with special fixing solutions and packed in polyethylene film. After a 10-year storage period, this waste is planned to be transported for further processing to an installation for melting scrap metal. Such installations are now being developed and will be ready to be implemented in the nearest future. Conditioned solid low-radioactivity and medium-radioactive waste will be packed in NZK-150 containers with a filled in passport system (further discussed in section 4.4.1.1).

Highly radioactive solid waste of the reactor will be placed in capsules, and installed in special shielding containers, which are transported to a solid radioactive waste storage site. At this site, these capsules will be unloaded from the containers into a storage cell to be stored for the whole period of NPP operation.

Technology for storage and final disposal of operational waste

Radionuclides such as Cs, Sr, Zr, Nb, and La are important during processing and conditioning radioactive waste; their content should be considered to ensure biological shielding of operational personnel. During storage, the content of long-lived radionuclides with a half -life exceeding 30 years is more important.

Storage of operational waste at plant

Storage of solid and solidified radioactive waste is considered at the NPP. Waste is kept in a specially equipped concrete surface vault, the walls of which ensure mechanical strength and biological shielding. Solid radioactive waste of class I (low level, see section 4.5.1 dealing with criterion CR4.1.1, classification of waste) and class II (intermediate level) is kept after processing in 200 liter barrels. Crushed waste of class III moves into storage in special drums. Storage of drums with solid radioactive waste is carried out in a cage for six drums with a possibility for further withdrawing and transportation for final disposal.

Storage capacity is considered in the design of the plant, ensuring storage of operational waste for 10 years. Waste of class III (high level) is foreseen to be stored at the site for 50 years.

There are, in principle, several types of final waste storage or disposal facilities — depending on the type of waste to be stored: near surface engineered disposal systems, rock cavern disposal facilities, deep geological disposal facilities, and landfill facilities.

Planned final depositories for operational waste

Special depositories with protective barriers in the form of engineering structures and natural geological environment pursuant to the laws of Belarus will be used as the end state for all these types of operational radioactive waste. The planned depositories for all types of operational waste are presented in the assessment of criterion CR3.1.5 and UR4.2 (section 4.4.1.5 and 4.5.2, respectively) together with the time schedule to realize them.

Final assessment of criterion CR3.1.1 — availability of technology (for end state)

This criterion states that technologies required to reach an end state of all radioactive waste should be available in time.

Two types of radioactive waste from an NPP were considered: spent fuel and operational waste.

Spent fuel assemblies are planned to be stored only in a national away-from reactor storage facility for a defined period of up to 50 years and afterwards returned to the supplier of the fuel outside Belarus. Thus, no technology for an end state of spent fuel assemblies is necessary in Belarus. However, optionally, radioactive waste may be returned to Belarus as a result of reprocessing the spent fuel in the Russian Federation that must be disposed in a final depository; for this option no data on the corresponding technology were available to the assessor.

All types of operational waste and its generation, treatment and storage at the plant site were investigated intensively by the responsible organization in Belarus. Packages for operational waste at the site of the NPP have been identified in the nuclear power project. However, no information was available on how the packages with operational waste would be disposed of in a final depository. (The issue of selecting the appropriate depository of the packaged operational waste is dealt within the assessment of criterion CR3.1.5 (section 4.4.1.5 and 4.5.2, respectively).

Thus, currently, the technology for reaching an end state for radioactive waste generated in the NPP is partly identified in Belarus, i.e. criterion CR3.1.1 is partly met.

4.4.1.2. Criterion C3.1.2 — time for technology development.

Indicator IN3.1.2: *Time required (for development of end state technology)*

Acceptance limit AL3.1.2: *Any time required to bring the technology to the industrial scale must be less than the time specified to achieve the end state.*

This criterion stipulates that the time estimated (by the owner/operator of the NPP) to develop the necessary technology for an end state should be less than the time specified (by the regulatory authority) to reach the end state.

Again two types of radioactive waste are considered: spent fuel and operational waste.

Time for development of technology for end state of spent fuel

For reaching an end state of spent fuel in Belarus, technology for an away-from-reactor storage facility and, optionally, a final depository for reprocessing waste is necessary. No direct information on technology development in Belarus regarding spent fuel was available to the assessor, but experience from other countries is presented as follows.

On the basis of experience — accumulated in Ukraine — on establishing a dry storage facility for VVER-1000 spent fuel, the time needed to construct such a facility may be as long as 10 years, including site selection, bidding process, design of storage and transportation system, licensing, construction, commissioning, and manufacturing of packages. It is assumed that a comparable time is needed in Belarus to develop and install the planned away-from reactor storage facility for spent fuel in Belarus.

On the basis of Finish experience[5], the time needed to establish a geological disposal of spent fuel assemblies may be as long as 20 years, including 12 years for constructing and operating ONKALO, a research facility, and eight years for site characterization, construction and commissioning of the final disposal facility. Moreover, 20–30 years may be spent on public discussions and political decision making.

A disposal facility for spent fuel assemblies is not planned to be located in Belarus but in the country that supplies the fuel, but the geological facility could also be used to dispose reprocessing waste.

Thus, technology is needed for the option to dispose of reprocessing waste in Belarus. No information was available to the assessor on the time needed to develop a technology for a disposal facility for radioactive waste generated during reprocessing spent fuel assemblies, and on the time it would take to reach this end state. These parameters will be determined within the strategy of radioactive waste management.

Time for development of technology for end state of operational waste

The time schedule for implementation of technologies needed for processing operational radioactive waste at the NPP has been coordinated with the time schedule for commissioning of the plant. The necessary waste management facilities and equipment at the plant and also a preliminary schedule of their commissioning have been defined within in the nuclear power programme of Belarus as presented in the previous section 4.4.1.2.

However, no specific information was available to the authors of the report how long it will take in Belarus to install the final depositories for all operational waste and the away-from-reactor storage facility for spent fuel. Also, times to reach end states for all operational waste from the NPP — to be prescribed by the responsible national authority — were not available to the authors. Also, no information was available about whether considered new technologies for processing waste before final disposal (see previous section 4.4.1.1) could be developed in time, i.e. less than the time prescribed to reach the corresponding end state.

Final assessment of criterion CR3.1.2 — time for technology development

This criterion states that the time needed (by the owner/operator of the NPP) to develop the technology for all end states should be less than that prescribed (by the responsible national authority) to reach the end states.

Information needed for the complete assessment of this criterion (e.g. prescribed times to reach end states, times to install final depositories) was not available to the authors of this report.

Thus, criterion CR3.1.2 has not been met completely.

It is recommended that the necessary information be collected to complete the assessment.

5 More information can be found on the website http://www.posiva.fi/en/final_disposal/general_time_schedule_for_final_disposal

4.4.1.3. Criterion CR3.1.3 — resources

Indicator IN3.1.3: *Availability of resources (needed for development of technology for end state).*

Acceptance limit AL3.1.3: *Resources (e.g. funding, space, capacity) available for achieving the end state compatible with the size and growth rate of the energy system.*

This criterion requires demonstration that all resources need to develop all end states are available in the country.

Funds for existing waste management facilities in Belarus are provided in the Government budget.

Two types of waste are considered: spent fuel and operational waste.

Although an end state of spent fuel assemblies is not foreseen inside Belarus, it is briefly discussed below.

Resources for development of technology for spent fuel end state

According to the estimation of POSIVA (organization in Finland responsible for radioactive waste management), the final disposal facility for spent fuel assemblies used in five light water reactors (LWRs) of different capacity (2 VVER-440, 2 BWR 860MW(e) each, 1 EPR with 1600 MW(e)) will cost about three billion euro[6].

The potential space needed [52] for the disposal of AP1000 spent fuel in a geological disposal facility has been assessed. The assumed operating scenario for an AP1000, i.e. 60 years of operation gives rise to an estimated number of 640 disposal canisters (with four fuel assemblies each), requiring an area of approximately 0.11 km^2 in the associated disposal tunnels.

No information was available to the assessor regarding availability of funds needed for an away-from-reactor storage facility for spent fuel assemblies and for the optional facility to dispose of high level waste from reprocessing spent fuel performed in Russia.

Resources for development of technology for operational waste end state

The operating organization, i.e. the utility responsible for the NPP AES-2006, will take measures [45] for staffing facilities for spent fuel and radioactive waste management with qualified personnel for radiation safety. The training of personnel is conducted at the course on radiation monitoring, other training courses, and by means of self-education.

The necessary level of training of specialists engaged in the management of the operational radioactive waste and spent fuel is also provided by involving highly-qualified and experienced professionals of the former Institute of Radio-ecological Problems (now it is a part of JIPNR-SOSNY) and training at IAEA training courses that contribute much to the development of national radiation safety culture and methodology for radioactive waste management.

In accordance with the regulatory requirements, personnel must receive training and instruction and prove their knowledge on nuclear safety before being granted access to work involving handling radioactive waste and spent fuel. Testing personnel for knowledge of safety rules is conducted not less than once per year; managers are examined not less than once in three years.

[6] Details available at website http://www.posiva.fi/en/final_disposal/total_costs_and_funding_for_final_disposal.

Funds for development of technology for treatment of waste at the NPP are assumed to be covered by O&M cost because the technology for processing and packaging all radioactive operational waste at the power plant is included in the design of the AES-2006 plant.

Information on availability of funds for further treatment of waste packages from the NPP to be disposed in final depositories is currently not available to the assessor.

Further, additional resources are needed to build up specialized national organization — the SPO — responsible for storage (outside the plant) and final disposal of radioactive waste. The siting requirements for SPO facilities have already been defined, taking into account geological, economic and other factors. Technology approaches for the management of radioactive waste are developed.

Final assessment of criterion CR3.1.3 — resources

This criterion requires that all necessary resources to develop the technology for the end state of all radioactive waste should be available.

Currently, the approach for storage and final disposal of radioactive waste produced in the planned NES of Belarus is under development and is being improved. Additional resources needed for the development of end states for operational waste, and for away-from-reactor storage of spent fuel assemblies (and optional final disposal of reprocessing waste of spent fuel assemblies) will considerably increase the feasibility of the Belarus nuclear power programme by establishing a complete national technological cycle of radioactive waste management.

Thus, criterion CR3.1.3 has been partially met.

4.4.1.4. Criterion C3.1.4 — safety

Indicator IN3.1.4: *Safety of the end state (long-term expected dose to an individual of the critical group).*

Acceptance limit AL3.1.4: *(a safety case has been made and) meets regulatory standards of Belarus*.

The criterion asks whether a safety case has been developed for all types of end states of the radioactive waste generated in the NES, and whether the safety case has been accepted by the national regulatory authority. A *safety case* is a documentation of safety analyses made to evaluate the safety of the all planned end states generated in the NES.

The law *On Radiation Safety* [18] establishes the main principles of safety for radioactive waste management, namely the:

- Protection of people's life and health, and environment — ensuring necessary and sufficient protection of personnel, public and environment against radiation exposure from radioactive waste;
- Control of radioactive waste generation and accumulation — limitation of radioactive waste generation and accumulation at the minimal practically achievable level.

In the following, a short outline of the results of the Belarus safety case [50] for the end state of radioactive waste is presented.

A model of natural evolution (degradation) of disposed waste during the foreseen period of preservation has been chosen as a model for assessment of the safety of radioactive waste disposal. During this typically very long preservation period the deterioration of engineering barriers against release of radioactive nuclides due to external factors such as temperature, humidity, mechanical load changes can be observed.

The performed calculations demonstrate that the value of the annual effective equivalent dose for any individual in the future population will not exceed the limiting value equal to 1.0 mSv/a (regulatory dose limit from a radioactive source) using the most probable models of natural evolution (degradation) of disposed radioactive waste that predict release of radionuclides from the waste due to natural and gradual processes.

Radiation exposure of the population from all types of radioactive waste management facilities should not exceed 0.1 mSv/a. Radiation exposure of the critical population group due to radioactive waste disposal must not exceed 0.01 mSv/a. Increasing the dose of public exposure during disposal activities of radioactive waste for a limited time span can be carried out in accordance with national regulations (paragraph 36 of the NRB-2000 [57]).

The dose constraint is determined by a factor of 0.1 applied on the dose limits and risk limits for the population established by the legal documents of Belarus.

In the safety considerations for disposal of radioactive waste, some individuals of future generations of the public are regarded as being exposed — at the same time — to two types of risk associated with radiation impact of waste disposal, namely the:

- Risk caused by negative stochastic effects of a constant irradiation of every person with a low dose rate;
- Risk of serious harm to the health of individuals as a result of low-probability accidents.

The minimum level of radiation exposure below which further minimizing is impractical (a non-significant dose) is 10 μSv/a.

The maximum acceptable value of individual doses caused by a waste depository are the doses for the critical group both for the most probable scenario of normal evolution (degradation) of a depository, and for a low-probability scenario with potential accidents in the depository.

The design of AES-2006 states that the exposure of persons engaged in the treatment of waste shall not exceed the regulatory dose limits set for the staff of all facilities at the plant site.

According to the safety considerations, the safety of solid waste management is achieved by consistent implementation of the principle of defense in depth.

The system design of physical barriers for storage of low and intermediate level solid and solidified waste includes hermetic enclosure (building), additional protection (storage compartments), and sealed barrels (sealed NZK-150 containers) containing this waste.

The system design of physical barriers for storage of high-level solid waste of the reactor includes a sealed enclosure (building), additional barriers (cell storage compartment and storage), and capsules containing this solid waste. Sufficient safety of these systems is confirmed by operating experience on existing Russian and foreign NPPs.

Final assessment of criterion CR3.1.4 — safety case

This criterion requires that a safety case for all end states has been made and approved by the regulatory authority.

Requirements to the safety analysis report are set by the regulatory body in the document [46].

Safety for the end state of operational waste from the NPP has been considered [49]. However, it is not clear whether in this document the following issues have been covered in detail:

- End states for all operational waste;

- End state for (optional) final depository of reprocessing waste (to be returned from the Russian Federation after reprocessing activities on spent fuel assemblies);
- Whether it has been approved by the national regulatory body of Belarus.

Thus, criterion CR3.1.4 has been partially satisfied.

4.4.1.5. Criterion CR3.1.5 — time for end state

Indicator IN3.1.5: *Time to reach the end state.*

Acceptance limit AL3.1.5: *As short as reasonably practicable*.

According to the INPRO methodology, a country has to fulfill the minimum requirements to meet this criterion are:

- A responsible organization has been identified to define and establish all end states of radioactive waste being produced;
- A plan for proceeding to reach the end states has been established;
- Publicly available evidence that progress is being made on the implementation of the plan.

Again two types of radioactive waste are considered: spent fuel and operational waste.

Time to reach spent fuel end state

The end state of spent fuel assemblies is not to be reached in Belarus because spent fuel assemblies are currently assumed to be sent back to the supplier and only away-from-reactor storage of spent fuel assemblies is foreseen. Thus, this issue is currently not relevant for the NES of Belarus. However, optionally, it has to be taken into account that reprocessing waste could be returned to Belarus from the Russian Federation where reprocessing of spent fuel assemblies might take place. In this case, conditioning, packaging and certification of waste is expected to be carried out in Russia, and it will be returned to Belarus in a prepared form for disposal. No information was available to the assessor about how long it will take to reach the end state of waste from reprocessing of spent fuel in Russia.

On the basis of information from the AP-1000 reactor, the time needed to store spent fuel assemblies in away-from-reactor storage facility before loading it into a final disposal facility is 75 to 100 years depending on the burnup of the fuel [52].

Time to reach the end state of operational radioactive waste

Operational radioactive waste contains long-lived radionuclides which are potentially harmful for very long time periods. The most dangerous nuclides are: ^{137}Cs and ^{90}Sr and also uranium isotopes and transuranics (Pu, Cm, Am).

One way to deal with waste that contains long-lived nuclides is to apply a ‘delayed decision’ concept. For such waste, long-term controlled storage in special containers of type NZK-150, a non-reusable shielding container, is considered as sufficient safe long term storage. The non-reusable shielding containers are placed in specially designed engineering facilities at the plant site enabling safe removal and processing of the waste in the future when technologies for such processing are expected to be available.

Another way to deal with waste that contains long-lived nuclides is the establishment of a specialized national organization for radioactive waste management called SPO in Belarus. This organization should be able to perform all technological operations related to processing, conditioning, storage and disposal of radioactive waste for a period of 300 and more years. Using this approach, the conditioned operational radioactive waste in containers of type NZK-

150 would be temporarily stored at the NPP for about five years with a possible prolongation of up to ten years. Then this waste would be transported to SPO for further storage and eventually disposal. At the moment of assessment the assessor had no information on the disposal options for this waste.

As outlined above, two possibilities to implement the technologies for operational radioactive waste management have been considered. One possibility is currently adopted in the nuclear power project, i.e. all operational waste will be stored at the plant until the end of the service life time of the plant. However, if all generated waste is to be stored at the plant, the question for further treatment will arise at the end of the service life time of the power station, i.e. after 50–60 years because at that time, all long-lived radionuclides will still remain hazardous to humans and the environment. Therefore, additional processing, change of the packaging container and reburial of radioactive waste will be necessary.

The second approach which introduces SPO is currently in an initial pre-project stage. The engineering solutions considered in SPO for radioactive waste management are also preliminary.

Time to reach a state of radioactive waste suitable for final disposal is determined by the need to store radioactive waste for short-lived radionuclide decay and to use processing technology. This time is consistent with the time of generation of radioactive waste within the life time of NPP with approximately a threefold safety factor. Waste generated in the form of solid and solidified waste conditioned in radioactive waste packages fully meets the current regulatory requirements for systems and technologies for long term storage. However, these packages contain a high degree of radioactivity that would be still a danger to the public and the environment over a much longer time than the operation of the nuclear power station.

Therefore, the best technological solution will be to include the proposed institution, SPO, in the strategy for waste management. Radioactive waste systems at NPPs will take care of collection, initial processing, conditioning and certification of all radioactive waste (passport system), and store it at the plant for about five years (max. ten years) with subsequent transfer to SPO for further treatment and final disposal.

Final assessment of criterion CR3.1.5 — time for end state

This criterion states that all end states should be reached as quickly as reasonable practicable.

Regarding spent fuel assemblies, the end state is assumed to be reached in the country that supplied the fresh fuel to Belarus, i.e. spent fuel assemblies — after interim storage in Belarus — are expected to be sent back to Russia.

No information was available to the assessor regarding the time needed to reach an end state of the, optionally, returned reprocessing waste from the Russian Federation (generated during reprocessing of spent fuel assemblies).

There are two approaches considered in Belarus regarding the treatment of operational waste. The first one is to store all waste generated at the plant site until the end of the service life time of the power plant.

The second approach is to establish a new organization/institution called SPO in Belarus that will be responsible to define and establish the end state of all operational waste. Before it would be placed into an end state the waste (in conditioned form) should be stored in SPO storage facilities. At present, work is underway to determine the engineering solutions for radioactive waste management within SPO. Terms of achievement of the end state are expected to be defined in the waste management strategy.

Both approaches for operational waste clearly do not fulfill criterion CR3.1.5, i.e. to demonstrate a reasonably short time to reach the end state of operational waste. Additionally, information on the time to reach the end state for reprocessing waste was not available to the assessor.

Thus, criterion CR3.1.5 has not been satisfied.

It is recommended that the concept of end state for operational waste should be further developed and the missing information on final disposal of reprocessing waste should be collected.

4.4.1.6. Final assessment of user requirement UR3.1 — end state

This user requirement stipulates that an reachable end state for all waste that provides permanent passive safety should be specified, should be licensed, and should be reached as soon as reasonable practicable

An end state for spent fuel assemblies does not need to be reached in Belarus but in the country that will supply the fresh fuel. Thus, an end state of spent fuel assemblies is not considered in Belarus, but there is an option that high radioactive reprocessing waste might be returned from the Russian Federation to Belarus. For this option no information was available to the assessor.

There are two options considered currently for the end state of operational waste. The first option is keeping the conditioned operational waste at the plant site until the service life time of the plant ends, and waiting until this time to select a solution how to manage the waste further.

The second option would be a radioactive waste management scheme which, in addition to the designed technologies and facilities at the plant as currently adopted in the nuclear power project, is supplemented by the establishment of a specialized organization (SPO) for processing, storage and then final disposal of operational radioactive waste. This scheme requires additional resources.

The considered two options of an end state of operational waste generated at the plant do not meet the requirement for definition and timely implementation.

Thus, user requirement UR3.1 has not been fulfilled.

It is recommended that the concept of end states for all operational waste and the option of a disposal facility for reprocessing waste (returned from the Russian Federation after reprocessing spent fuel assemblies) be further developed.

4.4.2. User requirement UR3.2 — attribution of waste management costs

User requirement UR3.2: *The cost of managing all radioactive waste in the life cycle should be included in the estimated cost of energy from the NES, in such a way as to cover the accumulated liability at any stage of the life cycle.*

INPRO has developed one criterion, CR3.2.1, for this user requirement.

4.4.2.1. Criterion C3.2.1 — cost of waste management

Indicator IN3.2.1: *specific line item in the cost estimate (of electricity production).*

Acceptance limit AL3.2.1: *cost of managing all waste is included (in the economic assessment of nuclear energy cost).*

This criterion states that in the assessment of economics and especially determining the costs of electricity production by nuclear power the costs of waste management should be included.

As shown in section 2 (economics) a line item for waste management costs was included in the economic assessment of nuclear power in Belarus.

The most difficult to handle and environmentally most hazardous waste is spent nuclear fuel. As already discussed, the costs associated with final treatment — i.e. reaching an end state of this category of waste— is delegated to the supplier of new fuel, the Russian Federation. No specific data on the costs for Belarus due to take back of spent fuel assemblies by the Russian Federation was available to the authors of this report and it is not evident whether these costs are included in the economic assessment in section 2. Also, no specific information on costs was available for an optional final depository for disposal of waste from reprocessing (returned from the Russian Federation to Belarus after reprocessing spent fuel assemblies)

Regarding costs for treatment of operational waste and waste arising during decommissioning of nuclear facilities, there was also no data available for assessment. However, there is a line item for waste management in the cost estimate (see section 2, economics) of nuclear electricity.

Thus, criterion CR3.2.1 could currently not be assessed due to lack of data.

4.4.2.2. Final assessment of user requirement UR3.2 — attribution of waste management costs

A line item for waste management costs is included in the economic assessment of the Belarus nuclear power project. However, at present, there is insufficient data to fully assess user requirement UR3.2.

Thus, this user requirement UR3.2 has currently been partially met.

It is recommended that the missing data be collected and the assessment finalized.

4.4.3. Final assessment of basic principle BP3 — burden on future generations

Basic principle BP3 requires avoidance of undue burden on future generations by defining clear end states for all radioactive waste generated in the planned NES.

Development of definition and implementation of end states is ongoing in Belarus but some of the decisions have not been made yet. Therefore, also some necessary information is not available yet.

Thus, the goal of BP3 has not been completely satisfied.

It is recommended that, at least, a clear end state for all operational waste be defined.

4.5. BASIC PRINCIPLE BP4 — WASTE OPTIMIZATION

Basic principle BP4: *Interactions and relationships among all waste generation and management steps shall be accounted for in the design of the NES, such that overall operational and long-term safety is optimized.*

INPRO has developed two user requirements, UR4.1 and UR4.2, for this basic principle.

4.5.1. User requirementUR4.1 — waste classification

User requirement UR4.1: *The radioactive waste arising from the NES should be classified to facilitate waste management in all parts of the system.*

INPRO has developed one criterion CR4.1 for this user requirement.

4.5.1.1. Criterion CR4.1.1 — classification

Indicator IN4.1.1: *Classification scheme (of radioactive waste).*

Acceptance limit AL4.1.1: *The scheme permits unambiguous, practical segregation and measurement of waste arising.*

The criterion requires that an adequate classification scheme for radioactive waste be established.

According to the law on radiation safety [17] radioactive waste in Belarus is defined as:

- Ionizing radiation sources being used during economic or other activities which the users do not intend or are able to use as before;
- Sources generated during the activities to eliminate the consequences of a radiation accident in which the content of radionuclides exceeds the limit stated in the national radiation safety standards.

Criteria which are used in Belarus to categorize radioactive waste are comprised in ref. [33, 45].

A radioactive waste from sources other than NPP is to be categorized according to sanitary regulation SPORO-2005 [64].

Depending on physical state, radioactive waste is divided into solid, liquid and gaseous. Liquid radioactive waste includes organic and inorganic liquids, pulps and tailings which are not supposed to be used anymore and have the specific activity of nuclides higher than the levels, given in Annex 3 of the SPORO-2005 [64]. Solid radioactive waste includes spent radionuclide sources, materials, manufactures, equipment, biological materials, soil and solidified liquid radioactive waste which have the specific activity of radionuclide exceeding the levels given in Annex 3 of the SPORO-2005 [64]. Gaseous radioactive waste includes radioactive gases and aerosols generated during the industrial processes, which have volume activities exceeding the limits defined in Ref. [65]. Few more new documents related to a gaseous radioactive waste are currently under development.

If the nuclide content of the waste is known, waste is considered as radioactive if the sum of the ratios of the specific activity of every radionuclide to corresponding minimal significant activity exceeds 1. In case of unknown radionuclide content, solid waste is considered radioactive if its specific activity is higher than:

- 100 kBq/kg - for beta emitters;
- 10 kBq/kg - for alpha emitters;
- 1 kBq/kg - for transuranium radionuclide.

Gamma-emitting waste of unknown content is considered radioactive if the measured dose rate at its surface (0.1 m) exceeds the natural background radiation by 0.001mSv/h (meeting conditions of approved measurement methods).

Solid and liquid waste are classified into three categories based on their specific activity (see table 23).

TABLE 23. CLASSIFICATION OF SOLID AND LIQUID RADIOACTIVE WASTE BY SPECIFIC ACTIVITY

Waste category	Specific activity, kBq/kg		
	Beta emitting radionuclides	Alpha emitting radionuclides (except the transuranium ones)	Transuranium radionuclides
Low level waste (LLW)	less than 10^3	less than 10^2	less than 10^1
Intermediate level waste (ILW)	from 10^3 to 10^7	from 10^2 to 10^6	from 10^1 to 10^5
High level waste (HLW)	more than 10^7	more than 10^6	more than 10^5

For preliminary sorting of solid radioactive waste, classification is according to the level of radioactive (surface) contamination (see table 24) and a gamma dose rate at a distance 0.1 m from the surface:

- Low activity (LLW) – from 0.001 mSv/h to 0.3 mSv/h;
- Medium activity (ILW) – from 0.3 mSv/h to 10 mSv/h;
- High activity (HLW)– more than 10 mSv/h.

TABLE 24. CLASSIFICATION OF SOLID RADIOACTIVE WASTE BY THE LEVEL OF RADIOACTIVE (SURFACE) CONTAMINATION

Waste category	Specific activity, particles/cm^2.min		
	Beta-emitting radionuclides	Alpha emitting radionuclides (except the transuranium ones)	Transuranium radionuclides
Low activity	from $5\cdot10^2$ to 10^4	from $5\cdot10^1$ to 10^3	from 5 to 10^2
Medium activity	from 10^4 to 10^7	from 10^3 to 10^6	from 10^2 to 10^5
High activity	more than 10^7	more than 10^6	more than 10^5

Besides the aggregative state (solid, liquid, gaseous) and the specific activity of the waste, in processing of radioactive waste the other physical and chemical characteristics must also be considered, such as organic/inorganic and fire/explosion risk/proofing.

A special category of radioactive waste includes the *waste of Chernobyl origin*. According to the rules [66], the waste of Chernobyl origin is defined as substances formed as a result of work to eliminate the consequences of the Chernobyl accident with the intention to bring the state of environment in industrial and civil facilities in the contaminated areas to an acceptable radio-ecological level. According to [66], such decontamination waste is classified as liquid or solid.

Solid material which has a specific activity of ^{137}Cs more than 10^3 Bq/kg or a level of surface contamination exceeding 20 beta-particles/cm$^2\cdot$min is categorized as solid radioactive waste.

Liquid waste produced by decontamination activities can be organic or inorganic liquids, pulps and tailings and is categorized as radioactive waste if it has a ^{137}Cs content more than 10 times higher than the intervention level for water used by people (according to Belarus regulation, Appendix 3 of [58]).

The requirements for liquid decontamination waste management are regulated by OSP-2002 [58] and SPORO-2005 [64].

Decontamination waste with a contamination level less than that mentioned above can be disposed of together with the waste from dismantling buildings or in solid domestic waste polygons to be covered with 0.2 m of loose soil.

Classification of radioactive waste from NPP

According to regulation [60] liquid and solid radioactive waste created in an NPP are to be classified by specific activity into categories displayed in Table 25. In a case when specific activities of different groups of radionuclides fall into the different waste categories the highest waste category has to be applied.

The waste should be released from the radiation monitoring, if its total specific activity is lower than 0.3 kBq/kg. This waste may be treated in accordance to the regulation for waste of common origin.

TABLE 25. CLASSIFICATION OF NPP SOLID RADIOACTIVE WASTE BY SPECIFIC ACTIVITY

Waste category	Specific activity, kBq/kg		
	Beta-emitting radionuclides	Alpha emitting radionuclides (except the transuranium ones)	Transuranium radionuclides
Very low activity*	from 0.3 to 10^2	from 0.3 to 10^1	from 0.3 to 1
Low activity	from 10^2 to 10^3	from 10^1 to 10^2	from 1 to 10^1
Medium activity	from 10^3 to 10^7	from 10^2 to 10^6	from 10^1 to 10^5
High activity	more than 10^7	more than 10^6	more than 10^5

Remark: * - when the nuclide content of the waste is known, the waste is considered to be very low radioactive if the sum of the specific activities is equal to or higher than 0.3 kBq/kg, and the upper limit of activity which is determined as the sum of the ratios of the specific activity of the radionuclide to its minimal significant specific activity does not exceed 1.

For a preliminary sorting of a solid radioactive waste at a place of its origin, and before it is transported into a storage facility, it is recommended to use the criteria for radioactive contamination levels, given in table 26. The criteria for gamma dose rate at a distance of 0.1 m from the surface are established as following:

- Very low activity – from 0.0001 mSv/h to 0.001 mSv/h;
- Low activity – from 0.001 mSv/h to 0.3 mSv/h;
- Medium activity – from 0.3 mSv/h to 10 mSv/h;
- High activity – over 10 mSv/h.

TABLE 26. CLASSIFICATION OF NPP SOLID RADIOACTIVE WASTE BY THE LEVEL OF RADIOACTIVE CONTAMINATION

Waste category	Specific activity, particles/cm^2·min		
	Beta-emitting radionuclides	Alpha emitting radionuclides (except the transuranium ones)	Transuranium radionuclides
Very low activity	from $2·10^2$ to $5·10^2$	from 20 to $5·10^1$	from 2 to 5
Low activity	from $5·10^2$ to 10^4	from $5·10^1$ to 10^3	from 5 to 10^2
Medium activity	from 10^4 to 10^7	from 10^3 to 10^6	from 10^2 to 10^5
High activity	more than 10^7	more than 10^6	more than 10^5

Further classification

The further classification scheme for radioactive waste depends on the way of disposal, which is specified taking into account its form, volume, total activity, and radioisotopic composition.

According to the classification defined in Refs [50] and [56]:

- Solid and solidified LLW can be disposed in near-surface repositories of radioactive waste;
- Liquid LLW should be transformed into solid form before disposal (e.g. cement, bituminous, vitreous).

The system of engineered safety barriers of shallow ground repositories of radioactive waste should correspond to classes within LLW and the form of the disposed waste. The allowable concentration of alpha-emitting radionuclides in waste placed in shallow ground repositories for radioactive waste, has been defined. The necessary research activities to classify the waste have been performed; the classification scheme enables optimum processing and disposal of LLW. The technological scheme for a management system for operational waste at the NPP and at SPO has been developed.

Design principles for waste classification system

The principles for designing the classification scheme of radioactive waste (set out in the draft strategy of waste management) are based on the concurrence of waste packaging features with the method of its disposal; they are formulated as follows:

(1) Threshold values of specific activity, classifying the necessary conditioning of radioactive waste of different classes, are to be set for each radionuclide from a list of selected isotopes with regard to the period of its potential hazard in a certain package of conditioned radioactive waste, to its migration characteristics and to its toxicity.

(2) A maximum of specific activity, corresponding to a permissible content of a radionuclide in a mono-nuclide radioactive waste package, is to be set for each radionuclide from a list of selected isotopes to be disposed of in a near-surface burial repository. Isolation of radioactive waste with a radionuclide content above the set maximum is to be isolated in a deep-laid depositary. The maximum allowed specific activity for short-lived radionuclides is 10^{10} Bq/kg, and the maximum value for long-lived radionuclides is set taking their migration characteristics into account. For waste containing a radionuclide mixture, total specific activity in the package is defined as a sum of individual shares.

(3) A value for the specific activity of each radionuclide from a list of selected isotopes in a mono-nuclide radioactive waste package is to be set, which will limit the activity of LLW and ILW to a level of 10^6 Bq/kg for radioactive waste with short-lived radionuclides (^{60}Co, ^{90}Sr, ^{137}Cs, ^{241}Pu). A value of specific activity and total activity should be established for radioactive waste with long-lived radionuclides (^{93}Mo, ^{94}Nb, ^{129}I) corresponding to the 100-year period of potential hazard of these nuclides.

According to Ref. [57], a value of *minimal significant volume (specific) activity* (MSVA) is acceptable as the minimum level for mono-nuclide LLW, containing a known radionuclide.

(4) Mono-nuclide LLW is not classified as radioactive waste, if it contains a radionuclide with MSVA within a range of activity of 10^6 to 10^9 Bq/kg from ^{3}H, ^{14}C, ^{59}Ni, ^{63}Ni, ^{99}Tc and 10^4 to 10^8 Bq/kg from ^{241}Pu, ^{242}Cm. Solid waste contaminated with these radionuclides within an activity range of 10^5 Bq/kg to MSVA, and with radionuclides ^{241}Pu, ^{242}Cm within a range of 10^3 to 10^5 Bq/kg, is classified as 'unusable' waste, entitled to disposal as industrial waste.

(5) Solid waste contaminated with radionuclides ^{3}H, ^{14}C, ^{59}Ni, ^{63}Ni, and ^{99}Tc to a level of 300 to 10^5 Bq/kg, or with ^{60}Co, ^{90}Sr, ^{94}Nb, ^{137}Sn, ^{129}I, ^{235}U, and ^{238}U to a level of 300 Bq/kg to MSVA, or with ^{241}Pu and ^{242}Cm to a level of 300 to 10^3 Bq/kg, is to be classified as solid waste of restricted use and, in a case of non-serviceability, is to be disposed of as industrial waste.

Some solid waste with an expired period of potential hazard may be qualified as raw material which is no longer used. It may be possible to deal with such waste in the same way as with industrial waste, i.e. to dispose of it in a near-surface special disposal area of a basic type.

(6) Values of specific activity of radionuclides entered in a list of selected isotopes are to be tabulated to characterize each category of conditioned mono-nuclide radioactive waste and solid waste containing these radionuclides.

(7) Acceptable values of radionuclides in the package of mono-nuclide conditioned radioactive waste for each nuclear waste repository are to be set in its design. For

waste containing a radionuclide mixture, their total volume activity in the package is defined as sum of shares.

(8) Exceeding a value of 1.0 of the sum of shares is a necessary condition to classify waste containing a mixture of radionuclides in any category of radioactive waste. In this case, each share is defined as the ratio of specific activity of a radionuclide in the package to the lower threshold value of its specific activity.

(9) The maximum specific activity of radionuclides in high-level radioactive waste that will be insulated in the deep geological depositary is to be established.

(10) Packages of conditioned radioactive waste to be disposed of — containing radionuclides with a very long period of potential hazard — that have a shorter service life time than needed for these packages by 1–50 years may be taken to SPO for storage for a reasonable time with subsequent transfer to a depositary. The conditioning method of such radioactive waste should allow, if necessary, their removal before burial and placement into a new container with a lifetime corresponding to the lifetime of the new repository.

(11) The threshold values of the specific activity of radionuclides not included in the adopted selection are to be set in a similar manner.

Discussion of the basic documents for waste management SR NPP–2010 [60] and SPORO-2005[64]

The document SPORO-2005 — developed in Belarus — used as the basis for defining the above principles for waste classification is not focused on specific waste management issues arising during NPP operation. It contains no requirements for the management of HLW and spent fuel, nor for possible partial processing of LLW and ILW at an NPP. A minimum activity limit for the LLW class is not specified in [64]. Regulation [60] has defined the minimum activity limit for the LLW class and has defined a class of very low level waste.

The classification scheme demonstrated in SPORO-2005 and SR NPP–2010 should be further elaborated and improved. This activity is currently in progress. It should be noted there is a need to introduce universal classification of waste.

The IAEA has developed safety standards [67] for classification systems of radioactive waste. Belarus experts are advised to consult this publication for the further development of the national waste classification system.

4.5.1.2. Final assessment of user requirement UR4.1 — waste classification

This user requirement states that a classification system for all waste should be developed and implemented.

Principles for developing a classification scheme for all radioactive waste ensuring concurrence of waste packaging and method of final disposal have been developed in the Belarus nuclear power project to enable optimum management of all radioactive waste generated in the NES.

However, the actual classification scheme to be used in reaching the end state for operational waste of the NPP is still under development, thus this user requirement UR4.1 has currently been partially met.

It is recommended that the waste classification system be further developed.

4.5.2. User requirement UR4.2 — predisposal waste management

User requirement UR4.2: *Intermediate steps between generation of the waste and the end state should be taken as early as reasonably practicable. The design of the steps should ensure that all-important technical issues (e.g. heat removal, criticality control, confinement of radioactive material) are addressed. The processes should not inhibit or complicate the achievement of the end state.*

INPRO has developed three criteria, CR4.2.1, CR4.2.2, and CR4.2.3, for this user requirement.

4.5.2.1. Criterion CR4.2.1 — time for waste form production

Indicator IN4.2.1: *Time to produce the waste form specified for the end state.*

Acceptance limit AL4.2.1: *As short as reasonably practicable.*

This criterion requires demonstration that the time to develop the form of the waste (packaging) suitable for final disposal (end state) be reasonably short.

The form (packaging) of each type of waste suitable to be disposed of in a final depository, i.e. specified for the end state, has been presented in the previous section. In the following, the time necessary to produce this suitable form is briefly discussed.

Solid HLW will be directly packaged and loaded into storage cells for long-term storage at the plant. The share of solid high-level operational radioactive waste of the total amount of radioactive waste generated in an NPP with a need for processing is relatively low: 0.5 m^3/unit a. The time required for treatment of this waste is minimal; it is determined by transport and loading operations.

Solid LLW and ILW) may be, if necessary, subject to volume reduction and forming of a compound before being placed (packaged) in containers of type NZK-150. Time management of this waste is determined by the filling of these containers and solidifying of the compound. The procedure takes several days before sending the waste for long-term storage.

The system for processing liquid radioactive waste involves holding (temporary storage) for at least three months to reduce their radioactivity by decay of short-lived radionuclides. This is followed by solidification, e.g. by mixing the waste in a container with cement and additives, and packaging it in protective concrete containers to ensure continued safe transport and storage.

Final assessment of criterion CR4.2.1 — time for waste form production

This criterion requires minimization of the time to produce the waste form specified for the end state.

The time, required to transform all types of operational radioactive waste generated at the NPP into a form suitable for long-term storage at the NPP or in a separate facility will be minimized by the technology used. However, it is currently not clear whether the waste form (packaging) produced at the plant can also be used in the final depository.

Thus, criterion CR4.2.1 has been partially satisfied.

4.5.2.2. Criterion CR4.2.2 — technical measures

Indicator IN4.2.2: *Technical indicators, e.g. criticality compliance, heat removal provisions, radioactive emission control measures, radiation protection measures (e.g. shielding), volume/ activity reduction measures, waste forms.*

Acceptance limit AL4.2.2: *Limits (of technical indicators are met) as prescribed by regulatory bodies of Member States.*

This criterion requires a check as to whether technical indicators, such as criticality or heat removal, have been considered in the design of the packages and the final depositories for all waste, and documented in a safety case that meets the national regulatory requirements.

The status of the safety case for the end states of radioactive waste generated in the NPP was discussed in section 4.4.1.4 (criterion CR3.1.4). No information about whether these technical indicators were covered in the safety case was available to the authors of the report to assess this criterion.

Thus, this criterion CR4.2.2 has not been met.

It is recommended that the missing information be collected and the assessment completed in a timely manner.

4.5.2.3. Criterion CR4.2.3 — process descriptions

Indicator IN4.2.3: *Process descriptions that encompass the entire waste life cycle.*

Acceptance limit AL4.2.3: *A complete chain of processes from generation to final end state (is available) and sufficiently detailed to make evident the feasibility of all steps.*

This criterion requires demonstration that complete process descriptions exist or are under development for all steps of waste management leading to the end states.

Process description for spent fuel management

At the end of every reactor cycle, some spent fuel assemblies (a certain share of the reactor core) are to be discharged from the reactor core and loaded into the near-reactor spent fuel pool by use of the fuel handling machine (a special reloading crane). An objective of the spent fuel pool and its cooling/cleaning systems is to safely remove residual decay heat from spent fuel bundles and to protect workers, equipment and all other possible ambient entities from the harmful irradiation of discharged fuel assemblies.

The spent fuel pool is a short-term wet type storage facility with a capacity of approximately 700 cells (in a VVER-1000/V-320 unit) in high-density racks for spent fuel assemblies. Spent fuel pool cells are made of borated steel and the pool itself is filled with borated water to ensure the necessary subcriticality for the theoretically possible worst case of the pool filled with maximum amount of bundles with maximum available initial enrichment. All transport operations are performed by the fuel handling machine with the spent fuel bundle in a vertical position under a protective level of water (three metres from the top of bundle). In VVER-1000 (V-320), every used fuel assembly should be stored in the spent fuel pool for at least three years.

During the refuelling of the reactor, 36–66 fuel assemblies may be reloaded depending on the fuel management strategy chosen for a specific NPP. One full reactor core (VVER-1000) comprises 163 fuel assemblies (FA) and the annual average offload is approximately 36 to 42 FA/a, which means that the spent fuel pool has a capacity for at least twelve years of reactor operation without a need for spent fuel shipment.

A core of the AES-2006 reactor also consists of 163 FA. Spent fuel management procedures in AES-2006 will incorporate experience obtained in VVER-1000.

Belarus experts currently assume that spent fuel from the near-reactor pool will be — after spending some time (up to 50 years) in a long term storage facility — duly transferred to the Russian Federation for final disposal (or reprocessing). Thus, only the installation of an interim storage facility is part of the process to reach the end state of spent fuel assemblies coming from the AES-2006 reactor in Belarus. No information on this process was available to the assessor.

Belarus experts also assume that in the case of reprocessing of spent fuel the HLW produced will either disposed on the territory of country performing the reprocessing, i.e. the Russian Federation or optionally this waste will be returned to Belarus. No information on this process was available to the assessor.

An example of a long-term spent fuel (dry) storage system — developed by the company HOLTEC — is described in Ref. [68]. This system is proposed as an option for AP-1000 spent fuel management. HOLTEC has also designed a long-term dry storage facility for VVER-1000 spent fuel, which is currently under construction in Ukraine.

An example of a final disposal facility for spent fuel currently being built in Finland is described in Ref. [69].

Process description for operational radioactive waste management

There are two options currently considered in the nuclear power project of |Belarus for treating operational waste (as discussed in section 4.4.5 dealing with assessment of criterion CR3.1.5). One option is to keep all operational waste at the site of the NPP until the end of service life time (60 years) and decide then what to do with it. The second option of operational radioactive waste management is to condition the waste at the plant site and transport it to a new organization (SPO) for storage and eventually disposal. At the moment of assessment the assessor had no information on the disposal options for this waste.

Final assessment of criterion CR4.2.3 — process descriptions

This criterion stipulates that the existence of processes must be demonstrated for all stages of radioactive waste management until all end states in the country are established. Currently, these data are not available.

Thus, criterion CR4.2.3 could not be assessed.

4.5.2.4. Final assessment of user requirement UR4.2. — predisposal waste management

This user requirement states that all intermediate steps should be specified until the end state is reached.

The intermediate steps of waste management towards the end state of all waste are under development currently in Belarus. Thus, there are currently not enough data available to assess user requirement UR4.2.

4.5.3. Final assessment of basic principle BP4 — optimization of radioactive waste management

This basic principle requires optimization of safety of the NES by considering all interactions and relationships among all waste generation and waste management actions.

There is insufficient data available to assess the successful implementation of this basic principle at this stage of the nuclear power programme.

It is recommended that waste management procedures be further developed to optimize the processes.

4.6. SUMMARY AND CONCLUSION OF ASSESSMENT OF WASTE MANAGEMENT

The INPRO methodology for waste management stipulates waste minimization at the source, protection of humans and the environment against radiation exposure, avoidance of undue burdens on future generations, and optimization of the waste management system.

All requirements of the INPRO methodology directly related to design and operation of the NPP are fulfilled by the AES-2006 design. However, as the development of the waste management system for treatment of radioactive waste outside the nuclear plant is ongoing in Belarus, for the assessment of this part of the waste management system insufficient data were available at the time the report was written.

It is recommended that the missing information be collected and the assessment finalized.

5. PROLIFERATION RESISTANCE

In this section, the proliferation resistance of the Belarus NES is assessed using the INPRO methodology [70] defined in Volume 5 of the INPRO manual, on proliferation resistance. This assessment of proliferation resistance assumed the application of IAEA safeguards.

5.1. INTRODUCTION

INPRO has developed one basic principle for this area.

Basic principle BP: *Proliferation resistance intrinsic features and extrinsic measures shall be implemented throughout the full life cycle for innovative NES to help ensure that NES will continue to be an unattractive means to acquire fissile material for a nuclear weapons programme. Both intrinsic features and extrinsic measures are essential, and neither can be considered sufficient by itself.*

INPRO has developed five user requirements for this BP, UR1–UR5.

5.2. USER REQUIREMENT UR1— STATE COMMITMENTS

User requirement UR1: *State commitments, obligations and policies regarding non-proliferation and its implementation should be adequate to fulfil international standards in the non-proliferation regime.*

INPRO has developed two criteria for this user requirement, CR1.1 and CR1.2.

5.2.1. Criterion CR1.1 — legal framework

Indicator IN1.1: *State commitments, obligations and policies regarding non-proliferation established?*

Acceptance limit AL1.1: *Yes, in accordance with international standards.*

The fulfilment of criterion CR1.1 is confirmed by the fulfilment of the set of evaluation parameters EP1.1.1–EP1.1.10, regarding realization of State obligations on non-proliferation treaties, as defined in Table 27.

TABLE 27. EVALUATION PARAMETERS OF INDICATOR IN1.1

Evaluation parameter	Status	Acceptability
EP1.1.1: Party to NPT	Came into force for Belarus on 22 July 1993	Acceptable; see notes below
EP1.1.2: Party to a regional treaty on nuclear weapon free zones	-	Not applicable in Belarus; see notes below
EP1.1.3: Comprehensive safeguards agreement on the admission of safeguards according to the NPT.	Came into force on 31 August 1995	Acceptable; see notes below
EP1.1.4 Additional protocol to the agreement between Belarus and the IAEA on the admission of safeguards according to the NPT	Signed on November 2005. Not ratified.	Partly acceptable; see notes below
EP1.1.5: For those States, who are not a party to the NPT: The other agreements on non-proliferation remain valid (for example INFCIRC/66).	-	Not applicable in Belarus; see notes below

TABLE 27. EVALUATION PARAMETERS OF INDICATOR IN1.1 (CONTINUED)

Evaluation parameter	Status	Acceptability
EP1.1.6: Policy of export control of nuclear material and technologies.	The law was adopted by House of Representatives on 25 November 1997. It was approved by the Council of the Republic on 19 December 1997.	Acceptable; see notes below
EP1.1.7: State or regional system on accounting for and control of nuclear material in use (SSAC or RSAC).	Registered in the national registry of Legal Acts of Belarus №8/3812 on 7 August 2000.	Acceptable; see notes below
EP1.1.8: Regulatory body for implementing and applying safeguards agreements.	Ministry for Emergency Situations was assigned as regulatory body responsible for implementation of safeguards in Belarus	Acceptable; see notes below
EP1.1.9: Other State commitments or conventions connected with NPT.	Lisbon's Protocol to the Comprehensive Nuclear Test Ban Treaty (CTBT)	Acceptable; see notes below
EP1.1.10: Records on violation of the NPT.	Absent	Acceptable; see notes below

Comments on the evaluation parameters are listed below.

5.2.1.1. EP1.1.1 — party to the NPT

The NPT was established by a resolution of the Supreme Council of Belarus [71], according to which *States which signed the treaty are obliged to cooperate in order to facilitate the application of IAEA safeguards on peaceful nuclear activities*.

5.2.1.2. EP1.1.2 — party to a regional non-proliferation regime

This indicator does not apply to Belarus, as there is currently no Eastern European nuclear weapon free zone. Neighbouring countries are also not party to the treaty on nuclear weapon free zones.

In accordance with the *Constitution of the Republic* 1994 (with changes and amendments):

Article 18: *Belarus in its foreign policy is based on the principles of equality of States, non-use or threat of force, inviolability of frontiers, peaceful settlement of disputes, non-interference in internal affairs, and other universally recognized principles and norms of international law*.

Belarus aims to make its territory a nuclear weapon free zone, and the State neutral.

In accordance with Article 3 of the law [1], activities on use of nuclear energy are based on principles such as a ban on the production of nuclear weapons and other nuclear explosive devices.

5.2.1.3. EP1.1.3 — comprehensive safeguards agreements in force

A safeguards agreement — based on the NPT, concluded between Belarus and the IAEA — came into force on 31August 1995, according to which Belarus accepts safeguards in accordance with the provisions of the agreement on all sources or special fissionable material in all peaceful nuclear activities within the whole territory, under its jurisdiction or carried out under its control anywhere, for the exclusive purpose of verifying that such material is not diverted to nuclear weapons or other nuclear explosive devices.

5.2.1.4. EP1.1.4 — additional protocol

An additional protocol to the safeguards agreement was concluded between Belarus and the IAEA

Belarus joined that protocol in November 2005. Plan for measures of ratification No.33/213–302 was confirmed by Deputy Prime-Minister on 19 October 2009. Thus, the ratification is envisaged in the near future.

5.2.1.5. EP1.1.5 — other agreements related to non-proliferation

These are agreements (for example INFCIRC/66) for countries that are not party to the NPT.

As Belarus is party to the NPT, this indicator is not relevant.

5.2.1.6. EP1.1.6 — export control policies of nuclear material and nuclear technology

According to the national *Law on Export Control* [19], Article 7: "*objects under the export control consist of … goods, technology and service, connected with nuclear fuel cycle and production of nuclear material, which can be used for nuclear weapons and nuclear explosive devices*".

The procedure for conducting export control is also defined in this law.

5.2.1.7. EP1.1.7 — State or regional system of accounting for and control of nuclear material

According to Article 2.4 of the SSAC [75, 76], the administrative and technical basis to fulfil the IAEA's safeguards requirements is the State's safeguards system, which includes an SSAC, and a State system for nuclear export control, a system for physical protection of nuclear material and facilities, and a set of organizational and technical measures aimed at implementing the commitments of Belarus under the agreement.

Also required by the SSAC are:

- Regulations on the supervision of the nuclear material accounting and control in Belarus.
- Requirements for organization and maintenance of accounting for and control of nuclear material, during use, storage and transportation, research and experimental reactors, critical and near-critical facilities, research laboratories and research facilities.
- Requirements to provide documentation to the national competent authority.

Thus, an SSAC is established in Belarus.

5.2.1.8. EP1.1.8 — regulatory body for implementing safeguards agreements

A national regulatory body, i.e. the Ministry for Emergency Situations is responsible for the implementation of safeguards agreements in Belarus.

5.2.1.9. EP1.1.9 — other treaties and conventions connected with non-proliferation

There are two additional international agreements in Belarus related to the NPT:

- The Lisbon Treaty is the Protocol to the Treaty on the Reduction and Limitation of Strategic Offensive Arms between the USSR and the USA, signed on May 23, 1992 by Russia, the USA, Ukraine, Belarus and Kazakhstan; and
- The CTBT, which is ratified by the national law [72].

5.2.1.10. EP1.1.10 — NPT violation

There was never a violation of the NPT on the part of Belarus according to the assessor's data.

Final assessment of criterion CR1.1 legal framework

On the basis of assessment results for all nine evaluation parameters, it can be concluded that CR1.1 has been satisfied completely.

All necessary international treaties and agreements are adopted and ratified in Belarus except for the additional protocol to the safeguards agreement with pertaining to the NPT concluded between Belarus and the IAEA. As mentioned above, there is a ratification plan, confirmed by the deputy prime-minister, 19 October 2009, № 33/213–302.

5.2.2. Criterion CR1.2 — institutional structural arrangements

Indicator IN1.2: *Institutional structural arrangements in support of proliferation resistance have been considered?*

Acceptance limit AL1.2: *Yes.*

Belarus is not expected to develop specific national institutional structures associated with spent fuel reprocessing. In the nuclear fuel cycle of Belarus, the introduction of a technology for nuclear fuel enrichment and reprocessing is not expected. Belarus considers the possibility of joining international centres for spent fuel reprocessing and natural uranium enrichment in the Russian Federation.

Criterion CR1.2 has been met.

5.2.3. Final assessment of user requirement UR1 — State commitments

On the basis of the evaluation above, almost complete fulfilment of user requirement UR1 can be confirmed, which defines Government obligations connected with the establishment of a legislative base for the non-proliferation of nuclear weapons.

Further activities should deal with the ratification of the additional protocol to the safeguards agreement concluded between Belarus and the IAEA. A plan for the ratification was approved by Deputy Prime Minister on 19 October 2009 № 33/213–302.

5.3. USER REQUIREMENT UR2 — ATTRACTIVENESS OF NUCLEAR MATERIAL AND TECHNOLOGY

User requirement UR2: *The attractiveness of nuclear material and nuclear technology in an innovative NES for a nuclear weapon programme should be low.*

INPRO has developed four criteria for this user requirement, CR2.1–CR2.4.

5.3.1. Criterion CR2.1 — attractiveness of nuclear material quality

Indicator IN2.1: *Nuclear material quality.*

Acceptance limit AL2.1: *Attractiveness based on nuclear material characteristics considered in NES design and found acceptably low according to expert judgment.*

INPRO has developed five evaluation parameters for this criterion, EP2.1.1 to EP2.1.5.

Most of these evaluation parameters are based on the amount and ratio of specific isotopes in the nuclear material. Therefore, as a first step the distribution of isotopes in fresh and spent fuel is determined.

Fresh fuel in an AES-2006 reactor is enriched to a maximum of 5% of ^{235}U.

The maximum mass of spent fuel which can be stored in the cooling pond of the AES-2006 reactor, in general, is 272 844 kgHM with a burnup approximately of 55 MWd/kgHM. The proportions of isotopes in the spent fuel is shown in Table 28.

TABLE 28. DISTRIBUTION OF ISOTOPES IN SPENT FUEL IN A COOLING POND

Isotope	^{235}U	^{236}U	^{238}U	^{237}Np	^{238}Pu	^{239}Pu	^{240}Pu
Fraction, %	0.8126	0.5915	91.56	0.07956	0.03566	0.65206	0.2072
Isotope mass, kg	2217	1614	249806	217.0	97.2	1779.1	565.3

Isotope	Pu^{241}	Pu^{242}	Am^{241}	Am^{242}	Am^{243}	Cm^{242}	Cm^{244}
Fraction, %	0.2339	0.1086	0.0078	0.0001	0.0293	0.0032	0.0128
Isotope mass, kg	638.2	296.2	21.2	0.3	79.9	8.6	34.9

An evaluation of nuclear material quality was carried out in accordance with the recommendations in Annex A of Volume 5 of the *INPRO Manual* [70].

In these recommendations, several evaluation parameters are defined and the proliferation resistance of each parameter can be quantified in either a two or a five range scale. The two-range scale shows 'weak' or 'strong' proliferation resistance and the five-range scale describes proliferation resistance as:

- Very weak
- Weak
- Moderate
- Strong
- Very strong.

Table 29 lists the evaluation parameters of nuclear material as defined by the INPRO methodology using the isotope concentration of fresh fuel and spent fuel (in Table 28) to define its quality in relation to proliferation resistance.

TABLE 29. PROLIFERATION RESISTANCE OF NUCLEAR MATERIAL BASED ON QUALITY

Indicator	Evaluation parameter		Result	PR level
IN2.1 Material quality	EP2.1.1 Material type/category of fresh fuel		LEU see note below.	Moderate
	EP2.1.2 Isotopic composition,	$^{239}Pu/Pu$ (wt%)	52.7% see note below	Weak
	EP2.1.3 Radiation		Not available.	
	EP2.1.4 Heat generation,	$^{238}Pu/Pu$ (wt%)	2.9% see note below.	Weak
	EP2.1.5 Spontaneous neutron generation rate	$(^{240}Pu+{}^{242}Pu)/Pu$ (wt%)	22.5% see note below.	No acceptance limit

5.3.1.1. EP2.1.1 — material type/category

The AES-2006 uses as fresh fuel uranium enriched with ^{235}U to less than 5%, which allows classifying it as low enriched uranium (LEU). According to the INPRO methodology LEU is associated with "moderate" proliferation resistance.

5.3.1.2. EP2.1.2 — isotopic composition

This parameter considers the ratio of ^{239}Pu concentration to the total concentration of plutonium in the fuel. This ratio is equal to 52.7%. A value of greater than 50% is classified according to the INPRO methodology as ‘weak’ proliferation resistant.

5.3.1.3. EP2.1.3 — radiation

The intensity of radiation from spent fuel is not determined in the provided data. Therefore, this parameter could not be evaluated.

5.3.1.4. EP2.1.4 — heat generation

This parameter considers the heat generation in spent fuel which is proportional to the ratio of ^{238}Pu to the entire amount of plutonium. For the spent fuel produced by the AES-2006, this ratio is 2.9%. According to the INPRO methodology, a value of less than 20% is defined as ‘weak’ proliferation resistant.

5.3.1.5. EP2.1.5 — rate of spontaneous neutron generation

This parameter considers the spontaneous neutron production rate in spent fuel which is proportional to the ratio of ^{240}Pu and ^{242}Pu to the entire amount of plutonium. For the spent fuel produced by AES-2006, this ratio is 22.5%. No clear level of proliferation resistance is defined by the INPRO methodology for this parameter.

Final assessment of criterion CR2.1 — quality of nuclear material

The results of the analysis above show that the quality of AES-2006 fuel has several characteristics with very different levels of proliferation resistance. The characteristics are determined by the basic design principles of the AES-2006 and an increase of proliferation resistance is not possible. However, similar characteristics are found in other LWRs which have been successfully safeguarded since the introduction of nuclear power. Thus, it can be concluded that the attractiveness of AES-2006 fuel based on quality of the nuclear material is sufficiently low.

5.3.2. Criterion CR2.2 — attractiveness of nuclear material quantity

Indicator IN2.2: *Nuclear material quantity*.

Acceptance limit AL2.2: *Attractiveness, based on nuclear material characteristics of quantity considered in NES design and found acceptable low according to expert judgment.*

INPRO has developed several evaluation parameters for this criterion. EP2.2.1 and EP2.2.2 dealing with mass and number of fuel will be assessed in the following

There are three categories of nuclear material according to the *IAEA Safeguards Glossary* [73]: unirradiated direct use material, irradiated direct use material, and indirect use material.

The nuclear material stored at the station will be:

- Fresh or clean (unirradiated) fuel, the chemical composition of which is UO_2 with an ^{235}U concentration equal to 4.71%. This fresh fuel is indirect use material.
- Spent fuel, in which the concentration of heavy elements is shown in Table 28. Such spent fuel is also indirect use material.

