STATE NUCLEAR REGULATORY INSPECTORATE OF UKRAINE

NATIONAL ASSESSMENT REPORT

TOPICAL PEER REVIEW 2023

Fire Protection

2023

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INTRODUCTION

According to Article 8e of Council Directive 2014/87/Euratom of 8 July 2014, amending Directive 2009/71/Euratom establishing a Community framework for the nuclear safety of nuclear installations (hereinafter the Nuclear Safety Directive), Member States should undertake, on a coordinated basis, topical peer reviews (TPRs). The first topical peer review to start in 2017, and for subsequent topical peer reviews to take place at least every six years.

Member States shall ensure that, on a coordinated basis:

(a) a national assessment is performed, based on a specific topic related to nuclear safety of the relevant nuclear installations on their territory;

(b) all other Member States, and the Commission as observer, are invited to peer review the national assessment referred to in point (a)

(c) appropriate follow-up measures are taken of relevant findings resulting from the peer review process;

(d) relevant reports are published on the above mentioned process and its main outcome when results are available.

The purpose of topical peer reviews is to provide a mechanism for EU Member States to examine topics of importance to nuclear safety, to exchange experience and to identify opportunities to strengthen nuclear safety.

In November 2020, at its 41st Plenary Meeting, ENSREG decided that the topic of the second Topical Peer Review (TPR II) would be “Fire Protection”.

TPR II on fire protection will:

• Enable participating countries to review their provisions for fire protection to identify strengths and weaknesses;

• Undertake a European peer review to share operating experience and identify findings: common issues or challenges at EU-level, good practices, areas of good performance and areas for improvement;

• Provide an open and transparent framework for participating countries to develop appropriate follow-up measures to address areas for improvement.

Participation in the European TPRs is very important for Ukraine, as it enables direct involvement in the process of exchanging experience and identifying opportunities to enhance nuclear safety in Europe. This, in turn, will contribute to elevating the safety level of Ukraine’s nuclear facilities to align with the best European standards and practices. Consequently, Ukraine joined the first TPR on the topic “Aging Management”, accepted the proposal of the Chair of ENSREG to participate in the second TPR on the topic “Fire Protection”, and aims to engage in further TPRs on a regular basis.

The National Assessment Report of Ukraine on fire protection has been developed according to the structure and contents defined by the WENRA Technical Specification for the National Assessment Reports [1].

ABBREVIATIONS

AFAS	Automatic Fire Alarm System
AFEC	Automatic Fire-Extinguishing Control
AFEI	Automatic Fire-Extinguishing Installation
AGFES	Automatic Gas Fire-Extinguishing System of Module Type
ALT	Automatic Load Transfer
ARMS	Automatic Radiation Monitoring System
C(I)SIP	Comprehensive (Integrated) Safety Improvement Program
CDF	Core Damage Frequency
ChNPP	Chornobyl Nuclear Power Plant
CPS	Control and Protection System
CSFSF	Centralized Spent Fuel Storage Facility
CSM	Concrete Storage Module
DC	Deaerator Compartment
DGS	Diesel Generator Station
DSFSF	Dry Spent Fuel Storage Facility
DSTU	State Standard of Ukraine
EAF	Engineered Automation Feature
ECR	Emergency Control Room
EDDFP	Emergency Diesel-Driven Fire Pump
Energoatom	National Nuclear Energy Generating Company “Energoatom”
ENSREG	European Nuclear Safety Regulators Group
EPRI	Electric Power Research Institute
FAAS	Fire Automatics and Alarm System
FACP	Fire Alarm Control Panel
FAS	Fire Alarm System
FDF	Fuel Damage Frequency
FFPS	Foam Firefighting Pumping Station
FHC	Fire Hose Cabinet
FPA	Fire Protection Automatics
FRV	Fire Retardant Valve
FS	Flammable Substances
FSD DO&FSS	Fire Safety Department – structural unit of the Departmental Oversight and Fire Safety Service
GFES	Gas Fire Extinguishing System
HFL	Highly Flammable Liquids
I&C	Instrumentation and Control System
IAEA	International Atomic Energy Agency
IE	Initiating Event
ISF	Interim Spent Fuel Storage Facility
KhNPP	Khmelnytsky Nuclear Power Plant
LERF	Large Early Release Frequency
LPSS	Low Power and Shutdown States
MCP	Main Coolant Pump

MCR	Main Control Room
NAR	National Assessment Report
NASU NRI	Nuclear Research Institute of the National Academy of Sciences of Ukraine
NFEI	Nonautomatic Gas Fire-Extinguishing Installation
NFME	Neutron Flux Monitoring Equipment
NPP	Nuclear Power Plant
NSW	Nonessential Service Water
PFFM	Primary Firefighting Means
PFPS	Production and Firefighting Pumping Station
PNPP	Pivdennoukrainsk Nuclear Power Plant
PSA	Probabilistic Safety Analysis
PUE	Rules for Design of Electrical Installations
PVDE	Power Valve Distribution Equipment
RC	Reactor Compartment
RNPP	Rivne Nuclear Power Plant
RVPK	Graphite-Moderated Channel-Type Reactor
SB	Special Building
SCFR	Self-Sustained Chain Fission Reaction
SDG	Standby Diesel Generators
SES	Special Equipment Set
SESU	State Emergency Service of Ukraine
SFP	Spent Fuel Pool
SFPS	Spent Fuel Processing Facility
SFRT	State Fire Rescue Team
SFRU	State Fire Rescue Unit
SS	Safety System
SSE ChNPP	State Specialized Enterprise “Chornobyl NPP”
TAMD	Thermal Automation and Measurement Department
TG	Turbine Generator
TPR	Topical Peer Review
TUCD	Thermal and Underground Communications Department
UPS	Unit Pumping Station
VACD	Ventilation and Air Conditioning Department
VVER	Water-Cooled Water-Moderated Power Reactor
VVR-M	Upgraded Water-Cooled Water-Moderated Research Reactor
WANO	World Association of Nuclear Operators
WENRA	Western European Nuclear Regulators Association
ZNPP	Zaporizhzhia Nuclear Power Plant

I. GENERAL INFORMATION

Ukraine is a country with a developed nuclear industry. At present, the following nuclear facilities at various life stages are located in Ukraine (see Figure 1.1):

– 15 power units on four sites of nuclear power plants (NPPs) with VVER reactors;
– 2 research reactors and 1 research nuclear facility;
– dry and wet spent nuclear fuel storage facilities.