As a result, there will be no material in the AES-2006 which can be referred to as direct use, and this reduces its attractiveness for a weapon programme.

According to section 5.6 of the general requirements for nuclear fuel management and in-vessel components (terms of reference for developing the basic design of AES-2006) it follows that:

- General stationary storage of fresh (clean) fuel should be provided within the framework of the basic design. For fresh fuel, conditions and equipment for simultaneous storage of fuel assemblies should be provided in a quantity required for normal reloading of two reactors with 20% spare capacity.
- The possibility to store the complete initial fuel loading of the reactor with a 10% spare capacity should be also provided. The initial fuel loading should be kept in the transportation packaging in which the fuel is delivered to the plant.
- A total fuel load for a VVER-1000 reactor consists of 163 fuel assemblies with 532 kg of UO_2 in each one, or 468 kg of heavy metal enriched to 4.71% in ^{235}U. 42 assemblies are reloaded into the reactor after every outage.

To fulfil the first condition, the necessary amount of fresh fuel should be equal to 42x2x1.2 = 100.8, i.e. 101 fuel assemblies with a mass of uranium 101x468=47.268 kg.

To fulfil the second condition, the required storage volume is equal to 1.1x163=180 fuel assemblies with a mass of uranium of 84 240 kg. As fulfilling the second condition requires a larger volume of fresh fuel, it is this amount which will be accepted as a maximum. Thus, the station will not store more than 84 240 kg of heavy metal enriched to 4.71% in ^{235}U.

At the same time, 163 fuel assemblies with a mass of heavy metal 163x468=76284 kg will be in the reactor permanently.

Accord to section 5.6.3.2 of the terms of reference on the development of the basic design [72]: after discharging, the spent fuel should be stored inside containment in the cooling pool, located near the reactor. Cooling pool capacity should provide storage of spent fuel in condensed racks for ten years, taking into account the emergency discharge of the complete core, including an arrangement for defective fuel assemblies in leak-tough casings.

Thus, the volume of fuel in the cooling pond may be equal to 42x10+163=583 fuel assemblies.

Table 30 presents the proliferation resistance level of the two selected evaluation parameters for the quantity of nuclear material, which is determined according to the INPRO methodology.

TABLE 30. PROLIFERATION RESISTANCE OF NUCLEAR MATERIAL BASED ON QUANTITY OF NUCLEAR MATERIAL

Indicator	Evaluation parameter	Result	PR level
IN2.2: Quantity of material	EP2.2.1: The mass of accounting fuel unit	1.7 kg see notes below	Very weak
	EP2.2.2: The number of accounting units for getting a significant quantity	1023 see notes below	Very strong

5.3.2.1. EP2.2.1 — item mass (accounting fuel unit)

Since fuel will be delivered to the plant in assemblies that could be disassembled, the unit of account will be a single fuel rod. The weight of a single AES-2006 fuel rod is 1.7 kg. This means that it is relatively easy to transport, and its reshipment does not require special lifting equipment. However, the length of a fuel rod is more than four meters, which somewhat complicates its transport. According to the INPRO methodology, a mass less than 10 kg results in a ‘very weak’ proliferation resistance.

Similar fuel has been successfully safeguarded at other LWR facilities.

5.3.2.2. EP2.2.2 — number of units for significant quantity of material

A significant quantity, required to obtain an explosive device using uranium with a concentration of ^{235}U <20%, is greater than 75 kg of ^{235}U. With fuel enriched to 4.71% ^{235}U, the weight of heavy metal required to achieve a significant amount is equal to 75/0.0471=1592.3 kg. There is 1.556 kg of heavy metal in one fuel rod. Thus, the number of fuel rods required to produce a significant quantity is equal to 1592.3/1.556=1023. According to the INPRO methodology, a number greater than 1000 corresponds to a ranking of 'very strong' proliferation resistance.

Final assessment of criterion CR2.2 — quantity of nuclear material

The above analysis shows two very different results regarding the proliferation resistance of two characteristics related to the quantity of the AES-2006 fuel. However, the low score is somewhat compensated by the physical size (large length) of a fuel rod.

Thus, it can be concluded that the attractiveness of AES-2006 fuel based on quantity of nuclear material is sufficiently low.

5.3.3. Criterion CR2.3 — attractiveness of nuclear material classification

Indicator IN2.3: *Nuclear material classification (form).*

Acceptance limit AL2.3: *Attractiveness, based on nuclear material characteristics of form considered in NES design and found acceptable low according to expert judgment.*

Three evaluation parameters are available for criterion CR2.3, EP2.3.1–EP2.3.3. Table 31 presents the results of an analysis of the proliferation resistance of AES-2006 fuel based on the form of nuclear material.

TABLE 31. PROLIFERATION RESISTANCE OF NUCLEAR MATERIAL BASED ON FORM

Indicator	Evaluation parameter	Result	PR level
IN2.3: Material classification	EP2.3.1: Chemical/physical form of uranium in fresh fuel.	Hydrous pitch blende; see notes below.	weak
	EP2.3.2: Chemical/physical form of uranium in spent fuel.	Spent fuel; see notes below.	strong
	EP2.3.3: Chemical/physical form of plutonium.	Spent fuel; see notes below.	Strong

5.3.3.1. EP2.3.1 — chemical/physical form of uranium in fresh fuel

In fresh fuel, uranium will be at the plant in the fuel rods of fuel assemblies in the form of uranium oxide, UO_2. This chemical form (oxide) corresponds to 'weak' proliferation resistance according to the INPRO methodology.

5.3.3.2. EP2.3.2 — chemical/physical form of uranium in spent fuel

Uranium will also be stored at the plant in spent fuel. The form spent fuel corresponds to 'strong' proliferation resistance according to the INPRO methodology.

5.3.3.3. EP2.3.3 — chemical/physical form of plutonium

Plutonium will be present only as spent fuel, which corresponds to 'strong' proliferation resistance according to the INPRO methodology.

Thorium will not be present at the AES-2006 plant.

Final assessment of criterion CR2.3 — form of nuclear material

Thus, on the basis of the above analysis, it can be concluded that the form of fuel used at the Belarusian NPP has a high ability to resist proliferation. The only problem is fresh fuel in storage, which has a low ability to resist proliferation; however, this is mitigated by the application of appropriate safeguards measures.

5.3.4. Criterion CR2.4 — attractiveness of nuclear technology

Indicator IN2.4: *Nuclear technology.*

Acceptance limit AL2.4: *Attractiveness of technology considered in design of NESs and found acceptable low according to expert judgment.*

INPRO has developed three evaluation parameters, EP2.4.1–EP2.4.3. Table 32 presents the results of an analysis of the proliferation resistance of the Belarus NES based on the availability of sensitive technology.

TABLE 32. PROLIFERATION RESISTANCE BASED ON AVAILABILITY OF NUCLEAR TECHNOLOGY

Indicator	Evaluation parameter	PR level
IN2.4 Nuclear technology	EP2.4.1 Enrichment	strong see notes below
	EP2.4.2 Extraction of fissile material	strong see notes below
	EP2.4.3 Capability to irradiate the undeclared fertile material	strong see notes below

5.3.4.1. EP2.4.1 — enrichment

In accordance with the resolution [41], the Belarus nuclear power programme does not assume installation of enrichment plants. For the AES-2006 plant, fuel will be purchased already enriched to the desired concentration of ^{235}U. This type of NES corresponds to ‘strong’ proliferation resistance according to the INPRO methodology.

5.3.4.2. EP2.4.2 — extraction of fissile material

Belarus does not plan to reprocess spent fuel, which corresponds to the ranking of ‘strong’ on the scale. After unloading the fuel from the reactor and its temporary storage in the reactor spent fuel cooling pond, it is planned to transport the fuel to temporary dry storage, or transfer it for recycling to other countries (presumably the Russian Federation). This type of NES corresponds to ‘strong’ proliferation resistance according to the INPRO methodology.

5.3.4.3. EP2.4.3 — capability to irradiate the undeclared fertile material

In Belarus it is not planned to build a research reactor or accelerator with sufficient power to allow irradiation of fertile nuclear material and to obtain weapon-usable nuclear material. This corresponds to ‘strong’ on the estimate scale. This type of NES corresponds to ‘strong’ proliferation resistance according to the INPRO methodology. However, an additional protocol must be in place in order for the IAEA to verify this declaration.

Final assessment of criterion CR2.4 — attractiveness of nuclear technology

On the basis of the above analysis, it can be concluded that the nuclear technology planned to be commissioned in Belarus — i.e. only an NPP and corresponding waste management facilities — has strong proliferation resistance.

5.3.5. Final assessment of user requirement UR2 — attractiveness of nuclear material and technology

This user requirement stipulates that nuclear material used in an NES should have a low attractiveness for a nuclear weapon programme.

The quantity and quality of the nuclear material used in the AES-2006 plant — nuclear fuel with low enriched uranium — shows high proliferation resistance, i.e. low attractiveness for proliferation. Also the form of the nuclear material, namely UO_2, used in the AES-2006 shows sufficient proliferation resistance although spent fuel with a clear radiation signature is superior in this respect than fresh fuel.

The technology planned to be used in the NES of Belarus — NPPs and waste management facilities — has very high proliferation resistance due to the absence of enrichment and reprocessing facilities in the country.

It is assumed that IAEA safeguards will verify the correctness of the declarations by the State. The assessment of the completeness of the declarations by the IAEA can only occur after an additional protocol has entered into force for the State.

5.4. USER REQUIREMENT UR3 — DIFFICULTY AND DETECTABILITY OF DIVERSION

User requirement UR3: *The diversion of nuclear material should be reasonably difficult and detectable.*

Diversion includes the use of an NES facility for the production or processing of undeclared material.

INPRO has developed two criteria for this user requirement, CR3.1 and CR3.2.

5.4.1. Criterion CR3.1 — quality of measurement system

Indicator IN3.1: *Accountability of nuclear material.*

Acceptance limit AL3.1: *On the basis of expert judgment, equal or better than existing facilities meeting international state of practice.*

Three evaluation parameters are available to assess this criterion, EP3.1.1–EP3.1.3. Table 33 presents the results of an analysis of the proliferation resistance of AES-2006 based on the capability of its measurement system of nuclear material.

TABLE 33. QUALITY OF MEASUREMENT SYSTEM

Indicator	Evaluation parameter		Error	PR level
IN3.1 Accountability	Measurement error (σMUF/SQ)*	EP3.1.1: Pu	0; see notes below.	Very strong
		U235 with low enrichment	0; see notes below.	Very strong
	Measurement capability by inspector	EP3.1.3: Measurement capability by inspector	passive system for non-destructive analysis; see notes below.	Very strong

Note: σ – standard deviation; MUF – material unaccounted for; SQ – significant quantity of nuclear material.

5.4.1.1. EP3.1.1 — measurement error of plutonium

The measurement error is defined as the ratio of material unaccounted for (MUF) and the significant quantity of that material. In Belarus spent fuel with certain plutonium content will exist only as fuel rods, similar to a pressure vessel in which the fuel is stored. Any destruction of a fuel rod is easily detectable. Accounting of fuel rods will be item accounting, with no measurement or measurement error. Thus, the amount of plutonium in spent fuel and uranium in both fresh and spent fuel, which is in the fuel rods, can be declared without measuring an error. This type of measurement error corresponds to ‘very strong, proliferation resistance of the system according to the INPRO methodology. Robust verification of the item accounting system by the IAEA is assumed.

5.4.1.2. EP3.1.2 — measurement capability by inspector

A safeguards inspector can identify fuel in the fuel rods with the help of a system of non-destructive testing. Fuel has no loose forms and resides in the sealed fuel rods, which facilitates the identification of this material. Such a high capability to identify nuclear material corresponds to ‘very strong’ proliferation resistance of the system according to the INPRO methodology. The right to routine access of the facility by inspectors is assumed.

Final assessment of criterion CR3.1 — accountability

On the basis of the above analysis, it can be concluded that the accountability of nuclear material is very high in the AES-2006 plant because of the high quality of nuclear material measurement and the capability of safeguards inspectors to identify nuclear material. Thus, the AES-2006 has a very strong level of proliferation resistance, i.e. criterion CR3.1 has been met.

5.4.2. Criterion CR3.2 — measures of containment/surveillance (C/S) and monitoring

Indicator IN3.2: *Amenability for C/S and monitoring systems.*

Acceptance limit AL3.2: *Systems, according to expert judgment, should be equal or better than in existing facilities meeting international state of practice.*

Nuclear fuel will be located in three places at the AES-2006 reactor: in storage of fresh fuel, and inside the containment in the reactor core and in the cooling pond.

According to section 5.6.3.2 of the terms of reference for the development of basic design [74]: after unloading spent fuel from the reactor core, it should be stored inside the containment in a cooling pond, located in close vicinity of the reactor.

Containment itself has three access points: the main access, emergency access and transportation hatch. Passing into the containment through these accesses is prohibited during reactor operation. Thus, a system of C/S and monitoring can be installed at the reactor and cooling pond and at all three access points using a video system and sealing of these openings. Moreover, such a system can be placed at the equipment that is used for replacement of defect fuel rods in a fuel assembly.

Due to the large number of operations with fresh nuclear fuel and the need for constant control and maintenance at the fresh fuel storage, this approach is difficult to implement for a long period of time. However, it is possible to organize such a system of C/S also at the fresh fuel storage.

Final assessment of criterion CR3.2 — C/S and monitoring systems

Thus, on the basis of the above analysis, it can be concluded that the measures of C/S and monitoring systems can cover all facilities in the AES-2006 where nuclear material is located.

Criterion CR3.2 has been met.

5.4.3. Criterion CR3.3 — detectability of nuclear material

Indicator IN3.3: *Detectability of nuclear material.*

Acceptance limit AL3.3: *Detectability, according to expert judgment, should be equal or better than in existing facilities meeting international state of practice.*

INPRO has developed two evaluation parameters for this criterion, EP3.3.1 and EP3.3.2. Table 34 presents the results of an analysis of the proliferation resistance of the AES-2006 based on detectability of nuclear material.

TABLE 34. DETECTABILITY OF NUCLEAR MATERIAL

Indicator	Evaluation parameter	Type of material	Result	PR level
IN3.3: Determination of nuclear material	EP3.3.1: Possibility to identify nuclear material using non-destructive inspection methods	Fresh fuel	Yes; see notes below.	Strong
		Spent fuel	Yes; see notes below.	Strong
	EP3.3.2: Detectability by radiation signature	Fresh fuel	No; see notes below.	Weak
		Spent fuel	Yes; see notes below.	Weak

5.4.3.1. EP3.3.1 — possibility to identify nuclear material using non-destructive inspection

AES-2006/V-491, to be installed in Belarus, is a typical pressurized reactor. In such a reactor type, the use or receipt of nuclear material is detectable, and the material can be identified with the help of non-destructive inspection. Both fresh and spent fuel will be contained in the sealed fuel rods of fuel assemblies. The weight of a single fuel rod is less than two kg, but the length of fuel rod is four meters, which requires the use of additional equipment for transportation. Removing a fuel assembly from the core is not possible during operation of the plant as the reactor cannot be reloaded during operation, i.e. this would require a reactor shutdown. In the case of theft, spent and fresh fuel are easily detected by radioactive radiation of fission products.

Thus, according to the INPRO methodology the good possibility to identify (and detect) nuclear material by non-destructive methods in the AES-2006 corresponds to strong proliferation resistance.

5.4.3.2. EP3.3.2 — detectability of nuclear material by radiation signature

Spent fuel will have a strong radiation signature. Belarus cooperates with the IAEA in programmes related to identification of nuclear material upon detection. All necessary information will be provided to the IAEA by Belarus and necessary measures will be taken for the identification of the material based on its radiation signature.

The planned measures for detection of spent fuel by its radiation signature in the AES-2006 correspond to strong proliferation resistance.

Fresh fuel will be supplied by another country, and it will not be processed in Belarus. For this reason, it is possible to identify only a commercial producer of fuel and this fresh material will not have a strong radiation signature, which corresponds to ‘weak’ proliferation resistance. Nevertheless, the weak proliferation resistance associated with fresh fuel is mitigated by safeguards at many LWRs.

Final assessment of criterion CR3.3 — detectability of nuclear material

Thus, on the basis of the above analysis it can be concluded that the detectability of nuclear material used in the Belarusian NPP is quite high, which corresponds to 'strong' proliferation resistance. The only drawback is the missing of a radiation signature of fresh fuel.

Criterion CR3.3 has been met.

5.4.4. Criterion CR3.4 — facility of process

Indicator IN3.4: *Difficulty to modify the process.*

Acceptance limit AL3.4: *According to expert judgment, should be equal to or better than that existing and accepted by international practice.*

INPRO has developed four evaluation parameters for this criterion, CR3.4.1–CR3.4.4. Table 35 presents the results of an analysis of the proliferation resistance of the AES-2006 based on the difficulty to modify its processes.

TABLE 35. PROLIFERATION RESISTANCE BASED ON DIFFICULTY TO MODIFY PROCESSES

Indicator	Evaluated parameter	Basis for evaluation	PR level
IN3.4: The difficulty to modify the processes.	EP3.4.1: Extent of automation.	Station management is partially automated, see notes below	Strong
	EP3.4.2: Availability of data for inspectors.	No data, see notes below	Weak
	EP3.4.3: Process transparency.	Yes, see notes below	Strong
	EP3.4.4: Accessibility of material to inspectors for verification.	Yes, see notes below	Strong

5.4.4.1. EP3.4.1 — extent of automation

The AES-2006 features:

- Automatic control;
- Functional-group control;
- Automated remote control (with the use of displays and using individual tools on panels and consoles);
- Management on the location of a process.

It is concluded that there is high grade of automation in the processes of the AES-2006 which corresponds to a "strong" proliferation resistance according to the INPRO methodology.

5.4.4.2. EP3.4.2 — availability of data for inspectors

On the basis of the information available to the assessor performing the evaluation, there is currently no evidence of a plan to implement system for access to data on processes in near real time (NRTA) in the AES-2006 for inspectors. This situation corresponds to 'weak' proliferation resistance according to the INPRO methodology. When a plan to implement NRTA is formulated, the safeguards system could take advantage of it to strengthen the proliferation resistance of this parameter from 'weak' to 'strong'.

5.4.4.3. EP3.4.3 — process transparency

According to national regulations [75, 76], IAEA inspectors will have sufficiently easy access to nuclear material to check. This is further described in item 6 of companies' duties: "…

arrange timely and unhindered access of IAEA inspectors to the plant and allow them to visit all locations of nuclear material, which are under safeguards and the locations of IAEA containment and surveillance measures”.

This situation corresponds to ‘strong’ proliferation resistance according to the INPRO methodology.

5.4.4.4. EP3.4.4 — accessibility of material to inspectors for verification

According to the regulations [75, 76], “the IAEA inspector is entitled within two hours to get access to any place and any equipment of the plant”.

At the plant, there is a possibility to get access to the reactor room on the inspector’s request even when the reactor is running. This situation corresponds to ‘strong’ proliferation resistance according to the INPRO methodology.

Final assessment of criterion CR3.4 — difficulty to modify process

Thus, on the basis of the above analysis it can be concluded that the nuclear power system of the AES-2006 has a high resistance to changing the process and a high level of monitoring systems. Additional installation of an NRTA system will allow this criterion to be fully met and to guarantee the impossibility of changing the processes of the system in order to use it in military programmes.

Criterion CR3.4 has been met.

5.4.5. Criterion CR3.5 — facility design

Indicator IN3.5: *Difficulty modifying the facility design.*

Acceptance limit AL3.5: *According to expert judgment, the difficulty should be equal or greater than that existing and accepted by international practice.*

According to item 8 of the terms of reference [74], the design of the AES-2006 allows:

- An increase in power level;
- An increase in annual output (for example, by increasing the load factor)
- Reduction of power consumption for own needs
- Improvement of working conditions
- Maintenance of the proper level of safety, referring to the ever-increasing requirements of regulatory documents and the need to periodically obtain a permit to operate during the design life of the plant.

However, upgrades that may affect the performance of IAEA safeguards are not planned. All the processes of fuel handling are essential for nuclear and radiation safety and their modification is possible only in the case of an agreement with the regulatory body. Concurrence of modifications with the regulatory body is a continuous process that requires time and a wide range of participants to justify upgrades.

Final assessment of criterion CR3.5 — modification of facility design

It can be concluded that the re-design of the AES-2006 plant is quite a difficult task, and to perform it in a short time and not be detected by IAEA safeguards is also rather difficult.

Thus, the criterion can be considered fulfilled.

5.4.6. Criterion CR3.6 — misuse of the installation

Indicator IN3.6: *Detectability of misuse of technology or facility.*

Acceptance limit AL3.6: *According to expert judgment, detectability should be equal or better than that existing, developed and accepted in international practice.*

Safeguards measures used in VVER-1000 reactors (AES-2006 is an evolutionary development of VVER-1000 and the changes made are not significant regarding proliferation resistance) are sufficient to ensure that misuse will be promptly detected. Spent nuclear fuel in the AES-2006, and also in the VVER-1000 reactor, is inside the containment, which enhances control and surveillance of containment systems.

Final assessment of criterion CR3.6 — misuse of facility

Thus, it can be concluded that misuse of the planned NPP and non-detection by IAEA safeguards is rather difficult.

The criterion can be considered fulfilled.

5.4.7. Final assessment of user requirement UR3 — difficulty and detectability of diversion

The user requirement stipulates that diversion of nuclear material in the NES should be reasonably difficult and detectable.

The assessment results show that the AES-2006 design ensures that it would be difficult to misuse the plant or to modify its design or processes. Further, the plant design enables a high detectability of diversion, a good accountability of nuclear material, and the installation of C/S measures by IAEA safeguards.

Thus, user requirement UR3 has been satisfied by the AES-design.

5.5. USER REQUIREMENT UR4 — MULTIPLE BARRIERS

User requirement UR4: *Innovative NESs should include multiple proliferation resistance measures and features.*

INPRO has developed two criteria for this user requirement, CR4.1 and CR4.2.

5.5.1. Criterion CR4.1 — defence in depth

Indicator IN4.1: *The extent by which the NES is covered by multiple intrinsic features and extrinsic measures.*

Acceptance limit AL4.1: *All plausible acquisition paths are (can be) covered by extrinsic measures on the facility or State level and by intrinsic features that are compatible with other design requirements.*

Possible paths to obtain (divert) nuclear material are:

- Transport to the NPP;
- Fresh fuel storage;
- Transport from storage to the reactor;
- Lifting of cases into transport hatch;
- Cooling pond;
- Shipment of spent fuel.

In this report, only a general analysis was made of all possible paths in the AES-2006 plant to divert nuclear material. To evaluate this criterion in detail, results from a comprehensive diversion and acquisition path analysis are required covering all possible ways to divert nuclear material in the plant. Such results were not available to the assessor. However, similar characteristics are found in other LWRs which have been successfully safeguarded.

Criterion CR4.1 was not assessed in detail due to lack of necessary input data.

5.5.2. Criterion CR4.2 — robustness of barriers

Indicator IN4.2: *Robustness of barriers covering each acquisition path.*

Acceptance limit AL4.2: *Robustness is sufficient according to expert judgment.*

Physical barriers against diversion of nuclear material in the AES-2006 design are:

- The isotopic composition of fresh and spent fuel, which does not allow — without reprocessing — the use of the nuclear material available at the plant for construction of a nuclear explosive device;
- The form of uranium in the fresh fuel — uranium oxide UO_2 — which makes its reprocessing difficult;
- The high radiation field of the spent fuel, which makes it difficult to work with;
- The weight of a single fuel assembly, 740 kg, which would make the use of heavy lifting equipment necessary for transportation and processing. Removal of fuel rods from a fuel assembly is possible only with specially designed equipment, which can be under supervision of the IAEA following the safeguard principle of C/S.

Technical barriers against diversion of nuclear material in the AES-2006 design are:

- Lack of support facilities (enrichment, fuel reprocessing) — a serious barrier to obtaining weapon material;
- The time required to obtain weapons grade material (or direct use material) from nuclear material present in the AES-2006 system (uranium fuel containing less than 20% ^{235}U enrichment), which is estimated by IAEA experts as 3–12 months. However, in the absence of equipment, this period increases significantly, which guarantees early detection;
- Accuracy of accounting ensuring that it is impossible to have undeclared material or to have a discrepancy between the amount of declared and the physical material by an amount sufficient to produce nuclear weapons.

Final assessment of criterion CR4.2 — robustness of barriers

There are sufficient robust physical and technical barriers in the design of the AES-2006 to prevent undetected diversion of nuclear material for a nuclear weapons programme.

Thus criterion CR4.2 has been met.

5.5.3. Final assessment of user requirement UR4 — multiple barriers

In this report, only a general analysis of all possible paths of diversion and acquisition of nuclear material in an AES-2006 was made. Evaluation of this user requirement requires the availability of results of a more comprehensive identification and analysis of such paths that may not be covered by existing barriers. Results of such an analysis were not available to the assessor. However, similar characteristics are found in other LWRs which have been successfully safeguarded.

A large number of physical and technical barriers considered to be robust have been identified in the AES-2006 design.

Thus, user requirement UR4 has currently partly been met if IAEA safeguards measures are taken into consideration.

5.6. USER REQUIREMENT UR5 — OPTIMIZATION OF DESIGN

User requirement UR5: *The combination of intrinsic measures and extrinsic measures, compatible with other design considerations, should be optimized in the design/engineering phase to provide cost-efficient proliferation resistance.*

INPRO has developed five criteria for this user requirement, CR5.1–CR5.5.

5.6.1. Criterion CR5.1 — inclusion of proliferation resistance in NES design

Indicator IN5.1: *Proliferation resistance has been taken into account as early as possible in the design and development of the NES.*

Acceptance limit AL5.1: *Yes.*

The evaluation produced no direct evidence that aspects of proliferation resistance had been taken into account at the earliest stage of development of the NES. However, it can be assumed that the experienced designer of the AES-2006 plant has taken them into account during design development.

To be able to assess this criterion, close cooperation with the developer is required to obtain necessary information about how proliferation resistance was incorporated in the design.

Criterion CR5.1 was not assessed due to lack of data. It is recommended that missing information be collected and the assessment finalized.

5.6.2. Criterion CR5.2 — cost of proliferation resistance features and measures

Indicator IN5.2: *Cost of incorporating those intrinsic features and extrinsic measures into NES which are required to provide or improve proliferation resistance.*

Acceptance limit AL5.2: *Minimal total cost for all of the intrinsic features and extrinsic measures implemented to increase proliferation resistance over the life cycle of the NES.*

The assessor does not have enough information to evaluate criterion CR5.2. The assessor recommends adding safeguards by design to the project management as part of the design and construction in order to facilitate the implementation of cost-efficient safeguards.

5.6.3. Criterion CR5.3 — verification approach

Indicator IN5.3: *Verification approach with a level of extrinsic measures agreed between the State and verification authority (for example, the IAEA).*

Acceptance limit AL5.3: *Yes.*

The verification approach for measures to ensure proliferation resistance represented in general features was approved by the agreement on safeguards implementation in connection with the NPT, which was signed by Belarus and has been in force since 1995.

Currently, this approach has not yet started for the Belarusian NPP because, practically, it should be done at later stages of project implementation. For similar NPPs existing outside Belarus, e.g. VVER-1000 (PWR type reactor), all requirements of the verification approach have been approved and met.

Before starting up the first nuclear power generating unit in Belarus, not much time is required to execute the verification approach, i.e. to develop a facility attachment to the existing safeguards agreement between Belarus and the IAEA to ensure proliferation resistance at this stage. Nevertheless, the activities related to specification and approval of the verification approach with IAEA safeguards must be carried out before the shipment of nuclear fuel to the NPP.

Criterion CR5.1 has been met.

5.6.4. Final assessment of user requirement UR5 — optimization of design

Some information needed to assess this user requirement was not available to the assessor, i.e. whether proliferation resistance was taken into account in early design stages and what the costs were to incorporate intrinsic features into the design.

The safeguard verification process will start in accordance with the comprehensive safeguards agreement in place before the nuclear fuel will be shipped to the NPP.

Thus, user requirement UR5 has been partly satisfied.

5.7. SUMMARY AND CONCLUSION OF THE ASSESSMENT OF PROLIFERATION RESISTANCE

The obligations of the State with regard to the establishment of a legal framework dealing with nonproliferation have been met by Belarus. The ratification of the additional protocol to the existing comprehensive safeguards agreement is ongoing.

The attractiveness of technology used in the NES of Belarus for a weapon programme is very low as there is no enrichment or reprocessing plant planned to be built in the country. However, if an additional protocol to the State’s safeguards agreement has not been implemented, then the IAEA safeguards approach cannot verify that no enrichment or reprocessing capability exists. The nuclear material used in the planned NPP AES-2006 is also not attractive for such a programme due to its form, quantity and quality.

The design of the AES-2006 ensures great difficulty to misuse the plant for proliferation and a high detectability of any activity to divert nuclear material for such a purpose.

Although no results of a detailed acquisition and diversion path analysis were available for assessment, a significant number of robust barriers could be identified in the AES-2006 design against diversion of nuclear material.

The status of activities regarding implementation of the safeguards agreement for the planned NPP AES-2006, i.e. the establishment of a facility attachment, is proceeding according to schedule. The verification process will start before the nuclear fuel is delivered to the plant.

It is recommended that also the planned national nuclear fuel cycle facilities be assessed regarding proliferation resistance, especially the interim dry storage facility for spent fuel.

It can be assumed that if the IAEA safeguards similar to those applied at most LWRs in non-nuclear weapon States are successfully applied, then appropriate levels of proliferation resistance will be reached.

6. PHYSICAL PROTECTION

6.1. INTRODUCTION

In this section, physical protection of the Belarus NES is assessed using the INPRO methodology as defined in Volume 6 of *IAEA-TECDOC-1575 Rev.1* (*INPRO Manual*).

INPRO has defined one **basic principle** for this area: *A physical protection regime shall be effectively and efficiently implemented for the full lifecycle of an NES.*

To check whether the goal of this basic principle has been met, INPRO developed twelve user requirements, UR1–UR12.

In a general way, this basic principle is also touched upon in the assessment of the INPRO methodology area of infrastructure in the evaluation of its first user requirement (UR1, legal and institutional framework).

6.2. USER REQUIEMENT UR1 — LEGISLATIVE AND REGULATORY FRAMEWORK

User requirement UR1: Prior to the deployment of the innovative NES, a legislative and regulatory framework to govern physical protection should be established.

INPRO developed three criteria for this user requirement, CR1.1, CR1.2 and CR1.3.

6.2.1. Criterion CR1.1 — roles and responsibilities of State

Indicator IN1.1.1: *Have the competent authorities (such as regulatory authorities, response force authorities) been designated, empowered and responsibilities defined (or planned)?*

Acceptance limit AL1.1: *Yes.*

The IAEA has published recommendations on the establishment of physical protection regimes in the Member States [77, 78] covering issues related to legislative and regulatory framework.

In the following the legal basis for designation, empowerment and responsibilities of authorities dealing with physical protection in Belarus is described.

The legislative basis and regulatory authorities in the area of physical protection are defined in the law [1], Chapter 2 of Article 5: "*For assurance of physical protection of nuclear power facilities the government of Belarus in the field of nuclear power application and within its competence defines conditions and procedures and implementation procedures of State surveillance*".

Chapter 2 Article 7 of the law [1] reads: "*Other State authorities for safety regulation of nuclear power applications within their competence carry out control of physical protection assurance of nuclear power facilities. The Ministry for Emergency Situations of Belarus within its competence carries out State surveillance in the field of assurance of nuclear and radiation safety as well as physical protection assurance of nuclear power facilities*".

The Decision of Council of Ministers of Belarus [79] reads: "*Issue of special permits (licences) to carry out activity in the field of industrial safety (hereinafter referred to as licences), their duplicates, to amend or supplement the licence, suspension, resumption, extension of validity term of the licence, termination of licences, control for carrying out activities in the field of industrial safety (hereinafter referred to as licensable activities) is implemented by Ministry for Emergency Situations in accordance with the provision on licensing of these activities, as approved by the Decree and this Provision*".

In accordance with the Decree of the President of Belarus [15] the department on nuclear and radiation safety (Gosatomnadzor) of Ministry for Emergency Situations has been established and the provision on Gosatomnadzor has been approved.

Gosatomnadzor, in accordance with its functions within its competence, arranges and conducts State surveillance to:

- ensure physical protection of nuclear material and facilities, radiation sources, and storage sites;
- maintain the SSAC, the integrated State system of accounting and control for sources of ionizing radiation, and storage sites;
- develop requirements and conditions eliminating possibility to commit terrorist acts at radiation facilities, nuclear installations, nuclear power facilities and storage sites.

In accordance with item 3.2.1 of the *Order of the State Committee on surveillance for safety working conditions in industry and nuclear power of Belarus* [80]:

- Ministry for Emergency Situations is the competent authority for physical protection of nuclear material and nuclear facilities.
- Ministry for Emergency Situations, Gosatomnadzor in cooperation with other concerned agencies and organizations, develops and reviews regulations and rules related to physical protection. Regulations, rules and other regulatory and technical documentation must not contradict the legislation of the Republic, the Convention on the Physical Protection of Nuclear Material and other international conventions and agreements which Belarus has acceded to or is going to accede to.

Final assessment of criterion CR1.1 roles and responsibilities of the State

In Belarus, competent authorities have been defined and empowered by appropriate laws. Currently, activities are carried out to improve the regulatory framework (see also section 3.2 of this report, assessment of user requirement UR1 in the area infrastructure of the INPRO methodology).

The requirements of criterion CR1.1 can be considered to be met.

6.2.2. Criterion CR1.2 — regulation development

Indicator IN1.2: *Has the legislative and regulatory framework related to physical protection been developed (or is it under development)?*

Acceptance limit AL1.2: *Yes, in accordance with international standards*.

Item 3.4.1 of the *Order of the State Committee on surveillance for safety working conditions in industry and nuclear power* of Belarus [80] deals with licensing of the activities related to use, storage and transportation of nuclear material:

All activities in Belarus, related to use and storage of nuclear material require a permit (licence). A permit from the Ministry for Emergency Situations is also required to transport nuclear material.

Assurance of physical protection is a compulsory prerequisite to obtain a permit (licence) for design and operation of nuclear installations and storage sites of nuclear material.

The procedure for issuing permits (licences) to industrial operators is regulated by a Decision of the Council of Ministers of Belarus [79]. The Ministry for Emergency Situations is the State authority in Belarus carrying out licensing of activities related to use, storage and transportation of nuclear material.

The following legal acts on licensing have been developed and are in force:

- Decree of the President of Belarus *On the procedure for licensing of activities related to specific goods (work, services)* [81];
- Decree of the President of Belarus *On the licensing of special kinds of activity* [82];
- Decision of Council of Ministers of Belarus *On approval of the provision on licensing of activities in the field of industrial safety and the provision on licensing the activity for assurance of fire safety* [79];
- Decision of Ministry for Emergency Situations of Belarus *On licensing the activity in the field of industrial safety, on fire safety assurance and the activity related to control of radioactive pollution* [83].

However, today not all physical protection areas are regulated by appropriate legal acts. There is a programme for development of required technical legal acts for physical protection. Thus, the following technical codes for the established practice have been developed:

- Procedure of determination of the physical protection level of material, nuclear installations and radioactive waste [84];
- Physical protection system of nuclear material and nuclear installation Manual on design organization [85];
- Basic rules of safety and physical protection by transportation of radioactive material [86];
- Provisions on general requirements for physical protection system of nuclear power facility [87]; and
- Physical protection system of nuclear material and nuclear installations. Requirements for design decisions [88].

Final assessment of criterion CR1.2 — regulation development

Certain parts of physical protection regulation have been established. Activities are currently being carried out to develop all required documents and organizational structures.

Thus, criterion CR1.2 has been met.

6.2.3. Criterion CR1.3 — responsibilities of licence holder

Indicator IN1.3: *Have the physical protection responsibilities and authorities of the facility operator and other stakeholders been clearly defined?*

Acceptance limit AL1.3: *Yes, in accordance with State physical protection regulations and other relevant legislation.*

Chapter 23 of the law [1] assigns the responsibility for physical protection to the operator of nuclear installation.

According to item 3.2.1 of the *Order of the State Committee on surveillance for safety working conditions in industry and nuclear power of Belarus* [80], the operator is responsible for establishment, implementation and content of the physical protection system in Belarus.

In accordance with item 6.6.7.3 of *Justification of Investments* [89], the basic regulatory documents considering organizational structure and peculiarities of the computer-based system for physical protection of the planned Belarusian NPP (references cannot be provided) include a:

- Provision on authorization system of access and access to nuclear material, accounting of nuclear material and storage site of nuclear material, and to information about operation of the computer-based system of physical protection;
- Manual on access control;
- Provision on security service;
- Security and defence plan of Belarusian NPP;
- Plan of cooperation for administration, security service, guards units and personnel of Belarusian NPP in standard and emergency situations;
- Plan of cooperation for administration, security service and guard units of Belarusian NPP with Ministry of Internal Affairs of the Russian Federation and Federal Security Service of the Russian Federation in standard and emergency situations;
- Plan for checking technical conditions and operability of computer-based system of physical protection.

Taking into account that not all manuals and laws on physical protection have been issued yet, there is currently no possibility to assess the clear definition and allocation of all duties for physical protection.

Final assessment of criterion CR1.3 — responsibilities of licence holder

Basic responsibilities of the licence holder are defined in different areas. However, there is no clear definition of all possible emergency situations. Currently, the documents on licensing activities related to nuclear power application are being developed, in which responsibilities of the licence holder will be more fully and clearly described.

Thus, the requirements of criterion CR1.3 have been met.

6.2.4. Final assessment of user requirement UR1 — legislative and regulatory framework

This user requirement states that a physical protection regime should be effectively and efficiently established.

Since all criteria of user requirement UR1 have been met or there is at least evidence that these criteria are going to be met as a result of ongoing development, this user requirement can be regarded as completely fulfilled.

6.3. USER REQUIREMENT UR2 — INTEGRATION OF PHYSICAL PROTECTION THROUGHOUT INPRO

User requirement UR2: *Physical protection should be integrated into all INPRO areas and throughout all phases.*

INPRO has developed three criteria for this user requirement, CR2.1, CR2.2 and CR2.3.

6.3.1. Criterion CR2.1 — physical protection integration with proliferation resistance, safety and operation

Indicator IN2.1: *Have synergies and divergences between physical protection, safety, proliferation resistance, and operations been addressed?*

Acceptance limit AL2.1: *Yes, through the review of a joint expert panel.*

In accordance with item 3.6.1, Requirements for physical protection of nuclear material, of the order [80] of the State committee, issues of physical protection should be considered at early stages of designing of a nuclear installation or storage of nuclear material.

There is no specific information available on how the designer took synergies and divergences between physical protection, proliferation resistance and safety into account in the AES-2006 design. However, some general considerations on this issue are presented.

Synergies and divergences between physical protection and nuclear safety

Close cooperation between specialists in physical protection and nuclear safety is important to ensure that a system of physical protection takes measures into account that are considered in the installation for safety purposes. During an accident, the measures for physical protection should not weaken nuclear safety and radiation protection.

According to item 5.17.2 of the terms of reference [74], a physical protection system must be fully active in normal operating conditions. During accident and emergency prevention activities, the physical protection system should not create obstacles for staff evacuation and for access of special purpose forces that are securing areas and carrying out emergency prevention activities, such as fire extinguishing, decontamination of buildings, constructions and territories).

Some of safety related features of AES-2006 design facilitate introduction and maintenance of the physical protection regime on the site. Irradiated nuclear fuel is normally to be stored in a spent fuel pool within the reactor containment and it will not be easily accessible during reactor operation.

The containment has only three spots of potential penetration (regular and emergency entrances and a loading hatch) and any two of them cannot be kept open simultaneously during reactor reloading for safety reasons, which in turn alleviates introduction of security measures.

During the reactor reloading, fuel assemblies are to be handled within one room, which is continuously under remote surveillance. This makes the monitoring of fuel security easier.

The relatively low initial enrichment of nuclear fuel (< 5%) of the AES-2006 design facilitates the handling of fuel in terms of security, e.g. during storage and transport, and also reduces its attractiveness to potential terrorists.

Synergies and divergences between physical protection and proliferation resistance

Synergy between physical protection and proliferation resistance is determined mainly by the:

- SSAC required for the non-proliferation system and physical protection;
- System of seals and surveillance needed for proliferation resistance taken into account when optimizing physical protection;
- Physical protection system helping to ensure the availability of the equipment and seals used for the implementation of safeguards.

Final assessment of criterion CR2.1 — physical protection integration with proliferation resistance and safety

As a result of the general considerations presented above, it can be concluded that synergies and divergences between physical protection, proliferation resistance, safety and operations have been considered in all three areas, physical protection, proliferation resistance and safety.

Thus, criterion CR2.1 has been met.

6.3.2. Criterion CR2.2 – physical protection in all INPRO areas

Indicator IN2.2: *Is there evidence that assessments in all areas of INPRO have accounted for physical protection?*

Acceptance limit AL2.1: *Yes.*

Physical protection is taken into account in the economic evaluation of the planned Belarus NES since establishing physical protection requires capital investments and maintenance costs (section 2 of this report); thus costs of the physical protection system in the NPP AES-2006 were considered in the justification of the investment.

The issue of staff preparation and involvement of national industry to establish the national physical protection system are discussed in the assessment of infrastructure (section 3 of this report).

The relationship of physical protection with safety and proliferation resistance has been discussed in the section (criterion CR2.1) before.

Physical protection is taken into account in nuclear waste management during transportation of waste and implementation of physical protection regime at a spent fuel storage facility.

Final assessment of criterion CR2.2 — physical protection consideration in all INPRO areas

As discussed above, physical protection is taken into account in all areas of INPRO methodology.

Thus, criterion CR2.2 has been met.

6.3.3. Criterion CR2.3 — physical protection consideration through all phases of NES

Indicator IN2.3: *Is there evidence of forethought into the issues of physical protection as the NES is shut down and decommissioned?*

Acceptance limit AL2.3: *Yes.*

The law [1], Article 23, *Physical protection assurance for facilities of nuclear power application*, states that:

Measures for assurance of physical protection of nuclear facilities or storage sites should be considered at all stages of designing, construction, commissioning, operation, limitation of operational characteristics, lifetime extension, decommissioning as well as during nuclear material management, spent nuclear material management and (or) management of radioactive operational waste.

It follows from the text of the law that physical protection has to be considered at all stages of design, construction and operation of the Belarus NES. For nuclear installations and storage sites, physical protection during decommissioning is to be defined five years prior to completion of designed service life time.

The considerations above clearly show that the national legislation requires the development of physical protection for the full lifecycle of an NES.

However, no information on a plan for decommissioning of the planned NES was available to the assessor. It is recommended that the missing information be requested from the responsible organizations or that the development of such a plan be initiated.

Thus, due to lack of information, criterion CR2.3 could not be assessed.

6.3.4. Final assessment of user requirement UR2 — integration of physical protection throughout INPRO

The above evaluations show that for the Belarus NES, physical protection has been considered in all areas of the INPRO methodology. Synergies and divergences between physical protection, proliferation resistance and nuclear safety have been addressed.

The legal basis for a lifetime provision of physical protection for the NES is in place; however, no information was available to the assessor on a plan on how to ensure physical protection during decommissioning.

Thus, user requirement UR2 can be considered to have been partially met.

6.4. USER REQUIREMENT UR3 — TRUSTWORTHINESS PROGRAMME

User requirement UR3: *A programme to determine trustworthiness should be defined and implemented.*

INPRO has developed one criterion for this user requirement, CR3.1.

6.4.1. Criterion CR3.1 — trustworthiness programme

Indicator IN3.1: *Is there a trustworthiness programme defined and implemented with established acceptance criteria?*

Acceptance limit AL3.1: *Yes.*

According to item 3.6.1, *Requirements for physical protection of nuclear material*, of the order [80] of the State committee, the following actions should facilitate the achievement of the goals of a physical protection system:

a) Limitation to a minimum of the number of people having access to nuclear material and installations. To achieve this, operator or State body responsible for physical protection can impose implementation of protected areas or areas of special importance. During the implementation of such areas it is necessary to consider the safety systems of the nuclear installation or the storage site, their location and circumstances creating a threat. Access to such areas must be limited and controlled.

b) Requirement of a preliminary trustworthiness test for all persons allowed access to nuclear material or installations on a regular basis. A physical protection system is to be developed for each specific installation and site, taking geographic location and evaluation of threat level into consideration. To ensure effective action during any possible threat, procedures for emergency situations have to be prepared.

Item 8.4 of the ‘investment justification’ [89] states that, during NPP construction, a programme for selection and preparation of staff should be started in time and in compliance with established procedures.

At present, it is recommended that selection, preparation, and definition of access for staff needed to work in an NPP be defined and operation of an NPP be controlled in accordance with the general requirements stated in the basic requirements [90] and other basic guidance documents for staffing NPPs in Russia. A list of these documents will be available at the next stage of the project.

The operator of the NPP has to ensure selection, preparation and permit for work independently and to provide support for the qualification of operator’s staff.

A set of organizational arrangements is prepared and carried out by services from the directorate of the Belarusian NPP; it consists of:

- Checking staff trustworthiness at the Belarusian NPP,
- Preparation of staff for activities in emergency situations;
- Preparation of plans, instructions, and guidance material on physical protection and safety;
- Access control of staff and vehicles to protected areas of NPP;
- Procedure for body and special search of NPP staff, contractors, visitors and vehicles;
- Access control for all areas of the NPP for staff and emergency teams in extreme situations.

The following documents have been developed for the NPP to establish a security regime, including assurance of trustworthiness:

- Regulation on the system of permission of authorization and access to nuclear material, nuclear installations and nuclear material storage and access to a computerized system for physical protection of NPP;
- Regulation on the physical protection regime at the NPP.

A programme of checking and training of nuclear specialists is planned to be developed within these programmes.

6.4.2. Final assessment of user requirement UR3 — trustworthiness

Taking into account the above evaluations, it can be concluded that certain activities on the development of a trustworthiness programme are currently being undertaken.

Considering the current early stage of the nuclear power programme in Belarus, user requirement UR3 has been met as much as can be expected now.

6.5. USER REQUIEMENT UR4 — CONFIDENTIALITY

User requirement UR4: *Sensitive information developed for all areas of INPRO should be protected in accordance with its security significance.*

INPRO has developed two criteria for this user requirement, CR4.1 and CR4.2.

6.5.1. Criterion CR4.1 — development of confidentiality programme

Indicator IN4.1: *Has a programme been developed for identifying and protecting sensitive information?*

Acceptance limit AL4.1: *Yes.*

Based on the law *On State Secrets* [91], a system for identification of sensitive information and its protection is being implemented in Belarus. Several State bodies of different levels are engaged to ensure the safety of sensitive information. They also perform regulatory, control, and coordinating functions and participate in development of programmes.

In every enterprise or institute involved in the nuclear power programme, a permanent commission has been established to perform analyses and to take decisions on the possible need to protect information.

According to item 3.7.1 *System of Information* and 3.8.1 *Protection of information on the physical protection* of the order [80] of the State committee, the physical protection system should include an information system to enable the relevant State authorities to obtain information on any changes in nuclear installations or transport of nuclear material that could affect the implementation of physical protection measures. Information on the physical protection of nuclear material in use, storage or transport, and also that on nuclear installations, which can become the object of sabotage, must be adequately protected.

A computerized system for physical protection in the Belarus NPP is being developed that takes into account organizational structure of the plant, peculiarities of operation, and regulatory framework at the object level. This system is discussed in more detail below.

It follows from the text on investment justification [89] that in a computerized system of physical protection, a data collection and processing subsystem (DCPS) and data protection subsystem are to be developed.

A DCPS is needed for collection, processing, maintaining and archiving operating data; its protection against unauthorized access to the database and to the software of the DCPS, management of initiating mechanisms, and monitoring and visualization of the status of DCPS components. The hardware of the DCPS includes a server with automated working stations, a main and peripheral controller, and data communication equipment.

A system of information protection is needed to prevent information leaks or illegal influence on information through technical channels, to warn of unintentional or deliberate programme and technical influences to break integrity (deletion, distortion) of information during its processing, transfer and storage or of destruction of hardware. The system of information protection includes the complex of tools and activities to protect the information at all management levels and stages of the computerized system of physical protection operation (transfer, collection, processing, analysis, data storage, transfer of control command).

Final assessment of criterion CR4.1 confidentiality programme

The general legal framework for identification and protection of sensitive information has been established in Belarus and a corresponding system of confidentiality has been implemented in all existing organizations dealing with nuclear energy. The development of the confidentiality programme for the planned NES will be based on this legal framework.

No detailed information was available to the assessor about the current status of measures to be taken to ensure adequate confidentiality of all documents related to the design and operation of all facilities of the planned Belarus NES, i.e. the NPP and waste management facilities.

The confidentiality of data collected by the computerized physical protection system of the AES-2006 plant is ensured by the design of this computerized system.

Thus, currently criterion CR4.1 is partly met.

6.5.2. Criterion CR4.2 — installation of confidentiality programme

Indicator IN4.2: *Have procedures been installed at all levels to identify and protect sensitive information?*

Acceptance limit AL4.2: *Yes.*

A confidentiality programme will be installed after the completion of its development.

The corresponding general legal provisions on how to protect all sensitive information in Belarus are described in more detail below.

Article 15 of the law of Belarus [91] *The classification of information as State secrets and determination of their degree of secrecy* stipulates that lists of information to be classified are produced by national authorities, other State bodies and organizations with a mandate to propose information as State secrets and their protection, according to a list of information constituting State secrets approved by the President of Belarus.

These lists of information to be classified have to be approved by national authorities, other Government agencies and organizations authorized to classify information as State secrets and to protect it, in coordination with the State security authorities of Belarus, They have to be reviewed as necessary, but not less than every five years.

Legal entities and individuals who are allowed to access State secrets and who receive — as a result of their activities — information that should be subject to secrecy are obliged to submit a proposal on the need to classify this information as State secret and its justification to the authority, other State body or organization that is authorized to classify information as State secrets and to protect it.

During compilation of the list of information to be classified, the degree of secrecy of information is to be included in the list.

Article 16, Classification of information constituting State secrets, of the law [91] states that the basis for classification of information received by a legal entity or individual as a result of activities is the list of information to be classified. During the classification of information the appropriate secrecy level is to be assigned to the item which bears the information or the accompanying documentation.

If one cannot classify the information within the existing list of classified information, the legal entity or individual who has received the information must send a proposal on modification of the list to the head of the responsible national authority.

The head of the authority body must arrange an expert review of proposals received in accordance with the second part of this article and take appropriate action to supplement or amend the list of information to be classified.

The head of the legal entity that created the information in this article specified above must take action on non-proliferation of this information in accordance with the laws of Belarus until the decision of the head of the authority that is authorized to classify information as State secrets and to protect it. Classification of the information received is to be carried out after appropriate modifications to the list of information to be classified.

Final assessment of criterion CR4.2 — installation of confidentiality programme

The legal requirements on how to protect sensitive information in Belarus have been described in detail. The programme can, however, be implemented only when the NES is installed.

Thus, currently, criterion CR4.2 cannot be assessed due to the early stage of the nuclear power programme.

6.5.3. Final assessment of user requirement UR4 — confidentiality

The legal basis for development and implementation of a confidentiality programme for the planned NES is available in Belarus.

However, no detailed information was available to the assessor on the status of development of this programme. It is recommended that the missing information be collected and the assessment finalized.

Thus, UR4 has been partly met.

6.6. USER REQUIREMENT UR5 — THREAT

User requirement UR5: *The physical protection systems should be based on the State's current evaluation of the threats.*

INPRO has developed four criteria for this user requirement, CR5.1 to CR5.4.

6.6.1. Criterion CR5.1 — development of a design basis threat

Indicator IN5.1: *Is there evidence that a design basis threat or other appropriate threat statement has been developed?*

Acceptance limit AL5.1: *Yes.*

IAEA recommends [92] that the overall responsibility for the development, use, and maintenance of a design basis threat (DBT) should rest with the State. The manner in which this is accomplished within a State depends on the State's own arrangements for developing policy, legislation, and regulation. There may be flexibility in having different competent authorities involved in the DBT process: one for development and maintenance of the DBT, and other(s) for use of the DBT. It is recommended that all these activities be assigned to the single competent authority responsible for the use of a DBT (e.g. regulatory body) owing to its insight into the physical protection that a DBT will influence; however, the decision on who will be the competent authority for DBT development and maintenance remains with the State. If the State decides to have separate authorities for these two roles, an important element of coordination is to ensure that DBTs are developed that fit into the regulatory scheme. In particular, close coordination is needed between these two authorities to identify the types of facilities/licensees for which DBTs are needed (based on the regulatory framework) and to ensure that the development of these DBTs take into account the potential consequences related to the theft and radiological sabotage of nuclear and other radioactive material for each type of facility and licensee.

In Belarus the development of DBT is entrusted to the design organization, as it develops all physical protection systems. A document [88] includes a section regulating the requirements for conducting an analysis of vulnerability of nuclear facilities. A procedure for forming "a model of an intruder" is set up. In addition to the programme "model of the offender", also a vulnerability analyshas been method is being developed (content of the programme is secret). According to the designer such a system has been developed and will be launched from the beginning of construction work. This programme takes into account the specifics of the location of NPPs.

The assessor assumes that the regulatory body of Belarus will review the DBT development results to be provided by designer and will have them adopted.

Thus, preparatory work to establish a design basis threat is conducted and criterion CR5.1 can be assumed as fulfilled.

6.6.2. Criterion CR5.2 — periodic review of threats

Indicator IN5.2: *Are there provisions for a periodic review of the threat by the State?*

Acceptance limit AL5.2: *Yes***.**

Currently, in the legislation and regulation of Belarus there is no explicit requirement on a periodic review of the major threats programme by the State but for the operating organization as outlined in the following.

Section 3.7.1 "*Ensuring the reliability and quality of physical protection*" of the order [80] reads: "*In order to maintain the physical protection measures in a good condition, in which an effective respond to potential threats is possible, the operating organization develops* *programmes, ensuring quality and reliability of physical protection at nuclear facilities and during transportation of nuclear material and coordinates these programmes with relevant government agencies”*.

Such programmes of the operator should include periodic testing of systems for detection, alarm and communication, and for periodic monitoring of the implementation of security procedures. They should also include trainings to test the skills and preparedness of accompanying staff**,** guards and response forces outside of the plants area.

However a new regulation [93] is under development that includes a requirement for periodic review of threats by the State and the utility. According to section 9.2 “Frequency of vulnerability analysis” of this new regulation [93]:

“*Frequency of vulnerability analysis on the existing nuclear facilities is determined by the utility in coordination with the regulatory body of Belarus”*.

In addition, vulnerability analysis is conducted in the following cases:

- Changes of a threat at the State level, determined by the relevant authorities;
- Changes of the internal and external design basis threat;
- Changes in the conditions of a nuclear facility, technology, production, usage and storage of nuclear material, equipment condition;
- Reconstruction of the nuclear facilities.

Nuclear facilities can also conduct vulnerability analysis and in other cases on their own initiative.

Final assessment of criterion CR5.2 — periodic review of threats

A regulatory document that requires periodic review of the threats by the State is under development. Thus, criterion CR5.2 has been satisfied.

6.6.3. Criterion CR5.3 — DBT as basis for physical protection systems

Indicator IN5.3: *Is there evidence that the concept of design basis threat (DBT) or other appropriate statement has been used to establish the physical protection systems (PPSs)?*

Acceptance limits AL5.3: *Yes.*

A document [88] specifies that the design of a PPS should take into account the results of a vulnerability analysis and other programmes performed.

According to experts, who are developing the physical protection system for the Belarusian NPP, a design basis threat concept, which is called the "Model of the offender", is used as the basis for development of the system. This model examines all possible ways of criminal (malicious) actions and provides corresponding barriers for these ways.

Thus, the design basis threat concept is being used as a basis for the development of the physical protection system of the planned NPP. However, no information was available to the assessor about physical protection systems needed for other facilities of the planned Belarus NES, e.g. for waste management facilities.

Criterion CR5.3 has been partly satisfied.

6.6.4. Criterion CR5.4 — flexibility in physical protection system

Indicator IN5.4: *Has the designer introduced flexibility in PPS design to cope with the dynamic nature of threat and prepared protection plans?*

Acceptance limit AL5.4: *Yes.*

Requirements for flexibility of PPS were not identified in the regulatory framework of Belarus. No information was available to the assessor on the introduction of flexibility in the physical protection plans for the nuclear facilities of the planned NES of Belarus. It is recommended that the missing information be requested from the designer of the PPS, i.e. the owner/operator of the nuclear facilities and complete the assessment.

Thus, due to lack of data criterion CR5.4 has not been fulfilled.

6.6.5. Final assessment of user requirement UR5 — threats

This user requirement requires that the PPS for all nuclear facilities should be developed (by the owner/operator) based on the design basis threat (DBT), which should be produced and regularly reviewed by the State.

For the planned NPP AES-2006 a DBT is under development, a regular review of it is foreseen, and it is being used to develop the PPS, i.e. all criteria of this user requirement are fulfilled, except criterion CR5.4 that requires built-in flexibility in the PPS. Work is needed to determine the requirements for flexibility of PPS and to use these requirements as a basis for developing PPS.

No information on PPS was available to the assessor regarding the other planned facilities of the NES, i.e. the waste management facilities.

Thus, user requirement UR5 has been partly fulfilled.

6.7. USER REQUIEMENT UR6 — GRADED APPROACH

User requirement UR6: *Physical protection requirements should be based on a graded approach.*

INPRO has developed two criteria for this user requirement, CR6.1 and CR6.2.

6.7.1. Criterion CR6.1 — limits for consequences

Indicator IN6.1: *Has the State defined limits for consequences of malicious acts directed against nuclear material and facilities (including transports)?*

Acceptance limit AL6.1: *Yes.*

The document [88] requires the determination and assessment of potential damages from threats, defined in the ‘offender model’ and by the analysis of vulnerabilities.

At this stage of the Belarusian nuclear power project, limits for consequences of malicious acts have not yet been determined, but there are requirements in the regulatory framework to identify these effects.

Final assessment of criterion CR6.1 limits of consequences

Belarus regulation requires the definition of limits for consequences of malicious acts against nuclear material and facilities. However, at this stage of the nuclear power programme these limits have not yet been defined.

Thus, criterion CR6.1 has currently been partially satisfied.

6.7.2. Criterion CR6.2 — graded approach

Indicator IN6.2: *Has the concept of a graded approach been used by the State to specify physical protection requirements and by the operator to define the physical protection system?*

Acceptance limit AL6.2: *Yes.*

The regulation [94] identifies requirements for the physical protection of nuclear material and installations, including.

Section 5.3.1 of [94], which reads: *[The classification of nuclear material] is provided for the purpose of proper correspondence between the concrete nuclear material and measures of its physical protection; it provides classification based on its degree of potential danger, which in turn is determined by: the type of material, isotopic composition, physical and chemical form, the degree of enrichment, and the level of radiation.*

3.6.1.1 of [94], which reads: *The concept of physical protection requires a planned set of equipment (technical equipment to ensure security), procedures (including the organization of security services and performance of its duties) and facility design (including location plan).*

The physical protection system is to be developed for each specific installation and storage site, taking geographic location and assessment of the degree of threat into account. To ensure effective action for any possible threat, emergency procedures should be prepared.

Final assessment of criterion CR6.2 — graded approach

In the regulation of Belarus, a requirement is defined to use a graded approach for developing threat assessment and the physical protection system.

However, no information was available to the assessor on whether such a graded approach has been used by the State in developing the design basis threat nor whether the owner/operator has used such an approach for developing physical protection systems. It is recommended that the missing information be collected and the assessment completed.

Currently, due to lack of data, criterion CR6.2 cannot be assessed.

6.7.3. Final assessment of user requirement UR6 — graded approach

This user requirement stipulates the application of a graded approach in the physical protection requirements, i.e. for the State to define unacceptable and acceptable consequences of malicious acts against nuclear material or installations.

The existing regulation in Belarus mentions the need to use a graded approach in developing physical protection requirements and a physical protection system based on these requirements.

However, at this early stage of the Belarus nuclear power programme no information was available whether such an approach is being used.

Thus, the user requirement has been partly satisfied.

6.8. USER REQUIREMENT UR7 — QUALITY ASSURANCE POLICY

User requirement UR7: *Quality assurance policy and programmes for all activities important to physical protection should be established and implemented.*

INPRO has developed one criterion for this user requirement, CR7.1.

6.8.1. Criterion CR7.1 — quality assurance policy

Indicator IN7.1: *Quality assurance policy is defined and implemented for all activities important to physical protection.*

Acceptance limit AL7.1: *Yes.*

Information on a quality assurance policy defined by the State to be applied by the operator in all nuclear facilities covering the aspect of physical protection was not made available to the assessor.

6.8.2. Final assessment of user requirement UR7

Thus, due to lack of information, criterion CR7.1 and consequently user requirement UR7 could not be assessed.

6.9. USER REQUIREMENT UR8 — SECURITY CULTURE

User requirement UR8: *All organizations involved in implementing physical protection should give due priority to development, maintenance and effective implementation of security culture in the entire organization*.

INPRO has developed one criterion for this user requirement, CR8.1.

6.9.1. Criterion CR8.1 — security culture

Indicator IN8.1: *Has a security culture programme been developed and implemented for all organizations and personnel involved in the NES?*

Acceptance limit AL8.1: *Yes.*

The IAEA has developed guidance on nuclear security culture [95] which should be implemented into the national NESs.

Necessary information on security culture in Belarus was not available to assessor. Thus, criterion CR8.1 has not been fulfilled.

6.9.2. Final assessment of user requirement UR8 — security culture

Due to lack of information, currently, this user requirement cannot be assessed.

6.10. USER REQUIREMENT UR9 — PHYSICAL PROTECTION CONSIDERATION IN SITING

User requirement UR9: *Physical protection should be considered when siting components of the NES.*

INPRO developed three criteria for this user requirement, CR9.1, CR9.2 and CR9.3.

6.10.1. Criterion CR9.1 — terrain, topography and geography

Indicator IN9.1: *Have the terrain, geography, and topography been assessed to preclude potential benefit to adversaries (e.g. high ground to observe, approach, and attack, air approaches, cover and concealment)?*

Acceptance limit AL9.1: *Yes.*

According to the information available to the assessor, in Belarus during site selection process the terrain, topography and geography of the location of the future NPP regarding their (potential) impact on the physical protection regime were not assessed.

Thus, criterion CR9.1 has not been satisfied.

6.10.2. Criterion CR9.2 — material transport and off-site response

Indicator IN9.2: *Have feasibility/flexibility, vulnerability, and efficiency of transportation and offsite response routes been assessed (air, sea, land)?*

Acceptance limit AL9.2: *Yes*.

The IAEA has developed guidance on the security of transportation of nuclear material [96] which should be implemented in the national NESs.

According to the regulation [86], vulnerability is to be analysed for transportation of nuclear material. Regulation requires that the physical protection measures provided during transportation of nuclear material ensure coping with an offender for as long as it takes rapid reaction forces to arrive.

Reliability of external response should be defined and determined on the basis of vulnerability analysis in accordance with regulatory documents under development.

During the site selection process, the transportation of nuclear material and off-site response regarding their impact on physical protection was not considered. It is recommended that the operator be requested to perform the defined assessment of transportation of nuclear material to be able to finalize the assessment.

Final assessment of criterion CR9.2 — material transport and off-site response

A regulation exists that requires physical protection of nuclear material during transport to and from the site of a nuclear facility. However, currently no data are available to the assessor to check whether this regulation has been fully implemented in corresponding procedures.

Thu, due to lack of information, this criterion could not be assessed.

6.10.3. Criterion CR9.3 — future public encroachment

Indicator IN9.3: *Has future development/encroachment by public been considered?*

Acceptance limit AL9.3: *Yes.*

This criterion overlaps partly with criterion CR5.4 (flexibility of physical protection system). Evaluation of CR5.4 resulted in a negative judgment on its fulfilment.

There are regulatory requirements for the development of physical protection systems stipulate consideration of physical protection during selection of the site. However, these regulatory requirements need further development to include actions against future public encroachment.

Final assessment of criterion CR9.3 — future public encroachment

Currently, no data are available to the assessor to evaluate this criterion.

6.10.4. Final assessment of user requirement UR9 — physical protection considerations in siting

Regulatory requirements exist (or are under development) that stipulate consideration of physical protection in siting of nuclear facilities and also cover the transport of nuclear material to and from such facilities. However, during the site selection process for the NPP, physical protection does not seem to have been taken into account. It is recommended that the missing data be collected and the assessment completed.

Due to lack of data, this user requirement could not be assessed.

6.11. USER REQUIREMENT UR10 — NUCLEAR ENERGY SYSTEM COMPONENT LAYOUT AND DESIGN

User requirement UR10: *Nuclear energy system component layout and design should be developed to minimize susceptibility and opportunities for malicious action.*

INPRO has developed two criteria for this user requirement, CR10.1 and CR10.2.

6.11.1. Criterion CR10.1 — design of NES

Indicator IN10.1: *Is there evidence that consideration has been given to physical protection in the design of the NES components?*

Acceptance limit AL10.1: *Yes.*

The AES 2006 design includes a physical protection system which is part of the complex technical and organizational measures to ensure nuclear safety and radiation protection in the plant.

Attractiveness of nuclear material used in the fuel of the reactor is rather low because its enrichment is below 5%. Spent fuel burnup is rather high (45 – 50 MWd/kgU), which means that plutonium produced in such a reactor is hardly applicable for a nuclear weapon programme. Comparing to other types of reactors, VVERs traditionally have the spent fuel pool within the containment, which provides a formidable barrier.

It should be noted that the AES-2006 is an evolution of the VVER-1000, which had no weaknesses regarding physical protection.

Final assessment of criterion CR10.1 — design of NES

A physical protection system is incorporated into the overall design of the AES-2006, which means that physical protection issues are considered at the design stage. It is assumed that physical protection will be considered also during the design phase of the other components of the NES in Belarus, i.e. the waste management facilities. Currently, there is no information available on these components.

Thus, criterion CR10.1 has been partly satisfied.

6.11.2. Criterion CR10.2 — NES layout

Indicator IN10.2: *Is there evidence that consideration has been given to physical protection in the layout of the NES components?*

Acceptance limit AL10.2: *Yes.*

No direct information was available to the assessor for evaluation of this criterion. However, it is assumed that in the layout of the AES-2006, physical protection is taken into account on the basis of the long term experience with VVER reactors in operation. It is recommended that the missing information collected and the assessment completed.

6.11.3. Final assessment of user requirement UR10 — component layout and design

Development of a physical protection system is incorporated in the overall design process of the AES-2006. No direct information was available to confirm the consideration of physical protection in the layout of the plant site, but it can be assumed that for the layout of the plant site physical protection issues have been considered.

Due to the early stage of the nuclear power programme, no information was available on the designs of the other facilities of the Belarus NES, i.e. the waste management facilities.

Thus, user requirement UR10 has been partly satisfied.

6.12. USER REQUIREMENT UR11 — DESIGN OF PHYSICAL PROTECTION SYSTEM

User requirement UR11: *The physical protection system of all NES components should be developed in uniform layers of protection using a systematic approach.*

6.12.1. Criterion CR11.1 — integrated physical protection system

Indicator IN11.1: *Has deterrence, detection, assessment, delay, and response been integrated to achieve timely interruption of a malicious act?*

Acceptance limit AL11.1: *Yes.*

According to section 6.6.3.1 of the *investment justification*, [89] the automatic system for physical protection (ASPP) of the AES-2006 is intended to:

- Establish the regime of staff access to the NPP;
- Prevent unauthorized access to protected areas, buildings, facilities;
- Create favourable conditions for guards and military forces to implement their missions, and to facilitate trespasser’s arrest;
- Provide remote monitoring of protected areas boundaries, protected buildings, premises, facilities and evaluation of the situation;
- Mark the boundaries of protected and controlled areas;
- Protect physical protection staff on duty at the border control checkpoint, at the guard positions and during the suppression of illegal actions and arrest of trespassers.

Final assessment of criterion CR11.1 — integrated system

The automatic system for physical protection of the AES-2006 has satisfied the requirements of criterion CR11.1.

6.12.2. Criterion CR11.2 — insider adversary considerations

Indicator IN11.2: *Has the physical protection system been designed with consideration of insider adversaries exploiting capabilities such as access, knowledge, and authority?*

Acceptance limit AL11.2: *Yes.*

The IAEA has developed guidance on preventive measures against insider threats [97], which should be implemented into the national NESs.

Necessary information on Belarus NPP’s physical protection system was not available to the assessor. Thus criterion CR11.2 was not assessed.

It is assumed that insider adversaries are taken into account in the physical protection system for the AES-2006. It is recommended that this assumption be confirmed to finalize the assessment.

6.12.3. Criterion CR11.3 — defence in depth

Indicator IN11.3: *Has the physical protection system been developed with several uniform and complementary layers and methods of protection?*

Acceptance limit AL11.3: *Yes.*

According to section 6.6.3.1 of the *investment justification* [89], the physical protection system should use complex engineering measures in order to enhance physical protection. Engineering measures in the physical protection system of the AES-2006 plant include:

- Physical barriers;
- Equipment at perimeter of protected areas and security posts, including an exclusion zone, special guard paths (sidewalks for military forces), trails for physical protection

engineers, engineering features and constructions, guard dogs, watchtowers, booths, warning signs, and drainage facilities;

- Protective defence for guards;
- Equipment at coach stops and places for guards on the railway stops;
- Equipment at checkpoints and posts within buildings and facilities.

In accordance with the *justification of investment* [89], the physical barriers are designed to prevent the access of unauthorized individuals and transports to/from the NPP. Besides those at the checkpoint, also other barriers block the penetration of offenders, restrict/eliminate other illegal actions, and impede unauthorized monitoring of the NPP site. The physical barriers are:

- Fortification of buildings and other constructions at the Belarusian NPP with harnened walls, floors, doors, doors, grates;
- Fortification of main control room and reserve control room, guard and security rooms, central and local control rooms (e.g. doors, shutters on windows, armored);
- Fences as the main enclosure of the plant; fencing of the external and internal exclusion zone and of protected areas;
- Engineering barriers;
- Engineered fortifications of doors, windows and other apertures;
- Fortifications of checkpoints (turnstiles, sluices, doors, anti-ram devices, guard post security features, armored chutes);
- Containers for nuclear material transportation and storage;
- Equipment for protection of operator, guards and attendants against a small arms sudden attack.

Final assessment of criterion CR11.3 — defence in depth

The defence-in-depth concept is properly applied to the physical protection system of the AES-2006 plant.

Thus, criterion CR11.3 has been met by the AES-2006.

6.12.4. Final assessment of user requirement UR11 — design of physical protection system

This user requirement stipulates a physical protection system design with uniform layers of protection, considering also insider adversaries.

The AES-2006 design satisfies this user requirement although information on dealing with insider adversaries is currently missing.

6.13. USER REQUIREMENT UR12 — CONTINGENCY PLANS

User requirement UR12: *Contingency plans to respond to unauthorized removal of nuclear material or sabotage of nuclear facilities/transport or of nuclear material, or attempts thereof, should be prepared and appropriately exercised by all licence holders and authorities concerned.*

INPRO has developed three criteria for this user requirement, CR12.1, CR12.2 and CR12.3.

6.13.1. Criterion CR12.1 — responsibilities for contingency plans

Indicator IN12.1: *Have responsibilities for the execution of emergency plans been identified?*

Acceptance limit AL12.1: *Yes.*

Necessary information was not available to assessor. CR12.1 has not been assessed.

6.13.2. Criterion CR12.2 — sabotage mitigation

Indicator IN12.2: *Have capabilities of the physical protection regime been established to prevent and mitigate radiological consequences of sabotage?*

Acceptance limit AL12.2: *Yes.*

Necessary information was not available to assessor. CR12.2 has not been assessed.

6.13.3. Criterion CR12.3 — recovery of nuclear material and facilities

Indicator IN12.3: *Have capabilities of physical protection regime been established to recover stolen nuclear material or recapture facilities before the adversary can achieve its objective?*

Acceptance limit AL12.3: *Yes.*

Necessary information was not available to assessor. CR12.3 has not been assessed.

6.13.4. Final assessment of user requirement UR12 contingency plans

The authors did not have enough information to assess UR12.

6.14. SUMMARY AND CONCLUSION OF ASSESSMENT OF PHYSICAL PROTECTION

The evaluation of the status of development of the Belarus nuclear power programme associated with physical protection of the future NPP yields the following conclusions.

A comprehensive legal framework for physical protection of nuclear installations has been established in Belarus and is currently being developed further to cover aspects of the nuclear facilities of the planned NES, especially the NPP. The legal framework includes the necessary regulations and regulatory bodies dealing with physical protection.

Physical protection is fully integrated into the design of the AES-2006 plant on the basis of long-term experience with earlier types of this design (VVER family).

Due to the early stage of the nuclear power programme sufficient information was not yet available to the assessor on some specific aspects of physical protection defined in the INPRO methodology, namely on security culture, insider adversaries, and contingency plans. It is expected that his information will become available in due time, enabling a complete assessment.

7. ENVIRONMENT

7.1. INTRODUCTION

Providing necessary energy with relatively low stress on the atmosphere, water and land resources can ensure steady development of nuclear energy. It would reduce the stress on the environment caused by electricity production using other technologies, in particular, the burning of fossil fuels.

In this section, the compatibility of the planned NES of Belarus with the environment is assessed using the INPRO methodology as defined in Volume 7 of the *INPRO Manual* [98].

INPRO developed two basic principles for this area, the first one, BP1, dealing with the impact of stressors, and the second one, BP2, covering the issue of depletion of resources.

7.2. BASIC PRINCIPLE BP1 — ACCEPTABILITY OF EXPECTED ADVERSE IMPACT ON ENVIRONMENT

Basic principle BP1: *The expected (best estimate) adverse environmental effects of the innovative NES shall be well within the performance envelope of current NESs delivering similar energy products.*

The goal of this basic principle is to ensure that new NESs installed in the 21st century should be at least as good as existing systems regarding impact on the environment.

INPRO has developed two user requirements for this basic principle, UR1.1 and UR1.2.

7.2.1. User requirement UR1.1 — controllability of environmental stressors

User requirement UR1.1: *The environmental stressors from each part of the NES over the complete life cycle should be controllable to levels meeting or superior to current standards.*

Any energy system inevitably creates sources of impact on the environment. Examples of such sources are radionuclides, non-radioactive chemical compounds, and residuals of used resources, which are potentially dangerous for the environment at a local, regional or global level. Design and operating organizations are responsible for reducing the impact below specified levels.

It is necessary to reach such levels of impact, in order to satisfy existing standards or to surpass them; in particular, standards are important which define the ecological requirements for assessment of an energy project.

Thus, to meet this user requirement, the engineering of an innovative NES has to provide control of the impact of all stressors at all stages and for all components of the system. The responsibility of the operator of nuclear facilities is to use these controls to meet the regulatory standards.

INPRO has developed one criterion for this user requirement, CR1.1.1.

7.2.1.1. Criterion CR1.1.1 — stressors

Indicator IN1.1.1: $L_{St\text{-}i}$, = level of stressor i.

Acceptance limit AL1.1.1: $L_{St\text{-}i} < S_i$, where S_i is the standard for stressor i.

The *INPRO Manual* (Volume 7 of *TECDOC-1575 Rev.1*) describes a simplified method for assessing stressors caused by release of radionuclides from new nuclear facilities. The prerequisite for that simplified approach is that a reference nuclear facility can be defined by the assessor that meets the following requirements — namely that the:

- New and reference facility release the same radioactive nuclides;
- Release rates of the new facility are equal or lower than those from the reference facility;
- Reference facility is comparable to the new facility from an environmental point of view, e.g. population density, wind patterns.

Such a reference facility was not found by the assessor for the AES-2006 plant to be built in Belarus, primarily because the environment around the new plant is too different from that of AES-2006 plants in the country of the supplier, the Russian Federation. However, a comprehensive national environmental impact study [99–102] for the planned installation of two units of AES-2006 at the chosen site in Belarus was available to the assessor. This was used as basis for the following assessment. This national study covers — in addition to release of radioactive nuclides — all other possible stressors, such as toxic chemicals.

For evaluation of criterion CR1.1.1 the assessor has considered several stressors, including:

- Release of radioactive gas and aerosols;
- Leakage of radioactive water into groundwater and surface water;
- Release of heat and humidity by cooling towers;
- Release of toxic chemicals into groundwater and surface water;
- Intake of water from the river;
- Change of landscape, vegetation and fauna at plant site during construction and operation.

For these stressors, seventeen evaluation parameters (EPs) were introduced with their corresponding acceptance limits (ALs) based on national standards.

Stressor No. 1: Potential radioactive gas-aerosol pollution of environment.
Source: Gas-aerosol emissions from the stack of the NPP.
EP1.1.1.1: Maximum soil pollution.
AL1.1.1.1: Maximum pollution is less than natural soil pollution with radionuclide, equal to 1.85 kBq/m^2.
EP1.1.1.2: Annual effective dose of critical group.
AL1.1.1.2: Annual effective dose of critical group of people is less the recommended dose limit.
EP1.1.1.3: Dose stress on the biota at the region of disposal.
AL1.1.1.3: Limit dose to biota for accidental exposure is 1Gy.

Radiation exposure and dose for the people living in the Ostrovetsky region, where an AES-2006 reactor is located, was forecast to estimate the level of possible environmental pollution caused by the gas-aerosol emission from the plant during its normal operation.

To calculate the influence of radiation released from the NPP on the environment and the dose to people, a computer system was used based on the general methods of environmental impact analysis and on consideration of both Russian and Belarusian regulatory documents, and also IAEA and ICRP documents. A technological standard [103] is taken as a basis for the design procedure. It uses, following a Gaussian model, equations of statistical theory for atmospheric diffusion stability with a system of classification categories by Paskeville. Additional guidance was used in developing the methods of calculation as documented in [104–107]:

To perform the calculation, the following parameters were determined: characteristics of the emission source, i.e. effective height of emission, the initial radius of the radioactive cloud, radionuclides and quantitative formulas of emission; meteorological conditions, i.e. wind speed and direction, type and rate of precipitation, and the class of atmospheric diffusion stability.

Weather conditions in the model are defined by the following parameters: the class of atmospheric diffusion stability by Paskeville (A to F); wind speed, and rainfall rate in mm/hr, i.e. a parameter that determines the rate of depletion of a cloud due to leaching of sediments; wind direction. The above parameters are assumed to be constant throughout the time of emission.

The geometry of the emission source is determined by its effective height and the initial radius of the radioactive cloud.

This technique allows the calculation of the radiation dose to the population in terms of long-term permanent or quasi-stationary time-emission during normal operation, and also short-term emission in emergency situations.

During the calculation, generally accepted methods can be used for calculating doses of external and internal exposure due to a radioactive emission cloud, radioactive fallout on the earth’s surface; penetration of radioactive substances into the human body via inhaled air and local food contaminated with radioactive substances.

The calculation results obtained by this method are valid up to a distance of 30 to 40 km from the source.

The obtained results of the calculation of radiation conditions and exposure of the population were compared with similar data presented in preliminary safety analysis reports [108] and [109]. A satisfactory concurrence of the results of calculations was found.

In estimating the gas-aerosol radioactive emissions of an AES-2006 plant, the basis was the emissions of a VVER-1000, presented in report [108]. Data of AES-2006 were obtained by extrapolation of radioactive gas-aerosol emissions from a VVER-1000 reactor running at a capacity of 1200 MW(e). [99]

Radioactive gaseous waste is generated in the containment and other rooms as a result of leakage of primary coolant, and released through the exhaust system into the environment. The air, emitted into the atmosphere from rooms with sources of radioactive contamination, passes through a two-step purification process removing aerosols and iodine by special filters.

Calculation of the emission of radioactive products into the environment is based on the:

- Activity of the primary coolant meeting the operational limit of damage to fuel rods;
- Release of IRG (inert radioactive gases) from stack via the exhaust system without any cleaning;
- Cleaning efficiency of filters of ventilation systems: aerosols — 99.9%; molecular iodine — 99.9%; organic iodine — 99%.

Table 36 shows the annual emission of gas-aerosols from the stack during normal operation of an AES-2006 plant.

In the calculations to assess the radiation impact on the environment during normal operation of an AES-2006, the data adopted were:

- Number of units: 2;
- Duration of emission: 60 years;
- Height of the stack: 100 metres

- Nature of emissions: continuous;
- Effective rate of dry deposition: IRG — 0 m/s; iodine — 0.02 m/s; aerosols — 0.008 m/s;
- Temperature difference between exhaust air from stack and environment: 10˚C;
- Surface roughness: 1 m.

Leaching of radioactive impurity by precipitation was neglected.

TABLE 36. ANNUAL EMISSION OF GAS-AEROSOLS FROM STACK DURING NORMAL OPERATION OF AES-2006 REACTOR, GBq/a

Radionuclides	**Half-life $T_{1/2}$**	**AES-2006**	
		1 unit	2 units
H-3	12.35 years	*	*
Kr-83m	1.84 hours	*	*
Kr-85m	4.48 hours	23.9	47.8
Kr-85	10.72 years	11.9	23.8
Kr-87	76.3 mins	2.62	5.24
Kr-88	2.84 hours	28.0	56.0
Xe-131m	11.9 days	*	*
Xe-133m	2.188 days	*	*
Xe-133	5.245 days	$3.039 \cdot 10^{4}$	$6.078 \cdot 10^{4}$
Xe-135	9.09 hours	$3.24 \cdot 10^{2}$	$6.48 \cdot 10^{2}$
Xe-138	14.17 mins	$5.06 \cdot 10^{-2}$	$1.01 \cdot 10^{-1}$
I-131	8.04 days	$1.28 \cdot 10^{-2}$	$2,56 \cdot 10^{-2}$
I-132	2.3 hours	$7.43 \cdot 10^{-3}$	$1.49 \cdot 10^{-2}$
I-133	20.8 hours	$8.78 \cdot 10^{-3}$	$1.76 \cdot 10^{-2}$
I-134	52.6 mins	$1.24 \cdot 10^{-3}$	$2.48 \cdot 10^{-3}$
I-135	6.61 hours	$2.50 \cdot 10^{-2}$	$5.00 \cdot 10^{-2}$
Sr-89	50.55 days	$6.62 \cdot 10^{-4}$	$1,32 \cdot 10^{-3}$
Sr-90	29.12 years	$3.66 \cdot 10^{-5}$	$7.32 \cdot 10^{-5}$
Cs-134	2.062 years	$1.96 \cdot 10^{-2}$	$3.92 \cdot 10^{-2}$
Cs-137	30.2 years	$2.77 \cdot 10^{-2}$	$5.54 \cdot 10^{-2}$
Cr-51	27.704 days	$7.97 \cdot 10^{-3}$	$1.59 \cdot 10^{-2}$
Mn-54	312.5 days	$6.21 \cdot 10^{-3}$	$1.24 \cdot 10^{-2}$
Co-60	5.271 years	$1.49 \cdot 10^{-2}$	$2.98 \cdot 10^{-2}$
IRG	-	$3.078 \cdot 10^{4}$	$6.156 \cdot 10^{4}$
iodine	-	$5.53 \cdot 10^{-2}$	$1.11 \cdot 10^{-1}$
aerosol	-	$7.71 \cdot 10^{-2}$	$1.54 \cdot 10^{-1}$
Total	-	$3.078 \cdot 10^{4}$	$6.156 \cdot 10^{4}$

Note: * - no data available

Assessment of evaluation parameter EP1.1.1.1 radioactive pollution of soil

The main results of the calculation of radioactive air and soil pollution during normal operation of AES-2006 (2 units) for Ostrovetsky territory are shown in Tables 37–40.

Analysis of the radiation impact on the environment during normal operation of two AES-2006 reactors shows:

- Maximum concentration of radioactive impurities in the air at ground level, depending on wind rose, varies from $4.91 \cdot 10^{-2}$ Bq/m^3 ($1.32 \cdot 10^{-15}$ Ci/l) to $2.71 \cdot 10^{-1}$ Bq/m^3 ($7.33 \cdot 10^{-15}$ Ci/l);

- Maximum surface soil contamination by radionuclides in the first year of operation of two nuclear units, depending on wind rose, varies from $2.63 \cdot 10^{-2}$ Bq/m^2 ($7.10 \cdot 10^{-7}$ Ci/km^2) to $1.44 \cdot 10^{-1}$ Bq/m^2 ($3.89 \cdot 10^{-6}$ Ci/km^2);
- Even given the fact that the region of the NPP (Ostrovetsky) is considered a ‘clean’ zone regarding the level of pollution, the proportion of ground contamination from emissions during normal operation of two nuclear reactors to natural contamination is negligible and varies from $7.8 \cdot 10^{-3}$% (after the first year of operation) to $9.0 \cdot 10^{-2}$% (after 60 years of operation).

TABLE 37. AIR CONTAMINATION DURING NORMAL OPERATION OF AES-2006 (2 UNITS), OSTROVETSKY TERRITORY

Distance to source of emission, km	Concentration of radioactive impurities in air at ground level	
	Maximum, Bq/m^3	Minimum, Bq/m^3
1	$2.66 \cdot 10^{-1}$	$4.86 \cdot 10^{-2}$
1.1	$2.71 \cdot 10^{-1}$	$4.91 \cdot 10^{-2}$
2	$2.11 \cdot 10^{-1}$	$3.85 \cdot 10^{-2}$
4	$1.09 \cdot 10^{-1}$	$1.98 \cdot 10^{-2}$
6	$6.95 \cdot 10^{-2}$	$1.51 \cdot 10^{-2}$
8	$4.99 \cdot 10^{-2}$	$9.12 \cdot 10^{-3}$
10	$3.85 \cdot 10^{-2}$	$7.00 \cdot 10^{-3}$
12	$3.11 \cdot 10^{-2}$	$5.64 \cdot 10^{-3}$
14	$2.58 \cdot 10^{-2}$	$4.69 \cdot 10^{-3}$
16	$2.20 \cdot 10^{-2}$	$4.00 \cdot 10^{-3}$
18	$1.90 \cdot 10^{-2}$	$3.46 \cdot 10^{-3}$
20	$1.68 \cdot 10^{-2}$	$3.04 \cdot 10^{-3}$
25	$1.27 \cdot 10^{-2}$	$2.32 \cdot 10^{-3}$
30	$1.02 \cdot 10^{-2}$	$1.86 \cdot 10^{-3}$

TABLE 38. SOIL CONTAMINATION AFTER FIRST YEAR OF OPERATION (NORMAL OPERATION) OF AES-2006 (2 UNITS), OSTROVETSKY TERRITORY

Distance to the source of emission, km	Surface soil contamination with radionuclides	
	Maximum, Bq/m^2	Minimum, Bq/m^2
1	$1.43 \cdot 10^{-1}$	$2.60 \cdot 10^{-2}$
1.1	$1.44 \cdot 10^{-1}$	$2.63 \cdot 10^{-2}$
2	$1.12 \cdot 10^{-1}$	$2.04 \cdot 10^{-2}$
4	$5.72 \cdot 10^{-2}$	$1.04 \cdot 10^{-2}$
6	$3.59 \cdot 10^{-2}$	$6{,}54 \cdot 10^{-3}$
8	$2.54 \cdot 10^{-2}$	$4.64 \cdot 10^{-3}$
10	$1.94 \cdot 10^{-2}$	$3.54 \cdot 10^{-3}$
12	$1.55 \cdot 10^{-2}$	$2.82 \cdot 10^{-3}$
14	$1.27 \cdot 10^{-2}$	$2.32 \cdot 10^{-3}$
16	$1{,}07 \cdot 10^{-2}$	$1.94 \cdot 10^{-3}$
18	$9.13 \cdot 10^{-3}$	$1.67 \cdot 10^{-3}$
20	$7.92 \cdot 10^{-3}$	$1.44 \cdot 10^{-3}$
25	$5.83 \cdot 10^{-3}$	$1.08 \cdot 10^{-3}$
30	$4.52 \cdot 10^{-3}$	$8{,}28 \cdot 10^{-4}$

TABLE 39. SURFACE SOIL CONTAMINATION AFTER FIRST YEAR OF OPERATION OF AES-2006 (2 UNITS) AND AFTER 60 YEARS OF OPERATION, IN DIRECTION OF MAXIMUM CONTAMINATION, OSTROVETSKY TERRITORY

Distance to source of emission, km	Surface soil contamination with radionuclides, Bq/m^2	
	After 1 year of operation	After 60 years of operation
1	$1.43 \cdot 10^{-1}$	1.63
1.1	$1.44 \cdot 10^{-1}$	1.67
2	$1.12 \cdot 10^{-1}$	1.30
4	$5.72 \cdot 10^{-2}$	$6.60 \cdot 10^{-1}$
6	$3.59 \cdot 10^{-2}$	$4.16 \cdot 10^{-1}$
8	$2.54 \cdot 10^{-2}$	$2.95 \cdot 10^{-1}$
10	$1.94 \cdot 10^{-2}$	$2.65 \cdot 10^{-1}$
12	$1.55 \cdot 10^{-2}$	$1.80 \cdot 10^{-1}$
14	$1,27 \cdot 10^{-2}$	$1.48 \cdot 10^{-1}$
16	$1,07 \cdot 10^{-2}$	$1,25 \cdot 10^{-1}$
18	$9.13 \cdot 10^{-3}$	$1.06 \cdot 10^{-1}$
20	$7.92 \cdot 10^{-3}$	$9.24 \cdot 10^{-2}$
25	$5.83 \cdot 10^{-3}$	$6.82 \cdot 10^{-2}$
30	$4.52 \cdot 10^{-3}$	$5.29 \cdot 10^{-2}$

TABLE 40. MAXIMUM GROUND CONTAMINATION WITH RADIONUCLIDES FROM AES-2006 EMISSION (2 UNITS)

Characteristics	Ostrovetsky territory		
Period of NPP operation, a	1	10	60
Maximum ground contamination from NPP emission, Ci/km^2	$3.90 \cdot 10^{-6}$	$2.29 \cdot 10^{-5}$	$4.50 \cdot 10^{-5}$
Natural soil contamination with radionuclides during the NPP life cycle, Ci/km^2	~0,05	~0,05	~0,05
Portion of soil contamination with radionuclides from NPP emission to natural pollution, %	$7,8 \cdot 10^{-3}$	$4,6 \cdot 10^{-2}$	$9,0 \cdot 10^{-2}$

Thus, the acceptance limit of evaluation parameter EP1.1.1.1 has been met.

Assessment of evaluation parameter EP1.1.1.2 — radiation exposure of critical group of people

Calculations of radiation dose on the population due to gas-aerosol emissions of NPPs during normal operation were carried out by:

- External gamma-irradiation when passing a radioactive cloud;
- External gamma-irradiation from radioactive material deposited on the ground surface and local facilities;
- Internal irradiation due to inhalation of radioactive aerosols (inhalation hazard);
- Internal irradiation resulting from consumption of local food products contaminated with radioactive material.

Table 41 presents the forecast of annual effective doses to critical groups of the population due to gas-aerosol emissions during normal operation of AES-2006 (2 units) in the Ostrovetsky region.

TABLE 41. FORECAST OF ANNUAL EFFECTIVE DOSES TO CRITICAL GROUPS OF POPULATION (CHILDREN 0 TO 1 YEAR) DURING NORMAL OPERATION OF AES-2006 (2 UNITS), OSTROVETSKY TERRITORY

Distance to source of emission, km	Annual effective radiation doses to critical group of population	
	Maximum, Sv	Minimum, Sv
1	$4.09 \cdot 10^{-7}$	$7.45 \cdot 10^{-8}$
1.1	$4.14 \cdot 10^{-7}$	$7.54 \cdot 10^{-8}$
2	$3.24 \cdot 10^{-7}$	$5.88 \cdot 10^{-8}$
4	$1.67 \cdot 10^{-7}$	$3.01 \cdot 10^{-8}$
6	$1.05 \cdot 10^{-7}$	$1.91 \cdot 10^{-8}$
8	$7.46 \cdot 10^{-8}$	$1.36 \cdot 10^{-8}$
10	$5.70 \cdot 10^{-8}$	$1.09 \cdot 10^{-8}$
12	$4.56 \cdot 10^{-8}$	$8.28 \cdot 10^{-9}$
14	$3.77 \cdot 10^{-8}$	$6.83 \cdot 10^{-9}$
16	$3.17 \cdot 10^{-8}$	$5.76 \cdot 10^{-9}$
18	$2.72 \cdot 10^{-8}$	$4.94 \cdot 10^{-9}$
20	$2.36 \cdot 10^{-8}$	$4.31 \cdot 10^{-9}$
25	$1.75 \cdot 10^{-8}$	$3.20 \cdot 10^{-9}$
30	$1.39 \cdot 10^{-8}$	$2.51 \cdot 10^{-9}$

Analysis of data on radiation dose to the population during normal operation of two nuclear reactors shows that the maximum annual effective radiation doses to critical groups of population at the Ostrovetsky territory region (30 km zone of surveillance) vary across sectors ranging from $7.54 \cdot 10^{-5}$mSv ($7.54 \cdot 10^{-3}$mrem) to $4.14 \cdot 10^{-4}$mSv ($4.14 \cdot 10^{-2}$mrem).

Tables 42 and 43 present data on the annual effective radiation doses of external and internal irradiation of gas-aerosol emissions from NPPs of AES-2006 (2 units) in the maximum contamination plume in the region of Ostrovetsky territory. Analysis of the results shows that for the critical group of population, the external radiation stipulates about 27% of dose of the first year of operation, inhalation – 0.02% and the consumption of 'contaminated' food – 73%. Among the considered radionuclides, the greatest contribution to the effective dose to a considered route of exposure is made by: external irradiation from ^{88}Kr, ^{133}Xe, ^{135}Xe, ^{88}Rb, ^{134}Cs, ^{137}Cs; irradiation from intake of radionuclides ^{134}Cs and ^{137}Cs from the inhaled air; irradiation from intake of radionuclides ^{134}Cs, ^{137}Cs, ^{131}I, ^{60}Co, and ^{99}Mo from 'contaminated' food.

TABLE 42. ANNUAL EFFECTIVE DOSES OF EXTERNAL IRRADIATION OF CRITICAL POPULATION GROUPS FROM GAS-AEROSOL EMISSIONS FROM NPPS OF AES-2006 (2 UNITS) AT POINT OF MAXIMUM POLLUTION OF OSTROVETSKY TERRITORY.

Radionuclide	Ground level concentration of contamination with air, Bq/m^3	Surface soil pollution, Bq/m^2	External irradiation, Sv		
			Cloud		Soil
			Photonic irradiation	β-irradiation	Photonic irradiation
^{85m}Kr	$2.09 \cdot 10^{-4}$	-	$7.00 \cdot 10^{-11}$	$1.13 \cdot 10^{-10}$	-
^{85}Kr	$1.04 \cdot 10^{-4}$	-	$4.91 \cdot 10^{-13}$	$5.54 \cdot 10^{-11}$	-
^{87}Kr	$2.23 \cdot 10^{-5}$	-	$3.74 \cdot 10^{-11}$	$6.28 \cdot 10^{-11}$	-
^{88}Kr	$2.41 \cdot 10^{-4}$	-	$9.89 \cdot 10^{-10}$	$2.45 \cdot 10^{-10}$	-
^{89}Kr	$6.84 \cdot 10^{-9}$	-	$3.01 \cdot 10^{-14}$	$1.33 \cdot 10^{-14}$	-
^{90}Kr	$4.61 \cdot 10^{-12}$	-	$1.76 \cdot 10^{-17}$	-	-

TABLE 42. ANNUAL EFFECTIVE DOSES OF EXTERNAL IRRADIATION OF CRITICAL POPULATION GROUPS FROM GAS-AEROSOL EMISSIONS FROM NPPS OF AES-2006 (2 UNITS) AT POINT OF MAXIMUM POLLUTION OF OSTROVETSKY TERRITORY. (CONTINUED)

Radionuclide	Ground level concentration of contamination with air, Bq/m^3	Surface soil pollution, Bq/m^2	External irradiation, Sv		
			Cloud		Soil
			Photonic irradiation	β-irradiation	Photonic irradiation
^{133}Xe	$2.66 \cdot 10^{-1}$	-	$1.42 \cdot 10^{-8}$	$7.66 \cdot 10^{-8}$	-
^{135}Xe	$2.84 \cdot 10^{-3}$	-	$1.49 \cdot 10^{-9}$	$1.90 \cdot 10^{-9}$	-
^{138}Xe	$3.80 \cdot 10^{-7}$	-	$8.83 \cdot 10^{-13}$	$5.36 \cdot 10^{-13}$	
^{131}I	$1.12 \cdot 10^{-7}$	$2.24 \cdot 10^{-3}$	$9.08 \cdot 10^{-14}$	$4.54 \cdot 10^{-14}$	$1.37 \cdot 10^{-11}$
^{132}I	$6.37 \cdot 10^{-8}$	$1.50 \cdot 10^{-5}$	$3.04 \cdot 10^{-13}$	$6.62 \cdot 10^{-14}$	$5.42 \cdot 10^{-13}$
^{133}I	$7.66 \cdot 10^{-8}$	$1.66 \cdot 10^{-4}$	$9.79 \cdot 10^{-14}$	$6.66 \cdot 10^{-14}$	$1.58 \cdot 10^{-12}$
^{134}I	$1.04 \cdot 10^{-8}$	$9.44 \cdot 10^{-7}$	$5.69 \cdot 10^{-14}$	$1.36 \cdot 10^{-14}$	$3.72 \cdot 10^{-14}$
^{135}I	$2.16 \cdot 10^{-7}$	$1.49 \cdot 10^{-4}$	$7.18 \cdot 10^{-13}$	$1.68 \cdot 10^{-13}$	$3.58 \cdot 10^{-12}$
^{51}Cr	$6.98 \cdot 10^{-8}$	$1.91 \cdot 10^{-3}$	$4.85 \cdot 10^{-15}$	$5.72 \cdot 10^{-16}$	$9.64 \cdot 10^{-13}$
^{54}Mn	$5.44 \cdot 10^{-8}$	$9.25 \cdot 10^{-3}$	$9.67 \cdot 10^{-14}$	$4.90 \cdot 10^{-16}$	$1.21 \cdot 10^{-10}$
^{58}Co	$1.72 \cdot 10^{-8}$	$1.17 \cdot 10^{-3}$	$3.56 \cdot 10^{-14}$	$5.84 \cdot 10^{-15}$	$2.23 \cdot 10^{-11}$
^{59}Fe	$7.10 \cdot 10^{-10}$	$3.12 \cdot 10^{-5}$	$1.80 \cdot 10^{-15}$	$1.76 \cdot 10^{-16}$	$5.47 \cdot 10^{-13}$
^{60}Co	$1.30 \cdot 10^{-7}$	$3.02 \cdot 10^{-2}$	$6.91 \cdot 10^{-13}$	$2.66 \cdot 10^{-14}$	$1.10 \cdot 10^{-9}$
^{88}Rb	$1.94 \cdot 10^{-4}$	$2.39 \cdot 10^{-3}$	$1.39 \cdot 10^{-10}$	$8.53 \cdot 10^{-10}$	$2.15 \cdot 10^{-11}$
^{89}Rb	$1.79 \cdot 10^{-8}$	$1.87 \cdot 10^{-7}$	$7.74 \cdot 10^{-14}$	$3.82 \cdot 10^{-14}$	$6.01 \cdot 10^{-15}$
^{89}Sr	$5.80 \cdot 10^{-9}$	$2.88 \cdot 10^{-4}$	$1.04 \cdot 10^{-18}$	$7.18 \cdot 10^{-15}$	-
^{90}Sr	$3.20 \cdot 10^{-10}$	$7.82 \cdot 10^{-5}$	-	$1.33 \cdot 10^{-16}$	-
^{91}Sr	$1.37 \cdot 10^{-9}$	$5.42 \cdot 10^{-7}$	$2.03 \cdot 10^{-15}$	$1.92 \cdot 10^{-15}$	-
^{95}Zr	$3.60 \cdot 10^{-9}$	$2.26 \cdot 10^{-4}$	$5.8 \cdot 10^{-15}$	$8.92 \cdot 10^{-16}$	$2.64 \cdot 10^{-12}$
^{95}Nb	$4.08 \cdot 10^{-9}$	$1.42 \cdot 10^{-4}$	$6.67 \cdot 10^{-15}$	$3.85 \cdot 10^{-16}$	$1.72 \cdot 10^{-12}$
^{97}Zr	$5.30 \cdot 10^{-9}$	$3.73 \cdot 10^{-6}$	$2.04 \cdot 10^{-15}$	$7.91 \cdot 10^{-16}$	$5.17 \cdot 10^{-14}$
^{99}Mo	$1.42 \cdot 10^{-10}$	$3.85 \cdot 10^{-7}$	$4.48 \cdot 10^{-17}$	$1.17 \cdot 10^{-16}$	$1.84 \cdot 10^{-15}$
^{103}Ru	$1.48 \cdot 10^{-9}$	$5.76 \cdot 10^{-5}$	$1.48 \cdot 10^{-15}$	$2.35 \cdot 10^{-16}$	$4.88 \cdot 10^{-13}$
^{106}Ru	$4.73 \cdot 10^{-11}$	$8.48 \cdot 10^{-6}$	-	$1.01 \cdot 10^{-18}$	$2.78 \cdot 10^{-14}$
^{106}Rh	$7.15 \cdot 10^{-13}$	$2.47 \cdot 10^{-13}$	$3.07 \cdot 10^{-19}$	$2.15 \cdot 10^{-18}$	$8.10 \cdot 10^{-22}$
^{97}Nb	$6.30 \cdot 10^{-9}$	$3.14 \cdot 10^{-7}$	$8.74 \cdot 10^{-15}$	$6.25 \cdot 10^{-15}$	-
^{132}Te	$1.88 \cdot 10^{-9}$	$6.14 \cdot 10^{-6}$	$9.36 \cdot 10^{-16}$	$4.10 \cdot 10^{-16}$	$3.07 \cdot 10^{-14}$
^{134}Cs	$1.72 \cdot 10^{-7}$	$3.60 \cdot 10^{-2}$	$5.68 \cdot 10^{-13}$	$5.95 \cdot 10^{-14}$	$8.95 \cdot 10^{-10}$
^{137}Cs	$2.42 \cdot 10^{-7}$	$5.95 \cdot 10^{-2}$	$2.92 \cdot 10^{-13}$	$9.65 \cdot 10^{-14}$	$5.48 \cdot 10^{-10}$
^{138}Cs	$3.54 \cdot 10^{-7}$	$8.20 \cdot 10^{-6}$	$1.74 \cdot 10^{-12}$	$9.07 \cdot 10^{-13}$	$2.62 \cdot 10^{-13}$
^{140}Ba	$6.50 \cdot 10^{-9}$	$8.26 \cdot 10^{-5}$	$2.52 \cdot 10^{-15}$	$4.31 \cdot 10^{-15}$	$2.68 \cdot 10^{-13}$
^{140}La	$7.03 \cdot 10^{-9}$	$1.18 \cdot 10^{-5}$	$3.46 \cdot 10^{-14}$	$7.94 \cdot 10^{-15}$	$3.85 \cdot 10^{-13}$
^{141}Ce	$4.26 \cdot 10^{-9}$	$1.37 \cdot 10^{-4}$	$6.90 \cdot 10^{-16}$	$1.55 \cdot 10^{-15}$	$1.68 \cdot 10^{-13}$
^{144}Ce	$2.08 \cdot 10^{-9}$	$3.41 \cdot 10^{-4}$	$9.07 \cdot 10^{-17}$	$4.01 \cdot 10^{-16}$	$1.25 \cdot 10^{-13}$
^{144}Pr	$1.70 \cdot 10^{-9}$	$2.05 \cdot 10^{-8}$	$1.16 \cdot 10^{-16}$	$4.39 \cdot 10^{-15}$	$7.48 \cdot 10^{-18}$
Total	$2.71 \cdot 10^{-1}$	$1.44 \cdot 10^{-1}$	$2.89 \cdot 10^{-8}$	$7.97 \cdot 10^{-8}$	$2.74 \cdot 10^{-9}$

TABLE 43. ANNUAL EFFECTIVE DOSES OF INTERNAL IRRADIATION OF CRITICAL POPULATION GROUPS FROM GAS-AEROSOL EMISSIONS FROM AES-2006 NPPS (2 UNITS) AT POINT OF MAX. POLLUTION OF OSTROVETSKY TERRITORY

Radionuclide	Internal irradiation, Sv		
	Inhalation	Food	Sum of all routes of irradiation
^{85m}Kr	-	-	$1.84 \cdot 10^{-10}$
^{85}Kr	-	-	$5.59 \cdot 10^{-11}$
^{87}Kr	-	-	$1.02 \cdot 10^{-10}$
^{88}Kr	-	-	$1.24 \cdot 10^{-9}$
^{89}Kr	-	-	$4.34 \cdot 10^{-14}$
^{90}Kr	-	-	$1.76 \cdot 10^{-17}$
^{133}Xe	-	-	$1.03 \cdot 10^{-7}$
^{135}Xe	-	-	$3.41 \cdot 10^{-9}$
^{138}Xe	-	-	$1.43 \cdot 10^{-12}$
^{131}I	$8.32 \cdot 10^{-12}$	$3.22 \cdot 10^{-9}$	$3.25 \cdot 10^{-9}$
^{132}I	$4.85 \cdot 10^{-14}$	-	$9.61 \cdot 10^{-13}$
^{133}I	$9.60 \cdot 10^{-13}$	$7.64 \cdot 10^{-14}$	$2.78 \cdot 10^{-12}$
^{134}I	$2.65 \cdot 10^{-15}$	-	$1.04 \cdot 10^{-13}$
^{135}I	$5.70 \cdot 10^{-13}$	-	$5.03 \cdot 10^{-12}$
^{51}Cr	$4.22 \cdot 10^{-14}$	$1.84 \cdot 10^{-13}$	$1.19 \cdot 10^{-12}$
^{54}Mn	$7.97 \cdot 10^{-13}$	$8.16 \cdot 10^{-11}$	$2.03 \cdot 10^{-10}$
^{58}Co	$2.81 \cdot 10^{-13}$	-	$2.26 \cdot 10^{-11}$
^{59}Fe	$2.41 \cdot 10^{-14}$	$1.68 \cdot 10^{-13}$	$7.42 \cdot 10^{-13}$
^{60}Co	$8.86 \cdot 10^{-12}$	$5.35 \cdot 10^{-9}$	$6.46 \cdot 10^{-9}$
^{88}Rb	$3.65 \cdot 10^{-11}$	-	$1.17 \cdot 10^{-9}$
^{89}Rb	$1.52 \cdot 10^{-15}$	-	$1.24 \cdot 10^{-13}$
^{89}Sr	$7.91 \cdot 10^{-14}$	$1.56 \cdot 10^{-12}$	$1.66 \cdot 10^{-12}$
^{90}Sr	$4.90 \cdot 10^{-14}$	$1.48 \cdot 10^{-11}$	$1.48 \cdot 10^{-10}$
^{91}Sr	$2.66 \cdot 10^{-15}$	-	$6.62 \cdot 10^{-15}$
^{95}Zr	$1.10 \cdot 10^{-13}$	$7.12 \cdot 10^{-13}$	$3.47 \cdot 10^{-12}$
^{95}Nb	$4.24 \cdot 10^{-14}$	$2.20 \cdot 10^{-12}$	$3.96 \cdot 10^{-12}$
^{97}Zr	$4.36 \cdot 10^{-14}$	-	$1.05 \cdot 10^{-13}$
^{99}Mo	$1.18 \cdot 10^{-15}$	$3.01 \cdot 10^{-9}$	$3.01 \cdot 10^{-9}$
^{103}Ru	$2.65 \cdot 10^{-14}$	$1.14 \cdot 10^{-13}$	$6.31 \cdot 10^{-13}$
^{106}Ru	$4.85 \cdot 10^{-14}$	$6.17 \cdot 10^{-13}$	$6.94 \cdot 10^{-13}$
^{106}Rh	-	-	$2.46 \cdot 10^{-18}$
^{97}Nb	$1.02 \cdot 10^{-15}$	-	$1.60 \cdot 10^{-14}$
^{132}Te	$3.40 \cdot 10^{-14}$	$6.77 \cdot 10^{-14}$	$1.33 \cdot 10^{-13}$
^{134}Cs	$1.90 \cdot 10^{-11}$	$1.28 \cdot 10^{-7}$	$1.30 \cdot 10^{-7}$
^{137}Cs	$1.80 \cdot 10^{-11}$	$1.62 \cdot 10^{-7}$	$1.63 \cdot 10^{-7}$
^{138}Cs	-	-	$2.90 \cdot 10^{-12}$
^{140}Ba	$5.39 \cdot 10^{-14}$	$2.20 \cdot 10^{-14}$	$3.50 \cdot 10^{-13}$
^{140}La	$7.08 \cdot 10^{-14}$	-	$4.99 \cdot 10^{-12}$
^{141}Ce	$8.30 \cdot 10^{-14}$	$8.98 \cdot 10^{-14}$	$3.43 \cdot 10^{-13}$
^{144}Ce	$1.68 \cdot 10^{-12}$	$1.58 \cdot 10^{-11}$	$1.75 \cdot 10^{-11}$
^{144}Pr	$1.60 \cdot 10^{-16}$	-	$4.69 \cdot 10^{-15}$
Total	$9.58 \cdot 10^{-11}$	$3.02 \cdot 10^{-7}$	$4.14 \cdot 10^{-7}$

Table 44 shows the values of annual effective irradiation doses to critical groups of population in the maximum contamination plume of the proximity of Ostrovetsky site during the AES-2006 (2 units) operation.

TABLE 44. ANNUAL EFFECTIVE DOSES TO CRITICAL GROUPS OF POPULATION IN MAXIMUM CONTAMINATION PLUME OF OSTRAVETSKY TERRITORY DURING AES-2006 (2 UNITS) OPERATION

Characteristic	Value			
Period of NPP operation, a	1	10	30	60
Annual average effective calculated dose, mSv	$4.14{\cdot}10^{-4}$	$4.26{\cdot}10^{-4}$	$4.36{\cdot}10^{-4}$	$4.5{\cdot}10^{-4}$
Recommended by [57] annual dose limit	1.0	1.0	1.0	1.0
Ratio of calculated dose to dose limit, %	$4.14{\cdot}10^{-2}$	$4.26{\cdot}10^{-2}$	$4.36{\cdot}10^{-2}$	$4.5{\cdot}10^{-2}$

Analysis of calculated data (Table 44) on radiation dose of gas-aerosol emissions from NPPs of AES-2006 (2 units) in normal operation shows that the effective irradiation dose for a critical population group during the operation of NPPs represents a small proportion (less than 0.05%) of the regulated dose by norms [57].

Thus the acceptance limit of evaluation parameter EP1.1.1.2 has been met.

Assessment of evaluation parameter EP1.1.1.3 — dose stress on the biota at the region of disposal

The maximum absorbed dose to biota is caused by γ-radiation during the release of radioactive gases and amounts to 0.2 mGy per year during normal operation and 1.3 mGy in the event of a maximum credible accident [110]. As in normal plant operation and in the case of a design basis accident the majority (95%) dose of animals and plants will be caused by inert radioactive gases. The total absorbed dose animals during normal operation over the entire lifetime of the plant, and in the case of maximum credible accident will not exceed the limit dose to biota for accidental exposure of 1 Gy.

Thus the acceptance limit of EP1.1.1.3 has been met.

Final assessment of stressor No.1 — radioactive gas aerosol pollution of environment

The results of forecasts on the possible environmental pollution with radioactive gas-aerosol emissions during normal operation of AES-2006 (2 units) show that the radiation situation in the region of the NPP territory remains virtually unchanged for the entire period of plant operation (60 years). The maximum surface soil contamination with radionuclides in the first year of plant operation will not exceed 0.144 Bq/m^2 ($3.89{\cdot}10^{-6}$ Ci/km^2). At the end of 60 years of operation, maximum soil contamination will increase up to 1.67 Bq/m^2 ($4.5{\cdot}10^{-5}$ Ci/km^2). The proportion of soil contamination from the plant emissions to natural pollution (0.05 Ci/km^2) is negligible and will be $9.0{\cdot}10^{-2}$ % at the end of the 60 year operation.

Individual annual irradiation doses of a limited part of the critical group of the population caused by gas-aerosol emissions during normal operation of AES-2006 (2 units) in maximum soil contamination plume are $4.14{\cdot}10^{-4}$ mSv after one year of operation of the plant and $4.5{\cdot}10^{-4}$ mSv after 60 years, which is 0.045% of the value recommended by the national standard [57] as the limit for annual dose of 1 mSv.

In the assessment of stressor 1 the assessor relied mainly on the results of investigation performed by the Joint Institute for Power and Nuclear Research (SOSNY) which are independent from, but complementary to and in compliance with major results of the report [53].

Thus, the acceptance limits of EP1.1.1.1 and EP1.1.1.2 have been met.

The evaluation parameter EP1.1.1.3 (radiation dose to non-human biota) was assessed. It was determined that the dose limit for normal operation and the maximum credible accident was not violated. No protected species of plants were found within the NPP site.

Stressor No. 2: Potential radioactive pollution of groundwater during the life cycle of the installation.
Source: Leakage of waste water.
EP1.1.1.4: Protection of groundwater against penetration of radionuclide from the ground surface.
AL1.1.1.4: At the NPP site the groundwater should be confirmed as protected against penetration of radionuclide from the ground surface.

Potential hazard of radiation contamination of groundwater during the operation of NPP at Ostrovetsky territory (in the surveillance area, i.e. within 30 km distance from NPP) was simulated with the help of mathematical modeling [100] (see stressor #5 below).

Assessment of natural protection of groundwater performed for:

- Ground water;
- Pressurized water of intermorainal aquifer of Dneprovsko-Sozhsky sediments.

On the basis of the assessment results of the protection of pressurized water of the intermorainal aquifer of Dneprovsko-Sozhsky sediments, a conclusion about the protection criteria of pressurized water in deeper layers can be drawn.

The following time limits for migration of contamination material are selected to assess the category of groundwater protection against contamination (t):

- Unprotected aquifers: t≤10 years;
- Vulnerability aquifers: 10 years < t ≤ 30 years;
- Nominally protected aquifers: 30 years < t ≤ 60 years;
- Protected aquifers: t > 60 years.

The evaluation of the groundwater protection was made using the programme SOL-97 MAC to calculate the migration of contamination material without considering sorption processes.

In estimating the possibility of groundwater pollution with radionuclides, the following factors are taken into account: absorption features, providing the interception of radionuclides by soil and solids of the vadose (groundwater horizon) zone, restriction of movement intensity (up to full immobilization) with infiltrating water flows down to the ground water; migration features of soil and solid of vadose zone, depending on mechanical-and-physical, water-physical, filtration properties and their mineralogical composition and characterizing the intensity of front advancement of contaminated infiltrating water deep into the vadose zone to ground water; the half-life of radionuclides; form of migration of radionuclides (such as ion, complex); the intensity of the dilution of contaminated infiltration flow with ground water.

Parameters of radionuclide transfer depend on various factors. The dependence of the diffusion coefficient of radionuclides on soil moisture is taken into account. It is common practice to estimate the general absorption capacity of the soil with the help of the distribution coefficient (Kp), equal to the ratio of the radionuclide volumetric concentration in soil to the equilibrium of its content in an aqueous solution in contact with the rock samples.

Radionuclides in soil are contained in a water-soluble (cationic, anionic and neutral), soluble (mobile), and in acid-soluble and amorphous forms. The general laws of behaviour of radionuclides include their high concentration in low places at the foot of slopes, at the bottom of ravines, terrace floodplains of rivers, in watershed swamps, which are local geochemical barriers for chemical elements. The minimum concentration of radionuclides was observed on the slopes and heavily irrigated soils, and also on well-drained and aerated sandy soils of watersheds. The dual role of organic matter and humic acids in the migration of radionuclides was noted. On the one hand, they help to increase the absorption and bonding strength of the radionuclides with the soil; on the other hand, they help to increase the transition of radionuclides to the mobile state.

At the NPP location on Ostrovetsky territory (in the surveillance area), hydromorphic soils, which are characterized by excessive moisture, have limited distribution in the project area.

It is known that ^{137}Cs is usually present in a fixed form and moves by diffusion, and ^{90}Sr is generally in an exchange form and, accordingly, moves (migrates) tens of times faster than ^{137}Cs, which follows a mechanism of movement more meeting conditions of convective transport. When the front of pollution moves, dispersion of flow velocity arises. From the viewpoint of mathematical modelling of mass transport, the diffusion model for ^{137}Cs and dispersion model for ^{90}Sr can be identified to transfer radionuclides; depending on the structure of the filtration medium, there are two modifications: micro-dispersion for a homogeneous medium with double porosity and macro-dispersion for heterogeneous environments (heterogeneous bloc and the environment ordered heterogeneity). Diffusion is characterized by the coefficient of molecular diffusion; dispersion is characterized by the dispersion coefficient for each radionuclide and the structural parameters of the environment, which are determined by a neutral component.

Migration of radionuclides is accompanied by physical and chemical processes.

Such processes include ion exchange, absorption–desorption, dissolution–sedimentation, desalinization, radioactive disintegration, osmosis and complex formation.

On the basis of literary and empirical data:

- On the migration velocity, ^{90}Sr is significantly faster than ^{137}Cs (convectional mechanism is dominant for the first one, and diffusion transport mechanism for the second one, which is expressed in different coefficients of dispersion and diffusion, usually by two orders of magnitude);
- ^{90}Sr is less absorbed by soil and rock of a vadose zone than ^{137}Cs. The highest absorption properties has humus Kp = 490 to 1150 (^{90}Sr) and 1200 to 10000 ml/a (^{137}Cs). For gray wooded soil – Kp = 6 to 180 (^{90}Sr) and 36 to 6100 ml/a (^{137}Cs). For podsolic soil – Kp = 3 to 700 (^{90}Sr) and 40 to 1500 ml/a (^{137}Cs) (clay sand and sandy loam soil). For silt and podsolic sandy soil – Kp = 5 to 10 (100) (^{90}Sr) and 20 to 400 ml/a (^{137}Cs). For rock of a vadose zone the following figures are typical: sand Kp = 1 to 100 (^{90}Sr) and 10 to 300 ml/a (^{137}Cs); loam (clay) Kp = 6 to 200 (^{90}Sr) and 26 to 1000 ml/a (^{137}Cs);
- Soil has the most holding capacity in relation to radionuclides, which defines it as a buffer of higher order than a vadose zone;
- Maximum speed of ^{90}Sr through a vadose zone is 10 cm/a, and of ^{137}Cs it is 3 cm/a.

Thus, to estimate the maximum possible impact of a potential source of radionuclides on the groundwater and to determine the level of natural protection from their introduction, first it is enough to perform an assessment of isotope ^{90}Sr migration in the area studied.

Assessment of groundwater protection from radionuclide pollution, possible in the terms of normal and emergency operation of NPPs in Ostravetsky territory (in the surveillance area), was made using the criteria:

- For ground water — the intensity of radionuclide migration through the vadose zone is 0.03–0.1 m/a, capacity of the vadose zone of groundwater is established by direct hydrometric measurements on the winter low water period.
- For pressurized water — the combination within model calculative units of the factors determines the migration of radionuclides through the zone of aeration (vadose zone) and aquiferous and low permeable layers of sediment.

To estimate the groundwater protection in the proximity of Ostrovetsky territory (in the surveillance area) from radionuclide contamination during normal NPP operation, depth of groundwater level (GWL) burial data and the criteria of the intensity of migration of ^{137}Cs and ^{90}Sr are used. The following spheres of security were identified:

- Weakly protected (average depth 1.5 m GWL) for time of radionuclide infiltration from 10 to 30 years.
- Nominally protected (average depth 4.0 m GWL) for time of radionuclide infiltration from 30 to 60 years.
- Protected (average depth of more than 7.5 m GWL) for time of radionuclide infiltration over 60 years.

On the basis of analysis of groundwater protection, it can be concluded that:

- Zones of nominally protected and protected ground water from radionuclide penetration are marked on Ostravetsky territory (in the surveillance area) of possible NPP allocation.
- Ground water is nominally protected in the valleys of the rivers, streams of smaller order and gullies drain or ephemeral streams;
- Ground water of plain floods such as Losha, Oshmyanka, Rytenka are weakly protected from radionuclide contamination.
- Groundwater, formed within the plain flood of the river Viliya, are weakly protected from contamination by radionuclide at the surveillance area surrounding NPP;
- Zones of groundwater protection are in good agreement with the areas of development of certain genetic types of soils, namely:
    (a) zones of weakly protected groundwater correspond to the areas of development of hydromorphic temporarily excessively wet floodplain soddy-gley soils on sandy alluvium (floodplain rivers and streams) and hydromorphic peaty and peaty-gley soils on the sedge and wood-sedge peat, with capacity 1,0 m and more;
    (b) zones of nominally protected groundwater corresponds to the areas of semi-hydromorphic, temporarily excessively wet, soddy-gley soils on loess loam, underlain by morainic sandy clay;
    (c) zones of protected groundwater corresponds to the areas of development, widely represented by automorphic soddy-podzolic soils on loess loam, underlain by moraine sandy loam, and semi-hydromorphic sod-podzolic soils on aqueoglacial sands, underlain by moraine loam.

Assessment of the protection conditions from radionuclide contamination of confined aquifers showed that intermorainal aquifer of Dneprovsko-Sozhsky sediments and also the underlying aquifer were protected from ingress of radionuclide for estimated length of plant operation. This conclusion is based on the fact that (as shown in the section ‘Chemical contamination of groundwater in the process of NPP operation’ of [100]), these aquifers are protected from chemical contamination during the current period (100 years). Only from 0.001 to 0.02% of prime chemical contamination of NPP waste water (1750 mg/dm^3 content of chloride) can get into the pressurized water through flowover during a normal mode of NPP operation. Radionuclides are actively absorbed in the geochemical barriers (e.g. soil, clay).

Final assessment of stressor No.2 — radioactive pollution of groundwater

Thus, in the zone of the NPP location on the Ostravetsky territory (surveillance area) there are categories of weakly, conditionally and protected groundwater from radionuclide contamination. Zones of weakly and conditionally protected groundwater have locally subordinated importance and are confined to the negative relief forms, which are characterized by excessively wet water regime of the hydromorphic soil.

Pressure water of deeper seated aquifers of intermoranial and interstratal prequaternary sediments are protected from radionuclide contamination by complex factors in the region of Ostrovetsky territory (surveillance area).

At the NPP site directly, the groundwater is protected from ingress of radionuclides from the ground surface.

The acceptance limit of EP1.1.1.4 has been met.

Stressor No. 3: Radioactive pollution of surface water during the life cycle of the installation.
Source: Leakage of waste water.
EP1.1.1.5: Possibility of radioactive pollution of surface water.
AL1.1.1.5: Leakage of waste water to the land drainage and further to surface water installation without proper clearing is prevented

Radioactive contamination of surface water is possible in an emergency situation with ingress of radionuclides into waste water and then into surface water. Waste water leakage into surface run-off and then into surface water bodies is not allowed by the water legislation of Belarus without proper treatment.

To cover emergency situations with ingress of radionuclides into waste water, it is enough to construct a simple partition below the waste water outlet during the construction of the waste treatment plant in order to intercept possible accidental pollution (recommendation of [100]).

Other contaminated water or liquids may escape the facility through malfunction, breaks or accidents which are covered in Chapter 8 (Safety of nuclear reactors). These releases indicate loss of control, are identified through the use of appropriate monitoring and would need to be mitigated on a case-by-case basis. The monitoring should be planned and implemented bearing in mind the possibility of unsuspected leaks in several locations.

The acceptance limit of EP1.1.1.5 has been met.

Stressor No. 4: impact of heat and damp emission on the microclimate change.
Source: Chimney-type evaporative cooling towers, which are coolers of the recycling water supply system.
EP1.1.1.6: Humidity and drops of moisture concentration made by cooling towers at atmospheric boundary layer at summer and winter time.
AL1.1.1.6: Concentration, made by cooling towers at atmospheric boundary layer, is less than recommended MAC (maximum allowed concentration), which are for: vapour — 1000 mg/Nm^3, hydro-aerosol — 200 mg/Nm^3
EP1.1.1.7: Most additional moisture contents at the cost of cooling towers emission at the summer time.

AL1.1.1.7: Additional moisture contents should be less the moisture contents at the air under adverse background circumstances at the summer time
EP1.1.1.8: Most additional moisture contents at the cost of cooling towers emission at the winter time.
AL1.1.1.8: Additional moisture contents should be less the moisture contents at the air under adverse background circumstances at the winter time

Influence of the NPP on microclimate and atmospheric processes is due to emission of heat and moisture from the evaporative cooling towers, which constitute the cooling system for water recycling.

Assessment of evaluation parameter EP1.1.1.6 — heat and damp from cooling towers

A variant for an NPP capacity of 2400 MW(e) is envisaged: Type of cooler – counter-flow natural draft cooling towers.

For an NPP of required capacity for cooling the circulating water, four cooling towers, having the following characteristics, can be fixed (in a single-back scheme of cooling turbines).

The cooling tower is made of reinforced concrete in a hyperbolic shape. The basic dimensions of the cooling tower, area of irrigation devices (horizontal section), are 9400 m^2 with a height of the exhaust tower of 150 m and an outlet diameter of 74.7 m. The density of irrigation is 9 to 10 $m^3/(m^2*h)$. As a result, 100 000 m^3/h of circulating water can be fed thought the cooling tower with a total irrigation area of 9400 m^2 to cool.

Cooling of circulating water in the cooling tower is mainly due to evaporation. The quantity of evaporated moisture, taking into account convective heat transfer, is 1.5-2%.

Water separators of block louvered plates are to be installed in the cooling towers. This feature, along with the gravitational separation of moisture in the exhaust tower, reduces release of water, which significantly reduces its impact on the environment.

The main characteristics of cooling towers (with moisture separating device) are:

- Height: 150 m;
- Diameter of the mouth of the outlet stream:74.7 m;
- Heat flow into the environment: 4184 GJ/h;
- Flow of circulating water: 100000 m^3/h;
- Air flow: 11000 m^3/s;
- Removal of condensed moisture (droplets d=0.3 ÷ 0.4mm) in the stream: 50 m^3/h (14000 g/s);
- Steam consumption: 1080 m^3/h (300000 g/s);
- Average temperature of the flow at the exit: in summer 40^{o}C, in winter 25÷30^{o}C.

To assess the effect of the steam plume of four evaporative cooling towers on the microclimate of Ostravetsky territory, the concentration fields of condensed moisture and water vapour released from the cooling towers into the atmosphere surface layer were calculated.

The calculation was performed with the programme ECOLOG, which realizes the basic principles of *All-Union normative document-86* techniques [111] and is the leading software product used to calculate dispersion of harmful pollutants in the atmosphere (since 2003, JIPNR-SOSNY has been a licensed user of version 2.55 of ECOLOG).

Although a cooling tower is not quite the standard object for calculating dispersion, it has such features that all the basic principles of *All-Union normative document-86* [111] techniques are applicable to. However, ECOLOG is used mainly to calculate the dispersion of harmful impurities of sources with generally much lower outlays of gas-air mixture and mass emission than from a cooling tower: the maximum mass of harmful impurities emission that can be handled by ECOLOG is 99 999 g/s, while a cooling tower releases moisture in vapour form into the atmosphere at a rate of 300 000 g/s.

Therefore, to obtain correct results of the calculation, a correction was performed of mass emission with a maximum single value of surface concentration (MACm.r). The value of a mass release of steam of 30 000 g/s, and the MACm.r of steam of 0.1 mg/m^3 were introduced. In this case, the obtained values for surface concentrations in the fractions of MAC will meet the real values in mg/m^3. To maintain uniformity in the presentation of output information for the condensed moisture the following value was chosen: MACm.r = 1 mg/m^3 (concentrations value in the fractions of MAC will match the values in mg/m^3).

In addition, UPRZA ECOLOG allows calculations for a source with a diameter of mouth of 74.7 m and with the speed of gas mixture exit not more than 2.28 m/s, which corresponds to a volumetric air flow of 9999 m^3/s, while the estimated consumption of air in the cooling tower is 11 000 m^3/s.

In nominal mode, the optimum air velocity in the showering device of modern cooling towers is 1.0–1.1 m/s and in accordance with [112] it could not be higher than 3 m/s below the water separators; otherwise, it is impossible to avoid a significant increase in droplet release.

Approximate calculations were carried out, for which the rate of exit gas mixture from the mouth of the cooling tower was taken at the level of air velocity in the irrigation device, i.e. 1.1 m/s.

This assumption significantly increases the impact of cooling tower emissions on the environment, since according to the regulation [111], the maximum surface concentration of harmful substances C_m (mg/m^3) for an ejection of a gas-air mixture from a single point source with a circular mouth is determined by the following equation:

$$c_м = \frac{A \cdot M \cdot F \cdot m \cdot n \cdot \eta}{H^2 \cdot \sqrt[3]{V_1 \cdot \Delta T}}$$

Where:

A = coefficient depending on the temperature stratification of the atmosphere;

M (g/s) = weight of harmful substances emitted into the atmosphere per unit of time;

F = dimensionless coefficient that takes into account the sedimentation rate of harmful substances in the air;

m and n = coefficients considering conditions of emission of gas-air mixture from the mouth of the source term;

H (m) = height of emission source;

η = dimensionless coefficient that takes into account the influence of landscape;

Δ T (^{o}C) = temperature difference between ambient air and emitted gas-air mixture;

V_1 (m^3/s) = spending of gas-air mixture, determined by the following equation:

$$V_1 = \frac{\pi \cdot D^2}{4} \cdot \omega_0$$

Where:

D (m) = diameter of the mouth of the emission source;

ω_0 (m/s) = the average speed of gas-air mixture emission from the mouth of the emission source.

As can be seen from the equations above, the magnitude of pollutant concentrations in the surface layer of air is inversely proportional to the cube root of the flow (and velocity) of the gas-air mixture, so the underrating of values ω_0 in the input data lead to overestimating the concentration values in the calculation results.

A square with sides 24 000 m was analysed. The calculation of ground-level concentrations was carried out in the nods of regular grid with a step of 200 m; calculations with a smaller grid size do not lead to any substantial improvement in precision.

Cooling towers were located in the centre of calculated area; the distance between them was taken commensurable with their height. Moisture and steam carry-over and also air consumption were taken as constant for summer and winter.

For calculation, the meteorological parameters used were:

- The average outside air temperature of the hottest month at 23.1°C;
- The average outside air temperature of the coldest month at 6.6°C;
- The maximum wind speed (frequency of excess of which is in the framework of 5%) is 9 m/s.

It was found during approximate calculations that higher ground level concentrations of condensed moisture and vapour were observed in summer period than in winter. Therefore, the main calculation was made for summer, when delivery speed of gas and air mixture is 2.28 m/s (or air flow rate is 9999 m^3/c) and this, as shown above, results in a slightly tougher environmental impact of a cooling tower. The results of the main calculation are given in the Table 45.

The calculations for four cooling towels shows that maximal concentrations in the summer period are observed within 3.6 km from the sources and do not exceed 135.7 mg/m^3 for vapour and 6.33 mg/m^3 for condensed moisture.

Since the absence of other data regarding maximum allowable concentration (MAC) for steam and hydro-aerosols from evaporative cooling tower, working on natural or technically improved (purified) water, received results were compared to MAC from [113]: MAC for vapour is 1000 mg/m^3 and for hydro-aerosol is 200 mg/m^3.

TABLE 45. RESULTS OF CALCULATION OF ENVIRONMENTAL IMPACT FOR EMISSIONS FROM FOUR EVAPORATIVE COOLING TOWERS

Variant	Name of admixture	Maximum ground level concentration C_m, mg/m^3 (part of MAC)	The distance from the centre of calculated site, on which C_m is observed, km	Calculation period
1	condensed moisture	6.33 (0.032)	3.4	Summer
	vapour	135.7 (0.136)		
2	condensed moisture	5.63 (0.028)	3.6	Winter
	vapour	120.71 (0.12)		

Table 45 shows that the comparison of the value C_m with supposed maximum ground level concentration, i.e. 1000 mg/m3 for vapour and 200 mg/m3 for condensed moisture confirms a quite moderate impact of evaporative cooling tower on territories of emissions. Calculated concentrations of condensed moisture and vapour do not significantly threaten the environment and the determining factor is vapour.

Thus, the acceptance limit of evaluation parameter EP1.1.1.6 has been met.

Assessment of evaluation parameter EP1.1.1.7 — additional moisture by cooling towers in summer time

Analysis of climatic conditions for areas of NPP location in combination with emissions of evaporative cooling tower allows the following conclusion on emission impact of vapour to be drawn.

In the summer period, water vapour content in 1 m^3 is 2.94g when there is lower humidity (approximately 30%) and no high temperature (approximately 10°C).

Additional moisture content due to emissions from cooling towers is estimated as 135.7 mg/m^3; which means it is approximately 22 times lower than the quantity of vapour in background conditions. This influence is within the precision of measurement and it changes relative humidity approximately by 1.4%, which is not essential and cannot affect atmospheric processes related to humidity (dewfall, fogging, and haze).

Thus, the acceptance limit of evaluation parameter EP1.1.1.7 has been met.

Assessment of evaluation parameter EP1.1.1.8 — additional moisture by cooling towers in winter time

In the winter period, relative humidity, as a rule, is not less than 50%. Such low humidity is observed when the temperature is higher than -15°C (negative).

Atmospheric conditions with a temperature of -15°C and a humidity of 50% correspond to water vapour content of 0.77 g/m^3. This is 6.38 times more than the maximum moisture concentration calculated for the winter period, i.e. 120.71 mg/m^3 as a conservative value, received as a result of calculations. In winter, consumption of circulation water reduces in half approximately and, therefore, emission of moisture decreases as well in comparison with the value used in the calculations. This additional humidity can change existing relative humidity by approximately 7.8%.

The above-mentioned value of humidity change is considerably lower than quadratic mean change of water vapour content, which is 1 g/m^3 in the winter period.

Thus, in winter, even when there are the most unfavourable conditions, which happens seldom (humidity 50%, temperature -15°C) the additional moisture from the cooling tower emissions does not essentially affect the processes related to humidity.

Thus, the acceptance limit of evaluation parameter EP1.1.1.8 has been met.

Final assessment of stressor No.4 — impact of heat and damp emission on micro climate

In the case of implementation of a circulation water supply system with two cooling towers in an NPP project of the same capacity, the calculated values of peak concentration will be much lower because, in compliance with methodology [111], reducing the height of source reduces pollutant dispersion.

Thus, the evaluations have shown that significant parameter changes of microclimate and atmospheric processes related to the impact of warm and moisture emission by evaporative cooling towers will not be observed at the NPP location. Conditions for dewfall, fogging, haze in the summer period and icing of wire in the winter period will not differ from the design conditions.

The influence of NPP emissions of heat and moisture on the microclimate of the site region is not substantial and does cause any significant changes either in the animal or in the plant environment.

Thus, evaluation parameters EP1.1.1.6, EP1.1.1.7, and EP1.1.1.8 have been satisfied.

Stressor No. 5: Chemical pollution of groundwater during operation.
Source: Leak of waste water.
EP1.1.1.9: Aquifer protection from ingress of chemical contamination from land surface.
AL1.1.1.9: In the NPP site and in its ambient area, the deep aquifers should be confirmed as protected from ingress of chemical contamination from land surface.

The potential hazard of chemical contamination of groundwater during NPP operation on Ostrovetsky site (in the surveillance area, i.e. within 30 km distance from NPP) was investigated using mathematical simulation. Simulation of geofiltration processes was carried out using a multifunctional computer-based system of simulation of ground water flow and environmental impact assessment of water intake, developed by the Belarus enterprise, CNIIKIVR [100]. The system of simulation was adjusted and tested during the environmental impact assessment of water-intake facilities of Minsk Novinki and Petrovschina and also during research on planning of territories of Minsk, preparation of decisions on rational use of natural resources. The system was also used by CNIIKIVR to research the impact of anthropogenic load on groundwater resources in the areas of water intake Recta in Gorky town and Karabanovskiy in Mogilev city and also at the other groundwater intakes in Belarus and the Russian Federation.

The transfer of substance in groundwater goes along with physical and chemical processes which change its quantity. First of all, this is substance absorption and ion exchange. That is why pollution components in filtering waste water display properties of conservative and non-conservative components.

Chlorine and bromine are the conservative components in the upper hydrodynamic zones of groundwater, and non-conservative components are oil-products. Most pollution components are non-conservative, spreading in polluted groundwater defined by set of hydrodynamic and hydrogeochemical environmental conditions. Clasifying components as conservative or non-conservative defines the prediction principles of spreading in groundwater. A balance method and also methods based on convectional mass transfer models, which do not consider interaction in the water–rock system, are applied for conservative components. Models that do not consider geochemical interaction cannot be applied for spreading prediction for non-conservative components as they do not reflect hydrogeochemical reality.

There is a clear regularity regarding spreading conservative and non-conservative components in groundwater: conservative components, all other conditions being equal, can migrate in groundwater flow for more considerable distances. Detection of pollution boundary for contaminated plumes of groundwater which has the multicomponent composition of the contaminant has to be done on the basis of MAC of conservative components.

Thus, to estimate the maximum possible groundwater impact by a potential source, it is enough to evaluate the maximum possible groundwater pollution by one of the conservative components in the studied territory. For this matter, the task of forecasting chloride migration was solved using a mathematical model of the studied area.

Waste water is the potential pollution source (chemical) at an NPP. Waste water generated in the technological cycle of an NPP can contain 1750 mg/dm^3 of chlorides. The water supply or water disposal system may leak, causing inflow of seepage into groundwater. However, this is a theoretical assumption because inflow of waste water leaking into the surface flow and further into the surface water body is not allowed by current water legislation of Belarus, i.e. it must be prevented by adequate design measures.

Using a mathematical model with this theoretical assumption, it is possible to determine areas of expected chemical pollution within territories adjoining the source of pollution. Depending on the expected value of pollution intensity of groundwater, it is possible to estimate the class of protection of groundwater. Calculated pollution intensity C_i is considered to be the criterion for groundwater protection from pollution:

- Protected: $C_i \leq 0.2$ of MAC (=350 mg/dm^3);
- Relatively protected: $0.2 \cdot MAC < C_i \leq 1 \cdot MAC$;
- Non-protected: $C_i > MAC$.

Natural shielding of aquifers was evaluated for:

- Groundwater;
- Pressurized water of intermorainal aquifer of the Dneprovsko-Sozhskiy sediment.

Groundwater protection was calculated with the help of the SOL-97 MAC programme for calculation of contaminant migration ignoring absorption processes.

A conclusion on protection (pollution) conditions of pressurized water of deeper-seated aquifers is made on the basis of evaluation results of pressurized water protection of Dneprovsko-Sozhskiy sediment.

Geomigratory calculations of conservative component (chlorides) potential migration from NPP territory into adjacent territories for 25 to 100 years show that:

- During NPP operation, an aureole of chemical pollution in groundwater in adjacent territories will form. The most significant pollution is possible in the highest aquifer (groundwater);
- Pollution intensity of ground water of chloride content in the NPP area (in the surveillance area, i.e. within 30 km distance from NPP) can be up to 1000 mg/dm^3. The total area of aureole of chemical pollution in adjacent territories during NPP operation based on isopleths of expected chloride concentration 70 mg/dm^3 (or 0.2 of MAC) is about 56.5 km^2.
- Calculated pollution intensity of intermorainal (deep) aquifer during normal NPP operation by increase of chloride content is no more than 0.1–0.5 mg/dm^3 (or 0.001 of MAC). A pollution aureole of intermorainal aquifer will also form outside an NPP site for a distance up to 2.5 km.

In the expected aureole spread of chemical ground water pollution, isopleths on all specified criteria are possible to distinguish: $C_i \leq 0.2 \cdot MAC$; $0.2 \cdot MAC < C_i \leq MAC$ and $C_i > MAC$. Breakdown of expected aureole based on protection isopleths for deep-seated aquifers of pressurized water is impossible because calculated intensity value of groundwater pollution is much lower than $0.2 \cdot MAC$. Therefore, using the established criteria for the evaluation, the intermorainal aquifer of Dneprovsko-Sozhskiy sediments at the Ostrovetskiy site of the possible NPP location is fully protected against chemical pollution. Thus, the pressurized water of a deeper-seated aquifer is protected against chemical protection as well.

Final assessment of stressor No.5 — chemical pollution of groundwater

With a theoretical assumption of waste water spill at the NPP site, the mathematical modelling shows that operation of the AES-2006 plant during its expected life-cycle, in the case of its location on the Ostrovetsky site, could form an aureole of chemical pollution, with chloride concentrations of pollution up to 1000 mg/dm^3 in the highest aquifer (groundwater). Thus, to protect the groundwater, spill of waste water at the NPP site has to be avoided by adequate design measures.

There are the spots of relatively protected and unprotected groundwater in the surveillance zone of Ostrovetsky site, i.e. within a distance of 30 km from the NPP. Because of these spots, the total area of the chemically polluted ground water can reach a value around 56.5 km^2.

Pressurized water in deep-seated aquifers of intermorainal and interstratial pre-quaternary sediments in the area of Ostrovetsky site and within its surveillance zone is protected against ingress of chemical contamination from the land surface.

The acceptance limit of EP1.1.1.9 has been met.

Stressor No. 6: Chemical contamination of surface water during operation.
Source: Waste water leak, waste discharge.
EP1.1.1.10: Waste water leak into surface flow and further, into surface water bodies.
AL1.1.1.10: Waste water leak into surface flow and further into surface water bodies is not acceptable in compliance with current water legislation of Belarus.
EP1.1.1.11: Contaminant discharged waste water concentration.
AL1.1.1.11: Contaminant concentration should not exceed MAC for fishery basin.

Waste water is a source of chemical contamination at an NPP. A waste water leak — without appropriate purification — into surface flow and further into surface water bodies is not acceptable in compliance with current water legislation of Belarus and therefore it is not assessed in this study.

At present, the anthropogenic impact of current waste discharge into the basin of river Vilia (before NPP construction) does not affect water quality in the river Vilia essentially as most of indicators are up to 0.1 of MAC for fishery basin, ammonia nitrogen and nitrite nitrogen are up to 0.35 MAC (Table 46).

Influence of additional purified domestic effluent from the NPP, considering flow decrease in the river Vilia by means of withdrawal for industrial water supply of the NPP does not affect water quality in the river Vilia, either. Increase of contaminant concentration in comparison with the situation before the NPP construction will be no more that 0.1 of MAC for fishery basin (details are given in the Table 46).

Calculations of water quality prediction in river Vilia after purified NPP effluent input [101] were carried out in compliance with the Decision of the Ministry of Natural Resources and Environmental Protection of Belarus and the Ministry of Health of Belarus No. 43/42. Prediction of water quality change in the river Vilia after input of purified effluent was found acceptable, using values of purified domestic effluent flow of an NPP after full biological treatment as was done at Khmelnitskiy NPP (Ukraine) for 95% consumption of spring flood in the river Vilia.

TABLE 46. QUANTITATIVE AND QUALITATIVE COMPOSITION OF WASTE DISCHARGE FROM SOURCES OF ANTHROPOGENIC ORIGIN AND ASSESSMENT OF IMPACT ON WATER QUALITY IN VILIA RIVER (WITHOUT NAROCH LAKE)

Name of indicator	Contaminants and concentration							
	BOD_5 (biochemical oxygen demand in five days)	Oil product	sulphate	chloride	ammonia nitrogen	nitrite nitrogen	nitrate nitrogen	total iron
MAC for fishery basin (mg/dm^3)	3	0.05	100	300	0.39	0.024	9.03	0.1
Quantity of contaminants at the part of river Vilia from river head up to Lithuanian border, t/a (waste water amount is $18.663 \cdot 10^6$ m^3/a)	145.33	1.12	665.76	1255.28	100.6	8.17	86.53	6201.85
Contaminant concentration in waste water composition, mg/dm^3	7.79	0.06	35.67	67.26	5.39	0.44	4.64	0.33
The changes of the concentration (mg/dm^3) in the river when it is minimal water content (minimum daily discharge 97% of spring flood) non-registered intake for NPP	0.149	0.001	0.683	1.289	0.103	0.008	0.089	0.006
Previous as portion of MAC	0.050	0.023	0.007	0.004	0.265	0.349	0.010	0.064
Input of purified domestic effluent of NPP, t/a (waste water amount is $0.33248 \cdot 10^6$ m^3/a)	0.997	0.017	33.248	99.744	0.130	0.008	3.002	0.033
Contaminant concentration in purified domestic NPP waste water, mg/dm^3 (waste water amount is 10.5 m^3/a)	3	0.05	100	300	0.39	0.024	9.03	0.1
The changes of the concentration (mg/dm^3) in the river when it is minimal water content (minimum monthly discharge 95% of spring flood) considering intake for NPP and amount of waste water which contains contaminants	0.180	0.001	0.858	1.664	0.124	0.010	0.110	0.008
Previous as portion of MAC	0.060	0.028	0.009	0.006	0.317	0.418	0.012	0.077

Final assessment of stressor No.6 — chemical contamination of surface water

EP1.1.1.10 was not assessed because ingress of waste water into the surface water is forbidden by water legislation in Belarus, i.e. the acceptance limit of this evaluation parameter is automatically met.

During construction and operation of the AES-2006 plant, discharge of waste (upon condition, that contaminant concentration of discharged waste is equal to MAC for fishery basin) will worsen only insignificantly for almost all parameters, but calculated values do not exceed values of MAC for the fishery basin, except the value for total iron; however, high concentration of iron in the river Vilia is explained by its natural origin.

The acceptance limit of EP1.1.1.11 has been met.

Stressor No.7: Water intake from the natural source.
Source: Surface water intake.
EP1.1.1.12: The water flow in Vilia river in case of intake for two power generating units for every season.
AL1.1.1.12: Minimum water flow in the river Vilia should not be less than 22.72 m^3/s after water intake during any hydrological conditions.

Evaluation of availability of water resources — the river Vilia — as source of water supply for surface water intake of the NPP is carried out on the basis of maintaining the ecological status of the aquatic ecosystem, i.e. maintaining a minimal acceptable flow in the river after the water intake [101]. This minimal acceptable flow corresponds to 75% of minimal monthly average water flow of 95% of supply during low water period of winter or summer (whatever is smaller). For the river Vilia, the value of minimal monthly average water flow (summer and autumn low water) is 30.30 m^3/s, taking into account an approximate location of the water intake. Therefore, minimal acceptable flow in the river Vilia after water intake during any hydrological conditions should not be less than 22.72 m^3/s.

Definition of calculated hydrological conditions for estimation of availability of water resources for surface water intake is carried out considering calculated minimum acceptable flow and regulatory requirements [114].

To secure reliable, uninterrupted industrial water supply for the two AES-2006 unit NPP, persistent replacement of fresh water is necessary with a volume flow of $2.20 \cdot 10^5$ m^3/day (2.54 m^3/s).

Along with this, during water intake from the river Vilia for two power generating units during the winter and summer-autumn low-water periods, the remaining water flow will be 28.31 m^3/s and 27.76 m^3/s respectively, which is more than the minimum acceptable flow of water in the river Vilia. Environmental restrictions will be observed during the location of two power generating units even during toughening requirements for an average monthly use of up to 97% of provision (24.82 m^3/s and 24.12 m^3/s accordingly). Thus, water flow in the river Vilia remains above the required minimum acceptable flow of river water during water intake needed for NPP operation in the area of Ostrovetsky site, considering hydrological conditions of the river,.

However, during the specifically low-flow period of summer and autumn or winter, short-term violations of environmental restrictions can be observed.

Water balance analysis, carried out for years with low water 95% and 97% of supply yearly average, indicates that the water balance of the river is positive, and satisfies both practical needs for river water intake, and reservation of adequate water in the river for environmental purposes during NPP location and also maintains the required level of the Viliiskiy water storage basin without disrupting the operation of Viliysko-Minskiy hydrologic system.

Calculation results of water balance and analysis of low-flow periods, during which environmental restrictions in the river Vilia concerning the industrial water supply of the NPP over 62 years (from 1946 to 2007) can be violated, show that during water intake for two power generating units, the duration of a period of insufficiency can be, on average, four days with water stress of $4.026 \cdot 10^5$ m^3. Exceptions are especially years (1950 and 1992) with low water, when insufficiency lasted up to 20 days. In summary, the quantity of insufficient days for the whole recorded period of 62 years (22 630 days) is 108 days. Provision of uninterrupted days considering insufficient periods is for two power generating units:

$$[(22630 - 108)/22630] \cdot 100 = 99.5\%.$$

Considering specifically years with low water, similar to 1950 and 1992, the probability of which for two power generating units is 0.09%, taking into account appropriate calculated water stress and active conservation storage (up to $2.6*10^6$ m^3), 0.6 m^3/s will be additionally taken from the river Vilia.

Along with that, considering appropriate specifically low water conditions of minimum water flow that are less than the minimum acceptable flow, the duration of which is no longer than one day, according to observation data, instead of 75% of minimum flow, 60% will remain in the river Vilia, and that during a very short period, which does not exceed one day. This will not considerably negatively affect the ecological state of the river.

Final assessment of stressor No.7 — water intake from natural source

On the basis of calculation results of water balance and analysis of low-flow period for secured, uninterrupted industrial water supply for the NPP, reserve water supply sources are recommended for use in years of low water.

The acceptance limit of EP1.1.12 is assumed to have been met.

Stressor No.8: Impact of NPP construction on landscape of 30 km zone of installation deployment.
Source: construction work, impoundment, facility operation.
EP1.1.1.13: Landscape stability of location site to human intervention.
AL1.1.1.13: Landscapes should be confirmed as stable or relatively stable to human intervention.

From the physiographic point of view, the analysed territory belongs to two regions of different provinces: Narochanskiy plain, which is a part of the Belarusian lakeland and the Oshmyanskiy highland, belonging to the province of Belarusian Ridge and the plains bordering on it [102]. The 30 km surveillance zone around the NPP is regionally located in the Belarusian lakeland and regions of the central part of the Belarusian elevations and ridges in the country’s western subregion. Svirsky Ridge and Narochansky Ridge in the Belarusian Lakeland, and Oshmynsky Ridge and Vileysky plain in the central part of Belarus are part of 30 km zone. Hilly flatlands and elevations of the sozhsky era extend in this territory in the western and southern regions, and aqueoglacial plain and lowlands.

The surveillance zone is located in in the lakeland province of glacio-lacustrine, moraine and hilly moraine–lake landscape and the Belarusian elevated province of glacio-lacustrine, moraine and erosion and also secondary moraine landscape. Most of the territory belongs to the Lakeland province.

The land zoning system defines the regions of Svencyansko-Narochansky as hilly moraine–lake and aqueoglacial with fir wood, pine forest and marsh; and Oshmyansky as hilly moraine–erosion with broad-leaved and spruce forests.

The natural complex of the 30 km zone around Ostrovetsky site is classified as eight types of landscape: aqueoglacial with lakes; secondary moraine; kame–moraine–lake, kame–moraine–erosion, moraine–lake, undifferentiated complexes, hilly–moraine–lake; and hilly–moraine–erosion.

Human impact on the environment during construction of an NPP will be manifest as firstly, decreasing natural vegetation, which can happen prior to construction; secondly, change in water table because of reservoir storage, for example; and thirdly, contaminant effects, which can be caused by operation of industrial facilities.

The reaction of the environment to these influences will differ. For example, decreasing natural vegetation may lead to a sharp increase in erosion, for others, on the contrary, does not lead to negative consequences; decrease or increase in water table may affect certain landscapes more than others, and contamination accumulate in some areas more than in others.

Landscape sustainability against each type of influence will obviously depend on its properties. Appropriately, evaluation should be based on quantitative indexes, specifying given properties. The main indicators for landscape reaction to the influences will be pointed out.

Regarding the decrease of natural vegetation, increased diminishing of topsoil and linear erosion are considered to be indicators. Landscape sustainability is inversely proportional to their numerical values. Landscape reaction to changes in water table will be in direct relation to depth — the deeper the land, the higher its sustainability. Contaminator accumulation in the environment is defined by its landscape and geochemical structure. They leave eluvial deposits and are accumulated in superaqual parts. Therefore, taking into account the mentioned subcompartments, it is possible to estimate what processes dominate in an analyzed natural complex — accumulation or loss of contaminators.

The variation range of the indicators was divided into three categories corresponding to sustainable, relatively sustainable and non-sustainable landscapes. According to the criterion of decreasing natural vegetation, landscapes are sustainable when there is no diminishing of topsoil and linear erosion does not exceed 2%, landscapes are relatively sustainable when diminishing of topsoil is 3 mm/a or linear erosion is more than 2%, and landscapes are non-sustainable when diminishing of topsoil is more than 3 mm/a. According to the criterion of change of the water table, landscapes are sustainable if their depth is more than 5 m, landscapes are relatively sustainable if it is 2–5 m and non-sustainable if it is 2 m or less. Using the contaminator accumulation criterion, landscapes with an obvious dominance of eluvial over superaqual sectors (2:1 rate) were classified as sustainable, and landscapes with roughly equal sectors were classified as relatively sustainable; landscapes with a dominance of superaqual over eluvial were classified as non-sustainable.

Landscape classification according to sustainability towards anthropogenic impact can be presented as a matrix (Table 47). It represents types of landscapes typical in the 30 km zone and reaction to influences connected with decrease of natural vegetation, changes of the water table and contaminant ingress.

TABLE 47. EVALUATION OF LANDSCAPE SUSTAINABILITY REGARDING ANTHROPOGENIC IMPACT (LANDSCAPES: S – SUSTAINABLE, RS - RELATIVELY SUSTAINABLE, NS- NON-SUSTAINABLE)

Types of landscapes	Influences		
	decrease of natural vegetation	changes of water table	contaminant ingress
hilly-moraine–lake	NS	S	S
hilly–moraine–erosion	NS	S	S
kame–moraine–lake	RS	S	S
kame–moraine–erosion	RS	S	S
moraine–lake	RS	RS	S
secondary moraine	RS	RS	S
aqueoglacial with lakes	S	S	S
bog	S	NS	NS
undifferentiated river valley	S	NS	NS

The given landscape distribution reflects firstly, its reaction similarity on such influences as change of water table and contaminant ingress and secondly, almost inverse correlation between them during evaluation of its capability to resist changes, caused by decrease of natural vegetation. Elevated hilly–moraine–lake, hilly–moraine–erosion, kame–moraine–erosion, kame–moraine–lake landscapes generally belong to the most sustainable ones regarding pollution and change of water table and the least sustainable ones regarding decrease of natural vegetation. On the contrary, low landscapes which are bog and undifferentiated such as a river valley are not sustainable towards pollution and change of water table but sustainable regarding decrease of natural vegetation. Medium altitude terrains of moraine lakes, secondary moraine, and aqueoglacial with lakes occupy an intermediate position.

Aqueoglacial landscapes with lakes, which are sustainable towards three considered types of influences, occupy about a third of the territory of 30 km zone. About 45% of territory consists of hilly–moraine–lake, kame–moraine–lake, moraine–lake landscapes which are defined as sustainable towards contaminant ingress, relatively sustainable (moraine–lake) and sustainable towards change of water table, relatively sustainable and non-sustainable (hilly-moraine–lake) towards decrease of natural vegetation.

Landscapes of undifferentiated complexes with bog dominance and landscapes of river valley (15% of the territory) are sustainable towards decrease of natural vegetation and non-sustainable towards change of water table and contaminant ingress.

Hilly–moraine–erosion, kame–moraine–lake and secondary moraine occupy no less than 10%. Hilly–moraine–erosion and kame–moraine–lake are sustainable against change of water table and contaminant ingress. However, the hilly–moraine–erosion is not sustainable, and kame–moraine–lake is relatively sustainable against a decrease of natural vegetation. Secondary moraine landscapes are sustainable against contaminant ingress, and relatively sustainable against change of water table and decrease of natural vegetation.

Final assessment of stressor No.8 — impact of power plant construction on landscape

The territory of the planned site of the NPP is totally located in moraine–lake hilly landscapes with discrete cover of aqua-glacial clay sands. It is sustainable against contaminant ingress and relatively sustainable against a decrease of natural vegetation and change of the water table.

Construction work does not cause activation of unfavourable geomorphological processes.

The acceptance limit of EP1.1.1.13 has been met.

Stressor No. 9: Impact of NPP construction on vegetation in the 30-kilometer zone around an NPP.
Source: Construction work.
EP1.1.1.14: Destruction of large forestry areas during the fulfilment of construction work.
AL1.1.1.14: Construction should not result in destruction of large forestry areas.
EP1.1.1.15: Possible physical destruction of rare species.
AL1.1.1.15: Construction should not result in destruction of large forestry areas.

Assessment of evaluation parameter EP1.1.1.14 — destruction of vegetation

With normal operation of an NPP, radioactivity discharge does not significantly affect vegetation. According to the information provided for stressor No.1 (possible environmental pollution caused by gaseous and aerosol radioactive discharges)the extent of soil pollution by radionuclides from discharges during normal use to the extent of natural pollution is so insignificant and varies from 7.8 10^{-3} % (after the first year of operation) to 9.0 10^{-2} % (after 60 years of operation). For example, the research conducted in the zone of impact of Ignalina NPP (Lithuania) showed that its discharge did not cause external changes to vegetation. This was caused by plants' tolerance towards low doses of radiation and also resistance to radiation of the plant community. Therefore, the following evaluation focuses on the construction work as a source of NPP impact on vegetation in the 30-kilometer zone territory around the plant.

The 30-kilometer zone around the Ostrovetsky site has same geo-botanical composition as the Oshmyany and Minsk northern subzone of oak and dark coniferous forests [102]. Nearly half of land reserves of this territory are agricultural lands.

Forest vegetation comprises 44.3% of the territory and is distributed relatively evenly in this territory except in its central and southern parts where forests occupy small areas. The share of meadow-swamp areas constitutes about 6%.

A large number of coniferous forests (75.2%) cover this territory. Small-leaved forests occupy 24%, and broad-leaved forests occupy less than 1%.

The average age of the pine forests is 55 years, average forest site quality is 1.7, average density is 0.69, and average stand volume is equal to 209 m^3/ha. Spruce forests are also highly-productive. Average stand volume of spruce forests is 233 m^3/ha, quality of forest site is 1.3. Concerning age, both pine forests and spruce forests have practically the same indicators. The average aged stand is up to 70%, about 10–14% for ripening and mature forest stand.

The coniferous plantings are the most productive. The percentage of forests of the first and second forest site classes (I and II class) is pine forests (87.2%), and spruce forests (96.2%). The broad-leaved forests are also productive, in particular, ash forests (100% of these forests have the first and second forest site classes). A significant proportion of small-leaved forests is also productive (more than 80% of forests have the first and second forest site classes).

The average density of forests is 0.69. The percentage of high-density stand is 5% of forests, medium stocked stand is 64.7%, and small stocked stand is 28.7%.

The formational structure of forests consists of stands of 21 types of forest, with a large varied typological range of birch forests (20 types), pine forests (15 types) and spruce forests (13 types).

Broad-leaved forests are not widespread in this territory. These forests are composed of oak, ash, maple, and lime, the majority of which are classified as the most valuable forest community. Oak forests are composed of orlyakov, wood sorrel and bilberry types.

Primary and secondary forest growth is found among small-leaved forests. They are composed of birch forests, aspen forest and alder stands. The secondary forest growth occupies a larger area.

Thus, the formational structure of forests is a combination of coniferous and small-leaved forests, including small quantity of swamp forests and a minimal quantity of broad-leaved forests. This generally corresponds to the formational structure of Oshmyany and Minsk geo-botanical zone.

Forests of the first group of forest use are referred to protected forest. In the 30-kilometer zone around the Ostrovetsky NPP site, the forests are distributed under the protection category in the following manner: forests of the first group comprise 62.0%, forests of the second group 38%. This ratio considerably differs from the average indicator in the country where merchantable and protected forests occupy approximately an equal area. The percentage of the first group forests is larger in the territory analysed because this territory contains a relatively large area of the specially protected natural sites of national significance.

Within the limits of the Ostrovetsky NPP site (about 25 km^2), forest vegetation occupies approximately 3.6 km^2 (14.3% of the area); therefore, during the construction work there will not be destruction of significant territories of forest areas.

The acceptance limit of evaluation parameter EP1.1.1.14 has been met.

Assessment of evaluation parameter EP1.1.1.15 — destruction of rare plants

Fifty five types of protected plants, among which 39 types of vascular plant, five types of bryophyte, six types of algae, four types of lichen, and one type of mushroom are found in the 30-kilometer zone of the Ostrovetsky site. The first category (category I) of protection is applied to four types: ordinary saw grass, andreaea rupestris (bryophyte), chrysolycos planktonicus, and chrysolycos angulatis (algae).

The growing areas of rare plant species are located in different directions from the site. They are mainly concentrated eastward in the territory of the Narochansky national park of a catchment area of the Stracha river. The second large area of these plants is situated in south-easterly direction from the site in the catchment area of the Stracha river.

The acceptance limit of evaluation parameter EP1.1.1.15 has been met.

Final assessment of stressor No. 9 — impact of NPP construction on vegetation

Only 14.3% of the Ostrovetsky site around the NPP is occupied by forests; therefore, during construction no significant forest territories will be destroyed.

Rare plant species are not found within the limits of the territory of the NPP location. Therefore, the construction work will not cause their destruction.

The acceptance limits of EP1.1.14 and EP1.1.15 have been met.

Stressor No.10: construction impact on fauna of 30 km zone of facility deployment.
Source: construction work.
EP1.1.1.16: Possibility of condition deterioration for reproduction of rare species.
AL1.1.1.16: Construction should not prevent reproduction of rare species.

Ichthyofauna: Fishery description of basic rivers, covered by 30 km zone of Ostrovetsky site, is given in Table 48. Values of general fish stock were taken as average on categories for all channels of Belarus. Five to ten species of fish are found in the smallest channels, with a length of 5 to 25 km, and a riverbed which is considerably or totally drained. General fish stock in such channels is decreased by 30 to 50% depending on decrease of species composition and does not exceed 50 kg/ha.

The river Vilia, with a length of 498 km, belongs to the second channel class (200-500 km in length) with a general fish stock of 96 kg/ha. However, considering that the species composition of ichthyofauna of the river Vilia is not poorer than that of the river basin Neman, the specific general fish stock of the river Vilia is 138 kg/ha.

The rivers Vilia, Stracha and Oshmyanka and also some smaller streams, mentioned in the Table 48, are the permanent habitation and breeding ground for a range of rare and endangered species, registered in the *Red Book* of Belarus [115], these rivers are in the first class of fish-breeding water in accordance with requirements for water quality of channels and water bodies in compliance with [116].

The territory of the Ostrovetsky site is a unique region for preservation of migratory fish in connection with uncontrolled flow of the River Vilia, its cold-water temperature conditions and hydro-chemical composition. This basin is basically the only breeding ground for salmon in Belarus.

TABLE 48. FISHERY DESCRIPTION OF RIVERS OF 30 KM ZONE OF OSTROVETSKY SITE

River title	Receiving river/ basin	Quantity of species	General stock, kg/ha	Protected species
Bol. Perecop	Lake Svir	12-15	71	-
Bystrica	Vilia	5-10	50	Tr
Vilia	Neman	37	138	RL, Tr, Eg, Bt, Ss, B, V, N
Gozovka	Vilia	5-7	50	Tr, Bt, Ss
Dydka	Vilia	3-7	36	Tr, Bt, Ss
Kernova	Oshmyanka	5-10	50	-
Losha	Oshmyanka	22	71	Tr, Eg, V
Lyntypka	Stracha	5-10	50	Tr
Oshmyanka	Vilia	25	71	Tr, Eg, V, N
Paroka	Kovalevka	3-7	36	-
Pelyaka	Stryna	13	50	Tr
Polovoyka	Vilia	3-7	36	-
Petropolsky	Vilia	3-7	36	Tr, Bt
Ratagol	Sikunka	3-7	36	Tr
Senkanka	Vilia	3-7	36	Tr, Bt, Ss
Sikunka	Oshmyanka	5-10	50	Tr
Sikunya	Oshmyanka	5-10	50	Tr
Sorochanka	Vilia	15-17	71	Tr
Stracha	Vilia	27	71	Tr, Eg, V, N
Struna	Stracha	12	71	Tr
Studenec	Sikunya	3-7	36	Tr
Tartak	Vilia	3-7	36	Tr, Bt
Tyshanka	Stracha	12-15	71	-
Ustizerka	Vilia	7-10	50	-

Note – Species of fish, registered in the *Red Book* of Belarus, marked:
RL – River lamprey; Ss – Salmo salar (salmon); Bt – bull-trout; Tr – trout; Eg – European grayling; B – barbel; V – vimba; N – nase.

Eight protected species of fish inhabit the water within the 30 km zone of the Ostrovetsky site. River lamprey (protection class II), Salmo salar (class I), bull-trout (class I), trout (class II), European grayling (class I), barbel (III class I), nase (class III), vimba (class III) are included in the list.

Avifauna in the 30 km zone include 149 nested and migratory species of birds, that comprise 47.9% of the country’s avifauna. Representative of passerine passeriformes as widespread, flexible, adapted to up-to-date conditions and the most sustainable group — 70 species dominate the assortment of birds inhabiting this territory. Also, other species were registered: Gaviiformes (1 species), Podicipediformes (3 species), Pelecaniformes (1 species), Ciconiiformes (5 species), Anseriformes (12 species), Accipitriformes (12 species), Galliformes (5 species), Gruiformes (6 species), Charadriiformes (16 species), Columbiformes (4 species), Cuculiformes (1 species), Strigiformes (3 species), Caprimulgiformes (1 specie), Apodiformes (1 species), Coraciiformes (2 species) and Piciformes (6 species).

The composition and structure of avifauna complexes in the analysed zone are typical for conifer and mixed forest of Belarus: 36% of all registered types here are forest dwellers and 13% are hardy-shrub dwellers (close to forests).

The existence of rivers Oshmyanka, Vilia, Bystrica and large channels, lakes Svir, Vishnevskoe, Tymskoe and others and also boggy areas in eastern and northern parts in certain degree expands the range of ecological conditions for avifauna. 38% are semi-aquatic – bog and coastal – water ecological complexes.

Cultivated fields, native and anthropogenous grasses, pasture for cattle attract species of birds for nesting that are ecologically connected with the area. The percentage of these species is 5%. Human settlements, collective farms and hamlets affect the species composition of synanthropic birds (8%). This is less than previous ecological groups.

Eighteen bird species inhabiting the area are registered in the *Red Book* of Belarus. They comprise 25.4% of all species of registered birds inhabiting Belarus. About half of these species nest in this territory. Examples are the bittern (Botaurus stellaris), little bittern (Ixobrychus minutus), black stork (Ciconia nigra), goosander (Mergus merganser), white-tailed eagle (Haliaeetus albicilla), lesser spotted eagle (Aquila pomarina), kestrel (Falco tinnunculus), European hobby (Falco subbuteo), corncrake (Crex crex), common crane (Grus grus), Ural owl (Strix uralensis), common European kingfisher (Alcedo atthis). Such species as Arctic loon (Gavia arctica), curlew (Numenius arquata), greenshank (Tringa nebularia), common gull (Larus canus) use this territory to rest and feed during spring and autumn migrations. The fish-hawk (Pandion haliaetus) and green woodpecker are visitors and use the territory rather as moor.

The territory of the NPP construction site is quite well investigated. There is practically no large forestland nor basins and channels.

The river Vilia flows very close by the site, and the valley of the river is a place of nesting of such rare species as goosander (Mergus merganser). This species nests in the northern part of Belarus. It inhabits mesotrophic and light eutrophic fishery lakes and parts of rivers with fast flow.

Changes of hydrological conditions of the river can lead to loss of nesting spots. Besides, habitation of two more species — the corncrake (Crex crex) and kestrel (Falco tinnunculus), which are registered in the *Red Book* — were recorded very close to the site.

In the 30-kilometer zone of the Ostrovetsky site, game animals are plentiful. Red deer, moose deer, roe deer, wild pig are hoofed animals in the area. Only the badger is on the list of the protected species in hunting grounds of the Ostrovetsky area.

Final assessment of stressor No.10 — impact of NPP installation on fauna

Possible hydrological and hydrochemical changes in the Vilia river regimes and its tributaries caused by the NPP construction could cause conditions to deteriorate for reproduction of valuable and rare species of salmon in the river and its tributaries. The river Vilia with its tributaries is the only hydrologic system in Belarus where salmon can reproduce.

Changes in the hydrological river regime can also result in loss of nesting places of rare bird species, such as the goosander.

Thus, during the construction work, measures to prevent such changes in the hydrological condition of the Vilia river should be developed and applied. Moreover, a monitoring system to verify the effectiveness of the preventive measures should be implemented.

Under the condition that careful activities are performed to prevent significant changes in hydrological conditions, the acceptance limit of EP1.1.1.16 is deemed to have been met.

Stressor No. 11: Influence of the NPP installation on specially protected natural areas and elements of ecosystem.
Source: Building and construction work, installation operating.
EP1.1.1.17: Possibility of direct violation of specially protected natural areas, because of the construction work.
AL1.1.1.17: Violation of specially protected natural areas should not happen during the construction.

All elements of the Belarusian national ecological system are present within the 30-km zone of Ostrovetsky territory of NPP location — ecological core, ecological corridor and buffer zone [103]. The European level ecological core is the Narochanskyalong national park with the adjoining national Sarochanskie lakes wildlife reserve . Lands adjoining these specially protected territories form the buffer zone of the ecological core.

The forestlands located east-west from the lake Naroch towards Lithuania function as an ecological corridor. Elements of the national ecological system are in the north of the 30-km zone. The NPP site lies within the ecological corridor. However it consists mainly of agricultural holdings, whereby its importance for the migration of fauna is not so great.

Specially protected natural territories of different states are part of the 30-km zone of Ostrovetsky territory. The Narochansky national park, national the Sarochanskie lakes wildlife reserve and four local wildlife reserves are among them.

Final assessment of stressor No.11 — impact of NPP installation on specially protected areas

All specially protected natural territories are located at various distances from the NPP site. There are no such territories within the site borders. Thus, the construction work does not lead to a direct encroachment on specially protected natural territories.

The acceptance limit of EP1.1.17 has been met.

Several additional stressors should be considered in a final environmental impact study:

Stressor No. 12: temporary and permanent land amortization.
Source: building and construction work, installation operating.

When the final design documents are available, losses due to temporary and permanent withdrawal of arable lands from agricultural operation should be estimated with due account taken of their value. The extent of farmland where vegetation destruction will occur should also be estimated.

Stressor No. 13: nuclear fuel transportation.
Source: operating of the plant.

When the design documents are available, assessment of the fuel transportation process from the point of view of the possible human and environmental impact is to be carried out.

Final assessment of criterion CR1.1.1 — stressors

All evaluation parameters for the AES-2006 are satisfied. Special activities are needed to satisfy the acceptance limit of EP1.1.1.16 (avoidance of interference with reproduction rate of rare species). It is recommended that some additional stressors be evaluated, i.e. temporary and permanent land amortization and nuclear fuel transportation

No information was available to the assessor regarding stressors of other planned nuclear facilities of the Belarus NES, especially the waste management facilities outside the NPP. It is recommended that the missing information be collected and the assessment finalized.

Criterion CR1.1.1 has been conditionally met.

7.2.2.2. Final assessment of user requirement UR1.1 controllability of environmental stressors

The user requirement UR1.1 has been satisfied for the AES-2006 plant.

7.2.2. User requirement UR1.2 — adverse effects as low as reasonably practicable

User requirement UR1.2: *The likely adverse environmental effects attributable to the NES should be as low as reasonably practicable (ALARP), social and economic factors taken into account.*

New NESs should correspond to higher ecological norms than already existing NES. However, in some cases, increasing ecological indicators of a particular installation or technology can cause more harmful effects in other segments of the system. Therefore, when assessing this user requirement, one should:

- Use a strategy of achievement of the best practically rational indicators for this NES;
- Cover all harmful ecological effects, but not only radiation impact on humans;
- Ensure that expenses aimed to improve ecological indicators do not cause unreasonably heavy economic penalties.

A common approach is to design the NES in accordance with modern technical principles and provide a practicable low-level risk for the environment, taking social and economic factors into account (ALARP).

7.2.2.1. *Criterion CR1.2.1 — ALARP principle*

Indicator IN1.2.1: *Does the NES reflect application of ALARP to limit environmental effects?*

Acceptance limit AL1.2.1: *Yes.*

As was mentioned during evaluation of user requirement UR1.1 and CR1.1.1 (stressors), the impact of stressors from the AES-2006 plant on the environment meets existing standards, and in some instances, it is much lower than the specified limit or insignificant. Therefore, it can be concluded that AES-2006 at its planned location in Belarus reflects the ALARP principle regarding environmental effects.

Thus, criterion CR1.2.1 has been met.

7.2.2.2. *Final assessment of user requirement UR1.2 — ALARP*

User requirement UR1.2 has been satisfied.

7.2.3. Final assessment of basic principle BP1 — acceptability of adverse impact on the environment

The goal of this basic principle is to confirm that the environmental impact of a new NES on its surrounding area is clearly within the national regulatory limits.

The evaluation of the environmental impact by stressors on the site of the AES-2006 plant was based on a comprehensive environmental impact analysis. The results of the analysis show that all impacts by stressors from the AES-2006 plant are within regulatory limits.

It is recommended that the environmental assessment be extended to include the planned waste management facilities, e.g. the interim storage facility of spent fuel.

7.3. BASIC PRINCIPLE BP2 — FITNESS FOR PURPOSE

Basic principle BP2: *The NES shall be capable of contributing to the energy needs in the 21st century while making efficient use of non-renewable resources.*

With a view to ecological acceptability, an NES should be stable and should not deplete valuable resources during its lifecycle. The resources include fissionable/fertile material, water (if the sources are limited or there are strict requirements on keeping its quality) and other critical material. Also, the system should use resources as acceptable alternative options (both nuclear and non-nuclear), or at least likewise effective. Even if there are no viable alternatives, it is necessary to use non-renewable resources in the best possible way.

7.3.1. User requirement UR2.1 — consistency with resource availability

User requirement UR2.1: *The NES should be able to contribute to the world's energy needs during the 21st century without running out of fissile/fertile material and other non-renewable material, with account taken of reasonably expected uses of these material external to the NES. In addition, the NES should make efficient use of non- renewable resources.*

To achieve fulfilment of this requirement, it is necessary to carry out careful analysis of all limitations imposed by existing world resources with appropriate choice of margins to the present system. Depletion of resources by other industries and the impact of this factor must also be taken into consideration.

INPRO has developed six criteria for this user requirement, CR2.1.1 to CR2.1.6.

7.3.1.1. Criterion CR2.1.1 — availability of fuel resources

Indicator IN2.1.1: *quantity of fissile/fertile material needed for use in the NES.*

Acceptance limit AL2.1.1: *quantity should be available continuously for 100 years*.

Belarus has no industrial scale deposits of fissile material on its territory [117]. Nuclear fuel for the Belarusian NPP is to be purchased on international markets. The modern international nuclear fuel market is well established, sustainable and has a quite significant capacity, so that introduction of two LWR units cannot produce any substantial influence on it. Thus, for the NES of Belarus the availability of resources should be analysed only at a global level.

Detailed analysis of fuel resources should include the consideration of known and foreseen uranium deposits [118] and also discussion of various fuel management strategies, e.g. a once-through fuel cycle, MOX fuel, uranium-thorium fuel. Assumptions on the technologies of extraction of fissile and fertile material, and conversion ratios should be carefully checked for practical implementation.

The INPRO project on investigation of *Nuclear energy development in the 21st century: global scenarios and regional trends* [119] comprised a numerical simulation of a wide range of scenarios of electricity consumption growth till the end of the century. Availability of fuel resources was the main constraint in those calculations. The results show that LWR reactors will dominate at least until 2100 and can be sufficiently supplied with fuel in any possible scenario. The installed capacity of LWR reactors at the end of the century varies from 1000 GW(e) to 2500 GW(e) depending on the scenario which is two–three orders of magnitudes higher than the expected capacity of the Belarus NPP.

Criterion CR2.1.1 has been met.

7.3.1.2. Criterion CR2.1.2 — availability of non-renewable resources

Indicator IN2.1.2: *quantity of non-renewable material needed for use in the NES.*

Acceptance limit AL2.1.2: *quantity should be available continuously for 100 years.*

Belarus possesses enough raw material deposits to supply the general construction process of an NPP with concrete [117]. NPP equipment, including non-uranium parts of fuel assemblies, should be imported and should be manufactured from foreign material. From the point of view of the consumption of non-renewables, the AES-2006 is similar to other modern PWRs. The share of non-renewable material consumed for NPP equipment fabrication (mainly steel) is negligible compared to production of that material [119]. Besides, the share of the NES of Belarus of the global NES is also negligible considering the size of the global system.

The authors suggest that requirements for non-renewable resources should be investigated in more detail on the global scale.

Criterion CR2.1.2 has been met.

7.3.1.3. Criterion CR2.1.3 — availability of power

Indicator IN2.1.3: *power $P_{NES}(t)$ needed for use in the NES.*

Acceptance limit AL2.1.3: *power P(t) from external and internal sources should be available continuously for 100 years.*

A NES requires energy for construction, operation and decommissioning. The power P(t) is the energy available for consumption by the NES at time t from internal and external sources of energy. At any time during the life cycle, this energy must be equal to or greater than $P_{NES}(t)$ — the energy required by the NES at time t. At the beginning of the life cycle, all necessary energy is available only from external sources, while later most of the energy, if not all consumed for the operation of the system and its development, may be supplied by internal energy sources of the NES.

Belarus imports the majority of its primary energy resources, including oil and gas. Currently, electricity is also partly imported from the Russian Federation or Ukraine. The energy needs during the construction period will be covered by imported electricity through the national grid and by imported primary energy resources. A peak-reserve heat station will be constructed at the NPP site to produce the heat necessary for construction, commissioning and operation when other heat sources (e.g. from reactors) are not available.

After the commissioning of the first NPP unit, electricity needs will be met through:

- Internal sources (operating unit transformers) when the unit is operated at power;
- The national electricity grid, which may supply either electricity from national power plants (including the NPP when it is in operation) or imported electricity.

Bearing in mind the large share of the first NPP in the national energy supply mix, the Government should take care of possible backup electricity sources. Heat may be supplied internally, either from the operating unit or from the peak reserve heat station. Primary energy resources, including oil fuel for the peak station, will be imported.

The acceptance limit of criterion CR2.1.3 is deemed to have been met conditionally.

Belarus authority should consider in detail possible options of electricity supply to the NPP site after a scram has occurred in the plant.

7.3.1.4. Criterion CR2.1.4 — efficient use of uranium resources

Indicator IN2.1.4: *end use energy delivered by NES per Mg of uranium mined.*

Acceptance limit AL2.1.4: *energy should be bigger than maximum energy achievable for a once through PWR.*

AES-2006 is a PWR reactor so the comparison should be made against a modern PWR instead of what is the maximum achievable for a once-through PWR.

The effectiveness of use of uranium fuel depends on the fuel management strategy to be applied in the NES of Belarus. The majority of modern VVER-1000 reactors (PWR type) are operated in a modernized once-through fuel cycle and the average burnup of their spent fuel of initial enrichment of 4.4% is at a level of 48 MW·d/kgHM, which corresponds to the average enrichment and burnup level of modern PWR of western types. The AES-2006 reactor consumes fuel of approx. 4.9% initial enrichment and discharges spent fuel with average burnup around 55.8 MW·d/kgHM.

Assuming that the thermal efficiency of a modern PWR and the AES-2006 are at the same level (e.g. 32%) and the content of ^{235}U in the tails of enrichment is the same (0.25%), the expenditure of natural uranium per unit of electricity produced may be estimated.

One kg of 4.4% enriched fuel of a modern VVER-1000 (PWR) is produced from 9 kg of natural uranium. It provides 15.36 MW·d (0.32·48 MW·d) of electricity, i.e. 1.71MW·d/kg.

To produce the same amount of 4.9% enriched fuel of AES-2006 one has to use 10.07 kg of natural uranium. It provides 17.86 MW·d (0.32·55.8MW·d) of electricity, i.e. 1.77 MW·d/kg.

Criterion CR2.1.4 has been met for the AES-2006.

7.3.1.5. Criterion CR2.1.5 — efficient use of thorium resources

Indicator IN2.1.5: *end use energy delivered by NES per Mg of thorium mined.*

Acceptance limit AL2.1.5: *energy should be bigger than maximum energy achievable for a current operating thorium cycle.*

At the current stage of NES development no thorium consumption is envisaged.

Criterion CR2.1.5 is not applicable for the planned NES of Belarus.

7.3.1.6. Criterion CR2.1.6 — efficient use of non-renewable resources

Indicator IN2.1.6: *end use energy delivered by NES per Mg of limited non-renewable resource consumed.*

Acceptance limit AL2.1.6: *energy to be determined on a case specific basis.*

The majority of products manufactured using non-renewable resources will be imported. The rate of non-renewables spent in AES-2006 per unit of electricity produced is expected to be at the same level as for other modern PWR.

The authors suggest that requirements for the efficiency of use of non-renewable resources should be corroborated in the INPRO methodology in more detail on a global scale.

Criterion CR2.1.6 has not been assessed.

7.3.2. User requirement UR2.2 — adequate net energy output

User requirement UR2.2: *The energy output of the NES should exceed the energy required to implement and operate the NES within an acceptably short period.*

Net energy production is the useful energy produced by the system in excess of the energy required for the establishment and operation of the system during its life cycle. The balance of energy production of the system should be positive within a reasonably short time. Obviously, the shorter this time is, the better.

INPRO has developed one criterion for this user requirement, CR2.2.1.

7.3.2.1. Criterion CR2.2.1 — amortization time

Indicator IN2.1.6: *time required to match the total energy input with energy output of the NES.*

Acceptance limit AL2.1.6: *time should be reasonable short in comparison to intended lifetime of NES.*

The NES of Belarus will be based on systems, including NPP systems, which are mainly to be manufactured abroad from raw material mined abroad. Nuclear fuel for the NNP operation will be produced also outside the country, including all steps of nuclear fuel cycle: mining, milling, conversion, enrichment, fabrication of assemblies. In the case of the Belarus NES, the amortization time may be analysed only at the global level.

A study on NPPs conducted by the World Nuclear Association (WNA) [120], has shown that the energy used for construction and operation of NPPs is far less (at least 20 times) than the energy produced by the NPPs. For the NES of Belarus, it is expected that this ratio will be even higher due to more efficient use of fuel, simplified design, and use of advanced material and construction methods.

The time needed to match the energy input with energy output was calculated to be about three years, which is much shorter than the service life time of the plant.

Criterion CR2.2.1 has been met.

7.3.2.2. *Final assessment of user requirement UR2.2 — adequate net energy output*

The time to match the total energy input into the AES-2006 plant is much shorter than the service life time of the plant.

The user requirement UR2.2 has been satisfied.

7.3.3. Final assessment of basic principle BP2 — fitness for purpose

The planned NPP with two units of an AES-2006 reactor will not run out of fissile/fertile material or other non-renewable material during their service life time of 60 years.

The AES-2006 design makes efficient use of non-renewable material.

7.4. SUMMARY AND CONCLUSION OF ASSESSMENT OF THE ENVIRONMENTAL EFFECTS

There are two kinds of environmental effects by an NES on the environment. The first effect is the generation of stressors (BP1) that could have an adverse impact on the surrounding area of nuclear facilities; the second one is the depletion of non-renewable resources (BP2) that are needed for construction and operation of the nuclear installations.

The results of an environmental impact study show that all impacts by stressors from the AES-2006 plant are clearly within national regulatory limits.

The assessment of necessary non-renewable resources needed for construction and operation of the NES of Belarus revealed that sufficient resources are available for the service life time of the AES-2006 plant.

8. SAFETY OF NUCLEAR REACTORS

In this section, the safety of the AES-2006 reactor design is assessed using the INPRO methodology [121] defined in Volume 8 of IAEA-TECDOC-1575 Rev.1 (INPRO manual of safety of nuclear reactors).

8.1. INTRODUCTION

8.1.1. Selection of reference plant

According to the INPRO methodology, an assessment in the area of safety should be primarily based on a comparison of the new reactor design — the AES-2006/V-491 design planned in the national NES of Belarus — against a reference design of a reactor, i.e. one that has been put in operation by the same supplier and could be considered as its most advanced design in 2004. Therefore, an advanced VVER design was selected as an appropriate reference design of an operating plant by the same supplier — the Russian Federation. Among various reactor types (e.g. PWR, BWR, HWR, gas cooled reactors) considered, which are currently in operation demonstrating benefits and also specific deficiencies, the LWR VVER-1000/V-320 (called V-320 in the following text) has been selected as the reference design.

The V-320 was chosen as the reference design because it is:

- Proven technology: the first V-320 unit was put in operation in 1984; in 2004 three new units were commissioned in the Russian Federation and Ukraine;
- Linked to the AES-2006/V-491 design: V-491 is considered as an evolutionary step in development compared to the V-320 design, and both belong to the ‘major series’ or ‘family’ of VVER-1000 concepts;
- A design known in Belarus: two V-320 units were under construction in Belarus in the 1980s (construction of the first unit obtained an 80% level of completeness; however, after the Chernobyl accident it was converted into a gas-fired plant);
- A popular design: currently operating in four European countries.

Both reactors — V-320 and V-492 — are large PWRs (with a power output of 1000 MW(e) and 1200 MW(e), respectively) developed by the same design institution (OKB Gidropress). The primary circuit of the V-320 and V-491 plant comprises four reactor coolant loops, each with a horizontal steam generator and a reactor coolant pump. Different from the V-320, the safety design concept of the V-491 is based on preferential use of passive safety systems for beyond design basis accident (BDBA) management. It is also designed to prevent design basis accidents (DBAs) becoming BDBAs (also called severe accidents), and uses a combination of active and passive systems for severe accident management.

A general description of the V-320 and V-491 design is presented in Appendix I.

8.1.2. Comparison of general design of VVER1000 type V-320 with V-491

Tables 49 and 50 present general design features of the selected type of plant for the national NES, i.e. the AES-2006/V-491 [122–124] and the chosen reference design VVER1000/V-320 [125].

TABLE 49. GENERAL SYSTEM DATA OF AES-2006/V-491 IN COMPARISON TO VVER1000/V-320 DESIGN

Value	**V-491**	**V-320**
Thermal power, MW	3200	3000
Electric (gross) power, MW	1160	1000
Coolant maximal temperature at the core inlet (full power), °C	298.6	290
Coolant maximal temperature at the core outlet (full power), °C	329.7	319.6
Primary circuit pressure at the core outlet, MPa	16.2	15.7
Nominal design coolant flow rate through the reactor, m^3/h	86000	84800
Minimum design coolant flow rate through the reactor, m^3/h	83100	80000
Re-criticality temperature, ºC	91	190
Secondary circuit steam pressure at the SG outlet, MPa	7	6.3
SG steam capacity, t/h	1602	1470
Generated steam temperature, °C	285.8	278.5
SG feedwater temperature, °C	225	220
Maximum burnup, average for fuel assembly, MW·d/kgU	70	55
Fuel campaign life, years	4 - 5	3 - 4
Annual average duration of scheduled shutdowns, days	<25	40-60
Reactor lifetime, years	60	30
Number of CPS drives	121	61

TABLE 50. SAFETY SYSTEM DESIGN FEATURES OF V-491 IN COMPARISON TO V-320

V-491	**V-320**
4 safety trains.	3 safety trains.
Severe accident management engineering features (e.g. H2 PAR, core catcher):	No special systems
Passive containment heat removal system and PHRS-SG for BDBA (circular rooms in the upper part of reactor building for HRS location);	Sprinkler system helps to decrease temperature in containment
Melting core catchers (water storage tanks supplying core catchers are located inside the containment).	No special systems (special shape of floor in the reactor room)
No need of use of the sprinkler system for residual heat removal from reactor. Low pressure safety injection system is used for residual heat removal from reactor	Sprinkler system is one of the design options for residual heat removal from reactor
One diesel-generator for power supply for loss of power on units of normal operation	Diesel-generators for safety systems only
Main electric generator with water cooling only (no hydrogen)	Main electric generator with hydrogen cooling
Double containment Inner containment is designed to ensure leak rate below 0.2% of total volume per day at 0.49 MPa. Outer containment is designed to withstand loads of wind of F3 - F4, (Fujita scale, i.e. with the speed ≤400 km/h); Snow and Ice Loads - 4.3 KPa; Aircraft Crash	Single containment, thickness – 1200 mm, design pressure - 0.55 MPa
Possibility of reverse water supply with use of cooling tower	No such possibility
Enlarged seismic stability compared to V-320	

Tables 49 and 50 illustrate the main differences in system design between the two plants selected. As discussed in the following sections, the new design V-491 demonstrates an increased safety level through several new features in comparison to the V-320 design.

Additional sources of data

To perform the assessment of several INPRO criteria, data of (probabilistic) analysis of the V-392M design will also be used, i.e. the Novovoronezh-2 variant of the AES-2006 design. This design has a different architecture of safety systems compared to V-491 [126] but in some aspects these two options are deemed sufficiently similar at the scale of consideration of our assessment. For example, core melting frequency of V-392M is $6.1 \cdot 10^{-7}$ a^{-1}, compared to $7.3 \cdot 10^{-7}$ a^{-1} of V-491. Calculations for the two designs were made by different organizations and in different years. Additionally, safety data of the earlier designed V-392M may be considered more mature compared to data for the V-491.

In the following the INPRO methodology as documented in Volume 8 of IAEA-TECDOC-1575 Rev.1 (*INPRO Manual*) will be used to assess the safety of the AES-2006/V-491 reactor design.

8.2. INPRO BASIC PRINCIPLE BP1 — DEFENCE IN DEPTH

Basic principle BP1: *Installations of an Innovative Nuclear Energy System shall incorporate enhanced defence-in-depth as a part of their fundamental safety approach and ensure that the levels of protection in defence-in-depth shall be more independent from each other than in existing installations.*

INPRO has developed seven user requirements for this basic principle.

8.2.1. User requirement UR1.1 — robustness

User requirement UR1.1: *Installations of an innovative NES should be more robust relative to existing designs regarding system and component failures as well as operation.*

INPRO has defined four criteria, CR1.1.1 to CR1.1.4, for this user requirement.

Assessment against criterion CR1.1.1 robustness

Indicator IN1.1.1: *robustness of NES design (simplicity, margins).*

Acceptance limit AL1.1.1: *new design (AES-2006) should be superior to existing designs (V-320 reference design) in at least some of the aspects of robustness (see evaluation parameters EP1.1.1.1 to EP1.1.1.5) presented.*

To facilitate the evaluation of criterion CR1.1.1, INPRO has developed five evaluation parameters, EP1.1.1.1–EP1.1.1.5.

a) Evaluation parameter EP1.1.1.1*: margins of design*

Examples of design parameters that could make a reactor more robust by increasing their design margins are: reactivity coefficients (e.g. Doppler-, void-, power-coefficients); fuel thermal design (centreline temperature at normal operation; stored energy in fuel; linear heat generation rate; margins on clad temperature); fuel mechanical design (margins on clad stress and strains; fission gas release); thermal hydraulic design (minimum critical heat flux ratio); resistance to instability or subcooling; decay ratio; fraction of core heat that can be removed by natural circulation; parameters characterizing possible overstressing and fatigue of the reactor system components; attributes of I&C systems.

Acceptability of EP1.1.1.1: *increased design margin (in the V-491 of the national NES in comparison to V-320, i.e. an existing reference design has been demonstrated).*

Measures are described below that resulted in an increased robustness of the AES-2006/V-491 design in comparison to VVER-1000/V-320.

Reduction of reactor pressure vessel embrittlement

The height and diameter of reactor pressure vessel (RPV) of the AES-2006 has been increased in comparison with VVER-1000 [127] to minimize irradiation of its sensitive areas, in particular welds, with fast neutrons that could lead to embrittlement (Table 51). The geometry change resulted in a decrease of fast-neutron flux density on the wall of the reactor pressure vessel. This enabled the assigned service life to be extended by a factor of 1.5.

Thus, this change of geometry leads to a higher reliability of the RPV and a longer service life.

TABLE 51. GEOMETRY OF RPV [128] AND RPV RADIATION LOADS [14].

Value	V-320	V-491
RPV height , mm	10897	11185
RPV inside diameter, mm	4000	4200
RPV wall thickness in the core area, mm	192,5*	197,5*
Maximum density of the flux of neutrons with the energy of > 0.5MeV at RPV inner surface, $sm^{-2}sec^{-1}$	$3.1 \cdot 10^{10}$	$2.3 \cdot 10^{10}$
Maximum life-time integrated flux of neutrons with the energy of 0.5MeV at RPV inner surface, sm^{-2}	$4.0 \cdot 10^{19}$	$4.2 \cdot 10^{19}$
RPV dose limit, sm^{-2}	$5.7 \cdot 10^{19}$	$6.4 \cdot 10^{19}$

Note: * anti-corrosion cladding at the inner surface of RPV is not included.

Increase of coolability of core

Hydraulic resistance of the core has been decreased in AES-2006 by optimization of spacer cell geometry (Figure 8), thereby avoiding a decrease in the number of lattices and, consequently, retaining same rigidness of fuel element structure.

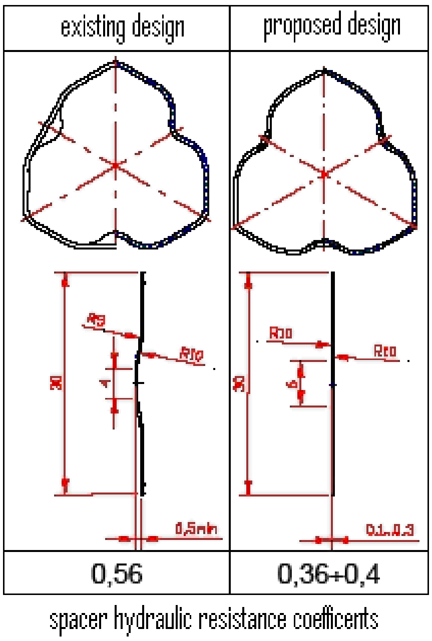

FIG. 8. Existing design of spacer cells for assemblies (TVS-2, TVS-2M) used in V-320 and proposed design of cells for assemblies in AES-2006 (Ref. [122]).

Decrease of the hydraulic resistance of AES-2006 fuel assembly provided an opportunity to include coolant mixing spacers with a cell design of ‘cyclone’ type. These mixing spacers force the coolant to rotate around the fuel rod (see Figure 9), thereby enabling trans-assembly mixing of the coolant.

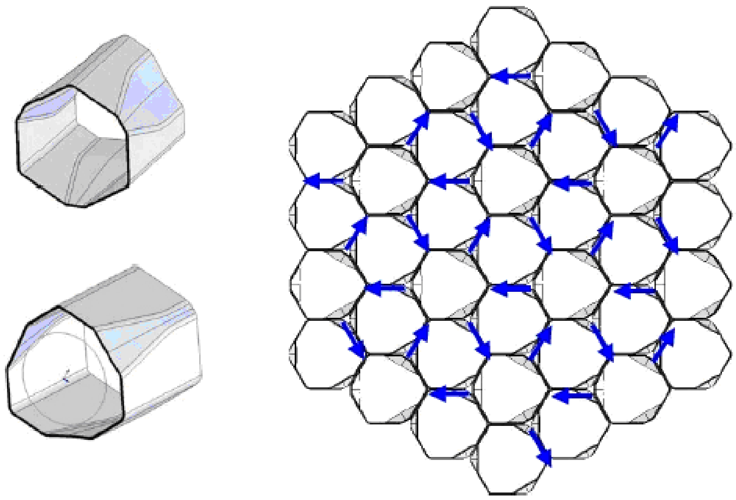

FIG. 9. Spacer cells and part of coolant mixing spacer of 'cyclone' type designed for AES-2006 (Ref. [122]).

The new spacer is also called a 'sector' type spacer (see Figure 10).

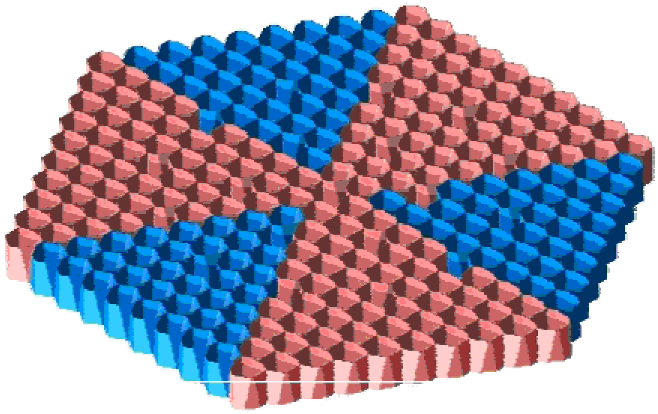

FIG. 10. Spacer of 'sector' coolant mixing type designed for AES-2006 [122].

Increased robustness of core design

After the Chernobyl accident (1986), rigid requirements on reactivity feedbacks were implemented in the Soviet Union. (Table 52)

Thus, currently, Russian design reactors require all reactivity feedbacks (including coolant temperature reactivity coefficient) to be negative in all critical conditions, including zero power. The distribution of fuel elements containing gadolinium (burnable absorber) in the V-491 reactor core is optimized to smooth out power spikes and to decrease concentration of boron acid in primary circuit at the beginning of cycle to provide negative feedbacks at low power.

TABLE 52. COMPARISON OF REACTOR CORE DESIGN OF AES-2006/V-491 WITH VVER-1000/V-320 (REFS [125, 129, 130])

Core design parameter	V-320	V-491
Doppler-coefficients	negative	negative
Power-coefficients	negative	negative
Max. linear heat generation rate (LHGR), W/cm	448	420
Centreline temperature at normal operation, ºC	1883 limit- 2600	Expected to be lower due to lower LHGR
Stored energy in fuel	estimated to be kept in V-491 at the same level as in V-320*****	
Margins on clad temperature, ºC (NO=normal operation, DBA= design basis accident)	350 – at NO; limit for NO- 352 max for DBA- 1200	354.1 – at NO; limit for NO- 355 max for DBA- 1200
Minimum DNBR	1,34 – at NO; 1,05 – at transients; >1.0 - limit	1,38 – at NO; >1.0 - limit
Fission gas release (the share of leaking fuel rods)	Operational limit: 0.2% - gaseous leak, 0.002% - leak with coolant-fuel contact Safety limit: 1% – gaseous leak, 0.1% – leak with coolant-fuel contact	Operational limit: 0.2% - gaseous leak, 0.002% - leak with coolant-fuel contact Safety limit: 1% – gaseous leak, 0.1% – leak with coolant-fuel contact
Margins to instability or margin on subcooling	estimated to be kept in V-491 at the same level as in V-320*	

Note: * Estimation of stored energy in fuel, margins to instability and sub cooling: standard height of VVER-1000 fuel rod is 3530 mm. In AES-2006 fuel rods will be filled with fuel pellets up to the 3730 mm. Tentatively, later it should be increased to 3780 mm, and central hole in pellets should be eliminated to increase content of uranium in the assembly. Thermal power ratio of V-491/V-320 is 3200/3000 = 1.0667; this value differs from fuel mass ratio 3730/3530 = 1.0567 for less than 1%. Thus, similar differences may be expected for “stored energy in fuel” and “margins to instability” or “margin on subcooling”.

Improved seismic design

Deep foundations for part of buildings are required for V-491 to achieve enlarged seismic stability (seismic design loads — 0.25 g) and taking into account high deformability of upper layers of grounds.

The V-320 plants located in the north-western part of Ukraine, neighbouring the originally planned Belarusian NPP (later converted to a gas fired plant), were constructed according to the regulatory requirements of the former USSR [131, 132]. Design stability of those reactors is characterized by a design base earthquake with a magnitude equal to 5 points (MSK-64 scale) and a highest calculated earthquake of 6 points of magnitude (MSK-64 scale); corresponding PGA values are ≈ 0.08 g and ≈ 0.15 g, respectively.

Since information on the seismic stability of the AES-2006 reactor design was not available directly from the designer at the time of assessment, the assessor has used the conclusion of the Finish nuclear licensing authority STUK [133], which made an assessment of several novel designs, including the AES-2006, selecting candidates for new NPP to be licensed in Finland:

The design objectives and principles associated with resistance to vibrations induced by earthquakes and other external hazards are consistent with Finnish safety requirements. The reference plant used in the design basis for earthquakes is Tianwan's PGA value of 0.2 g and Leningrad NPP-2's PGA value 0.12 g, which exceed the corresponding Finnish requirement of 0.1 g. The starting point for the design basis has been the predesign of the durability of the frame structures and vibration characteristics against all vibrations caused by external threats (loads). This provides a good basis for the detailed design also regarding the vibration resistance of the components. In terms of the decision in principle, the requirements presented in the design basis are adequate. The design principles for the vibration resistance of components must be verified when submitting the construction licence application.

Final assessment of evaluation parameter EP1.1.1.1

The potential for neutron embrittlement of the reactor pressure vessel was reduced, the coolability of the core, and the seismic design has been improved.

Thus, evaluation parameter EP1.1.1.1 has been met by the AES-2006 design.

b) Evaluation parameter EP1.1.1.2: *simplicity of design, (for example: reduced number of components of the reactor system or reduced number of active components).*

Acceptability of EP1.1.1.2: *demonstration of increased simplicity* of the new design (AES-2006/V-491) in comparison to existing design (VVER-1000/V-320).

There is no direct information available to the assessor regarding a simplification of the V-491 design in comparison to the V-320 design. However, there are some indications in the literature that could be interpreted in that direction. These indications are outlined below.

There is a special probabilistic requirement for the AES-2006 design [134] which stipulates less dependence on active components of the plant to mitigate anticipated operational occurrences or accidents; this results, for example, in a low sensitivity to loss of electric power from the grid.

The AES-2006 design needs a reduced quantity of metal and fewer investments as shown in Table 53 (based on Novovoronezh-2 design [135]):

TABLE 53. CHARACTERISTICS OF V-320 AND AES-2006 DESIGN

Characteristic	VVER-1000	AES-2006
Specific quantity of metal, rel. units	1	0.85
Specific capital investments, rel. units	1	0.8

Final assessment of acceptability of EP1.1.1.2

Only limited information was available with regard to simplification of the V-491 design. Nevertheless, EP1.1.1.2 is deemed to be met by AES-2006.

c) Evaluation parameter EP1.1.1.3: *Quality of manufacture and construction (for example reduction of welds in piping and vessels and application of automatic welding during manufacturing).*

Acceptability of EP1.1.1.3: *Demonstration of increased quality of manufacturing and construction* (*of the V-491 in comparison to V-320).*

The reactor pressure vessel of AES-2006 has only circular welds (VVER-1000 also has only circular welds although older designs also had longitudinal welds). A reduction of number of welds is a clear improvement of quality of manufacturing [14].

d) Evaluation parameter EP1.1.1.4: *Quality of material*: Improved quality of material and environments to reduce mechanical failures.

Acceptability of EP1.1.1.4: *Demonstration of increased quality of material (used in the V-491 in comparison to existing design V-320).*

The specification of material used for manufacturing of the VVER-1000/V320 nuclear reactor and for the AES-2006 is presented in Table 54.

TABLE 54. TYPES OF STEEL USED IN FABRICATION OF REACTOR PRESSURE VESSEL AND INTERNALS FOR V-320 [125] AND V-491 [55].

Structural element	**VVER-1000/V-320**	**AES-2006/V-491**
Compartment	08Kh18N10T	08Kh18N10T
Shroud	08Kh18N10T	08Kh18N10T
Block of protective tubes	08Kh18N10T	08Kh18N10T
Reactor pressure vessel	15Kh2NMFA	Three zones: 15Kh2NMFA, 15Kh2NMFA-A, 15Kh2NMFA class 1

The steel of the V-491 reactor pressure vessel has been modified in comparison tothat of V-320 to extend service life of the reactor from 30 to 60 years (see Table 49). Compared to the V-320, the content of nickel and admixtures in steel and weld composition of the new design was significantly reduced; for example, in material for the AES-2006 reactor pressure vessel, the fraction of nickel must be less than 1.3%, sulfur below 0.01%, copper below 0.06%, phosphorus below 0.08%) [14].

Since information on the quality of material used in V-491 reactor design was not available directly from the designer at the time of assessment, the assessor has used the statement issued by the Finish nuclear licensing authority STUK [133], which is reproduced in the following text. The link between V-320 and V-491 designs is stressed and main features inherited by AES-2006 from major equipment of the VVER-1000 family. Examples are presented that illustrate the use of improved material for the AES-2006 compared to earlier VVER-1000 designs.

The material and structural engineering solutions of the main nuclear components of the AES-2006 use the practical data gained from about 30 years of VVER reactor operation. The reactor pressure vessel is made of modern pressure equipment grade steel typical for such reactors. The forgings are welded into pressure vessels using known and qualified methods. The interior of the vessel is clad with stainless steel welded onto the surface. The internals of the reactor pressure vessel are made of stainless steel and other applicable material.

The typical ageing phenomena have been taken into account in material selection for the main equipment and in monitoring during operation. Radiation embrittlement in the core area of the reactor pressure vessel has been taken into consideration and is monitored with a programme for radiation embrittlement during operation. Attention must be paid to the analysis requirements (P, Cu and Ni) of the reactor pressure vessel steel so that the radiation embrittlement of the reactor pressure vessel core area remains within the allowed limits during the 60-year rated service life of the plant. This must be ensured in later stages of the licensing process.

Other main components, like the steam generators and the pressurizer, are manufactured in the same way as the reactor pressure vessel. The heat transfer pipes of the steam generators are made of stainless steel, which has been found to be a reliable solution in these plants provided that the water chemistry is well controlled. The damage detected earlier in the welding joints of the VVER-1000 plant’s steam generator’s collectors have been addressed through the material selection of the new steam generator type for the AES-2006.

The reactor coolant piping is made of low-alloy pressure equipment grade steel, which is lined with stainless steel. Thus no demanding, dissimilar metal joints are needed in the joints between the reactor coolant nozzles and the reactor coolant pipes.

The Finnish regulatory body spotted some advances of the AES-2006 design in comparison to its predecessor and defined a set of analyses to be performed at the latest stages of licensing process.

The design of the reactor coolant piping applies the ‘break preclusion’ principle, part of which involves the ‘leak before break’ principle. Thus, the intention is to eliminate a design-basis postulated break in the pipe with the largest diameter. This is, nevertheless, taken into account in the design of the emergency cooling systems. Further clarifications are still needed to ensure consideration of the dynamic effects of pipe breaks in the primary circuit, particularly if pipe whip restraints are not to be installed in the primary circuit.

Numerous smaller pipelines related to auxiliary and emergency systems are connected to the reactor coolant loop with welded joints, the integrity verification of which can pose challenges in conjunction with processing strength and ductility analyses and the implementation of periodic inspections and the related radiation protection goals. This must be taken into account in later stages of the licensing procedure.

The AES-2006 design objectives and principles presented for the main nuclear components are, for the most part, consistent with Finnish safety requirements. The effect of the reactor pressure vessel material’s analysis requirements on the rate of radiation embrittlement requires additional analyses, which can be assessed at later stages of the licensing procedure. Also the effects of the reactor coolant loop’s postulated sudden pipe breakages on the integrity of the reactor’s inner components, and the implementation, inspection and radiation protection principles of the reactor coolant loop joints must be clarified at later stages of the licensing procedure.

Final assessment of acceptability of EP1.1.1.4

Increased quality of material is demonstrated in V-491. Thus, the evaluation parameter EP1.1.1.4 is deemed to be met.

e) **Evaluation parameter EP1.1.1.5:** *redundancy of systems*.

Acceptability of EP1.1.1.5: *demonstration of increased redundancy of (operational) systems of the V-491 in comparison to existing reference design V-320* (*to help to avoid transients)*.

Reactivity management in the V-320 and AES-2006 plant is implemented by means of control rods, boron content in the reactor coolant, and burnable absorber contained in the fuel.

The chemistry and volume control system (CVCS) of the V-320 comprises three pumps of 60 t/h capacity for boron control and leaks, including a loss of coolant accident (LOCA). The CVCS of the AES-2006 comprises two pumps of 60 t/h capacity for ‘coarse’ boron control and LOCA, plus three pumps of 6.3 t/h capacity for ‘fine’ boron control and leaks.

In transient conditions, the reactor is shut down by dropping the control rods into the reactor core. The reactor scram system is passive in nature. The control rods drop into the reactor core by gravity after the reactor protection automation disconnects the power supply to the electromagnets, which hold the control rods.

With regard to shutting down the reactor, the diversity principle is realized with an emergency borating system designed with a capacity of 4 x 50% in the V-491 [133], vs. 3 x 50% in the V-320 (see also assessment of criterion CR1.3.3).

Owing to the burnable absorber mixed in the fuel of the AES-2006, the boron content of the primary coolant can be kept relatively low also after fresh fuel has been loaded in the reactor. Despite the lower boron content of the primary coolant and the more effective scram, the possibility of the boron content of the coolant being erroneously diluted has been taken into account in the design of the reactor. The management of the boron-free water slug in shutdown and startup situations and also in transient and accident conditions has been taken into account in the design process. Supplementary analyses/tests are needed to support the presented plans.

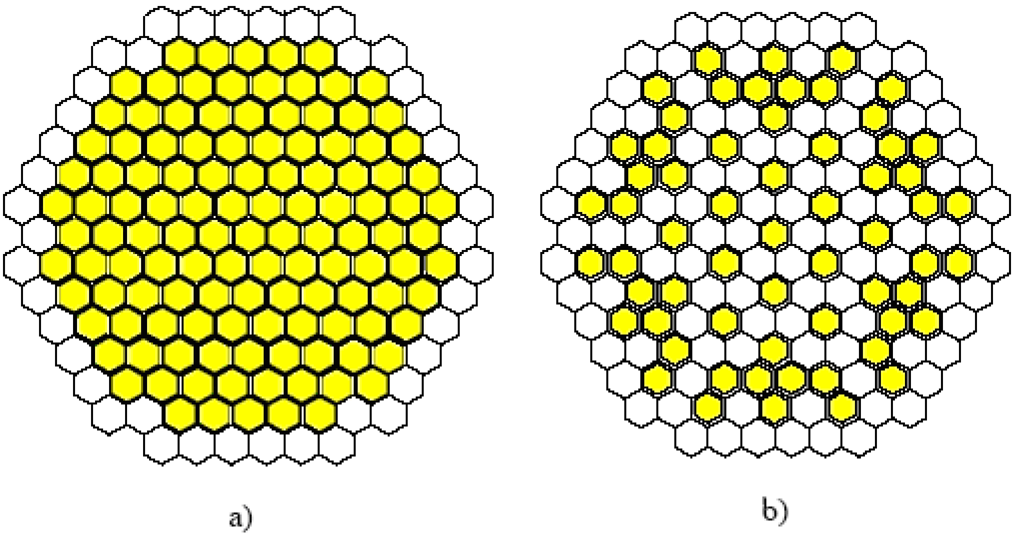

FIG. 11. Position and number of control rods (cells colored yellow) in reactor core of AES-2006 (a) and VVER-1000 (b) [122].

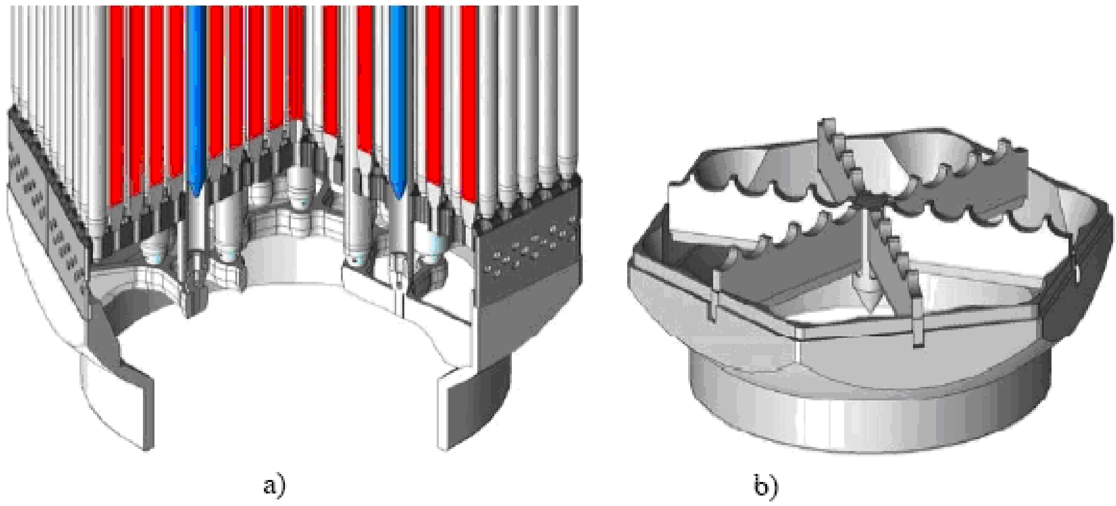

FIG. 12. Lower nozzles of fuel assemblies: (a) – new AES-2006 design with long guide tubes (control rods are blue, red are the fuel rods); (b) – existing nozzle design (TVS-2M, bottom spacer, fuel rods and guide tubes are not shown) has no contact with guide tubes [122].

AES-2006/V-491 design is equipped with 121 modernized control and protection system (CPS) drivers and corresponding 121 control rods which is approximately double the amount available in the VVER-1000/V-320 (see Figure 11). These additional 60 control rods increase the efficiency of reactor protection and also provide opportunities to implement modern and sophisticated algorithms of reactor control to ensure smooth power distribution at stationary conditions and transients. Also, the increased number of control rods leads to a drop of recriticality temperature from 190ºC to 91ºC (see also criterion CR1.3.6) in shutdown condition.

In Figure 12, the design of the lower nozzle of a fuel assembly of the V-491 reactor is compared with a fuel assembly design of the V-320 reactor. The V-491 fuel assembly design shows that the control rods can be inserted to a position down at the end of the fuel rods whereas in the V-320 fuel assembly design, the control rods can be inserted down to a position about 50 mm above the end of the fuel rods the lowest. This feature results in an increase of the shutdown capability of each control rod in the V-491 reactor.

Table 55 summarizes the information provided above.

TABLE 55. INCREASED REDUNDANCIES OF THE SYSTEM TO HELP TO AVOID TRANSIENTS.

№	Value	V-320	V-491
1	Number of CPS drives	61	121
2	Nominal distance between the control rod tips in the fully inserted position and the core bottom, mm	52.5	0
3	Number of safety trains	3	4*

*Notes: including an active emergency core cooling system (ECCS), a fully separated four-channel system of high- and low-pressure with a capacity of 4x100%; an emergency boron injection system — four-channel system with a capacity of 4 x 50%; emergency feedwater system (EFWS) — four-channel system with a capacity of 4 x 100% and with emergency feed water tanks; passive residual heat remove system (RHRS) — passive 4 x 33% system with 18 water-cooled heat exchangers in each channel.

According to Ref. [134], a high level of safety of the AES-2006/V-392M (Novovoronezh design) is attained on the basis of functional and structural diversity and the diversity of the operating regimes/states of backup components and safety systems. Specifically, diversity has been attained by use of active and passive safety systems for removing residual heat from the reactor.

These safety systems maintain sufficient coolant in the core also in situations with coolant leaks from the primary loop. Functional and structural diversity of safety systems will ensure deep protection from common-cause faults, and passive systems, which do not require operator intervention to function, will provide reliable protection from operator error.

A statement made by the Finnish licensing authority STUK is presented below regarding the capacity and redundancy of systems in the V-491 reactor [133] compared to the V-320 reactor. The statement includes a description of increased capacity and redundancy of the V-491 reactor compared to the V-320 reactor.

In hot shutdown conditions, as usual in PWRs including those of V-320 design, residual heat is removed from the V-320 reactor through steam generators directly to the turbine condenser using the turbine bypass lines. If this is not possible, residual heat can be removed by pumping water into the steam generators by means of an EFWS (4 x 100%) and blowing steam into the atmosphere with the secondary circuit dump valves (BRU-A).

After the pressure and temperature of the primary circuit of V-320 is reduced, the residual heat is removed directly from the primary circuit by means of the residual heat removal system (JNA, 4 x 100%), which uses the same pumps as the low-head safety injection system (JNG). The residual heat is transferred to the ultimate heat sink by means of the intermediate circuit cooling system (KAA, 4 x 100%) and the process water system for important consumers (PEB, 4 x 100%). These systems are used as the primary residual heat removal systems also in transient and accident conditions.

New possibilities of the shutdown reactor cooling are provided in the V-491 design. If the JNA (4 x 100%) cannot be used in a situation where the reactor pressure vessel head is open (transient in residual heat removal, e.g. in a 'mid-loop operation' situation), it can be replaced with the PHRS C (4 x 33%). In this case, residual heat is removed from the reactor by evaporating water into the containment. The residual heat from the containment is transferred by means of the PHRS C condensers into the atmosphere via the water pools located outside the containment. The system is always ready for operation and starts up without the need for any active component to function. The pools outside the containment are shared with the PHRS SG. Residual heat can be removed with the PHRS C for 24 hours after the accident without measures by an operator. With additional measures, the time can be lengthened to 72 hours by pumping water from the alternative water storage into the water pools. This solution is not described in more detail in the documentation nor is it certain that the arrangement is completely consistent with Finnish requirements that call for fixed pipelines and a refilling pump from the alternative water storage to the water pool. This issue can be reviewed when applying for the construction licence.

Cooling water for the reactor is supplied by means of the primary circuit's volume and boron control system (KBA) from the make-up water tank or by means of the JNG system from the in-containment refuelling water storage tank (IRWST).

Increased redundancy of systems has been demonstrated in the V-491. Thus, EP1.1.1.5 has been met.

Final assessment of criterion CR1.1.1 — robustness of design

The assessment of the evaluation parameters of the first criterion CR1.1.1 has confirmed an increased robustness of the V-491 reactor design in several aspects compared with the V-320 design, i.e. CR1.1.1 has been met by the AES-2006 design.

It is recommended that the additional information be requested from the designer of the AES-2006 for assessment of EP1.1.1.5 as defined in the text.

Assessment against criterion CR1.1.2 — operation

Indicator IN1.1.2: *High quality of operation*.

Acceptance limit AL1.1.2: *Superior to existing designs* in at least some of the operational aspects presented *(aspects are defined in eight evaluation parameters EP1.1.2.1 to EP1.1.2.8).*

a) **Evaluation parameter EP1.1.2.1:** *Margins of operation (increased operating margins will reduce the occurrence of abnormal plant states leading to reactor shutdown).*

Acceptability of EP1.1.2.1: *Demonstration of increased operating margin (in the V-491 in comparison to reference design V-320).*

There is no direct information available to the assessor for this evaluation parameter. However, indirect information is provided in the following, demonstrating an increased maneuverability of the AES-2006/V-491 design [136].

The V-491 reactor was designed for a manoeuvrable mode of operation and it has apparently more flexibility in the process of reactor power control. This flexibility assumes well-developed control methods (partly introduced in operating V-320) and equipment (e.g. increased amount of control rods) which provide availability of more accurate and reliable control of reactor parameters, and also some increased margins of operations, e.g. for the reactor core power distribution, for the limits on total number of manoeuvres. Because of more accurate controls and increased margins of operation, the V-491 reactor operating in a base load regime will probably have a reduced occurrence of abnormal plant states leading to reactor shutdown. The last statement may be not valid for a V-491 operating in manoeuvrable mode as no directly applicable data are available to the assessor to assess this evaluation parameter for V-491 reactor operating in the manoeuvrable mode.

TABLE 56. OPERATIONAL CHARACTERISTICS OF V-491 IN COMPARISON TO V-320

Value	V-320	V-491
Operation at different power levels	Base load mode	Base load and manoeuvrable mode
Speed of power variation, max.	Up to 3% N_{nom}/min, depending on conditions.	5% N_{nom}/min

Note: N_{nom} is normal operation power level

Unscheduled automatic shutdowns of the V-491 reactor are qualitatively predicted [14] to be less than one/year, i.e. 0.5, which is about the same level as currently achieved by V-320 reactors in operation (see also EP1.1.2.7).

Increased operational margin was demonstrated indirectly for the AES-2006 design, i.e. EP1.1.2.1 has been met.

b) **Evaluation parameter EP1.1.2.2***: reliability of control system (advanced control systems reduce the frequency of anticipated operational occurrences and the demand on operators).*

Acceptability of EP1.1.2.2: *demonstration of superior reliability (of the control systems of the V-491design in comparison to V-320).*

Since there is no direct design information available to assess this evaluation parameter, a statement made by the Finish licensing authority STUK [133] — which has preliminarily assessed and confirmed, in general, the reliability of the AES-2006 instrumentation and control (I&C) systems but criticized the available detail of information and some specific features — is presented below.

The safety principles of the automation systems were presented to STUK at a rather general level in the documentation of the application for a decision in principle. Before the specification of the design and the design material has reached the level of actual technical design, it is more a matter of the objectives of several safety principles, the fulfilment of which cannot be assessed from the documentation of the decision in principle. The genuine compliance of safety principles in the technical solutions of the plant has to be ensured as the design work advances including the subsequent phases of the project. Of these phases, the construction licence process is the first regulatory phase of the plant project that deals with concrete technical solutions of automation.

Automatic safety functions

AES-2006 plant automation includes several different lines of defence based on the defence-in-depth principle. The first line comprises normal process automation and control systems. The second line consists of the primary protection system that, if necessary, initiates all safety functions and is divided into two redundant, diverse parts, A and B. The third line includes a second protection system — hardwired diversity (HW-Div) — realized with a different technology and initiating the most important safety functions. The system includes the same functions as the protection system’s diversity A. The last line comprises the severe accident management system.

The automation systems of the different lines of defence are designed to automatically maintain the plant parameters within a safe range during operating transients and to limit the consequences of accident conditions.

The design objectives and principles of the automation systems used for actuation, control and monitoring of safety functions during transients and accidents are consistent with Finnish safety requirements.

I&C redundancy principle

The primarily operating protection system comprises four redundant subsystems. The protection function is actuated if two of the four redundant protection channels send a protection signal. The system meets the requirements of the Finnish Government decree with regard to the redundancy principle.

The most important normal process automation systems are realized as single failure tolerant. The design objectives and principles of the I&C system of the AES-2006 are consistent with Finnish safety requirements.

I&C separation principle

The parallel reactor protection systems have been physically and functionally separated from each other. The separation of the I&C systems and components of different safety classes from each other between and within subsystems has not been described in the documentation. Likewise, the separation of I&C and monitoring systems for severe accident management from other automation systems has not been addressed.

The documentation received does not provide adequate information regarding consistency with Finnish safety requirements in terms of design objectives related to the separation principle for I&C systems. The separation of automation systems of different safety classes from each other and the separation of the severe accident management system from the rest of the automation must be described and, if necessary, revised. Additionally, the separation principles of parallel I&C subsystems from each other must be clarified.

I&C diversity principle

Finnish safety requirements prescribe that at least two different process parameters must be measured in the reactor protection system, both of which must be physically dependent on a transient or accident and the triggering limits of which can be selected so that they are reached early enough. The application documentation does not indicate how the diversity principle is applied to the measurements of the reactor protection system and to the activation of protections. This matter can be reviewed when the application for the construction licence is submitted.

The AES-2006 plant’s automation is based on two computer-based system platforms. The reactor protection system, the engineered safety features system and the limiting system are based on one platform and the other I&C systems on the other platform.

The plant concept incorporates a HW-Div backup system for the computer-based protection system; the backup system is based on the diversity principle. The delivered documentation does not describe to what operational state the system can bring the plant in case of common cause failure of the programmable I&C system. The issue can be reviewed when applying for the construction licence.

The design objectives and principles of the system are consistent with Finnish safety requirements with regard to the diversity principle. The scope of the HW-Div system and the diversity principle of the reactor protection system with regard to measurements and activation of protections can be elaborated when the application for the construction licence is submitted.

Conclusion of STUK (Refs [133, 137])

The design objectives and principles associated with the separation principles of the I&C systems were not found to be fully consistent with Finnish safety requirements. The separation of I&C systems of different safety classes from each other and the separation of the management system for severe accidents from the rest of the plant I&C must be described and, if necessary, corrected. Additionally, the separation of the I&C's redundant subsystems from each other must be determined.

As outlined above, an independent expert organization (STUK) in general confirms the reliability of the AES-2006 I&C systems but criticizes the available detail of information and some specific features. The designer of the AES-2006 should analyse this statement and to implement necessary modifications into the design when appropriate. It is recommended that additional information on the I&C systems be requested to complete the assessment. It is assumed that the AES-2006 design will completely fulfil Belarus licence requirements. Thus, EP1.1.2.2 has been met.

c) **Evaluation parameter EP1.1.2.3:** *reduced impact of incorrect human intervention*: *(i.e. the reactor should be more tolerant to mistakes).*

Acceptability of EP1.1.2.3: *demonstration of less impact of incorrect human intervention (on operation of the V-491 in comparison to reference design V-320).*

There is no direct evidence available to the assessor to assess this evaluation parameter.

As discussed in the assessment of EP1.1.1.5, the increase of the number of control rods boosted their efficiency and minimized the potential for recriticality of the core in cooldown situations.

d) **Evaluation parameter EP1.1.2.4:** *Quality of documentation (e.g. records of abnormal occurrences, accumulated loads on equipment, have to be kept continuously from the start of operation; project documentation, processing docs, plant docs, safety and licensing docs, quality docs, operating docs, working docs must be available when the plant is close to start operation; operating manuals and manuals on chemistry, nuclear testing, conventional testing must be available).*

Acceptability of EP1.1.2.4: *Sufficient documentation is available (for the plant AES-2006 and updated properly).*

Plant documentation, such as records of operational behaviour, licensing documents or operating manuals, will be available only close to startup or after the plant is in operation. At the current stage of the Belarus nuclear power programme, it is too early to assess this evaluation parameter.

e) **Evaluation parameter EP1.1.2.5:** *Quality of training (appropriate training of personnel with regard to safety aspects shall comprise all staff members, who are directly involved in plant operation, plant and system maintenance, including managers; well-written training material is provided; use of simulators for operator training is mandatory).*

Acceptability of EP1.1.2.5: *Appropriate training programmes* (*are established and implemented).*

The designer claims [14] that a well-developed system — based on long time experience with this reactor family — has been implemented to training reactor staff for all VVER reactors. No detailed information was available to the assessor to study this system.

EP1.1.2.5 is deemed to have been met.

f) **Evaluation parameter EP1.1.2.6:** *Organization of plant (organization's structure, job descriptions, qualification requirements, authority and responsibility of personnel, lines of management, functions and the number of personnel required and qualification requirements in sufficient detail should be described by the owner).*

Acceptability of EP1.1.2.6: *Clear plant organization (with defined responsibilities has been established).*

There is no data available to the assessor to assess this evaluation parameter. However, because of the extensive experience of the designer, it can be assumed that a clear organization scheme will be installed in the AES-2006 plant.

Thus, EP1.1.2.6 has been met.

g) **Evaluation parameter EP1.1.2.7:** *availability/ capability of plant (scram frequency and number of nuclear events or unit capacity factor during the plant operation. During the development of plant – measures and features that ensure a high availability/ capacity factor).*

Acceptability of EP1.1.2.7: *plant to be installed demonstrates comparable or superior availability/capacity factors compared to existing designs (for plant under development measures and features are described that ensure these factors will remain comparable to existing designs or become superior).*

According to Ref. [138], in the Russian Federation a capacity factor of 81.8% for VVER reactors was achieved in 2006; this represents an increase of +8% compared with 2005. Other types of reactors in the Russian Federation achieved a capacity factor of 76.1% in 2006; this represents a decrease of 3.4% compared with 2005. Unscheduled automatic shutdowns of all VVER reactors are reported to be less than 0.5/year.

The designer expects [14] the frequency of unscheduled automatic shutdowns of AES-2006 reactors will also be less than 0.5 per year. The duration of scheduled shutdowns for reloading and maintenance should be under 25 days which should yield finally the capacity factor of 90%.

Thus, evaluation parameter EP1.1.2.7 has been met.

h) **Evaluation parameter EP1.1.2.8:** *use of worldwide operating experience (operation experience of existing NPPs collected by international organizations should be taken into account in the design of a new NPP).*

Acceptability of EP1.1.2.8: *Experience of operating NPPs has been taken into account (in the design of V-491).*

Since no direct data were available for the assessment of this evaluation parameter the assessor has used an example of operating experience of Swedish NPP Forsmark that had been considered in a statement [133] of the Finish licensing authority assessing the AES-2006 design. An excerpt is presented in the following.

The general lessons learned from the design errors leading to the malfunction of the electric system of Forsmark NPP in 2006, will be taken into account. In the design of the electrical systems and components, special attention will be paid, for example, to restraining voltage transients from spreading and the implementation of the diversity principle in the electricity distribution and in supplying power to I&C systems. Full analysis will be made to find out the most severe possible voltage transients and malfunctions of the in-house grid. Power consumers and systems are to be designed to withstand these transients and malfunctions. This will be reviewed in a more detailed manner at the construction licensing stage.

The designer of the AES-2006 had to analyse this statement and to implement necessary modifications into the design when appropriate. It is recommended that additional information be requested on the electric systems as outlined in the text to complete the assessment.

Final assessment of criterion CR1.1.2 — operation

This criterion has been met as several aspects defined in the evaluation parameters are fulfilled.

It is recommended that the designer be requested to comment on the concerns raised in the text and to request additional information related to EP1.1.2.2 and EP1.1.2.8 from the designer of the V-491.

Assessment against criterion CR1.1.3 — inspection

Indicator IN1.1.3: *Capability to inspect (more effective and efficient inspections may be performed in comparison to existing designs).*

Acceptance limit AL1.1.3: *Superior to existing design (V-491 should be easier to inspect than V-320).*

This criterion requires that the inspection programme should be based on understanding the failure mechanism in order to ensure the right locations of inspections.

Taking into account the evolutionary nature of the AES-2006 design and the vast positive experience of modern VVER operation, the designer introduced only minor modifications into the inspection procedures [14].

It is self-evident that the necessary knowledge about material and manufacturing processes for the V-491 is available from the designer. Examples of design features to facilitate the performance of inspections in V-491 are [139]:

- Improved access to the tube space of steam generators for inspection;
- The new programme of surveillance specimens (arrangement directly at RPV wall);
- The use of quick-detachable connectors for cables, heat insulation for equipment and pipes;
- Installation of additional operating platforms.

Final assessment of criterion CR1.1.3 — inspection

Criterion CR1.1.3 has been met by the V-491 design.

Assessment against criterion CR1.1.4 — failures and disturbances

Indicator IN1.1.4: *Expected frequency of failures and distur*bances *(for design V-491 the expected frequencies of initiating events (IE), i.e. failures and disturbances should be reduced relative to existing reference design V-320).*

Acceptance limit AL1.1.4: *V-491 is superior to existing design V-320 in at least some of the aspects discussed.*

Information on the V-320 and V-491 designs is shown in Table 57.

TABLE 57. FREQUENCY OF INITIATING EVENTS (IE) OF V-320 AND V-491 [14, 140] (OPERATING REGIMES AT POWER)

Initiating event	V-320, 1/a	V-491, 1/a
Medium coolant leak from primary circuit	4.30E-04	
Small non compensable leaks from primary circuit	9.43E-03	
Small compensable leaks from primary circuit	6.58E-02	below 0.14
Small coolant leak from the primary into the secondary loop	4.19E-02	1.5E-03
Medium coolant leak from the primary into the secondary loop	2.00E-03	
Leak from steam lines in the shut-off part	1.00E-03	
Leak from steam lines in the part not shut off from SG	2.45E-02	
Transients, leading to scram actuation	5.98E-01	
FACSV malfunction	2.22E-02	
Loss of electric power	1.85E-02	
Loss of turbine condenser vacuum	6.58E-02	
Loss of main feed water	5.10E-03	
Loss of industrial water of main consumers	2.53E-05	
Reactor vessel break	2.70E-07	

Final assessment of criterion CR1.1.4 — failures and disturbances

Not enough data on the V-491 design regarding criterion CR1.1.4 was available to the assessor.

It is recommended that the missing data be requested from the designer to complete the assessment. However, it is expected that the missing data will confirm that the probability (frequency) of initiating events has been clearly reduced in the AES-2006/V-491 design.

Thus criterion CR1.1.4 is expected to be met.

Final assessment of user requirement UR1.1 robustness

All criteria were judged to meet their acceptance limit. For criteria CR1.1.2 and CR1.1.4 it is recommended that additional information be requested from the designer.

Thus, user requirement UR1.1 is deemed to have been met by the AES-2006 design.

8.2.2. User requirement UR1.2 — detection and interception

User requirement UR1.2: *Installations of an innovative NES should detect and intercept deviations from normal operational states in order to prevent anticipated operational occurrences from escalating to accident conditions.*

INPRO has developed three criteria for this user requirement, CR1.2.1, CR1.2.2, and CR1.2.3.

8.2.2.1. Assessment against criterion CR1.2.1 — I&C and inherent characteristics

Indicator IN1.2.1: *Capability of I&C system and/or inherent characteristics to detect and intercept and/or compensate such deviations*.

Acceptance limit AL1.2.1: *Key system variables relevant to safety (e.g. flow, pressure, temperature, radiation levels) do not exceed limits acceptable for continued operation (no event reporting necessary).*

INPRO developed two evaluation parameters for this criterion, EP1.2.1.1 and EP1.2.1.2.

a) **Evaluation parameter EP1.2.1.1:** *Continuous monitoring of the plant health (Examples of the monitoring systems to be designed: Leak monitoring; Loose parts monitoring; Vibration monitoring system of reactor pressure vessel internals; Diagnostic of rotating* *machinery; Chemical monitoring; Seismic monitoring system; Environmental impact of radioactive releases; Computerized aids to operators).*

Acceptability of EP1.2.1.1: *design includes systems for continuous monitoring of plant health and computerized aids for the operators.*

In addition to V-320 monitoring systems (e.g. in-core power distribution monitoring) the AES-2006 reactor design includes the [14]:

- Leak monitoring system (SKT);
- Loose parts monitoring system (SOSP);
- Vibration monitoring system of reactor pressure vessel internals (SLE);
- Chemical monitoring (SHM)
- Complex analysis system (SCA).

Evaluation parameter EP1.2.1.1 has been met.

b) **Evaluation parameter EP1.2.1.2:** *Dynamic plant analysis (an analysis of the NPP dynamics is required to show how the different events causing a deviation from normal operation are detected and mitigated).*

Acceptability of EP1.2.1.2: *A deterministic and probabilistic plant analysis has been performed* (*and the results confirm that key system variables relevant to safety, e.g. heat flux, flow, pressure, temperature, radiation levels do not exceed limits acceptable for continued operation and do not result in any short term consequences affecting normal operation).*

No direct information on the V-491 design for assessment of this evaluation parameter is available to the assessor. The status of the deterministic and probabilistic safety analyses of the AES-2006 design is presented in the evaluation of criterion CR4.2.2 (computer tools). On the basis of the experience of the designer, it is expected that the plant analyses will confirm that all key system variables will not exceed their limits.

It is recommended that the missing information be requested to complete the assessment.

Final assessment of criterion CR1.2.1 — I&C and inherent characteristics

The AES-2006 design includes several systems for continuous monitoring of plant health. No direct results of dynamic plant analyses of the V-491 needed for the assessment of CR1.2.1 are available to the assessor. However, an independent expert organization (STUK) concluded that the analyses methods used for the design of V-491 are adequate. It is recommended that these data be requested from the designer of V-491.

Criterion CR1.2.1 is deemed to have been met by the AES-2006 design.

8.2.2.2. Assessment against criterion CR1.2.2 — grace period

Indicator IN1.2.2: *grace period until human action is required, i.e. the time available, in case of a failure or beginning of abnormal operation, before human (operator) action is required.*

Acceptance limit AL1.2.2: *grace period of at least 30 minutes (is ensured by the design of the plant).*

According to Ref. [140], the V-320 design ensures a 30 min grace period, which is defined in operational documentation of Ukrainian NPPs.

The grace period of the AES-2006 design is at least 30 minutes [140] before human action is required.

According to the data provided by designer [14], during a period of 10–30 minutes (depending on the specific system) after the automatic start of safety systems, the control safety system blocks intervention of the operator into the transient process.

Final assessment of criterion CR1.2.2 — grace period

Criterion CR1.2.2 has been met by the V-491 design.

8.2.2.3. Assessment against criterion CR1.2.3 — inertia

Indicator IN1.2.3: *inertia to cope with transients (capability of a nuclear reactor system to cope with anticipated operational occurrences, e.g. sufficient primary coolant, small reactivity holdup in the control system or additional secondary side mass).*

Acceptance limit AL1.2.3: a *higher inertia exists in a* V*-491 reactor compared to reference design V-320.*

The V-491 design has an increased coolant volume inside the reactor vessel and above the reactor core in particular [128], and somewhat increased volume of secondary water in comparison with V-320. Nevertheless, the ratios of coolant volume per installed capacity are approximately the same or even lower.

TABLE 58. CAPACITIES OF EQUIPMENT FOR V-320 AND V-491 DESIGNS

	V-320	**V-491**
Reactor pressure vessel, m^3	145.7	~156.4
Steam generator, m^3	81.5	83.7
Total primary loop, m^3	306.2	319.1

Reactors of Russian design traditionally have higher specific volume of coolant per fuel mass than other PWRs [14].

Final assessment of criterion CR1.2.3 — inertia

Criterion CR1.2.3 has been met by the V-491 design.

8.2.2.4. Final assessment of user requirement UR1.2 — detection and interception

This user requirement requires an adequate I&C system capable of detecting and intercepting abnormal operational states and preventing escalation of such states into accidents.

Sufficient grace period and improved inertia of the of the primary and secondary coolant system of AES-2006 have been demonstrated, i.e. criteria CR1.2.2 and CR1.2.3 are met by the AES-2006 design. For assessment of the capability of the I&C system, i.e. criteria CR1.2.1, not enough data are available to the assessor. It is recommended that these data be requested from the designer of AES-2006.

It is assumed that the assessment of CR1.2.1 will produce a positive result when the data are available.

Thus, user requirement UR1.2 is deemed to have been met by the AES-2006 design.

8.2.3. User requirement UR1.3 — design basis accidents

User requirement UR1.3: *The frequency of occurrence of design basis accidents (DBA) should be reduced, consistent with the overall safety objectives. If an accident occurs, engineered safety features should be able to restore an installation of an innovative NES to a* *controlled state, and subsequently (where relevant) to a safe shutdown state, and ensure the confinement of radioactive material. Reliance on human intervention should be minimal, and should only be required after some grace period.*

INPRO has developed six criteria for this user requirement, CR1.3.1 to CR1.3.6.

8.2.3.1. Assessment against criterion CR1.3.1 — frequency of DBA

Indicator IN1.3.1: *Calculated frequencies of occurrence of design basis accidents (DBA).*

Acceptance limit AL1.3.1: *Reduced frequency of accidents* that can cause plant damage relative to existing facilities, e.g. for a small break LOCA $<10^{-2}$ per unit-year, for a large break LOCA $<10^{-4}$ per unit-year.

In accidents where reactor coolant is lost as a result of a leak, the reactor can be cooled with emergency cooling systems designed for this purpose. LOCA frequencies of V-320 and V-491 reactors are presented in Table 59. Both reactors fulfil CR1.3.1.

TABLE 59. CALCULATED FREQUENCY (1/A) OF LOCA OF V-320 [140] AND V-491 [14]

Accident	V-320,	V-491
Large coolant leak from primary circuit (279 < D < 850 mm)	$8.80{\cdot}10^{-5}$	$5.25{\cdot}10^{-5}$
Small non compensable leaks from primary circuit	$9.43{\cdot}10^{-3}$	-

It is demonstrated that frequencies of a large break LOCA will be lower for the V-491 design. Similar results are expected for a small break LOCA as the V-491 design includes plenty of measures to cope with the occurrence of this type of accident.

Since only limited direct data were available for the assessment of this evaluation parameter, the assessor has used a preliminary evaluation performed by an independent expert organization (STUK) on the process of cooling of the reactor during loss of coolant accidents [133] in the V-491 reactor.

At the AES-2006 plant, emergency cooling of the primary circuit is implemented by means of active high-head safety injection system (JND, 4 x 100% vs. 3 x 100% in V-320), a JNG (4 x 100% vs. 3 x 100% in V-320) and four pressure accumulators. The pumps of the safety injection system take coolant from the IRWST through suction strainers. The reactor cooling water that has leaked into the containment drains back to the IRWST. The design of the suction strainers in the IRWST is not presented in the documentation (available to STUK). The design of the suction strainers and a test programme for them is currently under way. The suction strainers will be equipped also with a back-flushing system. This issue can be reviewed when the application for the construction licence is submitted.

For small coolant leaks, the diversity principle with regard to emergency cooling is realized so that the primary circuit is cooled quickly by means of the relief valves of the secondary circuit or with the safety valves of the primary circuit. The pressure in the primary circuit is reduced to a range where the JNG system and the safety injection accumulators can function. Cooling water for the JNG and JND systems is supplied from the IRWST.

The pumps of the high- and low-head safety injection system and the pressurized water tanks feed borated water directly into the reactor pressure vessel, both into the downcomer and above the reactor core. Additionally, with the JND pumps, borated water is pumped to two cold legs and, with the JNG pumps, to the two cold legs and hot legs. This makes it possible to ensure the supply of cooling water to the reactor in case of small coolant leaks in the primary circuit that are associated with a common cause failure in the components related to reactor cooling.

Residual heat is removed from the reactor using the JNA (4 x 100% vs. 3 x 100% in V-320), which uses the same pumps as the JNG. The residual heat is transferred to the ultimate heat sink through the intermediate circuit cooling system (KAA, 4 x 100% vs. 3 x 100% in V-320) and the process water system for important consumers (PEB, 4 x 100% vs. 3 x 100% in V-320).

The design objectives and principles of the systems associated with the cooling of the reactor core and the removal of residual heat are consistent with Finnish safety requirements.

Final assessment of criterion CR1.3.1 — frequency of DBA

Limited direct information on the frequencies of DBAs in the V-491 design is available to the assessor. On the basis of the information from V-320 design and significant improvements in the V-491 design, comparing to V-320 it is expected that for the V-491 design criterion, CR1.3.1 has been met for LOCAs.

It is recommended that additional information on the frequency of DBA in V-491 be requested from the designer.

8.2.3.2. Assessment against CR1.3.2 — grace period

Indicator IN1.3.2: *Grace period until human intervention is necessary (for DBAs it is required that actions of automatic and/or passive safety systems provide a sufficient grace period for the operator).*

Acceptance limit AL1.3.2: *The V-491 should have a grace period of at least 8 hours.*

According to Ref. [134], an important feature of the AES-2006 design (AES-2006/V-392M, Novovoronezh) is the capability of the systems which remove heat from the reactor core to operate for an unlimited period of time.

V-491 passive systems that perform safety functions are:

- Closed loops for natural circulation of the second-loop coolant with air condensers and equipment for regulating the direct load on each steam generator; this system can remove heat from the steam generators for an unlimited time;
- First-level water tanks;
- Second-level water tanks with flow normalization; the water stored in these tanks will allow emergency flooding of the core for at least 24 h without activation of active emergency makeup systems in a situation with primary-loop leaks with a size up to an equivalent full rupture of the main circulation pipeline;
- A system for catalytic burning of hydrogen in the atmosphere of the containment;
- (In case of severe accident) a system for catching and cooling the fuel melt; this system is located beneath the reactor vessel.

These passive systems can independently perform all safety functions without active systems and operator intervention for at least 24 h; they are capable of functioning even with complete loss of electric power for the internal needs of the NPP, including emergency sources of AC power.

Final assessment of criterion CR1.3.2 — grace period

Criterion CR1.3.2, i.e. a grace period of more than eight h, has been met by the V-491 design.

8.2.3.3. Assessment against CR1.3.3 — safety features

Indicator IN1.3.3: *Reliability of engineered safety features (probability of failure of engineered safety system per demand and unit).*

Acceptance limit AL1.3.3: *the V-491 in case of a DBA should show equal or higher reliability than reference design V-320.*

Due to the use of redundant and diverse systems, the reliability of engineered safety systems is higher for the V-491 design than for the conventional V-320 (See Table 60).

Table 60 clearly demonstrates an increased reliability of the safety systems in V-491 design compared to the V-320.

TABLE 60. COMPARISON OF INNOVATIVE (V-491) AND CONVENTIONAL (V-320) SYSTEM DESIGN

Value	V-320	V-491 [123]
ECCS active part	Separate three-channel systems of high and low pressure with channel reservation of 3 x 10% each	Separate four-channel systems of high and low pressure with channels reservation of 4 x 100% each
ECCS passive part (HA-1)	Passive four-channel system with channel reservation of 4 x 33%	Passive four-channel system with channel reservation of 4 x 33%
Emergency boron acid injection system	Three-channel system with channel reservation of 3 x 50%	Four-channel system with channel reservation of 4 x 50%
EFWS	Three-channel system (one channel in reserve)	Four-channel system with channel reservation of 4 x 100% with tanks of emergency feedwater reserve
Passive heat removal system (PHRS)	-	Passive four-channel system with channel reservation of 4 x 33% with 18 water-cooled heat exchangers in each channel

Since only limited direct information was available for the assessment of this specific evaluation parameter, the assessor used a detailed statement [133, 137] on a preliminary safety assessment of the AES-2006 design that was prepared by an independent expert organization (Finnish authority STUK). An excerpt is presented below.

The safety functions of the AES-2006 have been improved compared to the VVER 91/99 plant (and correspondingly to V-320). In the AES-2006 plant, both active and passive systems are used for the implementation of safety functions. The AES-2006 also has management systems for severe accidents. The level of maturity of the plant with regard to basic design is high. The design objectives and principles are for the most part consistent with Finnish safety requirements.

Cooling reactor in accident conditions with reactor primary circuit intact

If a transient or an accident prevents normal residual heat removal to the turbine condenser, residual heat can be removed from the primary circuit to the atmosphere using the EFWS (4 x 100%) of the secondary circuit and the steam generator dump valves (BRU-A). The EFWS is used to pump water from the emergency feedwater tank into the steam generators; the steam generated there is then transferred to the atmosphere through the dump valves. The EFWS features four lines (4 x 100%). The system can be used to bring the reactor into a controlled (hot shutdown) state and maintain it there for at least 24 hours. With additional measures, the time can be lengthened to 72 hours by pumping water from an alternative water storage into the water pools. This solution is not described in more detail in the documentation nor is it certain that the arrangement is completely consistent with Finnish requirements that call for fixed pipelines and a refilling pump from the alternative water storage to the emergency feedwater tank. This issue can be reviewed when applying for the construction licence.

Residual heat can be transferred to the atmosphere alternatively also with the steam generator's PHRS (4 x 33%). With the PHRS SG, the reactor's residual heat is transferred through the steam generators to the atmosphere via the heat exchangers in the water pools located outside the containment. The PHRS SG is activated from a protection signal, which opens the valve between the steam generator and the heat exchangers outside the containment. The heat is then transferred to the atmosphere via the water pools entirely without an external power source. The system can remove residual heat for 24 hours after an accident without measures by an operator. With the PHRS SG, the plant is brought to controlled (hot shutdown) state. With additional measures, the time can be lengthened to 72 hours by pumping water from an alternative water storage into the water pools. This solution is not described in more detail in the documentation, nor is it certain that the arrangement is completely consistent with Finnish requirements that call for fixed pipelines and a refilling pump from the alternative water storage to the emergency feedwater tank. This issue can be reviewed when applying for the construction licence.

In transient and accident conditions in which the reactor primary circuit is intact, the make-up water for the reactor and compensating for the volume decrease due to cooling is supplied primarily by means of the volume and boron control system (KBA). Alternatively, make-up water can be supplied by means of the JND (4 x 100%), which takes the make-up water from the IRWST located inside the containment.

If removal of residual heat through the secondary circuit is not possible, and pressure and temperature are high in the primary circuit, residual heat can also be removed directly from the primary circuit. This is done by pumping cold boron-containing water into the circuit by means of the JND pumps from the IRWST, and by removing hot water from the circuit through the safety valves back to the IRWST (feed and bleed cooling) via the containment. Residual heat is transferred to the ultimate heat sink by means of the intermediate circuit cooling system (KAA, 4 x 100%) and the process water system for important consumers (PEB, 4 x 100%).

Electrical systems

The supply of off-site power at the AES-2006 plant is realized through auxiliary transformers and a main transformer from the 400 kV grid or through standby auxiliary transformers from the 110 kV grid.

In case off-site power supplies fail, on-site power to the safety systems of the plant is supplied from:

- Emergency diesel generators (4 x 100%);
- A gas turbine-driven generator, which realizes the diversity principle (1 x 100%);
- Batteries during the startup of emergency power sources.

The alternating current power source presented in the concept realizes the diversity principle, but is not consistent with Finnish safety requirements in terms of the redundancy principle.

The severe accident management systems have their own separate on-site power supply systems. The description refers to separate battery sets, which have a discharge time of 72 h. No procedures for recharging the battery sets have been presented.

The separation principle applied to the electrical systems has not been clearly described. This matter can be reviewed when the application for the construction licence is submitted.

The design objectives and principles of the electrical systems are, for the most part, consistent with the Finnish safety requirements. The alternating current power source realizing the diversity principle, the separation principles of the electrical systems, the separate power supply system for the severe accident management system and the general lessons learned from the Forsmark incidence must be further analysed when the application for the construction licence is submitted.

Some features of the AES-2006 design were criticized by STUK (Refs [133, 137]).

The safety building's structural elements containing safety systems have been placed side by side and are connected by service corridors and air-conditioning system channels. These connections between the redundant subsystems and protected by doors and dampers make the adequate realization of physical separation questionable. According to STUK's assessment, the fulfilment of Finnish safety requirements in terms of protection against internal hazards, like floods and fires, has not yet been demonstrated. The solution presented requires more detailed designs and analyses, and apparently also plant modifications.

The AES-2006 safety systems are divided into four parallel, redundant subsystems. The subsystems are physically separated from each other. Those components of the safety systems located in the safety building are placed in adjacent room areas. Physical separation in the containment has been realized by dividing the annulus into four fire compartments.

The lower floors of the safety building contain the seawater heat exchangers and pipelines of the intermediate circuit cooling system. Controlling a major flood caused by the breakage of these components is challenging in the selected layout of the safeguards building. Likewise, in the safety building, each subsystem's low- and high-head pressure injection pumps and related equipment and pipelines have been placed in the same room space without physical separation.

Final assessment of criterion CR1.3.3 — safety features

The data available to the assessor show an increased reliability of the engineered safety features of the V-491 compared to the V-320 design. Thus, criterion CR1.3.3 has been met.

It is recommended that the designer be requested to comment on the concerns raised in this section regarding particular safety features.

8.2.3.4. Assessment against criterion CR1.3.4 — barriers

Indicator IN1.3.4: *Number of confinement barriers maintained*. The design of engineered safety features should deterministically provide for continued integrity at least of one barrier (containing the radioactive material) following any DBA.

Acceptance limit AL1.3.4: Deterministically, *at least one remaining barrier* against a release of fission products to the environment; or, probabilistically, a very low probability of failure of all barriers in the NES.

According to the designer [14], design calculations have demonstrated that during DBA conditions the temperature of fuel pellets does not exceed local melting criterion and temperature of fuel claddings remains below 1200˚C. Therefore at least two confinement barriers are expected to remain secured in any DBA – the fuel matrix and reactor containment building.

Little direct information was available for the assessment of the design and reliability of confinement barriers of the AES-2006. The assessor used a detailed statement [133] from an independent expert organization (Finnish authority STUK) on the containment design of the AES-2006. The statement discusses features of the AES-2006 design that during DBAs should guarantee the integrity of the containment as the last barrier against a major release of radioactivity into the environment. Direct information that the containment integrity is ensured for all DBAs is not available to the assessor.

The primary containment of the AES-2006 plant is a large dry containment built of pre-stressed reinforced concrete and provided with a tight steel liner. The containment is designed to maintain its integrity in compliance with approval criteria in transient and accident conditions. The primary containment is enclosed in a secondary concrete containment, which protects the primary containment against external hazards.

Removal of residual heat from the containment

At the AES-2006 plant, the removal of residual heat from the containment in transient and accident conditions is implemented with the containment sprinkler system (JMN, 4 x 50%).

The diversity principle for residual heat removal is realized by means of the containment's PHRS C (4 x 33%). The reactor's residual heat is removed from the containment and into the atmosphere via the water pools located outside the containment by means of the PHRS C. System activation requires no external power source. The system's water pools are shared with the PHRS SG. With PHRS C, the residual heat can be transferred for 24 hours after an accident without operator measures. With additional measures, the time can be lengthened to 72 hours as presented above.

The design objectives and principles of the systems involved in residual heat removal from the containment are consistent with Finnish safety requirements.

Containment isolation

At the AES-2006 plant, the intention is to implement containment isolation in each of the pipelines penetrating the containment by means of two isolation valves that operate on different principles. The design objectives and principles of the containment isolation are consistent with Finnish safety requirements.

In the following, a critique of the AES-2006 design by STUK [133, 137] of the protection strategy of the plant against external impacts is quoted.

The protection strategy of the AES-2006 plant against the impact of a large commercial airplane is based on constructing the outer containment building to withstand the impact of a large airplane. Additionally, the strategy uses principles of shielding and distance for the buildings of main steam valves, safety systems, control rooms and emergency diesel generators. Strengthened reinforced concrete structures are used to protect the fresh fuel storage, and the tanks for radioactive waste are located in underground rooms.

Structural protection against collision by a large commercial airplane focuses on the outer containment and on the fresh fuel storage. The safety buildings and steam cells are not designed to withstand the impact of a large airplane. Demonstrating the realization of the safety functions in an event of an aircraft collision is thus difficult. The plant supplier has presented options for expanding the structural protection of the buildings deemed most significant in terms of safety.

In STUK's opinion, fulfilment of Finnish safety requirements has not yet been demonstrated. The solution presented requires more detailed designs and analyses and plant modifications.

Final assessment of criterion CR1.3.4 — barriers

The Finnish statement is interpreted that the containment is correctly designed to withstand all conditions (e.g. pressure and temperature) caused by design basis accidents occurring inside the containment. However, one external accident seems to be analysed by Belarus' experts in detail. It is recommended that, in compliance with Belarus' regulation, additional information on the accidental collision with a large commercial airplane be requested and analysed. After receiving the additional information it is expected that criterion CR1.3.4 will be met by the AES-2006 design.

8.2.3.5. Assessment against criterion CR1.3.5 — controlled state

Indicator IN1.3.5: *Capability of the engineered safety features to restore the reactor to a controlled state (without operator actions). The reactor must be taken to a safe shutdown state at least within the designed grace period with the assurance that sufficient core cooling exists*.

Acceptance limit AL1.3.5: *The engineered safety features are sufficient to reach a controlled state after a DBA based on automatic actions within a grace period of at least eight hours.*

No direct information is available to the assessor to evaluate this criterion CR1.3.5.

8.2.3.6. Assessment against criterion CR1.3.6 — subcriticality

Indicator IN1.3.6: *Subcritically margins (sufficient shutdown reactivity must be available to make the core subcritical in the shortest possible time and to reliably keep it subcritical).*

Acceptance limit AL1.3.6: *confirmation for a minimum shutdown reactivity* margin *of 1% Δk/k including a consideration of uncertainties and of a worst single failure in the shutdown system.*

Subcriticality of the V-491 core is achieved by insertion of 121 control rods and addition of soluble poison (boron). Compared to the V-320 design, the subcritical state of V-491 is more reliable due to an increased number of control rods and their somewhat greater length. This leads to the drop of re-criticality temperature from 190ºC to 91ºC as shown in Table 61.

TABLE 61. DESIGN CHARACTERISTICS RELATED TO SUBCRITICALITY

Value	V-320	V-491
Number of control rod drives	61	121
Re-criticality temperature, ºC	190	91

Shutdown efficiency strongly depends on the (density and energy) distribution of neutrons in the core and is an important subject for consideration during optimization of reactor core composition.

For the V-320 core design, the minimum shutdown reactivity margin is -5.5% Δk/k at full power conditions and -3.3% Δk/k at zero power including the consideration of the worst single failure. These values cover all negative reactivity feedbacks, uncertainties (10%) and 1% Δk/k subcriticality margin. For the full power conditions in a typical modern V-320 core operating in equilibrium cycle with decreased leakage of fast neutrons the shutdown reactivity is approximately -7% Δk/k, including a single failure of the most effective control rod.

Taking into account the increased number of control rods and their distribution in a core of the AES-2006 (see also evaluation parameter EP1.1.1.5), the shutdown system of V-491 is expected to demonstrate outstanding efficiency at least as good as the V-320 design. Data on scram efficiency of the V-491 reactor are provided in Table 62 [14].

TABLE 62. SHUTDOWN REACTIVITY % ΔK/K IN EQUILIBRIUM REACTOR CYCLE

Reactivity effects	BOC	EOC
Insertion of all control rods into the core	-14.5	-14.5
Insertion of all control rods except one most effective into the core, %	-12.5	-12.5
Uncertainties (10%), %	1.25	1.25
Power effect (from full power to zero power), %	2.1	4.1
Operating margin assumed, %	0.5	0.5
Shutdown reactor subcriticality at 260˚C	-9.4	-7.1
Shutdown reactor subcriticality at 100˚C	-6.6	-1.6

Notes: BOC- beginning of reactor cycle; EOC- end of reactor cycle

A statement [133] of the Finnish authority STUK is quoted on shutdown safety.

The subcriticality of the AES-2006 reactor is ensured in all shutdown states by keeping the control rods inserted into the reactor and by adding boron solution with adequate concentration into the coolant water. The subcriticality of the reactor in shutdown states is monitored with neutron flux detectors positioned outside the reactor and with control procedures. The dump valves of the primary circuit are used to prevent the cold pressurization of the primary circuit.

The design objectives and principles of the systems associated with shutdown safety are consistent with Finnish safety requirements.

Final assessment of criterion CR1.3.6 — subcriticality

Criterion CR1.3.6 has been met by the V-491 design.

8.2.3.7. Final assessment of user requirement UR1.3 — DBA

This user requirement specifies a reduction of the frequency of DBAs, adequate engineered safety features capable to restore the plant to a controlled state and subsequently to a safe shutdown state avoiding release of radioactive material. Need for human intervention should be minimal and only required after an adequate grace period.

The main part of the user requirement, namely criteria CR1.3.1, CR1.3.2, CR1.3.3, CR1.3.4, and CR1.3.6, has been met. For assessment of the capability of engineered safety features (CR1.3.5), and of the frequency of DBAs (CR1.3.1), additional design information is necessary. It is recommended that this data be requested from the designer of AES-2006.

It is expected that – after the data have been received – the assessment of CR1.3.5 and CR1.3.1 will produce a positive result.

Thus user requirement UR1.3 is deemed to have been met by the AES-2006 design.

8.2.4. User requirement UR1.4 — release into containment

User requirement UR1.4: *The frequency of a major release of radioactivity into the containment / confinement of an NES due to internal events should be reduced. Should a release occur, the consequences should be mitigated.*

INPRO has developed three criteria for this user requirement, CR1.4.1, CR1.4.2, and CR1.4.3.

8.2.4.1. Assessment against criterion CR1.4.1 — major release into containment

Indicator IN1.4.1: *Frequency of major release of radioactive material into the containment/confinement* (based on frequency calculated for a highly degraded core).

Acceptance limit AL1.4.1: *calculated frequency of a highly degraded core is well below the recommended value by IAEA of* 10^{-5}*/(a·unit)*

The following information is based on the AES-2006/392M (Novovoronezh-2) design.

According to Ref. [134], the average total probability of core damage for all internal initiating events considered and all operating regimes, including shutdown, taking account of rupturing of the reactor pressure vessel and collector of the steam generator is $6.1{\cdot}10^{-7}$ a^{-1} for a 24 hour post-accident period and $4.3{\cdot}10^{-7}$ a^{-1} neglecting such a rupture. Shutdown regimes with partial or complete refuelling and unplanned shutdown of a unit for repair of first-loop circuits make the largest contribution to the total probability of core damage (Table 63).

TABLE 63. ESTIMATE OF THE CORE DAMAGE PROBABILITY FOR ALL OPERATING REGIMES OF AES-2006 [134]

Event	Probability, a^{-1}	Contribution to damage probability, %
Operating regimes at power	$1.3{\cdot}10^{-7}$	21
Unanticipated accidents	$1.8{\cdot}10^{-7}$	30
Total damage frequency:		
- taking into account unanticipated accidents	$6.1{\cdot}10^{-7}$	100
- neglecting unanticipated accidents	$4.3{\cdot}10^{-7}$	70
Shutdown:		
- unplanned	$8.5{\cdot}10^{-8}$	13
- planned with refuelling	$2.2{\cdot}10^{-7}$	36

TABLE 64. CONTRIBUTIONS OF ACCIDENTS IN AN AES-2006 TO THE CORE DAMAGE PROBABILITY

Initiating event	Contribution,%
Unit operating at power	
Large coolant leak from primary circuit (279 < D < 850 mm)	38
Electric power loss	16
Small coolant leak from the primary into the secondary loop	12
Small coolant leak from primary circuit (20 < D < 150 mm)	7
Loss of normal heat removal	6
Loss of water service	5
Small coolant leak from the secondary circuit	4
Power loss together with leak from steam lines in the shut-off part	2
Rupture of SG tube together with rupture of steam line	2
Other initiating events	8
Idling operation (shutdown) regimes of the unit	
Disruption of heat removal from the core through the first loop	41
Loss of electric power	16
Dropping of heavy loads	15
Partial loss of electric power	5
Coolant leak in first loop inside protective envelope	5
Leak from first loop to outside the protective envelope	4
Leak from first to second loop	3
Reactivity balance disruption	3
Other initiating events	8

Note: D - Nominal diameter.

Unanticipated accidents with catastrophic rupture of the reactor vessel (with a frequency of $1\ 10^{-7}$ a^{-1}) and collectors of the steam generators (frequency $8{\cdot}10^{-8}$ a^{-1}) make a considerable contribution. This can be explained by the high degree of conservatism in the estimate of the frequency of such events. Consequently, such analysis should be performed using improved best estimate methods. The remaining initiating events, making the largest contribution to the core damage probability during operating of a unit at power and in regimes with the reactor shutdown, are presented in Table 64.

Frequency of major release of radioactive material into the containment is defined by core melt frequency. As demonstrated in Table 65, core melt frequency for a V-491 design is approximately in 100 times less than for a V-320 design. It also means that the calculated frequency of major release of radioactive material into the containment will be much lower for V-491 design.

TABLE 65. CORE MELT FREQUENCIES FOR V-320 AND V-491 DESIGNS

Reactor type	**Core melt frequency, 1/a**
V-320	$4.018 \cdot 10^{-5}$
V-491	$7.3 \cdot 10^{-7}$

The total frequency of the core melting in the V-491 reactor design is $7.3*10^{-7}$ 1/a which consists of equal contributions of the core melt frequency in power operating regimes ($3.8\ 10^{-7}$ 1/a) and shutdown regimes ($3.5\ 10^{-7}$ 1/a). Four groups of initiating events contribute more than 82% to the melting frequency in operating regimes [14]:

- Compensated leakage of primary coolant yields $1.09\ 10^{-7}$ 1/a;
- Reactor vessel damage yields $7.8\ 10^{-8}$ 1/a;
- Small break LOCA yields $7.64\ 10^{-8}$ 1/a;
- Large break LOCA yields $4.74\ 10^{-8}$ 1/a.

Final assessment of criterion CR1.4.1 — major release into containment

Criterion CR1.4.1 has been met by the AES-2006 design.

8.2.4.2. Assessment against criterion CR1.4.2 — processes

Indicator IN1.4.2: *Natural or engineered processes sufficient for controlling relevant system parameters and activity levels in containment/confinement*. (*In a state with a highly degraded core, active or passive engineered or natural processes should be available to reduce the load on the containment barrier and to reduce and/or control the activity in the containment atmosphere).*

Acceptance limit AL1.4.2: *Such mechanisms and systems (processes) should be included in the AES-2006 design.*

These processes exist for V-491 design. Examples are the hydrogen recombination system, core catcher, passive heat removal system for steam generators and containment. Information on analytical modelling and experimental testing of these passive safety systems is available in Refs [141–144].

The evolutionary design AES-2006 envisages using a number of advanced safety features and corresponding new material. An important part of these features is the passive system of accidental gas release localization [145] to be used in the case of a theoretical accident caused by full loss of energy supply. The main unit of this filtration system is the heated (up to 300ºC) filter-scrubber which consists of 150 two-step scrubbers arranged in a row. The first step helps to scrub the air from radioactive aerosols and the second step cleans it from radioactive iodine in its various volatile forms. At the second step the designer applied a new sorbent material, Phizchemin KKL-7G(Fe)-300. The results of tests demonstrated high cleaning efficiency of the system:

- 99.9% for both radioactive aerosols and molecular iodine;

- 99% for volatile organic iodine compositions.

The following Figure 13 presents an overview of the AES-2006 safety systems for beyond design basis accidents (BDBA). These systems include: H_2 re-combiners, core catcher (water storage tanks inside the containment), and a passive heat removal system for containment and steam generators (storage tanks in circular rooms at the outside of the upper part of reactor building).

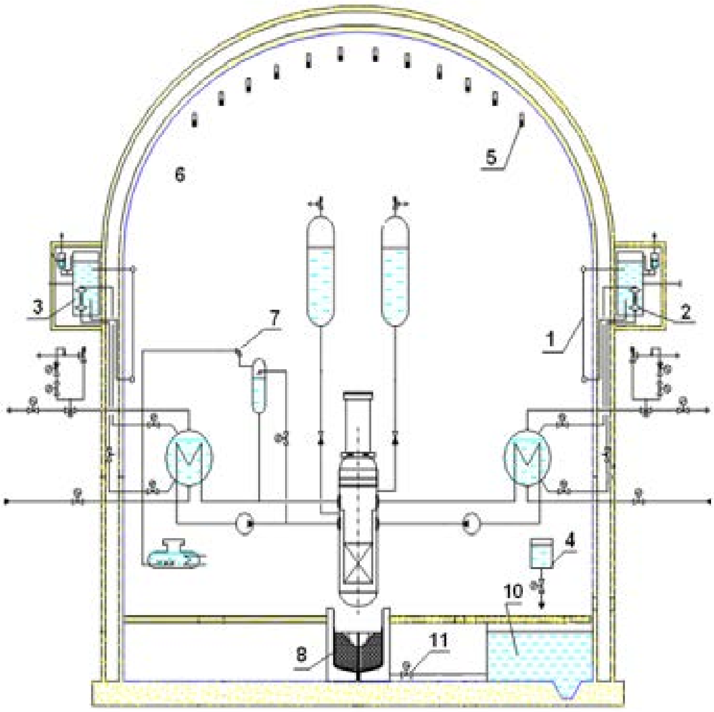

FIG. 13. Overview of BDBA systems of the AES-2006 reactor (reproduced from [123]).

Notes:
1 – system of passive heat removal (PHRS) from the containment;
2 – system of passive heat removal through SG;
3 – PHRS emergency water storage tanks;
4 – emergency chemical supply system;
5 – recombiners of the system of hydrogen removal from the containment;
6 – transducers of the hydrogen concentration monitoring system;
7 – pressurizer safety valve;
8 – core catcher;
9 – system of water supply from the reactor internals inspection shaft and fuel pool;
10 – borated water storage tanks of system JNK;
11 – valves in the connecting line between core catcher and JNK tanks.

More details of the safety systems for BDBA in the AES-2006 reactor are presented below.

The passive heat removal system (PHRS) (Figure 14) is sufficient to prevent a large release of radioactivity to the outside of the facility. It prevents core meltdown in the case of BDBA, i.e. it prevents the change of a BDBA into a severe accident. It is designed to cover BDBAs such as station blackout, complete loss of feedwater, and small-break loss-of-primary coolant accident. It reduces the radioactive consequences caused by a primary-to-secondary circuit leak accident.

The passive containment heat removal system (PHRS-C, Figure 15) is used for long-term heat removal from the containment in the case of any BDBA, including those associated with blackout and spray system failure.

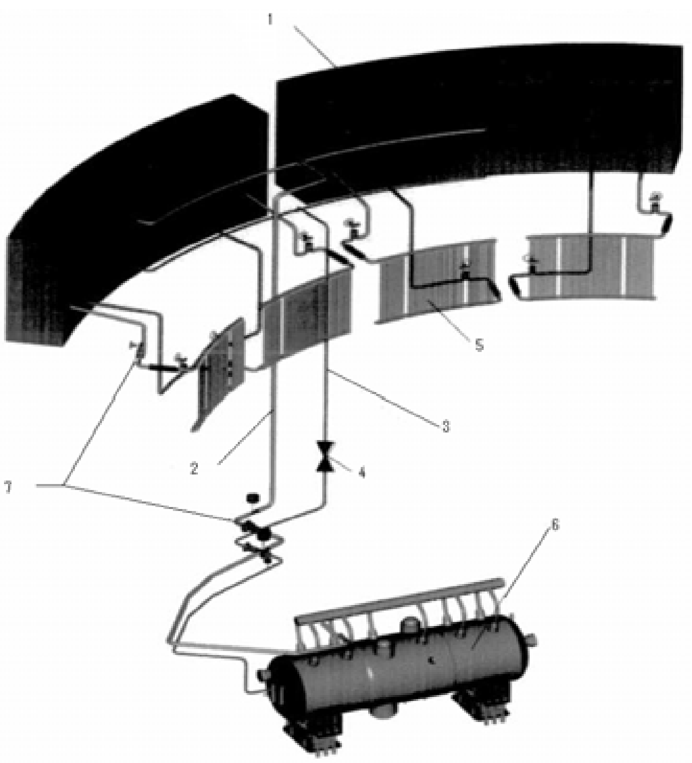

FIG. 14. Passive heat removal system via steam generators (PHRS-SG) of the AES-2006 design (reproduced from [123]).

Notes:
1 – emergency heat removal tanks;
2 – steam lines;
3 – condensate pipelines;
4 – valves of PHRS-SG;
5 – exchangers-condensers of PHRS-C;
6 – steam generator;
7 – cut-off valves

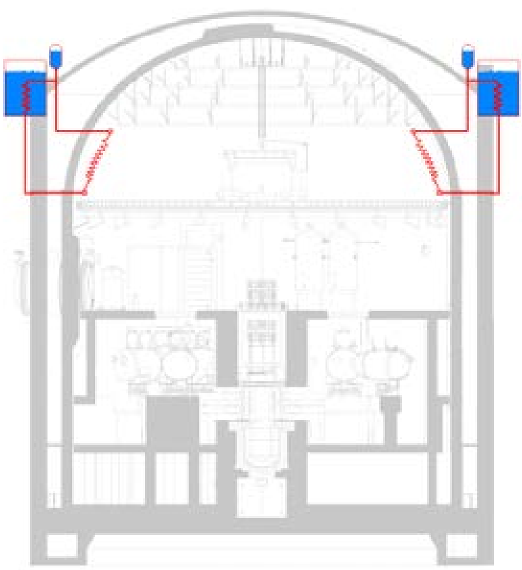

FIG. 15. Passive containment heat removal system (PHRS-C) in AES-2006 design (reproduced from [123]).

The core catcher (Figures 16 and 17) of the V-491 design provides support for the bottom of reactor vessel, protects the reactor cavity shielding from corium thermomechanical impact, allocates liquid and mechanical corium debris, provides continuous heat transfer from corium towards cooling water to ensure corium cool-down, ensures core melt subcriticality in the concrete cavity, and achieves a reduction of radionuclide and hydrogen releases into the containment.

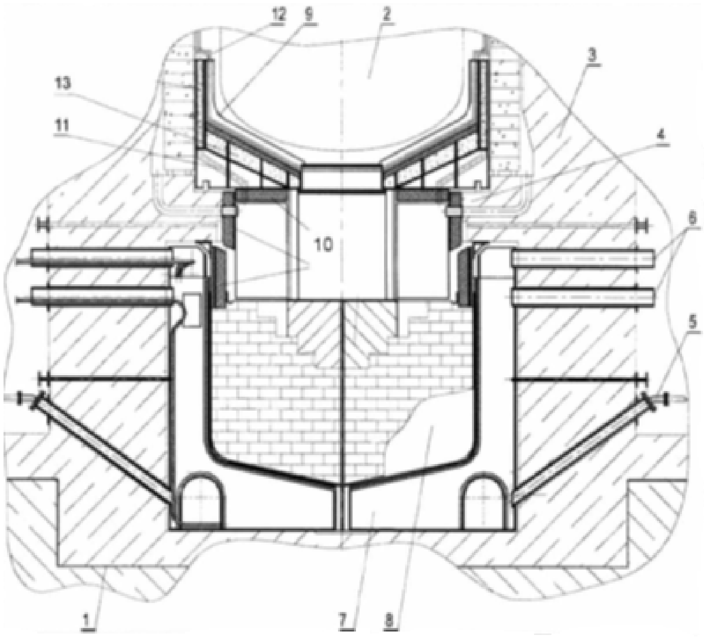

FIG. 16. Core catcher design of AES-2006 [146].

Notes:
1 – Containment
2 – Reactor
3 - Concrete cavity
4 - Concrete cantilever
5 - Device for coolant supply
6 - Device for coolant removal
7 - Ring section heat exchanger
8 - Basket
9 - Protective truss
10 - Heat insulation panels
11 - Air cooling channels
12 - Heat insulation
13 -Lower plate

In the severe accident management strategy of the AES-2006 plant, containment integrity is ensured by preventing the pressure vessel from bursting at high pressure, removing residual heat from the containment with the passive residual heat removal system, confining and cooling the core melt in the core catcher underneath the pressure vessel, and removing hydrogen with the recombiners.

To avoid forming of high speed jets of the core melt at the loss of RPV integrity during BDBA thereby reducing its potential impact on the reactor containment the standard approach of accident management requires decreasing of the primary pressure through the relief valves. According to the designer data, the reactor operator must blow off the steam-gas mixture from the reactor top head, pressurizer and from the SG collectors having opened the system valves in BDBA conditions after the reactor core melting. To reduce the primary pressure down to 1 MPa, alongside with opening the pressurizer safety valves, the operator must open the valves in the line between the pressurizer and the relief tank to discharge steam from the pressurizer into the relief tank. According to the designer the operator can use these valves under the DBA conditions as well.

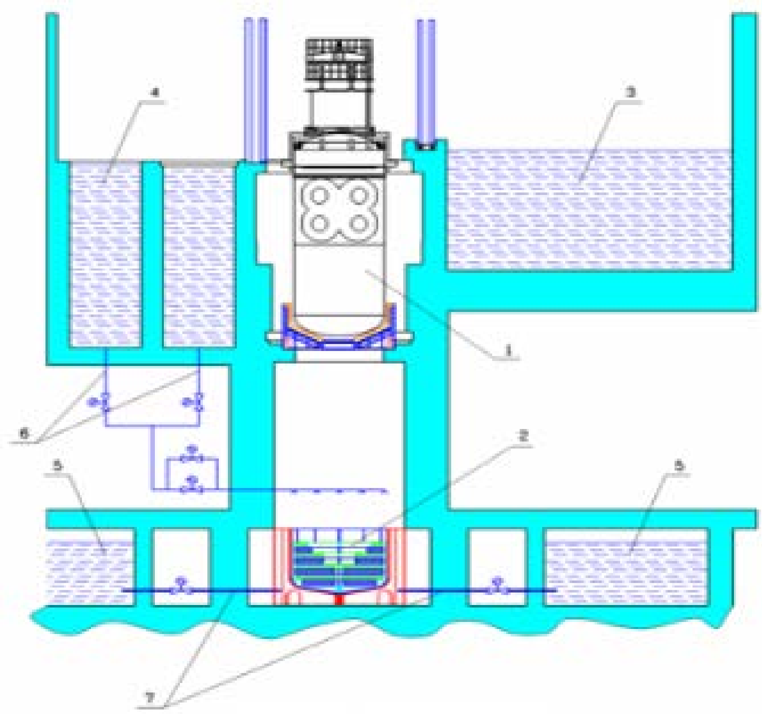

FIG. 17. Water supply to core catcher in case of location of tanks-pits inside containment (AES-2006 design) (reproduced from [123]).

Notes:
1 – reactor;
2 – core catcher;
3 – fuel pool;
4 – reactor internals inspection shaft;
5 – tanks-pits;
6 – pipelines of water supply to the core melt surface;
7 – pipelines of water supply to heat exchanger of core catcher

IAEA safety standard [147] requires analysis of the independence of safety features designed for BDBA (or design extension) conditions from the systems used in other levels of defence in depth:

"The analysis undertaken shall include identification of the features that are designed for use in, or that are capable of preventing or mitigating, events considered in the design extension conditions. These features shall be independent, to the extent practicable, of those used in more frequent accidents; …".

The assessor acknowledges that the IAEA requirements [147] were published in 2012, i.e. six years after the basic design of the AES-2006 had been developed. The regulatory body of Belarus should analyse consistency of the reactor depressurization system design with national regulation.

A statement [133] by the independent expert organization (Finnish authority STUK) is quoted below. It is based on a preliminary assessment of the safety systems other than relief valves for BDBA in the AES-2006 reactor.

Core melt at the AES-2006 plant is retained and cooled in a core catcher installed underneath the reactor pressure vessel. The core catcher operates without an external power source.

Coolant flows into the core catcher from a coolant tank inside the containment. The steam generated in the core catcher is condensed in the containment's passive residual heat removal system, from which the coolant flows via the coolant tank back to the core catcher. The AES-2006 core catcher has been developed from the previous VVER-91 plant's solution, the functionality of which has been ensured with an extensive test programme. Separate tests have been performed on the impact of the differences in the solutions.

The containment's PHRS C transfers heat from the containment into the atmosphere via the water pools on the containment roof. These water pools are shared with the steam generator's PHRS. In the PHRS C system, the water flows by force of gravity from the pools into the condensers installed in the upper space of the containment. In the condenser, the water evaporates and rises through the return pipe back into the pool, where some of the steam condenses into water and some of it is released into the atmosphere. The water inventory of the pools is sufficient for removing residual heat for 24 hours, after which they must be refilled from the storage tank outside the containment. The PRHS C has four parallel subsystems, each having the capacity of 33% of the required total capacity. The system's capacity, 4x33%, fulfils Finnish requirements. They require that the systems needed to ensure the integrity of the containment in conjunction with a severe reactor accident must be able to perform their safety function also in the event of a single failure.

A considerable amount of hydrogen is generated during a severe accident. This hydrogen pressurizes the containment and if present in high concentration, it may burn or explode. The containment of PWRs is filled with air during operation, which means it contains oxygen needed for the burning process. However, the large containment of PWRs, which is made of pre-stressed concrete, is quite strong against the effects of hydrogen burns and explosions. The AES-2006 plant will be equipped for the purpose of hydrogen removal with passive autocatalytic recombiners. The recombiners require no external power source and they remove hydrogen at such low levels that there is not enough time for a flammable gas mixture to be generated.

Finnish requirements call for NPPs to be equipped with a filtered containment venting system to mitigate the consequences of severe accidents. A filtered containment venting system that can be used to remove non-condensable gases from the containment in a later phase of an accident is not planned for installation in the AES-2006 plant. According to the plant supplier, with the exception of hydrogen, there is not a significant amount of containment-pressurizing by non-condensable gases generated in a severe accident. Hydrogen can be removed using recombiners. The need for a filtered venting system must be assessed when applying for the construction licence.

Final assessment of CR1.4.2 — processes

Assuming that the regulation in Belarus will follow the regulation in the Russian Federation, criterion CR1.4.2 has been conditionally met by the AES-2006 design.

8.2.4.3. Assessment against criterion CR1.4.3 — accident management

Indicator IN1.4.3: *In-plant severe accident management (accident management measures should be considered in the design).*

Acceptance limit AL1.4.3: *such procedures, equipment and training should be available in AES-2006, sufficient to prevent large releases to environment and regain control of the facility*.

According to the designer [14], all systems of normal operation and all safety systems may be used for the management of a severe accident.

The design safety concept includes the measures for management of design basis accidents, prevention of their transition into severe accidents, and also mitigation of their consequences. The general goals of accident management procedures are:

- Prevention of core melting;
- Prevention of reactor vessel damage;
- Prevention of containment failure;
- Mitigation of radioactive releases into the environment.

Core damage and melting can be prevented by restarting the residual heat removal process. The heat can be removed via steam generators and secondary circuit or by pumping cooling water into the primary circuit with active safety system pumps.

By using the secondary circuit (or loop) to prevent damage to the core, the operator can gain some time before the primary coolant circulation fails, e.g. during black-out conditions (full loss of electricity supply from external sources) and the loss of feedwater supply into the steam generators, the primary coolant circulation may not fail earlier than after one hour. The reactor operator should re-establish the secondary cooling process within this period. The supply of water from one of the feedwater electric pumps would be sufficient to prevent a core damage. A second system available for residual heat removal is the system PHRS-SG.

When the secondary loops are not available for residual heat removal from the core, the operator may apply the procedure of primary coolant feeding-bleeding by supplying water with any available pump from either the boron regulation system, or the emergency boron injection systems and bleeding the primary coolant into the containment. To limit or decrease the pressure in the primary circuit the opportunity of coolant release via the pressurizer through special valves is envisaged.

Severe overheating and destruction of the core can cause physical phenomena jeopardizing the RPV’s integrity. According to the accident management procedure, the operators must continuously keep working on restoration of the cooling systems. Timely actions of the operators to supply water from active emergency cooling systems will allow restoration of core cooling and prevention of RPV damage. The emergency cooling water contains sufficient boron acid to allow subcriticality of the reactor core to be maintained.

In the case of low effectiveness of operator’s actions and the failure of efforts to avoid RPV melting, the operator will reduce pressure in the reactor to ensure the lowest possible pressure during the vessel failure. In the AES-2006, for such a situation, a special system is envisaged for reactor depressurization below 1 MPa.

Design measures and equipment for preventing containment damage and for mitigating consequences of radioactive releases into the environment are:

- Avoiding direct impact onto the containment walls of the media and items capable to damage;
- The walls of passages between the containment premises providing softening of the possible impact loads on the containment walls;
- The core catcher and a large volume of water inside containment storing energy of molten core (corium) and preventing quick heating of the walls;
- The primary circuit pressure reduction system reducing the loads caused by the discharge of molten corium from the RPV;
- Hydrogen control and removal system preventing dangerous hydrogen concentrations;

- Spray system (active system) allowing long-term heat removal;
- Passive containment heat removal system allowing long-term heat removal passively;
- The system of suppression of generation of volatile iodine forms;
- The emergency inter-containment gap venting system equipped with the high efficiency iodine and aerosol filters.

To further confirm an affirmative evaluation of the accident management arrangements in the AES-2006 design a statement by the independent expert organization (Finnish authority STUK) [133] is quoted below.

Loss of ultimate heat sink

In case the ultimate heat sink, i.e. the possibility to transfer residual heat via the turbine's condenser or the essential service water system into the ultimate heat sink (such as the sea) is lost when the reactor circuit is closed, residual heat can be removed from the reactor cooling circuit by pumping water with the EFWS into the secondary side of the steam generators and releasing the steam into the atmosphere. With this arrangement, the reactor can be brought to and maintained in a controlled state (hot shutdown) for at least 24 hours. With additional measures, the time can be lengthened to 72 hours, as presented above.

Alternatively, the PHRS SG (4 x 33%) of the steam generators can be used. The PHRS SG can remove residual heat 24 hours after an accident without operator measures. With additional measures, the time can be lengthened to 72 hours by pumping water from alternative water storage into the water pools. With the PHRS SG, the plant can be brought to a controlled state. Cooling water into the reactor is supplied by means of the primary circuit's volume and boron IRWST inside the containment.

When the reactor pressure vessel head is open, the normal residual heat removal system can be replaced by evaporating water into the containment and transferring the residual heat by means of the passive containment's residual heat removal system (PHRS-C, 4 x 33%). Residual heat can be removed with PHRS-C for 24 hours after an accident without measures by an operator. With additional measures, the time can be lengthened to 72 hours, as presented above. Cooling water for the reactor is supplied by means of the primary circuit's volume and boron control system (KBA) from the make-up water tank or by means of the JNG system from the IRWST located inside the containment.

The design objectives and principles of the systems associated with managing the loss of ultimate heat sink are consistent with the STUK safety requirements.

Final assessment of CR1.4.3 — accident management

Criterion CR1.4.3 has been met by the AES-2006 design.

8.2.4.4. Final assessment of user requirement UR1.4 — release into containment

This user requirement specifies a reduction of the frequency of major release of radioactivity into the containment and for adequate engineered processes to mitigate such severe accidents.

All three criteria have been met and, therefore, also user requirement UR1.4 has been met by the AES-2006 design.

8.2.5. User requirement UR1.5 — release into environment

User requirement UR1.5: *A major release of radioactivity from an installation of a NES should be prevented for all practical purposes, so that NES installations would not need relocation or evacuation measures outside the plant site, apart from those generic emergency measures developed for any industrial facility used for similar purpose.*

INPRO has developed three criteria for this user requirement, CR1.5.1–CR1.5.3.

8.2.5.1. Assessment against criterion CR1.5.1 — frequency of release

Indicator IN1.5.1: *Frequency of a major release of radioactive material into the environment.*

Acceptance limit AL1.5.1: *Calculated frequency is well below 10^{-6}/(unit·a) or practically excluded by design*.

The calculated frequency of a major release of radioactive material from a V-320 plant to the environment equals $2.12 \cdot 10^{-5}$ 1/a [140].

In accordance with preliminary estimates, the calculated frequency of a major release of radioactive material from AES-2006 to the environment equals $1.8 \cdot 10^{-8}$ 1/a [148]. This very low frequency is achieved by implementation of advanced design features such as a double containment with venting annulus and a core catcher.

According to Ref. [134], the results of a level-2 probabilistic safety analysis (which are systematized in Table 66) make it possible to conclude that the requirements for the AES-2006 design with regard to the probability of exceeding the maximum accidental emission are satisfied with a considerable margin ($1.8 \cdot 10^{-8}$ vs. $1 \cdot 10^{-7}$ a^{-1} according to the regulatory requirements). In addition, sequences for which protective measures may not be required for three days or longer, i.e. accident scenarios with a late failure of the protective envelope, make the main contribution to this probabilistic indicator. The possibility of using (e.g. relocation, evacuation) measures to protect the public remains for such severe accidents.

TABLE 66. RESULTS OF MAXIMUM ACCIDENTAL EMISSIONS ANALYSIS [134] (BASED ON AES-2006/V-392M NOVOVORONEZH DESIGN)

Maximum emission	Time, h	Probability, average, a^{-1}	Contribution to the total probability, %
Emission of radionuclides, contained in the coolant, and gaseous fission products through a leaky protective envelope, i.e. containment (no melting of nuclear fuel)	-	$4.01 \cdot 10^{-12}$	0.02
Emission of radionuclides through the bypass of the protective envelope or leaky protective envelope during accidents with melting of nuclear fuel from the onset of the accident in the time	24	$1.64 \cdot 10^{-9}$	9.25
	24–50	$6.79 \cdot 10^{-10}$	3.83
	72–96	$1.54 \cdot 10^{-8}$	86.89
Total value	-	$1.77 \cdot 10^{-8}$	100

Final assessment of CR1.5.1 — frequency of release

Criterion CR1.5.1 has been met by the AES-2006 design.

8.2.5.2. Assessment against criterion CR1.5.2 — consequences

Indicator IN1.5.2: *Consequences of releases during severe accidents* (e.g. dose).

Acceptance limit AL1.5.2: *In the design basis of the NES the calculated consequences of releases are sufficient low to meet the requirement that no evacuation or relocation is needed outside the plant site*; temporary food restrictions are possible

The AES-2006 design has included a number of advances to mitigate severe accident consequences, namely:

- Passive containment heat removal system in addition to a spray system, which allows maintenance of containment integrity and limitation of the pressure inside the containment;
- In-containment iodine removal system;
- Emergency inter-containment gap venting system and the utilization of releases removed from the gap;
- Containment recirculation venting system equipped with aerosol and iodine filters;
- Post-accident containment recirculation venting system;
- High efficiency filtering material.

Consequences of radiation release from the AES-2006 to the public in the case of a DBA do not exceed established regulatory limits [149].

In the case of a BDBA, according to the data provided by the designer [14], the release of fissile products at the early phase , without electricity supply, is specified mainly by the leaks and bypasses of the double containment. Maximal value of this release is characterized by 10^4 TBq of ^{133}Xe, 50 TBq of ^{131}I and 5 TBq of ^{137}Cs.

At the intermediate phase of accident when external energy supply is restored, the radioactive gases would be released mainly via the venting stack. Maximum value of this release is characterized by 105 TBq of ^{133}Xe, 50 TBq of ^{131}I and 5 TBq of ^{137}Cs.

The radius of the area for obligatory emergency evacuation of the population does not exceed 800 m from the reactor building within the first ten days of the BDBA. The area of planning of obligatory population protection measures during the first ten days lies within 3000 m radius. Within this time, there is no need for evacuation [14, 149] because, according to the regulation of the Russian Federation, no people are allowed to live closer than a certain distance to the plant, normally 3000 m.

In Table 67, the calculated data of radiation releases for AES-2006 are compared with EUR limits. The data were provided by designer. AES-2006 characteristics are clearly lower than EUR requirements.

TABLE 67. RADIATION RELEASE FOR THE AES-2006 DESIGN IN THE CASE OF BDBA

Nuclide	Calculated Release, TBq	EUR Limits, TBq
Iodine-131	35	4000
Caesium-134	7	-
Caesium-137	4.4	30

In Table 68, the calculated doses to the public after a BDBA caused by a major radiation release from an AES-2006 reactor are presented. The information was provided by designer. It demonstrates that, even in the case of a major radiation release, there is no need for evacuation. Sheltering and use of iodine tablets may be necessary only for those who are at a distance of up to 3000 meters from the plant.

To confirm general conclusion on the consequences of severe accidents, in the following a statement [133] by the independent expert organization (Finnish authority STUK) is quoted that evaluates the dose calculations after accidents in an AES-2006 reactor.

As part of the design process of the AES-2006 plant, Atomstroiexport has calculated the radiation exposure of the population in areas surrounding the plant in accident situations. The results of this calculation show that the radiation doses of the population will be below the dose limits defined for accidents in Finnish requirements.

TABLE 68. DOSES TO PUBLIC FROM MAJOR RADIATION RELEASE FROM AES-2006

Distance from location of release, km	Dose to the public, mGy		Dose limits during first 10 days after accident, sheltering/evacuation, mGy	
	Thyroid	Whole body	Thyroid	Whole body
0.8	770	246	500 / 5000	50 / 500
1	503	160		
3	63	20		
20	1,9	0.6		
25	1.3	0.4		

On the basis of the analysis results and the design features of the plant concept, it can be assessed that analyses consistent with Finnish requirements can be performed on this plant alternative at later stages of the licensing procedure.

Final assessment of CR1.5.2 — consequences

Criterion CR1.5.2 has been met by the AES-2006 design.

8.2.5.3. Assessment against criterion CR1.5.3 — risk

Indicator IN1.5.3: *Calculated individual and collective risk.*

Acceptance limit AL1.5.3: (*AES-2006 should show) a risk comparable to other facilities used for similar purposes.*

Several energy sources are available for electricity production. The most important are coal, oil, gas, hydroelectric, wind and nuclear and the most electricity is generated from these sources throughout the world.

A comparison of health risks of energy sources is difficult because use of fossil energy or renewable energy sources cause damage mainly locally (within a region) and for the present generation, while damage from radiation exposure is more global and also affects future generations [121]. Such a comparison can be performed in terms of 'years of life lost' for a production of 1 TW·h. Table 69 contains these data for different types of facilities.

TABLE 69. 'YEARS OF LIFE LOST' PER TWH [150] OF DIFFERENT ENERGY SOURCES

Effects	Years of life lost per TWh					
	Coal	Lignite	Gas	Oil	Nuclear	Wind
Non-radiological effects	138	167	359	42	9.1	2.7
Radiological effects during normal operation	-	-	-	-	16	-
Radiological effects due to accidents	-	-	-	-	0.015	-

Table 69 clearly demonstrates that for the same amount of electricity produced, the risk for personnel and population caused by nuclear power is very low.

Final assessment of criterion CR1.5.3 — risk

Assuming that the AES-2006 produces a risk comparable to the reactors considered in Ref. [150], criterion CR1.5.3 has been met.

8.2.5.4. Final assessment of user requirement UR1.5 — release into environment

This user requirement stipulates that in the AES-2006 no major release of radioactivity should occur thereby avoiding relocation or evacuation measures.

All three criteria of UR1.5 have been met, and therefore UR1.5 has been met by the AES-2006 design.

8.2.6. User requirement UR1.6 — independence of defence-in-depth levels

User requirement UR1.6: *An assessment should be performed for a reactor to demonstrate that different levels of defence in depth are met and are more independent from each other than for existing systems*.

INPRO has developed one criterion for this user requirement, CR1.6.1.

8.2.6.1. Assessment against criterion CR1.6.1 — independence of defence-in-depth levels

Indicator IN1.6.1: *Independence of different levels of defence in depth. Probabilistic safety analysis (PSA) should identify cross-links which compromise the independence of the levels of defence in depth.*

Acceptance limit AL1.6.1: *Adequate independence of the different levels of defence in depth should be demonstrated on the basis of deterministic and probabilistic methods*.

No information is available to the assessor to evaluate this criterion.

8.2.6.2. Final assessment of user requirement UR1.6 — independence of defence-in-depth levels

There is no information available to the assessor to assess the independence of the defence-in-depth level in the AES-2006 design. It is recommended that the missing information be requested from the designer.

It is expected that the assessment of CR1.6.1 — after the missing data have been received — will produce a positive result.

Thus, UR1.6 is deemed to have been met by the AES-2006 design.

8.2.7. User requirement UR1.7 — human/machine interface

User requirement UR1.7: *Safe operation of installations of a NES should be supported by an improved Human Machine Interface resulting from systematic application of human factors requirements to the design, construction, operation and decommissioning*.

INPRO has developed two criteria for this user requirement, CR1.7.1 and CR1.7.2.

8.2.7.1. Assessment against criterion CR1.7.1 — human factors

Indicator IN1.7.1: *Evidence that human factors are addressed systematically in the plant life cycle*.

Acceptance limit AL1.7.1: *Human factors are considered during the lifetime of a plant (including the planning-, construction-, operating- and decommissioning phase).*

Examples of features and measures that should be implemented or improved are:

- Feedback of experience including a formal methodology;
- A PSA taking human error into account;
- Use of adequate, quantitative models considering the causes of human error;
- The existence of a main control room (MCR), a remote shutdown station (RSS), a technical support centre and the short-term installation of an emergency support centre (ESC);

- Visualization of the status of equipment and the dynamics of the processes, resulting in a guidance for operator;
- Monitoring by knowledge-based systems;
- Appropriate ambient conditions in the relevant rooms (e.g. MCR);
- Appropriate plant operating procedures (e.g. for normal, incident and accident situations);
- Verification of adequacy of design implementation;
- Control of human reliability (e.g. selection, training).

According to the data provided in Ref. [14], the main focus of human factor considerations in AES-2006 design is the development of effective human-machine interfaces, high qualification of personnel and introduction of systems tolerant to human errors. To improve interaction of humans and machine, the designer thoroughly considered provision of data to operators taking into account:

- Optimization of the amount of data delivered simultaneously;
- Application of a hierarchical structure to ensure a convenient search of information;
- Different levels of the formats with different stages of data generalization;
- Clarity of data presentation;
- Application of a general system of codes for all formats (shape, colour, sound);
- Identification of time of occurrence and category of importance for every event reported to the operator.

To reduce the information burden on the operator, a video-screen for the message sequence protocol and a classification of all messages according to the safety criteria have been introduced.

To prevent or at least mitigate consequences of the operator’s mistakes which may potentially cause the failure of removing heat from the reactor, a set of measures is envisaged. A single mistake by the operator causing a reactor cooling failure is eliminated by design due to automatically engaging backup systems, introduction of technological protection systems, block systems and preventive protection systems. In case of multiple mistakes, the automatic shutdown system, passive and active safety systems should protect the reactor.

During the design process of engineered safety systems, the increased defence considering human factors was implemented by:

- An increase in the level of automatic control (elimination of human actions) during some design basis accidents, particularly during leaks from first circuit (primary loop) to second circuit (secondary loop);
- The use of passive safety systems, which do not need human actions for their activation.

A statement [133] from an independent expert organization (STUK), which evaluated the design of the control rooms, is quoted below.

Control room

The control room contains control consoles and a display panel. The control consoles of the turbine, the reactor and the auxiliary systems are used to control the plant in normal operating conditions, transient conditions and accident conditions. In addition, all the information needed for execution of control actions is transmitted to the control consoles.

Part of the display panel comprises fixed indicators and control switches. These include e.g. the protection system panel and the control panels for the safety-relevant components.

The design objectives and principles of the control room are consistent with Finnish safety requirements.

Emergency control room

The AES-2006 plant features an emergency control room, which can be used for control of safety-relevant systems independently of the main control room. The plant can be brought into a controlled (hot shutdown) state and further into a safe (cold shutdown) state from the emergency control room. The emergency control room is located in a separated building from the main control room. The design objectives and principles of the emergency control room are consistent with Finnish safety requirements.

Final assessment of CR1.7.1 — human factors

Criterion CR1.7.1 has been met by the AES-2006 design of the control rooms.

8.2.7.2. Assessment against criterion CR1.7.2 — human response model

Indicator IN1.7.2: *Application of formal response models from other industries or development of nuclear-specific models.*

Acceptance limit AL1.7.2: *A reduced likelihood of human error relative to existing reactors, as predicted by HF models; use of artificial intelligence for early diagnosis and real-time operator aids; less dependence on operator for normal operation and short-term accident management relative to existing plants.*

Modern computerized control systems are used for V-491 designs. Digital control systems provide more adequate prediction of events' development. Decrease of erroneous human actions is provided by elimination of human intervention during actions of control systems.

This CR1.7.2 is related to INPRO evaluation parameter EP1.1.2.3, where the impact of incorrect human intervention was evaluated.

Final assessment of CR1.7.2 — human response model

No data of the V-320 design are available that would be needed to be compared with the V-491 design. Thus, an assessment of this criterion CR1.7.2 was not possible.

It is expected that the assessment of CR1.7.2 — after the missing information has been received — will produce a positive a result. Thus CR1.7.2 is deemed to have been met by the AES-2006 design.

8.2.7.3. Final assessment of user requirement UR1.7 — human/machine interface

Human factors have been addressed systematically in the AES-2006 design, i.e. criterion CR1.7.1 has been met. No information is available as to whether human response models (CR1.7.2) have been used for AES-2006. It is recommended that the missing data be requested from the designer.

User requirement UR1.7 has been met by the AES-2006 design.

8.2.8. Final assessment of basic principle BP1 — defence in depth

Enhanced defence in depth is incorporated into the AES-2006 design, i.e. user requirements UR1.1 to UR1.5 are met.

Not enough data are available to the assessor for a detailed assessment of independence of defence-in-depth levels (UR1.6) and of improvement of human–machine interfaces (UR1.7) in the AES-2006 design. However, it is expected that the assessment — after the missing data has been received — of these two user requirements will produce a positive result.

Thus, basic principle BP1 is deemed to have been met by the AES-2006 design.

8.3. INPRO BASIC PRINCIPLE BP2 — INHERENT SAFETY

Basic principle BP2: *Installations of an innovative NES shall excel in safety and reliability by incorporating into their designs, when appropriate, increased emphasis on inherently safe characteristics and passive systems as a part of their fundamental safety approach.*

INPRO has developed one user requirement for this basic principle, UR2.1.

8.3.1. User requirement UR2.1 — minimization of hazards

User requirement UR2.1: *NES should strive for elimination or minimization of some hazards relative to existing plants by incorporating inherently safe characteristics and/or passive systems, when appropriate.*

INPRO has developed four criteria for this user requirement, CR2.1.1–CR2.1.4.

8.3.1.1. Assessment against criterion CR2.1.1 — hazards

Indicator IN2.1.1: Stored energy, flammability, criticality, inventory of radioactive material, available excess reactivity, and reactivity feedback.

Acceptance limit AL2.1.1: Superior to existing designs (see evaluation parameters).

To enable the assessment of CR2.1.1, INPRO has defined six evaluation parameters EP2.1.1.1–EP2.1.1.6.

a) **Evaluation parameter EP2.1.1.1:** *stored energy (reduction of stored energy in a reactor leads to a reduction of the corresponding hazard).*

Acceptability of EP2.1.1.1: *amount of stored energy within or outside the primary coolant system should be limited to the minimum amount possible.*

Consideration of energy stored in the reactor core fuel is the part of evaluation of evaluation parameter EP1.1.1.1 (‘margins of design’ — fuel thermal design margins). It was discussed in a section 8.2.1.1.

EP2.1.1.1 has been met.

b) **Evaluation parameter EP2.1.1.2:** *Flammability (The design should minimize the amount of flammable material and explosive gases; include a fire alarm and suppression system; take into account smoke and heat removal; include the separation of systems with redundant safety functions by distance and barriers; ensure that a fire does not lead to core degradation).*

Acceptability of EP2.1.1.2: *Minimization of flammable material has been achieved.*

An example of reducing flammable material is given in the following.

In the V-491 design: main electric generator with water cooling only (no hydrogen); water cooling is used for main coolant pump.

In the V-320 design: main electric generator with hydrogen cooling; oil cooling is used for main coolant pump.

Since only limited input data related to flammability were available for the assessment, a complementary statement [133] by an independent expert organization (the Finnish authority STUK) based on a preliminary safety assessment of the AES-2006 design is quoted.

The design objectives and principles associated with the fire protection concept of the AES-2006 plant are consistent with Finnish safety requirements, with the exception of the separation of the different room areas of the safety buildings, which, in terms of the design requirements, is not unambiguously consistent with Finnish requirements. In this respect, and in terms of controlling possible consequential fires caused by earthquakes, the need for seismic resistance of the plant's fire extinguishing systems and the design basis must be verified in the possible construction licensing phase.

EP2.1.1.2 has been met.

c) **Evaluation parameter EP2.1.1.3:** *Inventory of radioactive material (The radioactive inventory within the reactor should be ALARP. The radioactive material outside the reactor should be minimized to decrease the potential for a major release).*

Acceptability of EP2.1.1.3: *The inventory of radioactive material has been minimized.*

No data are available to the assessor to assess this parameter.

d) **Evaluation parameter EP2.1.1.4:** *criticality* (*To reduce the hazards of criticality outside the core (e.g. in fuel storage facilities), any geometry and material that could create criticality should be avoided).*

Acceptability of EP2.1.1.4: *possibility for criticality outside the core is avoided.*

No data are available to the assessor to assess this parameter.

e) **Evaluation parameter EP2.1.1.5:** *Available excess reactivity (excess reactivity should be kept to the minimum possible. However, some excess reactivity is necessary to cope with the fuel burnup, to reach full power operating conditions)*

Acceptability of EP2.1.1.5: *excess reactivity in the core is kept ALARP.*

Burnable absorbers are used in the neutronic fuel design — a measure that reduces excess reactivity of the core.

Thus, EP2.1.1.5 has been met.

f) **Evaluation parameter EP2.1.1.6:** *Reactivity feedback (feedback of changing conditions in the core should lead to self-compensation, see criterion CR1.1.1).*

Acceptability of EP2.1.1.6: *Changing conditions in the core should lead to a compensatory reactivity feedback.*

This evaluation parameter, EP2.1.1.6 is part of EP1.1.1.1 ('margins of design' — reactivity coefficients). It was considered in section 8.2.1.1.

EP2.1.1.6 has been met.

Final assessment of criterion CR2.1.1 — hazards

Several hazards were eliminated or reduced in the AES-2006 design. Examples of elimination of the fire hazard (EP2.1.1.2) in two AES-2006 components (generator, and main coolant pump) are presented. Two evaluation parameters, stored energy (EP2.1.1.1) and reactivity feedback (EP2.1.1.6) are positively covered by assessment of another evaluation parameter called 'margins of design' (EP1.1.1.1). Reactivity control is improved in the AES-2006 core design. No data were available to the assessor on a reduction of radioactive inventory and criticality outside the core. It is recommended that the missing information be requested from the designer.

Criterion CR2.1.1 has been met by the AES-2006 design.

8.3.1.2. Assessment against criterion CR2.1.2 — frequency of anticipated operational occurrences and design basis accidents

Indicator IN2.1.2: *Expected frequency of abnormal operation and accidents.*

Acceptance limit AL2.1.2: *Due to the introduction or enhancement of inherent safety characteristics and use of passive safety systems (or components) lower frequencies of occurrence of AOO and DBA can be expected.*

The quantitative part of the assessment of CR2.1.2 (frequency of anticipated operational occurrences and design basis accidents) overlaps with assessment of CR1.1.4 (failures and disturbances) and CR1.3.1 (frequency of DBA). It was already considered in the sections 2.1.4 and 2.3.1.

Final assessment of criterion CR2.1.2 frequency of — AOO and DBA

Criterion CR2.1.2 has been met by the AES-2006 design.

8.3.1.3. Assessment against criterion CR2.1.3 — consequences

Indicator IN2.1.3: *Consequences of abnormal operation and accidents (design of a reactor should be such that no undue radiation exposures to workers, the public and environment should occur during abnormal operation and accidents).*

Acceptance limit AL2.1.3: *it should be demonstrated that due to the introduction or enhancement of inherent safety characteristics and use of passive safety systems the consequences of abnormal operation and accidents are lower than in existing designs.*

This criterion, CR2.1.3 (consequences), is closely related to CR1.5.2 (consequences) and was considered in subsection 8.2.5.2.

Final assessment against criterion CR2.1.3 — consequences

Criterion CR2.1.3 has been met by the AES-2006 design.

8.3.1.4. Assessment against criterion CR2.1.4 confidence in innovation

Indicator IN2.1.4: *Confidence in innovative components and approaches (For radically new (innovative) designs of reactor components or systems, special attention should be directed to detect, study and model new phenomena as well as scaling considerations within experimental and analytical work).*

Acceptance limit AL2.1.3: *Before the introduction or enhancement of inherent safety characteristics and use of passive safety systems, the validity of these approaches has been established by appropriate RD&D programmes.*

Examples of results of numerical modelling and thorough experimental justification of the innovative passive systems embedded in the V-491 design are published in Refs [141–144]:

- Experimental validation of the cooling loop for a system removing heat from containment [141];
- Numerical and experimental modelling of processes in the containment equipped with a passive heat removal system (PHRS) [142];
- Experimental thermohydraulic study of the PHRS removing heat from steam generators [143];
- Investigation of the chemistry regime in the passive safety system [144].

A complimentary statement [133] from an independent expert organization (the Finnish authority STUK) that evaluates the status of experimental qualification of the new safety systems in AES-2006 is quoted below.

Passive systems that have not been used previously at NPPs have been planned for the AES-2006 plant. The passive systems to be used in transient and accident situations are the reactor circuit cooling PHRS SG connected to the steam generators and based on natural recirculation, and the natural circulation PHRS C. The systems are in the process of testing-based qualification. Test assemblies exist and the testing is partially completed. The results of these tests have been and will be used in the qualification process for computational models. The correct functioning of the systems can be confirmed only after the test results are ready. This matter can be reviewed when the application for the construction licence is submitted.

The AES-2006 core catcher has been developed from the previous VVER-91 plant's solution, the functionality of which has been ensured with an extensive test programme. Separate tests have been performed on the impact of the differences in the solutions.

Final assessment of criterion CR2.1.4 — confidence in innovation

Criterion CR2.1.4 has been met by the AES-2006 design.

8.3.1.5. Final assessment of user requirement UR2.1 — minimization of hazards

This user requirement specifies elimination or minimization of hazards by incorporating inherently safe characteristics or passive systems into the reactor design.

Several hazards (CR2.1.1) have been reduced in the AES-2006 design: flammability, stored energy, and reactivity related core parameters. Frequency (CR2.1.2) and consequences (CR2.1.3) of abnormal operation and accidents has been reduced in AES-2006 design. Confidence in the innovative components and approaches (CR2.1.4) in the AES-2006 design has been established through intensive R&D.

Thus UR2.1 has been met by the AES-2006 design.

8.3.2. Final assessment of basic principle BP2 — inherent safety

Basic principle BP2 requires incorporation of increased emphasis on inherently safe characteristics and passive systems into the reactor design.

The goal of BP2 is clearly met by the AES-2006 design.

8.4. INPRO BASIC PRINCIPLE BP3 — RISK OF RADIATION

Basic principle BP3: *Installations of a NES shall ensure that the risk from radiation exposures to workers, the public and the environment during construction/commissioning, operation, and decommissioning, are comparable to the risk from other industrial facilities used for similar purposes.*

INPRO has defined two user requirements for this basic principle, UR3.1 and UR3.2.

8.4.1. User requirement UR3.1 — radiation protection of workers

User requirement UR3.1: *nuclear installations should ensure an efficient implementation of the concept of optimization of radiation protection for workers through the use of automation, remote maintenance and operational experience from existing designs.*

INPRO has defined one criterion for this user requirement, CR3.1.1

8.4.1.1. Assessment against criterion CR3.1.1 — occupational dose

Indicator IN3.1.1: *Occupational dose (workers) values. (Decrease of doses at normal operation can be achieved, e.g. through minimization of source terms (e.g. avoiding cobalt impurities in material, using erosion corrosion resistant material for steam line designs to limit deposits, achieving adequate coolant chemistry), layout features which reduce the collective dose, e.g. strict physical separation/shielding of systems, accessibility, shielding, handling, set down areas, and through a maintenance friendly design of equipment).*

Acceptance limit AL3.1.1: *Doses to workers are less than defined by national or international standards and the health hazards to workers in an AES-2006 plant is comparable to that from other energy converting plants.*

Radiation protection of workers in the AES-2006/V-491 plant is based on operational experience for existing NPPs with precursors of V-491. The radiation protection system has been optimized for the V-491 design and it is expected that the annual dose for workers in the plant during normal operation and maintenance will be below a value of 5 mSv/a [149], i.e. below the regulatory occupational dose limit.

Several examples [14] of reduction of radiation exposure of workers by specific design measures are presented below.

A requirement for reduced content of cobalt — which should be less than 0.05% — in the steel of steam generator (SG) heat-exchange tubes of the AES-2006 was introduced. This requirement reduces the dose on workers during SG inspection. In addition to regular deactivation systems, special methods and gauges, e.g. mobile venting systems, are designed to ensure ambient conditions for repair and maintenance of radioactive equipment.

In the AES-2006, the efficiency of coolant cleaning during operation is to be higher than: iodine – 99.9%, caesium – 99%; corrosion products – 90%; this reduces the radioactive inventory in the coolant.

An industrial television system and systems of automatic diagnostic of pipes and equipment are introduced.

A venting system eliminates the flow of air from more contaminated rooms into less contaminated ones and ensures the access of workers into containment (except reactor and SG rooms) even at full power conditions. The AES-2006 is equipped with a special system for separation of areas in the containment to ensure necessary environment for personnel.

Final assessment of user requirement UR3.1.1 — dose to workers

This user requirement stipulates implementation of the ALARA concept in the design through the use of automation or remote maintenance.

Criterion CR3.1.1 has been met; therefore, also user requirement UR3.1.1 has been fulfilled by the AES-2006 design.

8.4.2. User requirement UR3.2 — radiation protection of the public

User requirement UR3.2: *Dose to an individual member of the public from an individual NES installation during normal operation should reflect an efficient implementation of the concept of optimization, and for increased flexibility in siting may be reduced below levels from existing facilities.*

INPRO has developed one criterion for this user requirement, CR3.2.1

8.4.2.1. Assessment against criterion CR3.2.1 — public dose

Indicator IN3.2.1: *Public dose values.*

Acceptance limit AL3.2.1: *Calculated doses to the public are less than defined by national or international standards and health hazards to the public are comparable to that from other energy converting plants.*

A general comparison of public health hazards due to radiation exposure by nuclear plants to hazards of non-NPPs has been discussed in section 8.2.5.3 (criterion CR1.5.3).

Following the recommendation given in the *INPRO Manual* [121], the assessment of public dose has been performed in the area of environment.

Criterion CR3.2.1 and, consequently, user requirement UR3.2 have been met.

8.4.3. Final assessment of basic principle BP3 — risk of radiation

The radiation protection system was optimized for the V-491 design. Occupational dose (UR3.1) at the AES-2006 plant is lower than the regulatory limits in Belarus. It is recommended that information on the health risk of workers in nuclear facilities be compared to health risk of workers occupied in non-nuclear facilities with similar purpose.

The issue of dose to the public (UR3.2) is covered appropriately in the environmental assessment using the INPRO methodology.

Thus, the goal of basic principle BP3 has been met by the AES-2006 design.

8.5. INPRO BASIC PRINCIPLE BP4 — RD&D

Basic principle BP4: *The development of NES shall include associated Research, Development and Demonstration work to bring the knowledge of plant characteristics and the capability of analytical methods used for design and safety assessment to at least the same confidence level as for existing plants.*

INPRO has developed four user requirements for this basic principle, UR4.–UR4.4.

8.5.1. User requirement UR4.1 — safety basis

User requirement UR4.1: *The safety basis of nuclear installations should be confidently established prior to commercial deployment***.**

INPRO has developed two criteria for this user requirement, CR4.1.1 and CR4.1.2.

8.5.1.1. Assessment against criterion CR4.1.1 — safety concept

Indicator IN4.1.1: *Safety concept defined*?

(The safety basis is the documentation of the safety requirements and safety assessment of the plant design before it is being constructed and operated. The safety basis includes a well-defined concept for achieving safety).

Acceptance limit AL4.1.1: *Yes. (A consistent safety basis demonstrates that the safety goals are met).*

According to Ref. [123, 149] a consistent safety basis has been developed for the AES-2006 design that is based on:

- The defence-in-depth principle;
- Implementation of national regulatory requirements, IAEA requirements and EUR outlines;
- Experience of safety analysis for existent NPP designs;

- Integrated safety assessment approach (complementary deterministic and probabilistic analyses); and
- Results of supporting research activities.

Final assessment of CR4.1.1 — safety concept

Criterion CR4.1.1 has been met by the AES-2006 design.

8.5.1.2. Assessment against criterion CR4.1.2 — safety requirements

Indicator IN4.1.2: *Clear process for addressing safety issues?*

(Iterations among design, RD&D and safety analysis are necessary to achieve an optimized design with a high safety level. For the final design it must be demonstrated that all safety issues are covered and the results are well documented).

Acceptance limit AL4.1.2: *Yes. (Well-documented results of the process address the safety issues including sensitivity and uncertainty analyses and independent reviews).*

This criterion is aimed at the organization of the regulatory process in the country of design origin (in this case, the Russian Federation). Corresponding issues relevant to Belarus are addressed in the INPRO area of Infrastructure.

The structure and description of the organization of the regulatory body in the Russian Federation, an overview of the structure of nuclear legislation and its content are represented in Appendix II. Overview of Russian nuclear power licensing regulations and guidelines on how to fulfil these regulations are represented in Appendix III. Overview of results of the AES-2006 licence application, including comments and conclusions by the regulator, is available in Ref. [151]. It confirms the existence of a clear process for addressing safety issues and represents a good documentation of the results of this process.

Final assessment of CR4.1.2 — safety requirements

Criterion CR4.1.2 has been met by the AES-design.

8.5.1.3. Final assessment of user requirement UR4.1 — safety basis

This user requirement stipulates the establishment of an adequate safety basis.

A safety basis for AES-2006 has been confidently established in the Russian Federation. Both criteria of this user requirement have been met.

Thus UR4.1 has been met by the AES-2006 design.

8.5.2. User requirement UR4.2 — research, development and demonstration

User requirement UR4.2: *Research, development and demonstration on the reliability of components and systems, including passive systems and inherent safety characteristics, should be performed to achieve a thorough understanding of all relevant physical and engineering phenomena required to support the safety assessment.*

INPRO has developed three criteria for this user requirement, CR4.2.1–CR4.2.3.

8.5.2.1. Assessment against criterion CR4.2.1 — RD&D

Indicator IN4.2.1: *RD&D defined and performed and database developed?* (*To identify state of knowledge and importance of phenomena and system behaviour an appropriate tool has to be used, e.g. phenomena identification and ranking table (PIRT). The adequacy and applicability of design and safety computer codes have to be assessed. Reliability data including uncertainty bands for designated components should be evaluated to the extent* *possible. This is especially valid for passive safety systems. Qualified data should be included in a technology base which is also addressed by CR2.1.4).*

Acceptance limit AL4.2.1: *Yes. (Measured data are available in the region of application; it was demonstrated that all phenomena are understood; data uncertainties are quantified, and documented in reports. For PSA the availability of reliability data with uncertainty bands is required).*

Some new systems incorporated into the AES-2006/V-491 design and some technical design decisions made for this design need additional research, development and demonstration (RD&D) to confirm their reliability. Thus, a lot of RD&D activities are still being performed in the frame of AES-2006 project. These activities include studies on:

- Removal of conservatism in design of reactor (taking into account increasing of power level and other technological parameters);
- Increase of fuel burnup;
- Increase of equipment reliability (including investigation in the area of material science);
- Maneuverable regimes (changes of power level);
- Radiation protection and nuclear safety; and
- Enhancement of I&C systems.

Currently, some of these studies have been finished; some are being continued.

The designer is focused on coverage of safety related issues, namely the:

- Chosen combination of conservative assumptions being really the worst one in every specific case of DBA analysis;
- Criterion of fuel rod integrity loss as the combination of two conditions — fuel clad temperature is higher than 800˚C and the fuel rod gas pressure is more than 2MPa higher than the pressure of ambient coolant;
- Operational limits;
- Selection of protection and blocking parameters.

Currently, the numerical modelling of the new (passive) safety system behaviour is being fulfilled by the traditional tools using special conditions at the system's border to simulate characteristics of these passive systems. These design characteristics are still to be confirmed and the tools are to be validated for the modelling of passive safety systems at both DBA and BDBA conditions [14] although some experimental qualification of passive heat removal systems of the AES-2006 design was done using the following Russian test facilities:

- KMS test facility, NITI, Sosnovy Bor (modelling of containment PHRS);
- SPOT test facility, CKTI, St.Petersburg (modelling of SG PHRS);
- SMK test facility, Krylov'CNII, St. Petersburg (modelling of containment PHRS); and
- OKBM, Nizhni Novgorod (modelling of containment PHRS). Containment PHRS test facility (C-PHRS Bench).

For severe accidents with core melting and reactor vessel damage, the simulation of the process is performed only by the instant of molten core exit out of the reactor pressure vessel into the core catcher. The process in the core catcher has not been modelled adequately yet [14]. This model should be developed and verified to prove the fulfilment of a design criterion on the concentration of gases released in the reactor and core-catcher to be kept below explosion limits.

Since the conclusion on completeness of the R&D performed could not be substantiated from the data available for the assessment, a statement [133, 137] of an independent expert organization (the Finish authority STUK) is quoted that defines some additional RD&D effort (i.e. analyses, engineering and experimental qualification to be demonstrated), including:

- Demonstration of the functionality of the passive residual heat removal systems (PRHR SG, PRHR C) with additional tests;
- Analysis of requirements for the reactor pressure vessel's material, and implementation, inspection and radiation protection principles for the pipe nozzles related to the reactor coolant loops;
- Effects on the integrity of the reactor's inner components in postulated sudden pipe breaks in the primary circuit;
- Need to equip the containment with a filtered containment venting system;
- Installation of strainers (filters) at the suction of emergency core cooling system's and verification of their functionality with tests;
- Technical solutions related to the supplying of cooling water for systems (EFWS, PRHR SG, PRHR C, FAL) that realize the diversity principle and are related to the 72-hour removal of residual heat;
- Alternating current supply equipment realizing the diversity principle;
- Electric power supply system of the systems for management of severe accidents;
- Consideration of general lessons learned from the Forsmark incidence;
- Separation principles for both electric and automation systems;
- Scope of the HW-Div system;
- Application of the diversity principle to measurements of the reactor protection system and to the activation of protections.

In STUK's opinion, the required tests, further engineering and modifications can be carried out at later licensing stages.

Final assessment of CR4.2.1 — RD&D

Only limited information is available to assess this criterion. It is recommended that additional information be requested prior to the beginning of construction of the AES-2006.

Due to the vast experience of the designer it is expected that CR4.2.1 will be met.

8.5.2.2. Assessment against criterion CR4.2.2 — computer codes

Indicator IN4.2.2: *Computer codes or analytical methods developed and validated? (For an innovative NES new or more detailed models developed using a representative data base must be implemented in computer codes, verified and validated. International standards, e.g. validation matrices, uncertainty quantification approaches combined with scaling considerations should be used to the extent possible).*

Acceptance limit AL4.2.2: *Yes. (For computer codes used in design and analysis: The region of code application is covered by their validation matrix including quantification of* *uncertainties and sensitivities; independent reviews have been performed; a complete documentation including detailed code manuals are available).*

According to Ref. [121], the requirements of basic principle BP4 for safety are aimed at the designer of NPP and the country of design origin.

TABLE 70. CODES USED FOR VVER REACTORS (INCLUDING V-320 AND V-491) DESIGN AND ANALYSES [14]

Code name	Area of application	Validation
MCU-RFFI/A	Monte-Carlo code, neutron physics calculation	Certified
TVS-M	Spectral code for calculation of cross-sections, neutron physics calculation	Certified
PERMAK-A	2-D pin-by-pin burnup simulation and stationary calculation	Certified
BIPR-7A	3-D reactor core burnup simulation and stationary calculation	Certified
SOKRAT/V.1	accident simulation (includes codes RATEG, SVECHA and GEFEST)	Validation in progress, see section 5.2.1
TRAP-KS	Transients	Certified
RAPTA	Fuel behaviour in LOCA	Certified
ANGAR	Containment code	Certified
KUPOL	Containment code	Certified

Design companies in the Russian Federation possess a full set of computer codes necessary for design calculation, including safety analysis of VVER type reactors and codes necessary for operational calculation including simulation of various regimes.

The appraisal of computer codes is one of the functions of the Russian regulatory body which has a special department (see Appendix II) and a special ‘council for computer code certification’ in its structure. The evaluation results of the computer codes performed in 2009 are documented in [152]. Some examples of these codes are presented below.

The MCU-RFFI/A is a Monte-Carlo code for modelling the transport of neutrons in the range of energies from 10 MeV through 10^{-5} eV. The code is applicable for various system geometries and various boundary conditions. MCU-RFFI/A is being used for the verification of codes of reactor calculation, the verification of neutron cross-section libraries and for a precise neutronic calculation of complicated systems. The code uses the DLC/MCUDAT bank of evaluated nuclear data which ensures an accuracy of calculation of VVER assemblies at a level of 0.3 - 0.4 k_{eff} corresponding to the accuracy of MCNP (ENDF/B-V) calculations.

The TVS-M code is used for the preparation (approximation) of multi-parametric functions of the low-group neutron cross-sections and a derivative of these cross-sections depending on the fuel burnup and reactor core parameters variations.

Steady state power regimes and power changes during normal operation, including reactor startups and shutdowns are being simulated with the KASKAD tool. KASKAD consists of two major codes — BIPR and PERMAK — and two additional codes — PIR and PROROK. The tool allows simulation of fuel burnups, calculation of reactivity balances, effects and coefficients, including Xe and Sm transients, and also analysis of deviations of the calculated data of core power distribution from the distributions measured by in-core power monitoring system. KASKAD is currently used for VVER calculations in the Russian Federation, Ukraine, Armenia and Bulgaria.

The SOKRAT tool has been developed in the Russian Federation for the analysis of BDBA and severe accidents. SOKRAT is a package of the codes RATEG, SVECHA and GEFEST for realistic estimation and the numerical simulation of physical processes inside of the reactor vessel. SOKRAT provides opportunity to couple its codes with the codes of severe accident modelling like KUPOL and ANGAR (thermohydraulics of containment), VAPEX (steam explosions), LOVUSHKA (core catcher processes), NOSTRADAMUS (aerosols), BONUS (release of volatile fission products). SOKRAT was verified and tested for the safety analysis of previous generations of VVER. Later it was additionally verified for AES-2006 and is used for the design of systems necessary for severe accident management (core catcher, hydrogen burn and explosion mitigation system, passive safety systems) [14].

Reactivity related accidents are being calculated with ATHLET/BIPR-VVER tool which was developed in cooperation of “Kurchatov Institute” and GRS (Germany). This tool uses 3-D kinetic neutron-physical model of the core and quasi-3-D model of coolant flow in the reactor vessel and SG. For the regimes (the majority of leakages, coolant flow rate variations, heat remove variations via secondary circuit) where point-kinetics assumptions are acceptable and the coolant mix-up description is not important the code TRAP (developed by Gidropress) is used.

Internationally accepted codes DOT-III and ANISN are used for the estimation of impact of fast neutrons irradiation on the reactor vessel.

Final assessment of criterion CR4.2.2 — computer codes

Criterion CR4.2.2 has been met by the AES-2006 design.

8.5.2.3. Assessment against criterion CR4.2.3 — scaling

Indicator IN4.2.3: *Scaling understood and/or full-scale tests performed?* (*Scaling investigations can be performed with analytical methods and by carrying out experiments with different sizes. To the extent possible both methods should be applied).*

Acceptance limit AL4.2.3: *Yes. (Scaling considerations including uncertainty analyses have been performed and are well documented).*

Some of the passive safety systems (e.g. systems of passive heat removal, hydro-accumulators, system of fast boron injection) have been studied in experimental installations at OKB Gidropress and the State Scientific Centre of the Russian Federation, the A.I.Leipunski Institute for Physics and Power Engineering. As documented in Ref. [153] scaling factors are known. (see also assessment of criterion CR4.2.1)

Final assessment of criterion CR4.2.3 — scaling

Criterion CR4.2.3 has been met by the AES-2006 design.

8.5.2.4. Final assessment of UR4.2 — research, development and demonstration

This user requirement stipulates sufficient RD&D on the reliability of (new) components and systems.

Assuming that the findings of the section 8.5.2.1 are valid for the Belarus licensing authority, to meet criterion CR4.2.1 (RD&D) additional analyses, some experimental qualification and some engineering should be done for the new components and systems.

Adequate computer codes (CR4.2.2) have been developed and scaling (CR4.2.3) has been taken into account in the AES-2006 design.

It is expected that — after the missing information is available — the assessment of UR4.2 for the AES-2006 design will produce a positive result.

8.5.3. User requirement UR4.3 — pilot plant

User requirement UR4.3: *A reduced-scale pilot plant or large-scale demonstration facility should be built for reactors and/or fuel cycle processes, which represent a major departure from existing operating experience.*

INPRO has developed two criteria for this user requirement, CR4.3.1 and CR4.3.2.

8.5.3.1. Assessment against criterion CR4.3.1 — novelty

Indicator IN4.3.1: *Degree of novelty of the process. (In case of high degree of novelty: Facility specified, built, operated, and lessons learned documented. In case of low degree of novelty: Rationale provided for bypassing pilot plant).*

Acceptance limit AL4.3.1: *The degree of novelty of new SSC has been identified and an appropriate RD&D programme has been established.*

The AES-2006 design is considered evolutionary, i.e. it is an advanced design that has improved on existing designs (VVER-1000) through small to moderate modifications with a strong emphasis on maintaining design probity to minimize technological risks. There are some innovative features in the AES-2006 design: namely, the use of passive safety systems in addition to active systems. The innovative features of the AES-2006 have been designed on the basis of extensive analytical and experimental activities performed at qualified institutions and reviewed and licensed by Russian regulatory bodies.

To confirm identification of the degree of novelty of the AES-2006 design, a statement [133] by an independent expert organization (the Finish authority STUK) is quoted below.

The AES-2006 is a PWR with a power output of about 1200 MW(e) marketed by the Russian company Atomstroyexport (ASE). The AES-2006 is based on the VVER 91/99 plant, which was developed from the VVER-1000 plants in operation. VVER type plants have been built in the Russian Federation and many other countries for over 30 years. The reference plants for the AES-2006 include Tianwan 1 and 2 in China, and Leningrad NPP-2 currently under construction in Russia. Leningrad NPP-2 consists of two units, which together with the Novovoronesh-2 plant unit are the first AES-2006 type plants in Russia. There are also several AES-2006 plants in the planning stage in other countries.

The AES-2006 plant's safety functions have been improved compared to the VVER 91/99 plant. The safety functions are, as a rule, implemented by means of active systems that are supplemented, as is typical with PWRs, with passive systems. Examples of these passive systems include pressure accumulators for use in emergency core cooling situations and also passive systems designed for removing the plant's residual heat and which have previously not been used in NPPs. The new passive systems based on natural recirculation for residual heat removal in transient and accident conditions are the primary circuit cooling system connected to the steam generator, and the containment system. The AES-2006 also has severe accident management systems. The rated service life of the plant is 60 years. The level of maturity of the plant with regard to basic engineering is high. The secondary circuit is essentially identical to the existing VVER-type PWRs. The design objectives and principles of this plant are, for the most part, consistent with Finnish safety requirements.

Final assessment of criterion CR4.3.1 — novelty

The degree of novelty in the AES-2006 has been established, i.e. it is classified as an evolutionary design, and necessary R&D activities have been performed. Criterion CR4.3.1 has been met by the AES-2006 design.

8.5.3.2. Assessment against criterion CR4.3.2 — pilot facility

Indicator IN4.3.2: *Level of adequacy of the pilot facility.*

Acceptance limit AL4.3.2: *Results are sufficient to be extrapolated. (A peer review about the adequacy to build and operate a pilot plant has been performed).*

As stated before for criterion CR4.3.1, the AES-2006 is an evolutionary design derived from the VVER 91/99 designs and VVER-1000 reactor family (currently operated in more than five modifications). According to Ref. [121], the construction of a pilot facility may be not vital for an evolutionary design. The Russian Federation has started two first-of-a-kind reference reactors of AES-2006 type at the Novovoronezh-II and Leningrad-II site. Belarus pursues the plan to install an exact copy of the Leningrad NPP on its territory.

Construction of the first unit of Leningrad-II NPP started in October 2008.

Final assessment of CR4.3.2 — pilot facility

Criterion CR4.3.2 has been met by the AES-2006 design.

8.5.3.3. Final assessment of user requirement UR4.3 — pilot plant

This user requirement stipulates construction and operation of a pilot plant if the new design represents a major departure from existing operating experience.

The AES-2006 is an evolutionary design, i.e. it is an advanced design that achieved improvements over existing designs (VVER-1000) through small to moderate modifications with a strong emphasis on maintaining design probity to minimize technological risks. Thus, no pilot plant is needed.

User requirement UR4.3 has been met by the AES-2006 design.

8.5.4. User requirement UR4.4 — risk and uncertainties

User requirement UR4.4: *For the safety analysis, both deterministic and probabilistic methods should be used, where feasible, to ensure that a thorough and sufficient safety assessment is made. As the technology matures, "Best Estimate (plus Uncertainty Analysis)" approaches are useful to determine the real hazard, especially for limiting severe accidents.*

INPRO has developed two criteria for this user requirement, CR4.4.1 and CR4.4.2.

8.5.4.1. Assessment against criterion CR4.4.1 — risk informed approach

Indicator IN4.4.1: *Use of a risk informed approach? (It includes design criteria that implicitly involve probabilistic considerations and are complemented by explicit probabilistic arguments clarifying design objectives. A risk-informed approach is appropriate for existing reactor designs with well recorded operational behaviour).*

Acceptance limit AL4.4.1: *A careful use of risk informed approaches based on proven data sets has been performed by the designer.*

At the time of the assessment no direct information on application of the risk-informed approach in the AES-2006 design was available to the assessor. However, indirect information is available through an independent expert organization (the Finish licensing authority STUK), which has discussed [133] the status of the deterministic and probabilistic safety analyses of V-491 based on the input provided by designer. In the following STUK concludes that the methods used for the design of V-491 are deemed to be sufficient.

Deterministic analysis methods and preliminary results

For the assessment and verification of safety of the AES-2006 plant, analysis methods have been maintained and qualified for the intended purpose of use. The methods have been used during the design and construction of the plant units in operation. Early versions of the analysis methods presented now have been used in the design of the Loviisa 1 and 2 plant units, among others. The analyses performed on the AES-2006 plant lead to the impression that transient and accident analyses consistent with Finnish requirements can be performed on this plant alternative.

Probabilistic analyses

Probabilistic risk analysis (PRA) methods have been used for a level 1 PRA analysis for the AES-2006 plant. The analyses cover the most important initial events in all the plant's operational stages. On the basis of the data on analysis methods and the results of the PRA pertaining to AES-2006, it can be assessed that analyses consistent with Finnish PRA requirements can be performed on this plant alternative.

Assuming that Belarus' regulatory requirements are based on the same principles as the requirements of the Russian Federation or Finland, criterion CR4.4.1 is deemed to have been met.

8.5.4.2. Assessment against criterion CR4.4.2 — uncertainties

Indicator IN4.4.2: *Uncertainties and sensitivities identified and appropriately dealt with?*

Acceptance limit AL4.4.1: *A thorough analysis of uncertainties including complementary sensitivity studies has been performed by the designer. An independent review is recommended.*

According to the PSA data provided by the designer [14], the frequency of core melting has been calculated with due attention to uncertainties. The borders of a 90% interval of confidence for a frequency of reactor core melting at operation (on power) lie at:

- Upper border (95%) 1.08 10^{-6} 1/a.
- Bottom edge (5%) 5.79 10^{-8} 1/a.

The borders of 90% interval of confidence for a frequency of reactor core melting at maintenance (shutdown regimes) lie at:

- Upper border (95%) $9.92 \cdot 10^{-7}$ 1/a.
- Bottom edge (5%) $9.04 \cdot 10^{-8}$ 1/a.

Other data on the consideration of uncertainties are not available to the assessor.

Final assessment of CR4.4.2 — uncertainties

Only a limited amount of data to assess this criterion CR4.4.2 is available to the assessor. However, it is expected that — after the missing information is available — the assessment of CR4.4.2 will produce a positive result.

8.5.4.3. Final assessment of user requirement UR4.4 — risk and uncertainties

This user requirement stipulates that a combination of deterministic and probabilistic methods should be used to analyse safety.

For the safety analyses of AES-2006, deterministic and probabilistic methods have been used. However, the available information was limited. It is expected that the assessment — after the missing data have been received — will produce a positive result.

Thus, user requirement UR4.4 has been met.

8.5.5. Final assessment of basic principle BP4 — RD&D

This basic principle requires sufficient performance of research, development and demonstration for a new reactor design to achieve the same level of knowledge of plant characteristics and the capability of analytical methods as for existing designs.

A safety basis (UR4.1) has been established for the AES-2006 and intensive RD&D (UR4.2) performed. For the AES-2006 — as an evolutionary design — a pilot plant (UR4.3) was not deemed to be necessary. For a full assessment of analysis methods (UR4.4) used for the design of the AES-2006, not sufficient data were available but it is expected to be positively assessed after the data have been received. It is recommended that the missing information be requested from the designer.

Thus, BP4 is deemed to have been met by the AES-2006.

8.6. SUMMARY AND CONCLUSIONS OF ASSESSMENT OF SAFETY OF NUCLEAR REACTORS

Within the AES-2006 reactor design, clearly the defence-in-depth concept has been enhanced (BP1). For the assessment of the independence of defence-in-depth levels and of the application of a human response model, not enough data were available to the assessor.

The AES-2006 design has placed increased emphasis on inherently safe characteristics and passive systems in its safety approach (BP2).

Radiation exposure to workers in the AES-2006 reactor is below the regulatory limits (BP3). Not sufficient data were available to the assessor to compare the radiation risk in an AES-2006 plant with the risk in non-NPPs.

Intensive R&D activities have been performed (BP4) to ensure reliable behaviour of all new engineered features in the AES-2006 design, such as the use of additional passive systems especially for prevention and mitigation of severe accidents.

9. GAPS AND FOLLOW-UP ACTIONS

The detailed assessment of the Belarus NES using the INPRO methodology found some so-called gaps, i.e. not complete fulfilment of INPRO criteria for certain issues, which are listed below together with recommendations for follow-up actions. Most of these gaps are data that were not available to the assessor at the time the report was written.

9.1. ECONOMICS

9.1.1. Risk of investment in nuclear power

Criterion CR3.1: To limit the risk of investment in nuclear power, INPRO methodology criterion CR3.1 requires an adequate status of the licensing process, depending on the experience of the country that intends to install an NPP. In a case where the first few NPPs are to be deployed in a country — which is the situation in Belarus intending to install the latest VVER1000 design, the AES-2006, as its first NPP — CR3.1 stipulates that nuclear plants of the same basic design should have been constructed and operated in the country of the supplier. At the time the assessment was performed, the AES-2006 was licensed in the country of origin and construction projects were ongoing with an AES-2006 type of reactor. However, the absence of operational experience with NPPs of AES-2006 design in the supplier country (the Russian Federation) leads to the conclusion that criterion CR3.1 has not yet been completely satisfied. However, the assessor acknowledges that other novel PWR reactor designs, e.g. EPR, APR-1400 and AP-1000, do not have operational experience in the supplier countries yet, either.

Criterion CR3.2: To limit the risk of investment in nuclear power criterion CR3.2 requires evidence that the construction schedule (of the nuclear plant type to be installed) considered in the economic analysis has been met in previous construction projects for the same basic design. As construction of AES-2006 reactors is currently not yet completed, CR3.2 has not been fully satisfied (for the same reason as CR3.1), i.e. the absence of experience with construction schedules and operation of NPP of AES-2006 type in the supplier country. The assessor acknowledges that other novel PWR reactors available at the market do not currently have enough experience, either, with the construction schedules and operation.

9.1.2. Recommendation on economics

A possible follow-up action for both gaps could be to include adequate content into the contract with the supplier of the AES-2006 plant to reduce the risk of disturbances of the construction and operation of the plant.

9.2. INFRASTRUCTURE

9.2.1. Adequacy of text of nuclear law

Evaluation parameter EP1.1.1: The nuclear law does not fully present the issues to ensure the safe handling of radioactive waste and spent fuel.

Evaluation parameter EP1.1.2: Ministry for Emergency Situations is a nuclear regulatory body of Belarus since it fulfills key regulatory functions, e.g. licensing, has necessary administrative and financial autonomy. However Ministry for Emergency Situations performs several other than regulatory functions in the area of nuclear energy.

Gosatomnadzor is a structural unit of the Ministry for Emergency Situations. While it has own legal status and extensive regulatory functions in the field of nuclear energy Gosatomnadzor administratively and financially reports to the Ministry for Emergency Situations. Perhaps the decision to grant full autonomy and a full set of regulatory functions to

Gosatomnadzor could become an alternative approach, possibly more effective, than the existing system of Government regulation of the use of nuclear energy.

Some of the important terms used in the legislation do not have clear and consistent definitions in the nuclear law — for example:

- There is no definition in the nuclear law [1] of ionizing radiation and ionizing radiation source, although, these terms are used in several articles of the law;
- Ionizing emission sources are not included in nuclear facilities, although, the text of the law says clear that they are such sources;
- The first paragraph of Art.6 of the nuclear law [1] contradicts the last paragraph of Art. 7. The Ministry for Emergency Situations is mentioned in these articles as an organ of State management and as an organ of State regulation on the safe use of nuclear energy. However, the last paragraph of Art.7 declares the independence of regulatory bodies from management bodies;
- Some safety specific terms in the nuclear law [1] are not defined according to *IAEA Safety Glossary* [26], e.g. 'nuclear safety'.

The institutional responsibilities for regulating nuclear related activities are not absolutely clear and consistent: Only the regulatory functions of the Ministry for Emergency Situations are clarified. Regulatory functions of the Ministry of Natural Resources and Environment of Belarus, the Ministry of Health, Ministry of Internal Affairs, Committee for State Security have not identified and separated.

9.2.2. Institutions to implement nuclear law

Evaluation parameter EP1.2.1: Regulation of the activities on safety of nuclear energy use in Belarus is carried out by a Governmental system. The nuclear law [1] defines the independence of this system. However, this declaration must be supported by a foundation of financial independence, such as the presence of a separate line in the budget of Belarus for regulatory activities. The financing scheme described in the statute of Gosatomnadzor is not completely transparent, because — although it is financed from the Belarus budget — Gosatomnadzor is a subdivision within the Ministry for Emergency Situations. Under the current regulatory system, it is impossible to confirm its financial independence since regulatory activities are only part of the activities of other relevant Government bodies.

A possible scheme for full financial independence of regulatory activities would be the separation of Gosatomnadzor into an independent organization, empowering it with all the powers and functions of a regulatory body and giving it financial independence by allocating a separate budget line to it.

The law [1] and other legislation on the use of nuclear energy have no articles relating to other aspects of independence of regulatory activities: technical and managerial competence, the availability of adequate human resources, effective leadership, and reporting mechanisms.

Evaluation parameter EP1.2.3: In 2010, Gosatomnadzor has applied an updated IAEA tool, Systematic Assessment of Regulatory Competence Needs (SARCoN). The SARCoN guidelines are intended to help analyse the training and development needs of regulatory bodies in Member States. Results of a self-assessment using SARCoN are not available to the assessor. The authors of this study do not have any information about a review of the national safety regime by an independent authority.

Evaluation parameter EP1.2.4: In 2010, upon the request from Belarus Government, an emergency preparedness and review (EPREV) mission assessed the national system of emergency preparedness for nuclear and radiation accidents. The main conclusion of the IAEA expert group was that Belarus had a reliable system of emergency preparedness and response, but it needed to be reviewed in connection with the plans to build an NPP in Belarus. The mission also gave recommendations for further improvement of the existing system of preparedness and emergency response in accordance with international requirements and standards.

9.2.3. Industrial and economic infrastructure

Evaluation parameter EP2.3.2: Currently, only construction of a temporary storage facility of spent fuel is foreseen in Belarus. Possibly (depending on contract conditions for NPP construction), a geological disposal of high level waste from reprocessing is to be built in the future. However, sizes of these facilities are not defined yet.

Evaluation parameter EP2.5.2: The authors of this study have no information about Governmental expertise regarding a potential benefit to society by the planned nuclear programme.

9.2.4. Public acceptance

Evaluation parameter EP3.1.3: A policy (by the owner/operator of nuclear facilities) on public communication should be in place and its effectiveness should be demonstrated by surveys.

9.2.5. Human resources

Evaluation parameter EP4.1.2: In the available data taken for the calculation of economic parameters, wages at the nuclear power station were compared to the average wages in Belarus for workers of the same qualifications. Also, a sensitivity analysis on wages was performed. With an increase in absolute value of wages up to 400% to 7.7 million rubles (US $2500), production cost will increase by 23.1%, while the share of wages in the production cost structure will increase from 7.7% to 25%. However, the NPP's competitive advantage (electricity production cost) is still maintained compared to non-nuclear power stations. In the reports [43, 44], it was announced that the wages of workers with the same skills in Western Europe are about US $6000 and in the Russian Federation wages are also at this level. Thus, wages in Belarus for nuclear power related jobs are not competitive with similar jobs outside the country.

Criterion CR4.2: This criterion requires confirmation of a safety and security culture in nuclear organizations. Necessary support to build up the culture of nuclear (and radiation) safety in all nuclear power related organizations is provided by the Government. It is expected that — once the organizations for operating the NPP are established — periodic reviews will be performed of the safety culture by competent institutions such as the IAEA. According to the information available to the assessor, no review of the safety and security culture has taken place until now.

9.2.6. Recommendations on infrastructure

It is recommended that:

- An update of the text of nuclear law be initiated.
- A positive result of the independent safety regime assessment be confirmed.
- The Belarus Government confirm that the IAEA recommendations from the EPREV mission have been fulfilled.
- The size of the HLW disposal facilities necessary for Belarus' nuclear programme be defined in time.

- A study be initiated on potential benefits to society from the planned nuclear programme.
- A public communication policy be developed before the startup of the NPP.
- Activities be started to address the issues regarding competitiveness of the wages in Belarus for nuclear power related jobs.
- An IAEA mission be requested on safety and security culture.

9.3. WASTE MANAGEMENT

9.3.1. Waste minimization

Criterion CR1.1.1: This criterion requires that technical indicators, such as total activity, mass, and volume of waste of an NES should be kept ALARP. There is no direct evidence available to the assessor — other than the increased burnup of nuclear fuel — that the designer of the AES-2006 has applied the ALARP concept to the generation of radioactive waste. Also it is not clear whether special emphasis has been placed on dealing with waste containing long-lived toxic components that would be mobile in a repository environment.

9.3.2. Protection of human health and environment

Criterion CR2.1.1: The AES-2006 reactor design clearly meets the relevant national standards (dose limits) for the public; the planned national facilities for final disposal or intermediate storage of radioactive waste are assumed to produce much less public dose than the nuclear reactor. However, no concrete data on public dose from planned national waste management facilities during normal operation were available to the authors of this report. Additionally, information on public dose due to accidents related to spent fuel storage was absent, such as consequences of accidents at a spent fuel storage facility and, in particular, release of radioactive material into the environment because of overpacking of spent fuel into cask transportation or storage.

Criterion CR2.1.2: This criterion requires that exposure of workers (occupational dose) in nuclear facilities meet regulatory standards of Belarus. Data of occupational dose in waste management facilities planned in Belarus were not available to the authors.

Criterion CR2.1.3: This criterion requires that estimated concentrations of chemical toxins in working areas (of waste management facilities) meet regulatory standards of Belarus. There are no specific data available to the authors to assess this criterion.

Criterion CR2.2.1: This criterion requires that estimated releases of radioactive nuclides and chemical toxins from waste management facilities into the environment meet national regulatory standards. No relevant data were available to the assessor.

Criterion CR2.2.2: Only general information about releases of radionuclides from fuel cycle facilities located outside Belarus was available to the authors of this report to assess this criterion.

9.3.3. End state

Criterion CR3.1.1: This criterion requires that technologies required to achieve an end state of all radioactive waste should be available in time. Spent fuel assemblies are planned to be stored in a national intermediate storage facility for only up to 50 years and afterwards returned to the supplier of the fuel outside Belarus. Thus, no technology for an end state of spent fuel assemblies is necessary in Belarus. However, optionally, radioactive waste may be returned to Belarus as a result of reprocessing the spent fuel in Russia, which must eventually be held in a final depository. For this option, no data on the corresponding technology were available to the assessor.

All types of operational waste and its generation, treatment and intermediate storage at the plant site were investigated intensively by the responsible organization in Belarus. Packages for operational waste at the site of the NPP have been identified in the nuclear power project. However, no information was available how the packages with operational waste would be disposed in a final depository. Thus, currently, the technology for achieving an end state for radioactive waste generated in the NPP is only partly identified in Belarus.

Criterion CR3.1.2: This criterion requires that the time needed (by the owner/operator of the NPP) to develop the technology for all end states should be less than a prescribed (by the responsible national authority) time to reach the end states.

Information needed for the complete assessment of this criterion — e.g. prescribed times to reach end states, times to install final depositories — was not available to the authors of this report.

Criterion CR3.1.3: This criterion requires that all necessary resources to develop the technology for the end state of all radioactive waste should be available. No information was available to the assessor about the additional resources needed for the development of end states for operational waste, and for away-from-reactor storage of spent fuel assemblies (and optionally final disposal of reprocessing waste of spent fuel assemblies).

Criterion CR3.1.4: This criterion requires that a safety case for all end states has been made and approved by the regulatory authority. A safety case for the end state of operational waste from the NPP has been made. However, it is not clear whether in this document the following issues have been covered in detail, such as end states for all operational waste and the end state for (optional) final disposal of reprocessing waste (to be returned from the Russian Federation after reprocessing activities on spent fuel assemblies), and whether it has been approved by the national regulatory body of Belarus.

Criterion CR3.1.5: This criterion requires that all end states should be reached as quickly as reasonable practicable. Regarding spent fuel assemblies, the end state is assumed to be achieved in the country – the Russian Federation – which supplied the fresh fuel to Belarus, i.e. spent fuel assemblies after interim storage in Belarus are expected to be sent back to Russia. No information was available to the assessor regarding the time needed to achieve an end state of the optionally returned reprocessing waste from the Russian Federation (generated during reprocessing of spent fuel assemblies).

Two approaches are being considered in Belarus regarding the treatment of operational waste. The first one is to store all waste generated at the plant site until the end of the service life time of the power plant. The second approach is to establish a new organization/institution, called SPO, in Belarus that will be responsible for characterizing all operational waste and establishing its end state. At SPO, the waste should be stored for up to 300 years in interim storage facilities before it would be placed into an end state.

Both approaches for operational waste are clearly not fulfilling INPRO criterion CR3.1.5, i.e. to demonstrate a reasonable short time to achieve the end state of operational waste. Additionally, information on the time foreseen to reach the end state for reprocessing waste was not available to the assessor.

Criterion CR3.2.1: This criterion requires that in the assessment of economics — and especially in determining the costs of electricity production by nuclear power — all costs of waste management should be included. In the economic assessment of nuclear power in Belarus a line item for costs for waste management is included. However, it is not evident whether the specific costs for Belarus due to takeback of spent fuel assemblies by the Russian Federation are included in this economic assessment. Also, no specific information was available on costs for an optional final depository for waste from reprocessing (returned from the Russian Federation to Belarus after reprocessing spent fuel assemblies). Regarding costs for treatment of operational waste and waste arising during decommissioning of nuclear facilities, also no direct data were available for assessment.

9.3.4. Waste optimization

Criterion CR4.1.1: This criterion requires that a classification system for all waste should be developed and implemented. Principles for developing a classification scheme for all radioactive waste ensuring concurrence of waste packaging and way of final disposal have been developed in the Belarus nuclear power project to enable an optimal management of all radioactive waste generated in the NES. However, the actual classification scheme to be used in achieving the end state for operational waste of the NPP is still under development.

Criterion CR4.2.1: This criterion requires that the time to produce the waste form specified for the end state be minimized. The time required to transform all types of operational radioactive waste generated at the NPP into a form suitable for long term storage at the NPP or in a separate facility, will be minimized by the technology used. However, it is currently not clear whether the waste form (packaging) produced at the plant can also be used in the final depository (end state).

Criterion CR4.2.2: This criterion requires a check whether technical indicators, such as criticality and heat removal, have been considered in the design of the packages and the final depositories for all waste (end state) and documented in a safety case that meets the national regulatory requirements. No information on whether these technical indicators were covered in the safety case for the end state was available to the authors of the report to assess this criterion.

Criterion CR4.2.3: This criterion requires that a description of all intermediate processes be available (or under development) for all stages of radioactive waste management until all end states in the country are established. Currently, these data are not available to the assessor.

9.3.5. Recommendations on waste management

It is recommended that:

- The concept of end state for operational waste be further developed and that missing information be collected on final disposal of reprocessing waste.
- All costs of waste management be included in the line item of the economic assessment.
- Waste classification system be further developed.
- Missing information be collected and the assessment of criteria CR1.1.1, CR2.1.1, CR2.1.2, CR2.1.3, CR2.2.1, CR2.2.2, CR3.1.1, CR3.1.2, CR3.1.3, CR3.1.4, CR4.2.1, CR4.2.2, CR4.2.3 be finalized.

9.4. PROLIFERATION RESISTANCE

9.4.1. Legal framework

Criterion CR1.1: All necessary international treaties and agreements are adopted and ratified in Belarus, except for the additional protocol to the safeguards agreement with a view to The NPT concluded between Belarus and the IAEA.

Criterion CR4.1: This criterion requires the confirmation that a diversion and acquisition path analysis has been performed of all possible paths. Only a general analysis was made of all possible paths in the AES-2006 plant to divert nuclear material. To evaluate this criterion in detail, results are required from a comprehensive diversion and acquisition path analysis covering all possible ways to divert nuclear material in the plant. Such results were not available to the assessor.

Criterion CR5.1: This criterion requires the confirmation that aspects of proliferation resistance were taken into account by the designer at the earliest stage of development of the design. Necessary information on how proliferation resistance was incorporated in the design was not available to the assessor. However, it can be assumed that the experienced designer of the AES-2006 plant has taken into account aspects proliferation resistance during his design development.

Criterion CR5.2: This criterion requires that the costs of incorporating those intrinsic features and extrinsic measures into NES which are required to provide or improve proliferation resistance over its life cycle be optimized. The assessor does not have enough information to evaluate this criterion.

9.4.2. Recommendations on proliferation resistance

It is recommended that:

- The ratification of the additional protocol, which was confirmed by the Government, be finished.
- A comprehensive analysis of the nuclear material diversion and acquisition paths be initiated.
- The missing information be obtained and the assessment of CR5.1 and CR5.2 be finalized.

9.5. PHYSICAL PROTECTION

9.5.1. Gaps in physical protection

Criterion CR2.3: This criterion requires the development of physical protection for the full lifecycle of an NES. However, currently no information on a plan for decommissioning the planned NES is available to the assessor.

Criterion CR4.1: No detailed information is available to the assessor about the current status of measures to be taken to ensure adequate confidentiality of all documents related to the design and operation of all facilities of the planned Belarus NES, i.e. the NPP and waste management facilities.

Criterion CR5.3: The design basis threat concept is being used as a basis for the development of the physical protection system of the planned NPP. However, no information is available to the assessor about physical protection systems needed for other facilities of the planned Belarus NES, e.g. for waste management facilities.

Criterion CR5.4: This criterion requires the designer to introduce flexibility into the PPS design to cope with the dynamic nature of threat and prepared protection plans. Requirements for such flexibility were not identified in the regulatory framework of Belarus. No information was available to the assessor on its introduction in the physical protection plans for the nuclear facilities of the planned NES of Belarus.

Criterion CR6.1: Belarus regulation requires the definition of limits for consequences of malicious acts against nuclear material and facilities. However, at this stage of the nuclear power programme, these limits have not yet been defined.

Criterion CR6.2: In the physical protection regulations of Belarus, a requirement is defined to use a graded approach for developing a threat assessment and the physical protection system. However, no information is available to the assessor as to whether such a graded approach has been used by the State in developing the design basis threat or whether the owner/operator has used such an approach for developing physical protection systems.

Criterion CR7.1: This criterion requires that a quality assurance policy be defined and implemented for all activities important to physical protection. Information on a quality assurance policy defined by the State to be applied by the operator in all nuclear facilities covering the aspect of physical protection has not been available to the assessor.

Criterion CR8.1: This criterion requires that a security culture programme be developed and implemented for all organizations and personnel involved in the NES. Necessary information on security culture is not available to assessor.

Criterion CR9.1: This criterion requires that the terrain, geography, and topography be assessed to preclude potential benefit to adversaries (e.g. high ground to observe approach and attack, air approaches, cover and concealment). According to the information available to the assessor in Belarus during the site selection process the terrain, topography and geography of the location of the future NPP regarding their (potential) impact on the physical protection regime were not assessed.

Criterion CR9.2: Regulation exists in Belarus that requires physical protection of nuclear material during transport to and from the site of a nuclear facility. However, currently no data are available to the assessor to check whether this regulation has been fully implemented in corresponding procedures.

Criterion CR9.3: Regulatory requirements for the development of physical protection systems specify consideration of physical protection during the selection of the site. However, these regulatory requirements need further development to include actions against future public encroachment.

Criterion CR10.1: It is assumed that physical protection will be considered also during the design phase of the other components of the NES in Belarus, i.e. the waste management facilities. Currently, there is no information available on these components.

Criterion CR10.2: The criterion requires that there be evidence that consideration has been given to physical protection in the layout of the NES components. No direct information is available to the assessor for evaluation of this criterion. However, it is assumed that in the layout of the AES-2006, physical protection is based on the extensive experience with VVER reactors in operation.

Criterion CR11.2: This criterion requires that the physical protection system of all nuclear facilities of the NES be designed with consideration of insider adversaries exploiting capabilities such as access, knowledge, and authority. Necessary information is not available to the assessor. It is assumed that insider adversaries are taken into account in the physical protection system for the AES-2006.

Criterion CR12.1: This criterion requires that responsibilities for execution of the emergency plans have been identified. Necessary information is not available to assessor.

Criterion CR12.2: This criterion requires that capabilities of the physical protection regime have been established to prevent and mitigate radiological consequences of sabotage. Necessary information is not available to assessor.

Criterion CR12.3: This criterion requires that capabilities of the physical protection regime have been established to recover stolen nuclear material or recapture facilities before the adversary can achieve its objective. Necessary information is not available to assessor.

9.5.2. Recommendations on physical protection

It is recommended that:

- The missing information on a plan for decommissioning of the planned NES be requested from the responsible organizations or that the development of such a plan be initiated.
- Confirmation be received from the responsible organizations that adequate confidentiality of all documentation related to the nuclear power programme will be achieved.
- The development of the limits for consequences of malicious acts against nuclear material and facilities be initiated by the responsible government institutions.
- An assessment be initiated of the terrain, topography and geography of the location of the future NPP regarding their (potential) impact on the physical protection regime, that the information be collected and that the assessment be completed.
- The further development be confirmed of the regulatory requirements which need to include actions against future public encroachment and complete the assessment.
- Physical protection be considered during the design phase of the other than NPP components of the NES.
- The missing information be collected and the assessment of CR5.3, CR5.4, CR6.2, CR7.1, CR8.1, CR9.2, CR10.2, CR11.2, CR12.1, CR12.2, CR12.3 be finalized.

9.6. ENVIRONMENT

Criterion CR1.1.1: All evaluation parameters evaluated for the AES-2006 have been satisfied but for several points, special conditions are to be fulfilled.

Special activities are needed to avoid interference with reproduction rate of rare species including specific actions to prevent this interference and a monitoring system to verify the effectiveness of these measures.

Special measures are necessary to make sure that contaminant concentration of discharged waste from NPP will not be higher than MAC for fishery basin.

The reserve water supply sources are recommended to be available for NPP in years of low water.

It is recommended that some additional stressors be evaluated, i.e. temporary and permanent land amortization and nuclear fuel transportation

No information was available to the assessor regarding stressors of other planned nuclear facilities of the Belarus NES, especially the waste management facilities outside the NPP. It is recommended that the missing information be collected to finalize the assessment.

Criterion CR2.1.3: Bearing in mind the large share of the first NPP in the energy supply mix of Belarus, the Government should take care of possible backup electricity sources, for instance, after a scram has occurred in the plant.

9.7. SAFETY OF NUCLEAR REACTORS

9.7.1. Enhanced defence in depth

Evaluation parameter EP1.1.2.8: This evaluation parameter requires that worldwide operating experience of existing NPPs recorded by international organizations should be taken into account in the design of a new NPP. No direct data are available for the assessment of this evaluation parameter.

Criterion CR1.1.4: This criterion requires that the expected frequency of failures and disturbances (for design V-491 should be reduced relative to existing reference design (V-320). Not sufficient data of the V-491 design was available to confirm this criterion.

Criterion CR1.2.1: This criterion requires demonstration of the capability of the I&C system to detect and intercept deviations from normal operation. This capability is usually demonstrated via a dynamic plant analysis. The AES-2006 design includes several I&C systems for continuous monitoring of plant health. No direct results of a dynamic plant analyses of the V-491 are available to the assessor.

Criterion CR1.3.1: Limited direct information on the frequencies of design basis accidents (DBAs) in the V-491 design is available to the assessor.

Criterion CR1.3.3: Acceptability of the physical separation of the engineered safety feature should be analysed by the national regulatory body.

Criterion CR1.3.4: Limited information on the accident ‘collision by a large commercial airplane’ is available to the assessor.

Criterion CR1.3.5: This criterion requires that the engineered safety features be sufficient to reach a controlled state after a DBA based on automatic actions within a grace period of at least eight hours. No data are available to the assessor.

Criterion CR1.4.2: Acceptability of the reactor depressurization system design should be analysed by the national regulatory body.

Criterion CR1.6.1: This criterion requires that adequate independence of the different levels of defense in depth should be based on deterministic and probabilistic methods. No information is available to the assessor.

Criterion CR1.7.2: This criterion requires that by application of human factors models, the new design should demonstrate a reduced likelihood of human error relative to existing reactors, use of artificial intelligence for early diagnosis and real-time operator aids, and less dependence on the operator for normal operation and short-term accident management relative to existing plants. No data of the V-320 design are available that would be needed to be compared with the V-491 design.

9.7.2. Recommendations on safety of nuclear reactors

It is recommended that the general lessons learned from the design errors leading to the malfunction of the electric system of Forsmark NPP in 2006 be taken into account. In the design of the electrical systems and components, special attention should be paid, for example, to restraining voltage transients from spreading and the implementation of the diversity principle in the electricity distribution and in supplying power to I&C systems. It is recommended that the designer of the AES-2006 be requested to comment on these issues.

It is recommended that the designer of the AES-2006 be requested to comment on the physical separation of safety systems and to provide additional information on the accident ‘collision by a large commercial airplane’. The regulatory body of Belarus should analyse consistency of the reactor depressurization system design with the national regulation.

It is recommended that the missing information be collected to finalize the assessment of CR1.1.4, CR1.2.1, CR1.3.1, CR1.3.5, CR1.6.1, CR1.7.2.

Appendix I

COMPARISON OF VVER FEATURES WITH THOSE OF WESTERN PWR

Near reactor storage of spent nuclear fuel

Spent fuel and the systems necessary for its safe storage are placed inside the containment, which also means that they are not accessible during reactor operation. General layout of reactor building is demonstrated in Figure 18. In spite of the large capacity of spent fuel storage racks (usually enough for ten years of operation) and a certain amount of additional equipment, Russian designers succeeded to keep an acceptable size of the containment.

Hexagonal fuel assemblies

Unlike designers of most PWRs in the world, the designers of Russian Federation traditionally use the hexagonal fuel assemblies (see Figure 19). Although the size (length and diameter) of VVER-1000 and AES-2006 assemblies is kept the same, the fuel rod length and the mass of fuel in the AES-2006 assembly is greater.

Fuel cladding material

Cladding of fuel rods, spacers and guide tubes of these assemblies are fabricated from Zr+1%Nb alloys (E-110, E-635) unlike those made of zircalloy (which is Zr+Sn alloy) and stainless steel, which are traditionally used in other reactors.

Horizontal steam generators

All commercial reactors of Russian design are traditionally equipped with horizontal steam generators (Figure 20) which, in the opinion of Russian designers [154], have significant advantages over vertical steam generators used in other designs, including:

- Moderate steam load (steam outflow rate from the evaporation surface 0.2 to 0.3 m/sec); simple gravity-based separation scheme;
- Moderate velocity of the medium in the second loop (up to 0.5 m/sec), preventing any danger of vibrations of the heat-exchange tubes and damage from foreign objects;
- Validated serviceability of the 08Kh18N10T austenitic steel tubes;
- Vertical arrangement of the first-loop collectors, preventing accumulation of sludge deposits on their surfaces, thereby decreasing the danger of corrosion damage to the heat-exchange tubes in the region where the tubes are built into the tube sheet;
- Larger store of water in the secondary loop, enabling cool-down of the reactor via the steam generator in the case where normal and emergency water feeding has stopped;
- The principle of stepped evaporation, making it possible to maintain an admissible concentration of dissolved impurities in the critical zones and increasing the reliability from the standpoint of corrosion effects;
- Horizontal arrangement of the heat-exchange surface, enabling reliable natural circulation of the first-loop coolant even with a massive water level below the top rows of the heat-exchange tubes;
- Convenient access to the tube sheet for servicing and checking from the primary- and secondary-loop sides; there are no heat-exchange tubes at the bottom of the housing, so that sludge is more easily removed through the purge system;
- Presence of equipment for disconnecting the collectors from the main circulation pipelines, making it possible to decrease the time required to perform scheduled–

preventative maintenance work and to increase the installed capacity utilization factor by performing work simultaneously on several steam generators and refuelling the reactor.

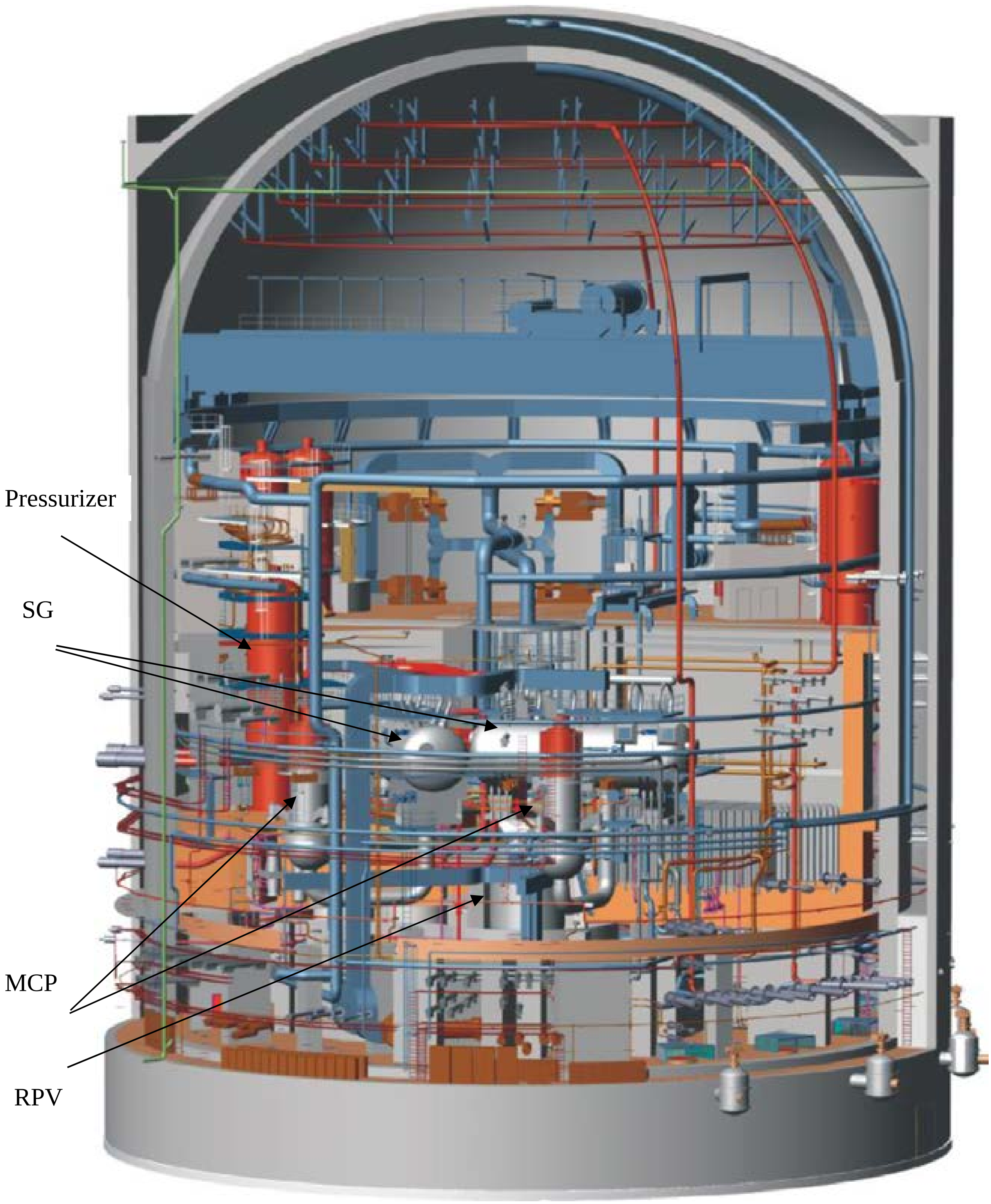

FIG. 18. AES-2006 general layout of reactor building (picture taken from Ref. [123]).

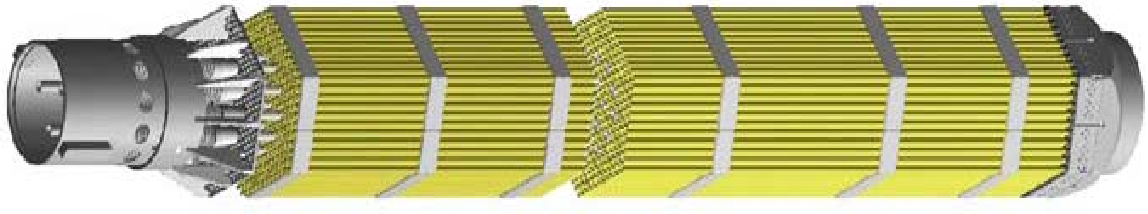

FIG. 19. VVER-1000 fuel assembly of TVS-2M type (figure from Ref. [122]).

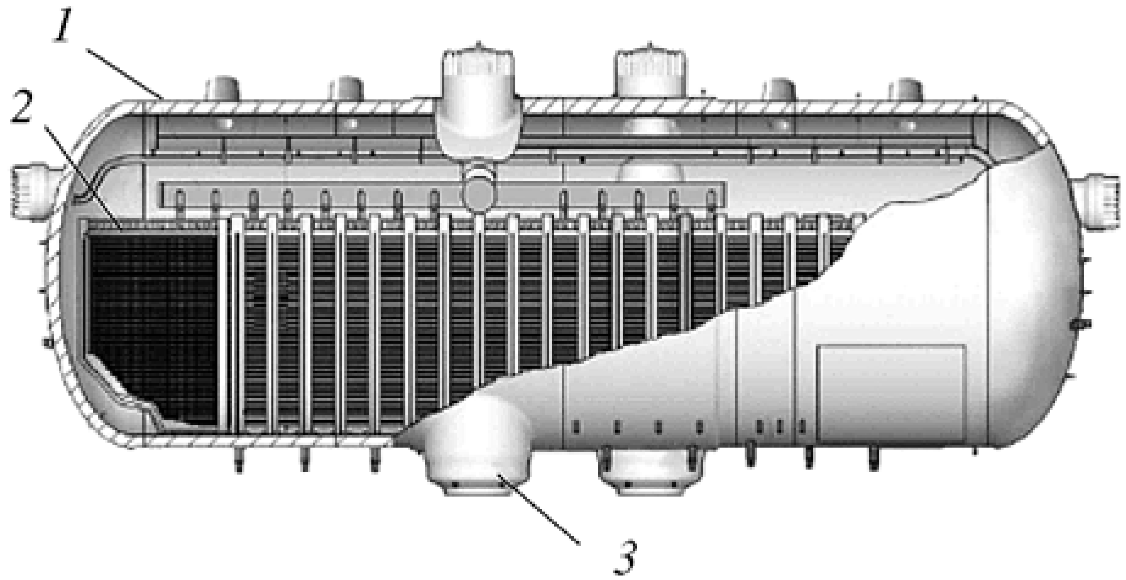

FIG. 20. PGV-1000MK steam generator: 1) housing; 2) tube bank; 3) coolant inflow and outflow stub pipes (figure from Ref. [154]).

Appendix II

OVERVIEW OF NUCLEAR LEGISLATION STRUCTURE AND ORGANIZATION OF REGULATORY BODY IN THE RUSSIAN FEDERATION

According to Art. 7 of the *Convention on Nuclear Safety* [155], State legislative and regulating basis provides for:

- Introduction of corresponding national requirements and regulating provisions for safety;
- A system of licensing with regard of nuclear installations and ban on operating a nuclear installation without a licence;
- A system of regulatory control and assessment of nuclear installations for the purpose of control over observance of operative regulating provisions and licence conditions;
- Enforcement of operative regulating provisions and licence conditions, including suspension, making amendments or annulment.

In the Russian Federation, these issues are regulated in the following basic legislative and regulatory legal acts:

- Federal *Law on the Use of Atomic Energy* [156];
- Federal *Law on Radiation Safety of the Public* [157];
- Federal *Law on Protection of Population and Territories from Natural and Industrial Emergencies* [158];
- Federal *Law on Financing of Particularly Radioactive-Hazardous and Nuclear-Hazardous Industries and Facilities* [159];
- Federal *Law on Special Ecological Programmes of Rehabilitation of Radiation-Contaminated Territories* [160];
- Federal *Law on Rosatom State Nuclear Energy Corporation* [161];
- Federal *Law on Amendments to Some Legal Acts of the Russian Federation in Connection with the Adoption of the Federal Law on RosatomState Nuclear Energy Corporation* [162];
- Federal *Law on Protection of the Environment* [163];
- Federal *Law on the Technical Regulation* of 27 December 2002184-FZ [164];
- Federal *Law on the Peculiarities of Managing and Handling the Property and Shares of the Organizations Performing Activities in the Area of Atomic Energy Use and Making Amendments to Certain Legislative Acts of the Russian Federation* of 5 February 200713-FZ [165];
- Federal law, *Town-Planning Code of the Russian Federation* of 29 January 2004190-FZ [166].

Apart from that, in what concerns establishing legal administrative and penal responsibility for atomic energy use, legal framework also includes:

- *Code of Administrative Offences of the Russian Federation* [167];
- *Criminal Code of the Russian Federation* [168].

The most important bylaws are the Russian Federation Government Ordinances [169–174].

State legislative and regulating framework could be represented as a hierarchical pyramid of regulations, governing relations in atomic energy use. (see Figure 21).

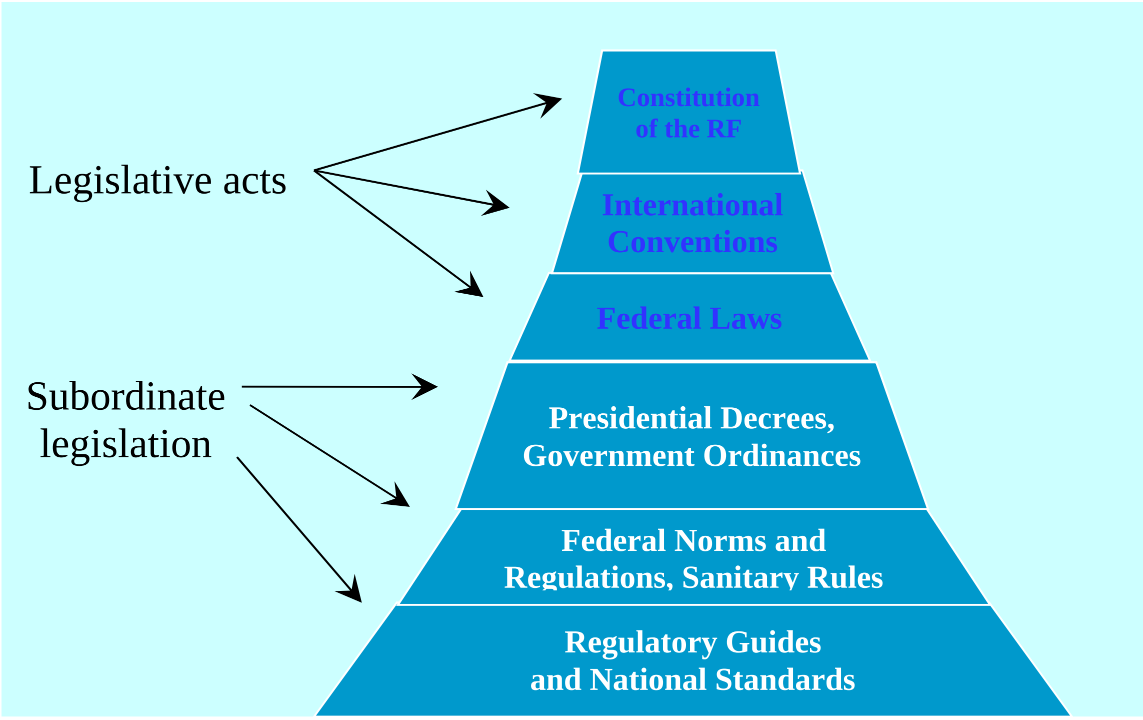

FIG. 21. Pyramid of regulations, governing relations on atomic energy use.

On top of the pyramid of legal regulations there is the *Constitution of the Russian Federation*, which has supreme legal power. In accordance with its provisions (Art.15), international treaties ratified by the Russian Federation make an integral part of its legal system. If an international treaty establishes rules different from those provided for by national law, the former are implemented. For atomic energy use the Russian Federation has joined the following conventions:

- *Convention on Nuclear Safety*
- *Joint Convention on the Safety of Spent Fuel Management and on the Safety of Radioactive Waste Management*
- *Convention on Early Notification of a Nuclear Accident*
- *Convention on Assistance in the Case of a Nuclear Accident or Radiological Emergency*
- *Convention on Physical Protection of Nuclear Material*
- *Vienna Convention on Civil Liability for Nuclear Damage*

The next level of the pyramid is comprised of federal laws. Those laws which regulate f atomic energy use are listed below.

The *Law on the Use of Atomic Energy* establishes:

- Definitions of the main terms used in the law;
- Guidelines and aims of legal regulation of atomic energy use (guaranties of safety in use of atomic energy, availability of information on the atomic energy use, participation of citizens and organizations in discussing State politics, drafts of federal laws and other national legal acts, and also in day-to-day activity, concerning atomic energy use, compensation for radiation-provoked damages);

- Types of installations in the atomic energy use, covered by the law (e.g. nuclear installations, radiation sources, nuclear radioactive material and radioactive waste storage facilities — so the law covers all types of man-made ionizing radiation sources existing in Russia);
- Types of activities in atomic energy use;
- Ownership matters, concerning nuclear installations, nuclear material and radioactive substances;
- General requirements to federal norms and regulations for atomic energy use and establishing their generally binding nature;
- Powers and rights of the authorities and other parties in the field of atomic energy use;
- State regulation in use of atomic energy (in compliance with the Law it is carried out by specially authorized federal authorities, disposing of the power to implement State policy on atomic energy use, to work out and put into practice safety measures in atomic energy use in the regulated companies, to perform State control over and accounting of nuclear material and radioactive substances, to certify an operating organization as being fit to operate a nuclear installation).
- State regulation of safety in atomic energy use (carried out by specially authorized authorities, which perform, in particular, supervision and licensing, ratify federal norms and regulations, carry out inspections, apply administrative sanctions, observe fulfilment of obligations under international treaties, exercise other powers);
- Procedure of siting and construction of atomic energy facilities;
- Legal status of an operating organization (such organization bears, in particular, full responsibility for ensuring safety of an atomic energy facility) and organizations, carrying out work and providing services;
- Special requirements for construction of transport nuclear installations;
- Requirements for handling nuclear material, radioactive substances and waste, requirements for their physical protection;
- Requirements for the SSAC;
- Liability for loss and damages, incurred as a result of atomic energy use.

Radiation safety principles and objectives and dose limits are established by federal *Law on Radiation Safety of the Public* [157]. Three main principles of securing radiation safety, established in Art. 3 of the law are: 1) dose limiting principle; 2) substantiation principle (i.e. benefits from radioactive sources usage shall outweigh possible risk induced by additional exposure); 3) optimization principle (doses and number of irradiated persons shall be as low as it is economically and socially achievable).

Presidential Decrees and Government Ordinances make part of the bylaws and together form the next level of legal regulation.

Federal norms and regulations for atomic energy use, their requirements being — in accordance with Art. 6 of the federal *Law 170-FZ* [156] — binding for everybody, form the next level of legal regulation. At the moment, 85 documents of this type are in force in the Russian Federation (see Figure 22), some of which cover all atomic energy facilities and all kinds of activities in this area while others refer only to specific types of atomic facilities and activities.

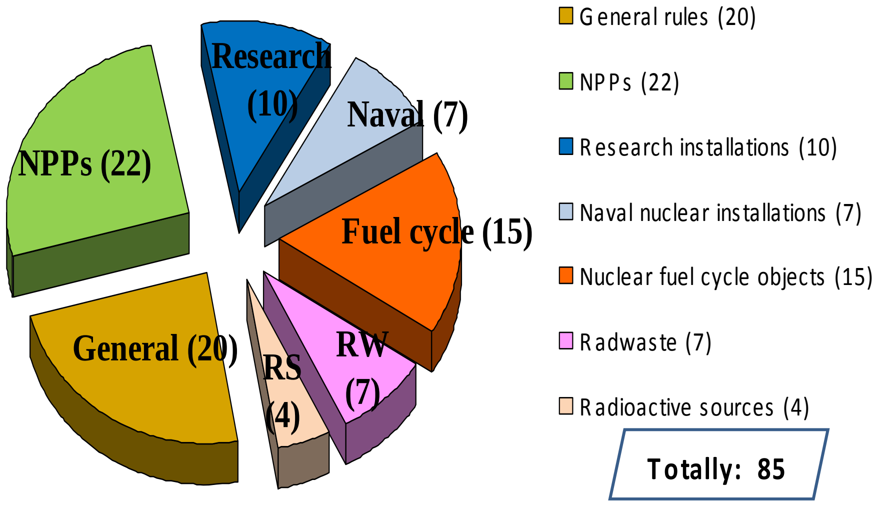

FIG. 22. Present composition of federal norms and regulations for atomic energy use.

Federal sanitary (hygienic) rules also belong to the same hierarchical level as federal norms and regulations but they are approved by a different authority. These rules also have obligatory nature.

Safety guides, not being obligatory, are at the bottom of the pyramid of regulations, governing atomic and radioactive safety. Safety guides describe ways and methods which could be used in order to meet the requirements of federal norms and regulations and which, at the same time, are acceptable to Rostechnadzor. A licence holder is free to use other methods to meet the requirements of federal norms and regulations than those described in the safety guides. In this case the licence holder has to produce substantiation for the chosen methods. Safety guides are not obligatory for use and this fact leaves the licence holder free to implement new, modern methods for safety substantiation. Rostechnadzor, in its turn, may from time to time revise the safety guides, taking experience from new approaches of the licence holder into consideration. Rostechnadzor can make certain safety guides (or parts thereof) obligatory by introducing a respective requirement into the licence validity conditions (attachment to the licence).

In compliance with the Government Ordinance [169], the Russian Federation Ministry for Civil Defence, Emergency Management and Liquidation of the Consequences of Natural Calamities, Ministry of Natural Resources and Ecology of the Russian Federation, Federal Environmental, Industrial and Nuclear Supervision Service, the Federal Service for Supervision in the Area of Protection of Consumer Rights and Human Well-being, and the Federal Medical-Biological Agency (FMBA) take part in the State regulation of safety in the use of atomic energy.

The Ministry of Natural Resources has the authority over:

- Preparation of draft legislation;
- Approval of norms and regulations for atomic energy use;
- Working out requirements for a nomenclature of a set of documents, substantiating safety;
- Controlling and coordinating Rostechnadzor.

Rostechnadzor has the authority over:

- Licensing for atomic energy use;
- Working out norms and regulations for of atomic energy use (submitted for approval to the Ministry);
- Overseeing nuclear and radiation safety and physical defence of the licensed facilities;
- Safety evaluation of the licensed facilities;
- Inspection of activities connected with use of atomic energy[7];
- Control over observation of the requirements, resulting from international obligations of the Russian Federation for atomic energy use;
- Law enforcement for atomic energy use.

Rostechnadzor is responsible not only for the supervision of nuclear and radiation safety, but also for industrial and ecological supervision. The structure of Rostechnadzor and its nuclear division is represented in Figures 23 and 24.

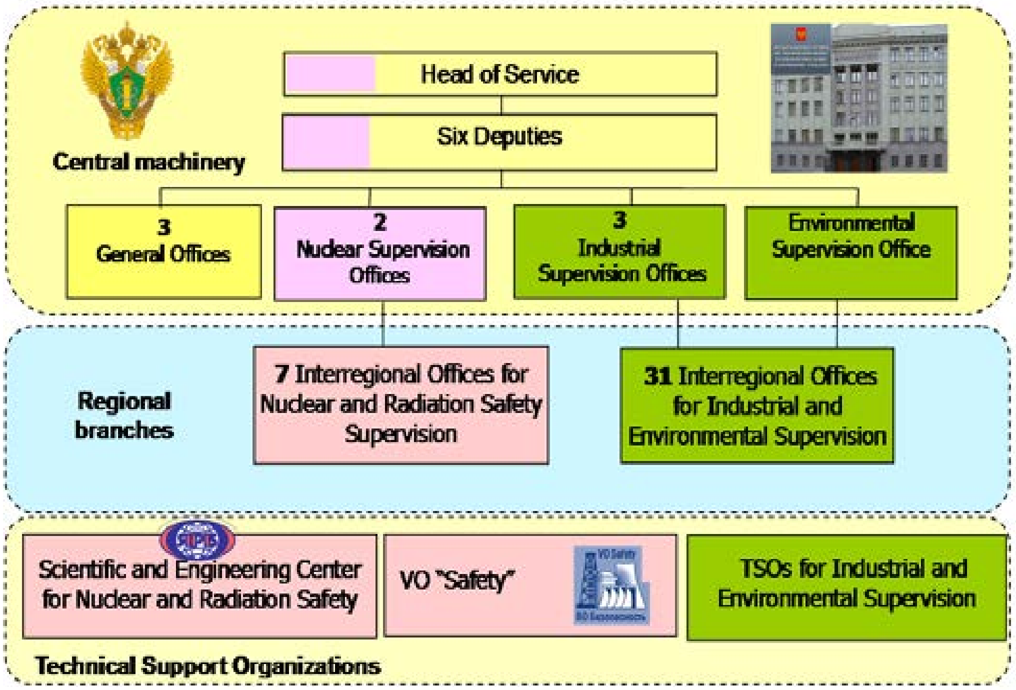

FIG. 23. Structure of federal environmental, industrial and nuclear supervision services (agencies of nuclear supervision are highlighted in pink).

The total number of employees in Rostechnadzor nuclear division is 1250.

The leading organization for providing Rostechnadzor with scientific and engineering support is the Scientific and Engineering Centre for Nuclear and Radiation Safety. It has about 250 employees and its structure is represented in Figure 24. The Centre is a State organization, created as a support for Rostechnadzor.

[7] All the licence holders are subject to Rostechnadzor inspections, which fall into one of the categories – complex, targeted and operational. A number of inspections is rather high. For example, for an NPP with a VVER-type reactor, a number of Rostechnadzor inspection is, on average, about 400 per NPP.

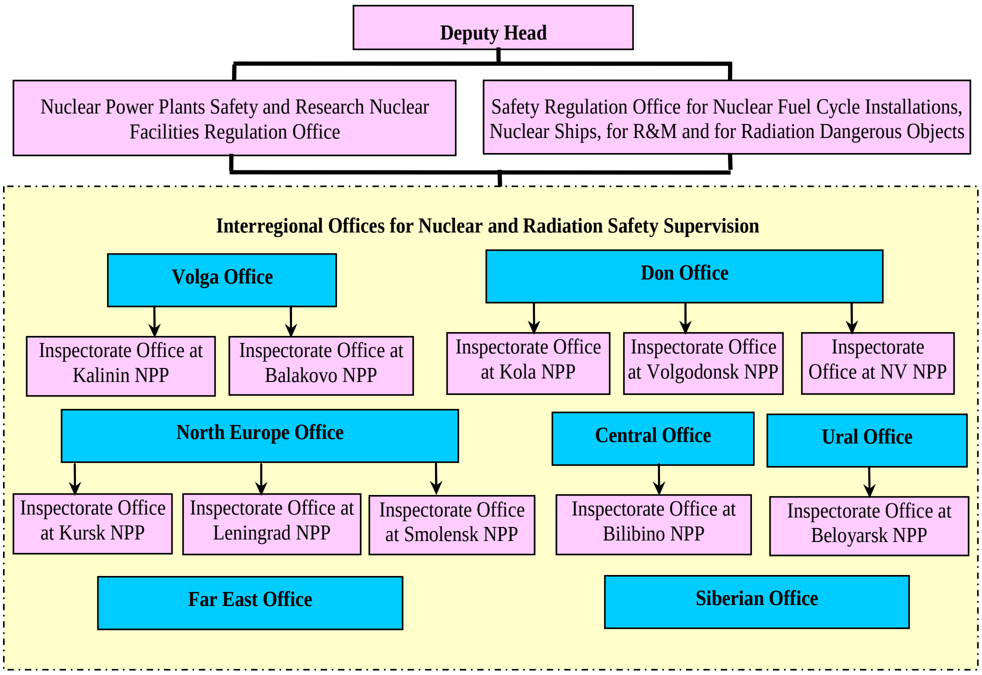

FIG. 24. Structure of Nuclear Division of Rostechnadzor.

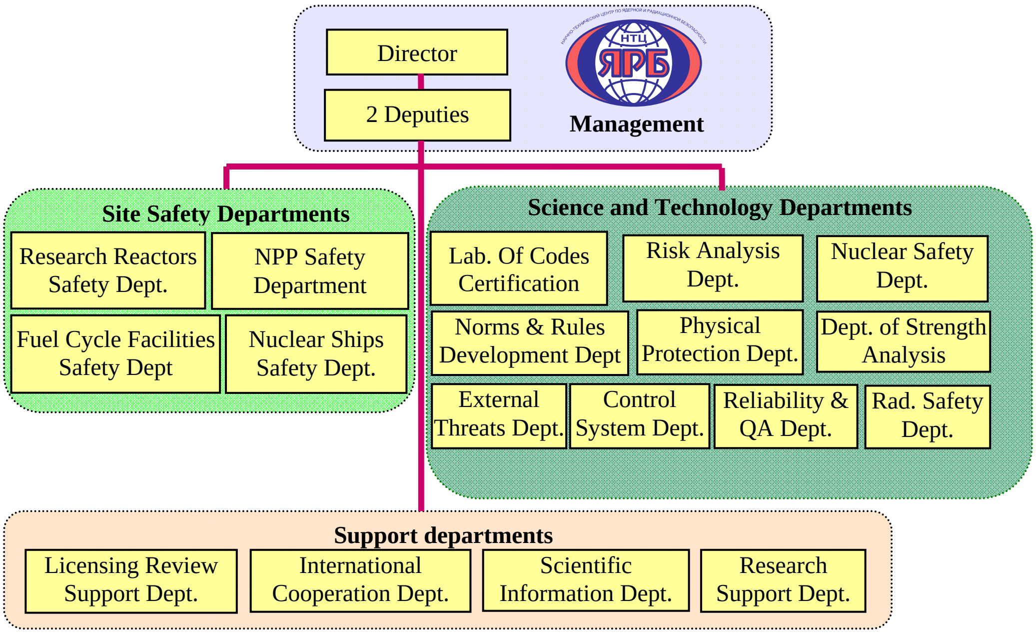

FIG. 25. Structure of Scientific and Engineering Centre for Nuclear and Radiation Safety.

Rostechnadzor is provided with technical support from the Scientific and Engineering Centre for Nuclear and Radiation Safety in:

- Evaluation of current operational safety level of NPP (and other atomic energy facilities);
- Working out drafts of regulatory documents;
- Expertise of safety substantiating of NPP (and other atomic energy facilities);
- Research in substantiating criteria of nuclear and radioactive safety;
- Further professional training of Rostechnadzor inspectors;
- Software appraisal;
- Publishing activities.

The Ministry for Emergency of the Russian Federation supervises fire security (including inspections, examination of substantiations of safety and reports, law enforcement) and does not carry out licensing for the use of nuclear energy. Rospotrebnadzor and the FMBA exercise control over sanitary aspects of radiation safety, coordinate, in accordance with federal *Law 170-FZ* projects for sanitary protection zones of NPPs and other nuclear facilities, approve federal sanitary norms of general character and do not carry out licensing in use of nuclear energy.

So, legislative framework in the Russian Federation is established in accordance with contemporary international standards. It covers:

- The regulatory body with its functions, such as licensing , inspection and enforcement [156, 170];
- Radiation protection [156, 157];
- Environmental protection [181];
- Safety of nuclear installations, including emergency preparedness and response, use of sources of radiation and radioactive material, transport of nuclear and radioactive material, management of radioactive waste and spent fuel, and mining and milling [156];
- Nuclear liability and coverage [156];
- Control over export and import of nuclear material [156];
- Safeguards in respect of nuclear material, ensuring non-proliferation, security and physical protection of nuclear material and nuclear facilities [156].

Thereby the nuclear legislative framework in the Russian Federation complies with evaluation parameter EP1.1.1 of [175].

The national nuclear legislative framework can be assessed as satisfactory since:

- The legislation clearly determines that public health, safety, security and the environment are overriding considerations in the use of nuclear energy [156],
- No significant gaps can be found in the legal structure regarding the treatment of nuclear-related activities or material, both those currently being conducted or used and those that could reasonably be expected to appear in the future;
- The main terms used in the legislation have clear and consistent definitions in the statutory documents, e.g. [156, 157, 176];
- Institutional responsibilities for regulating nuclear-related activities are generally clear and consistent, permitting efficient regulation e.g. [170]. (At the same time, some difficulties still exist in establishing intercommunications between various regulating authorities, so this aspect can be improved);
- The present regulatory system does not involve unnecessary financial or administrative burdens on regulated entities or licensees (licensee fee has symbolic size, time for licence application treatment is comparable with other countries' practice, inspection activities and law-enforcement practice do not cause significant disruption of normal operation).

So, general compliance with evaluation parameter EP1.1.2 of [175] can be acknowledged.

Since all the above mentioned international treaties form part of the Russian legislative framework, a conclusion can be drawn that evaluation parameter EP1.1.3 of [175] has also been met.

It can also be concluded that federal norms and regulations and federal sanitary rules accompanied by non-obligatory documents of a lower level, such as regulatory guides, form a comprehensive set of legislative requirements which account for all the main aspects of international standards. Nevertheless, minor gaps exist, such as a lack of:

- Special requirements and guides on computerized control system design and operation;
- Detailed regulatory requirements or guidelines on operational and emergency response documents (such as technical specifications, BDBA management guidelines) development.

General compliance with evaluation parameter EP1.1.4 of [175] can be acknowledged.

In accordance with Art.2 of the *Convention on Nuclear Safety* [155], Rostechnadzor should be recognized as Russian Regulatory Body and has the necessary independence from the supervised entities to implement regulation effectively. For this it has all the necessary conditions, such as comprehensive legislative framework, sufficient funding, competent staff, effective operational event reporting system and also necessary technical support. Nevertheless, some areas for improvement can be pointed out – e.g. number of competent employees and financial resources available may become insufficient shortly, bearing in mind national plans for nuclear energy expansion.

So, evaluation parameter EP1.2.1 of [175] has generally been met, but some predicaments may be experienced in the future.

Russian regulatory framework fully satisfies evaluation parameter EP1.2.2 of Ref. [175] since:

- Regulatory standards, codes and criteria, and also guidelines for the design, construction, operation and decommissioning of nuclear facilities, including radioactive waste management, are established;
- Review and evaluation of licensing documents, such as the physical protection plan or SAR, are conducted by the regulatory body;
- Licensing of construction, operation, and decommissioning of nuclear facilities is fulfilled by the regulatory body;
- Inspections, reviews and enforcement activities to ensure compliance with established rules and regulations are performed by the regulatory body;
- Information about safety and security aspects of facilities and activities is regularly distributed to the public, the media and the interested parties;
- Coordination with other regulatory bodies exists.

The Russian regulatory framework generally satisfies evaluation parameters EP1.2.3, EP1.2.4, EP1.2.5 of [175] — as confirmed by the IRRS mission (November 2009), whose final report to be issued soon. For details see also [177]).

Appendix III

OVERVIEW OF RUSSIAN FEDERATION NUCLEAR POWER LICENSING REGULATIONS AND GUIDELINES ON FULFILLING THEM

In compliance with Art. 23, 24 of the *Law on the Use of Atomic Energy* [156], licensing of the activities of atomic energy use in the Russian Federation is one of the functions of specifically authorized State authorities, namely, regulatory agencies for safe use of atomic energy.

In compliance with Government Ordinance [169], the Russian Federation Ministry for Civil Defence, Emergency Management and Liquidation of the Consequences of Natural Calamities, Ministry of Natural Resources and Ecology of the Russian Federation, Federal Environmental, Industrial and Nuclear Supervision Service, the Federal Service for Supervision in the Area of Protection of Consumer Rights and Human Well-being, and the FMBA take part in the State regulation of safety in the use of atomic energy.

Nevertheless, according to the Government Ordinance [170], licensing of activities for atomic energy use is carried out by only one of the aforementioned authorities, namely, Federal Environmental, Industrial and Nuclear Supervision Service.

Thus, in the Russian Federation, the functions of a regulatory body (the way this term is defined in Art. 2 of the *Convention on Nuclear Safety* [155]) are carried out by the Federal Environmental, Industrial and Nuclear Supervision Service (Rostechnadzor).

Provisions on licensing of activities for atomic energy use are established by the Government Ordinance [171]. In accordance with [171], the types of activities for atomic energy use subject to licensing are:

- Siting, construction, operation and decommissioning of nuclear installations, and storage of radiation sources, nuclear/radioactive material and radioactive waste;
- Handling nuclear material and radioactive substances, including during exploration and production of uranium ore, during production, use, processing, transportation and storage of nuclear material and radioactive substances[8];
- Handling radioactive waste during its storage, processing, transportation and burial[9];
- Use of nuclear/radioactive material in carrying out research and development activities[10];
- Designing and construction of nuclear installations and storage facilities for radiation sources, nuclear material, radioactive substances and radioactive waste[11];
- Designing and construction of equipment for nuclear installations and storage facilities for radiation sources, nuclear material, radioactive substances and radioactive waste[12];
- Assessment of project, engineering and production documentation, of documents justifying nuclear and radiation safety of nuclear installations, radiation sources,

[8] licence-holders are operating organizations (the term ‘operating organization’ is defined in Art. 34 of the Federal Law 170-FZ [1]. With reference to the nuclear plants of the Russian Federation, there is only one operating organization — Rosenergoatom Concern).

[9] licence-holders are operating organizations.

[10] licence-holders are operating organizations.

[11] licence-holders are research and design organizations (such as, for example, design institute “Atomenergoproekt” or “Gidropress” Design Bureau (OKB).

[12] licence-holders are organizations, designing and constructing equipment for the nuclear power facilities.

nuclear/radioactive material and radioactive waste storage facilities , and also of handling nuclear material and radioactive substances and radioactive waste[13].

As is clear from the aforesaid, Rostechnadzor issues licences to the operating organizations, and to the organizations performing work and providing services for nuclear energy use (in particular, services of design, engineering and production of equipment), and also to specialized organizations.

In [171] it is stated that a licence is issued for a period not less than three years (a licence can be issued for up to three years on request of the applicant). In reality, in the Russian Federation licences for operating NPP units are issued for a period of up to 10 years.

Provisions on licensing, established by the Government Ordinance [171], state that the licensing procedure includes:

- Examination of the licence application and preliminary check of all the documentation, submitted in order to obtain a licence;
- Thorough review of all the documentation, submitted in order to obtain a licence, including a set of documents, substantiating nuclear and radiation safety of the nuclear installation; and storage facilities for radiation sources, nuclear material, radioactive substances and radioactive waste; and/or the declared activity14;
- Decision is made whether to grant a licence or to turn the application down;
- Granting a licence and stating its validity conditions;
- Following the licence granted by way of performing inspections in order to control how the licence validity conditions are observed, and also by introducing the necessary changes into the validity conditions;
- Change (prolongation) of the licence period, suspension or termination (revocation) of a licence.

In accordance with [171], an applicant for a licence is to submit documentation to Rostechnadzor comprising:

- An application for a licence with the name of the organization, form of incorporation, registered address, current account and the name of the bank, type of activity, operating facility and licence period;
- A copy of the articles of association;
- A copy of a certificate of record in the unified state register of legal entities;
- A registration certificate from a tax authority;
- A copy of a certificate for the right of the applicant to own and to make use of nuclear material, nuclear installations, radiation sources, storage facilities, radioactive substances and waste;
- Copies of decisions taken by the duly authorized federal, regional or local authorities on siting, construction or decommissioning of nuclear installations, radiation sources or storage facilities;

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[13] licence-holders are expert organizations (such as, for example, “Scientific and Engineering Centre for Nuclear and Radiation Safety”).

[14] Activity, included in one of the aforementioned types of activities.

- Three sets of documents substantiating nuclear and radiation safety of the nuclear installation, radiation source, storage facilities and/or the declared activity (description of requirements for the structure of the set and for the contents of the documents follow);
- Certification of payment of the State duty for licence application processing.

If the applicant is an operating organization, submission [171] is required, apart from those documents listed above, of:

- A certificate from a federal body of executive power which performs State management of atomic energy use [15] stating that the applicant is found qualified to operate the nuclear installation, radiation source or storage facility and to carry out, by its own means or subcontracting other organizations, activities of siting, design, construction, operation and decommissioning of the nuclear installation, radiation source or storage facility, and also handling nuclear material and radioactive substances;
- A document classifying the installation where the declared activity is to be performed in one of the categories (i.e.: nuclear installations or storage facilities for radiation sources, nuclear material, radioactive substances or radioactive waste) provided for by Art.3 of the federal law [156];
- State environmental expert review[16;]
- A copy of a certificate of hygiene or any other authorization document from the sanitary and epidemiological inspection bodies for the right to operate radiation sources;
- Documents, confirming that the applicant disposes of financial security for civil liability for loss and damage, caused by radiation exposure, as provided for by the applicable law of the Russian Federation;
- Documents confirming a possibility of further transfer for burial of operational or interim radioactive waste;
- A report on operational fire protection of an atomic energy facility — for NPPs and other facilities, defined by federal norms and regulations for atomic energy use;
- Documents, confirming that the applicant disposes of sources of financing work on decommissioning of nuclear installations, radiation sources or storage facilities, including a special fund for financing costs of decommissioning of the said facilities and for financing research and development of verification and safety improving of these facilities.

Provision [171] forbids requiring the applicant to provide any documents, not directly specified in [171].

According to the provisions [171], a period of review of an application by Rostechnadzor must not exceed 15 days from the date of registration of the documents submitted for obtaining a licence, including preliminary check for completeness of a set of documents and their conformity to the established rules of document presentation.

On the basis of the results of this preliminary check, Rostechnadzor decides whether to accept for review the documents, submitted for obtaining a licence, or to decline to review them. The applicant is notified in writing of the decision taken on the results of the preliminary check

[15] Such a certificate is required in accordance with Art. 34 of the Federal Law 170-FZ [1]. Federal Body of Executive Power, which Perform State Management of Atomic Energy Use in respect of NPP is the Federal Atomic Energy Agency Rosatom.

[16] State environmental expert review is carried out by Rostechnadzor in compliance with Laws [7] and [9].

(within three days of the date of confirmation of a corresponding decision). In case of a decline to review the documents, submitted for obtaining a licence, a justified reason for such a rejection is indicated in the notes.

On affirmation of accepting the documents submitted for obtaining a licence for review, Rostechnadzor carries out thorough review of their compliance with the established requirements, reliability of the information, and analysis of a set of documents, substantiating nuclear and radiation safety of the nuclear installation, radiation source, storage facility and/or the declared activity.

According to [171], in the process of a review of a set of documents substantiating nuclear and radiation safety of a nuclear installation, radiation source, storage facility and/or the declared activity, Rostechnadzor is bound to analyse:

- Compliance of project, constructive and process solutions with the federal norms and regulations for atomic energy use, correspondence of operating personnel's qualifications to the accepted requirements, and conditions for keeping it on the required level, and also availability and correspondence to the accepted requirements of a system of collection, storage, processing and burial of radioactive waste in the course of the declared activity;
- A completeness of a system of technological and organizational measures of nuclear and radiation safety in performing the declared activity;
- Availability of appropriate conditions of storage and management of accounting and control over nuclear material, radioactive substances, providing physical defence of nuclear installations, radiation sources, storage facilities, nuclear material and radioactive substances, action plans for defence of the operating personnel of the atomic energy facility and of the civilian population in case of a nuclear emergency and emergency preparedness, and also systems of quality assurance and the necessary engineering and technical support of the declared activity;
- Ability of the applicant to guarantee safe termination of the declared activity and decommissioning of a nuclear installation, and also availability of the corresponding project documentation.

In reviewing the documents submitted for obtaining a licence, Rostechnadzor organizes:

- Information validity check of the documentation, submitted by the applicant (if necessary, on-site inspections of the applicant's facilities may be carried out);
- Expertise of the documents, substantiating nuclear and radiation safety of a nuclear installation, radiation source, storage facility and/or the declared activity. If necessary, on-site inspections of the applicant's facilities may be carried out (bringing in an organization holding a licence for such expertise[17], and, if need may be, cooperation with the applicant for the scope of elimination of the identified deficiencies is organized).

The inspection procedure for checking the reliability of the information contained in the documentation submitted to obtain a licence, the expertise of the documents substantiating nuclear and radiation safety of a nuclear installation, radiation source, storage facility or the declared activity, and for performing inspections is established in the Administrative Procedure [178] (see below).

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[17] As a matter of practice, in reviewing applications for siting, construction, operation and decommissioning of NPPs (as well as applications for introducing changes into the previously granted atomic power station licenses) expertise is carried out by the same organization (although this is not a regulation requirement), namely - Scientific and Engineering Centre for Nuclear and Radiation Safety.

Provision [171] establishes that the decision to grant or to refuse a licence is taken by the duly authorized Rostechnadzor officers on the grounds of a) results of checking reliability of information, contained in the documentation, submitted to obtain a licence, b) results of the expertise of documents substantiating nuclear and radiation safety of a nuclear installation, radiation source, storage facility and/or the declared activity, c) results of inspections.

Decision to grant or to refuse a licence is taken within the period of not more than 30 days of the date of ending of expertise of the documents, substantiating nuclear and radiation safety of a nuclear installation, radiation source, storage facility and/or the declared activity (time limits for carrying out such an expertise are set in the Administrative Procedure [178] –see below).

Provision [171] establishes that in case of refusal to grant a licence, a notification to the applicant must contain a justified reason for refusal, which is to be:

- Unreliable or distorted information in the documents submitted to obtain a licence;
- Expertise that has ascertained insufficient substantiation of nuclear and radiation safety of a nuclear installation, radiation source, storage facility and/or the declared activity; or
- Inconsistency between the declared activity and requirements of nuclear and radiation safety.

In accordance with [171], the licence is issued by Rostechnadzor within the period of 20 days of the date of the decision to grant it.

According to the provision [171], licence validity conditions make the integral part of a licence and those include Rostechnadzor requirements for safety of the licenced type of activity in consideration of its specific features. If necessary, conditions of switching from one stage of work to the other are included in the licence and, if the licenced activity presupposes handling nuclear material — a requirement for the licence holder to have already obtained by the beginning of such activity a contract for transfer to the licence holder of nuclear material for use, stipulated with an authority, specifically authorized by the government.

As a rule, Rostechnadzor formulates licence validity conditions in such a way that documentation submitted by the applicant substantiating nuclear and radiation safety (e.g. safety report, technical specifications, accident-prevention regulations), is to be kept in a state of full conformity with the atomic energy facility, and any changes in the said documentation are allowed only on submission to the Rostechnadzor of an appropriate application with enclosure of the necessary safety justifications and on obtaining changes in the licence validity conditions.[18]

Provision [171] also presupposes a procedure of revocation of a licence. Rostechnadzor can deprive the licence holder of the right to perform a certain activity, provided for in the licence, by suspending or terminating a licence. According to [171], grounds for depriving a licence holder of the right to perform a certain activity provided for in the licence could be:

- Breach by a licence holder of federal laws and other regulatory legal acts of the Russian Federation on atomic energy use;
- Unreliable information in the documents submitted to obtain a licence;
- Breach by a licence holder of licence validity conditions;

[18] It is the duty of the licence holder, stated in Provision [5] as well, to inform Rostechnadzor of new data or of changes in the information, provided at the license application stage, which has anything to do with the safety of the licensed type of activity.

- Non-fulfilment by a licence holder of directions of the State authorities for safety regulation of the atomic energy use;
- Non-fulfilment by a licence holder of directions or orders of the State authorities or suspension of the licence holder's activity by the State authorities in compliance with the Legislation of the Russian Federation;
- Request from the licence holder.

Rostechnadzor's decision to suspend or terminate a licence is communicated to the licence holder in writing, not later than the date from which licence becomes suspended or terminated. Within three days from the date of the decision to suspend or terminate a licence, Rostechnadzor is to inform the corresponding executive body which certified the licence holder's right to own or to use nuclear material, nuclear installation, radiation source, storage facility, radioactive substance or radioactive waste. If a licence holder is a an operating organization, Rostechnadzor is to inform the regulatory agency for atomic energy use which has recognized this organization as fit to operate a nuclear installation, radiation source, or a storage facility and to perform, alone or with participation of other organizations, activities of siting, designing, construction, operation and decommissioning of the nuclear installation, radiation source or storage facility, and also handling nuclear material and radioactive substances.

Provision [171] establishes that in case of a licence being suspended, the licence holder is to stop performing the activity for which the licence is granted. If the circumstances leading to suspension of a licence are to change, the licence could be renewed. If a licence is revoked, the licence holder is to stop performing the activity for which the licence is granted and to return the licence to Rostechnadzor.

To develop provisions on licensing [171], the Ministry of Natural Resources and Ecology of the Russian Federation in 2008 approved the *Administrative procedure for carrying out, by the Federal Environmental, Industrial and Nuclear Supervision Service, a State function of licensing of activities in the field of nuclear energy use* [178].

This document contains the following sections:

I. General provisions

II. Requirements for the procedure of exercising State function of licensing of activities for atomic energy use

III. Administrative procedures

IV. Procedures and forms of control for exercising State functions

V. Procedure for filing an appeal against actions (failure to act) of a public officer, and against a decision taken by this person at exercising a State function of licensing of activities for atomic energy use.

Appendix 1. Separation of powers between Rostechnadzor central office and its regional offices in performing State duty of licensing activities for atomic energy use and maximum period of time for review of the documents, submitted to obtain a licence.

Appendix 2. List of constituent entities of the Russian Federation, on the territory of which Rostechnadzor regional departments exercise a State function of licensing of activities for atomic energy use.

Appendix 3. Summarized information on the state of licence application processing (a form).

Appendix 4. Requirements for the nomenclature of a set of documents, substantiating nuclear and radiation safety of a nuclear installation, radiation source, storage facility and/or the declared activity, established by the Federal Environmental, Industrial and Nuclear Supervision Service in accordance with Provision [171]

Appendix 5. Block diagram of performing an administrative procedure of reviewing an application for a licence and carrying out a preliminary documentation check.

Appendix 6 Block diagram of performing an administrative procedure of reviewing the documents, submitted to obtain a licence.

Appendix 7 Sample copy of a decision to grant licence (refusal to grant licence).

Appendix 8 licence sample copy.

Appendix 9 Block diagram of performing an administrative procedure of making a decision to grant or to refuse a licence.

Appendix 10 Block diagram of performing an administrative procedure of issuing a licence with establishing its validity conditions.

Appendix 11 Block diagram of performing an administrative procedure of following an issued licence by carrying out an inspection to control the observance of the licence validity conditions.

Appendix 12 Sample copy of a decision to introduce changes (refusal to introduce changes) into the licence validity conditions.

Appendix 13 Sample copy of changes in the licence validity conditions.

Appendix 14 Block diagram of performing an administrative procedure of changing the licence validity conditions.

Appendix 15 Sample copy of a decision about suspension or termination (revocation) of a licence.

Appendix 16 Block diagram of performing an administrative procedure of suspension or termination (revocation) of a licence.

Appendix 17 Sample copy of a decision to renew a licence.

Appendix 18 Block diagram of performing an administrative procedure of renewing licence validity.

Appendix 19 Block diagram of performing an administrative procedure of reissuing a licence.

Section I, General provisions [178], contains a list of regulatory documents, on the authority and inclusive of which Rostechnadzor carries out licensing, and also separation of powers among the central Rostechnadzor administrative office and regional offices in the process of licensing (this separation is represented in Attachment 1 to [178]).

Section II, Requirements for the procedure of exercising State function of licensing of activities in the field of atomic energy use [178], contains:

- Addresses for submitting applications and attendant documentation for licences, opening days and hours of Rostechnadzor departments;
- A requirement of information on the progress of licensing being available on the Internet;
- Rostechnadzor consultancy methods in the matters of licensing (personal meetings, by ordinary post, by e-mail, by means of setting up information stands in Rostechnadzor offices);

- Time limits for exercising State function of licensing and its constituent procedures;
- Requirements for the places of exercising State function of licensing.

Section III, Administrative Procedures [178], establishes a nomenclature of procedures in the framework of exercising State function of licensing and a way of implementation for each of them. The following matters are being regulated: who is held responsible for implementation of a procedure, which conditions are to be fulfilled before the beginning of the procedure, possible results of the procedure and what the criteria for achieving these results are, block diagram of performing a corresponding procedure (represented in Attachments to [178]).

In particular, in this section [178], rules are established for the expertise procedure of documentation substantiating safety, comprising:

- Expertise of documentation, submitted to obtain a licence is carried out by expert organizations, holding a Rostechnadzor licence for performing expertise. Information on expert organizations, holding appropriate Rostechnadzor licences can be found on the internet site www.gosnadzor.ru;
- In the framework of appropriate resources from the State federal budget, Rostechnadzor is acting in the capacity of a State customer for the safety expertise of an atomic energy facility and is stipulating a State contract in accordance with the regulations, stated in [179]
- Expertise of documentation, submitted by the applicant, is carried out in accordance with performance specifications for carrying out of an expertise, approved by a duly authorized representative of Rostechnadzor;
- Development and approval of performance specifications for carrying out of an expertise are put into effect within 30 days of the applicant's documentation being submitted to the responsible department. Said performance specifications include expertise issue-related questions and time limits of it being carried out;
- Expertise time limits are defined (in accordance with Attachment 1 to [178]) depending on the documentation volume, submitted to obtain a licence, on the potential nuclear and radiation hazard of the operational facility for the declared type of activity;
- Responsible department within three days of approval of the performance specifications for carrying out of an expertise, forwards it to the expert organization of the applicant's choice (or to the expert organization with which Rostechnadzor has stipulated a State contract) together with the applicant's set of documents, substantiating nuclear and radiation safety;
- If, in the course of an expertise, questions on substantiating nuclear and radiation safety in the documentation, submitted by the applicant, have arisen, expert organization is entitled to discuss the said questions with the applicant;
- At the conclusion of expertise, expert organization draws an expert conclusion on substantiation of nuclear and radiation safety of the nuclear installation, radiation source, storage facility and/or the declared activity, which is approved by the Head of the expert organization;
- Expert organization forwards the approved expert conclusion to the responsible department, which, in its turn, within a time limit not exceeding 20 days evaluates it from the point of view of correspondence to the requirements of the performance specifications for carrying out of an expertise and notifies the expert organization in writing whether expert conclusion has been accepted or not;

- If expert conclusion is not accepted as not corresponding to the performance specifications for carrying out of an expertise, the responsible department returns expert conclusion with a cover letter, stating the inconsistencies, to the expert organization for follow-up revision.

Section IV, Procedures and forms of control for exercising State function [178], define procedures of carrying out current control on exercising of State function and for the decision-making process by State civil employees of Rostechnadzor.

In Section V [178], a procedure is established for filing an appeal against actions (failure to act) of a public officers of Rostechnadzor, and also against a decision taken by them at exercising a State function of licensing of activities for atomic energy use.

Rostekhnadzor in accordance with [170], besides being a licensing authority, is also authorized to grant work licences for atomic energy to nuclear facility staff, taking guidance in the list of job positions endorsed by the Russian Federation Government [180].

Hereby, licensing procedure for atomic energy is established legally, is regulated in detail and corresponds to international standards requirements.

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ABBREVIATIONS

AES-2006	modern NPP design based on VVER (PWR) technology
ALARA	as low as reasonably achievable
ALARP	as low as reasonably practicable
BDBA	beyond design basis accident
BISS	Institute of Social Science [of Belarus]
bln	billion
CEEBS	central eastern European and Baltic States
CHP	combined heat and power
CIS	Commonwealth of Independent States (of the former Soviet Union)
CPS	control and protection system
C/S	containment/surveillance
CTBT	Comprehensive Nuclear Test Ban Treaty
DBA	design basis accident
DBT	design basis threat
DFDW	disposal facilities for decontamination waste of Chernobyl origin [in Belarus]
ECCS	emergency core cooling system
EFWS	emergency feedwater system
FA	nuclear fuel assembly
FMBA	Federal Medical-Biological Agency
GDP	gross domestic product
HL	half-life of isotope
HLW	high level radioactive waste
HM	heavy metal
HW-Div	hardwired diversity
I&C	instrumentation and control
ILW	intermediate level radioactive waste
IPPAS	International Physical Protection Advisory Service
IRWST	in-containment refuelling water storage tank
JNA	residual heat removal system
JND	high-head safety injection system
JNG	low-head safety injection system
LLW	low level radioactive waste
LOCA	loss of coolant accident
LUEC	levelized unit energy cost

LWR	light water reactor
MAC	maximum allowable concentration
MSVA	minimal significant volume activity
MUF	material unaccounted for
NAS	National Academy of Science [of Belarus]
NES	nuclear energy system
NPP	nuclear power plant
NPT	Treaty on the Non-Proliferation of Nuclear Weapons
PGA	peak ground acceleration
PHRS [C]	passive residual heat removal system [of the containment]
PP	power plant
PPS	physical protection system
PR	proliferation resistance
PSA	probabilistic safety analysis
PWR	pressurized water reactor
RD&D	research, development and demonstration
RPV	reactor pressure vessel
RW	radioactive waste
SARCoN	Systematic Assessment of Regulatory Competence Needs
SG	steam generator
SOSNY	State Joint Institute for Power and Nuclear Research
SPO	specialized organization for radioactive waste management
SQ	significant quantity of nuclear material
SSAC	State system of accounting for and control of nuclear material
STUK	Radiation and Nuclear Safety Authority of Finland
tce	tonnes of coal equivalent

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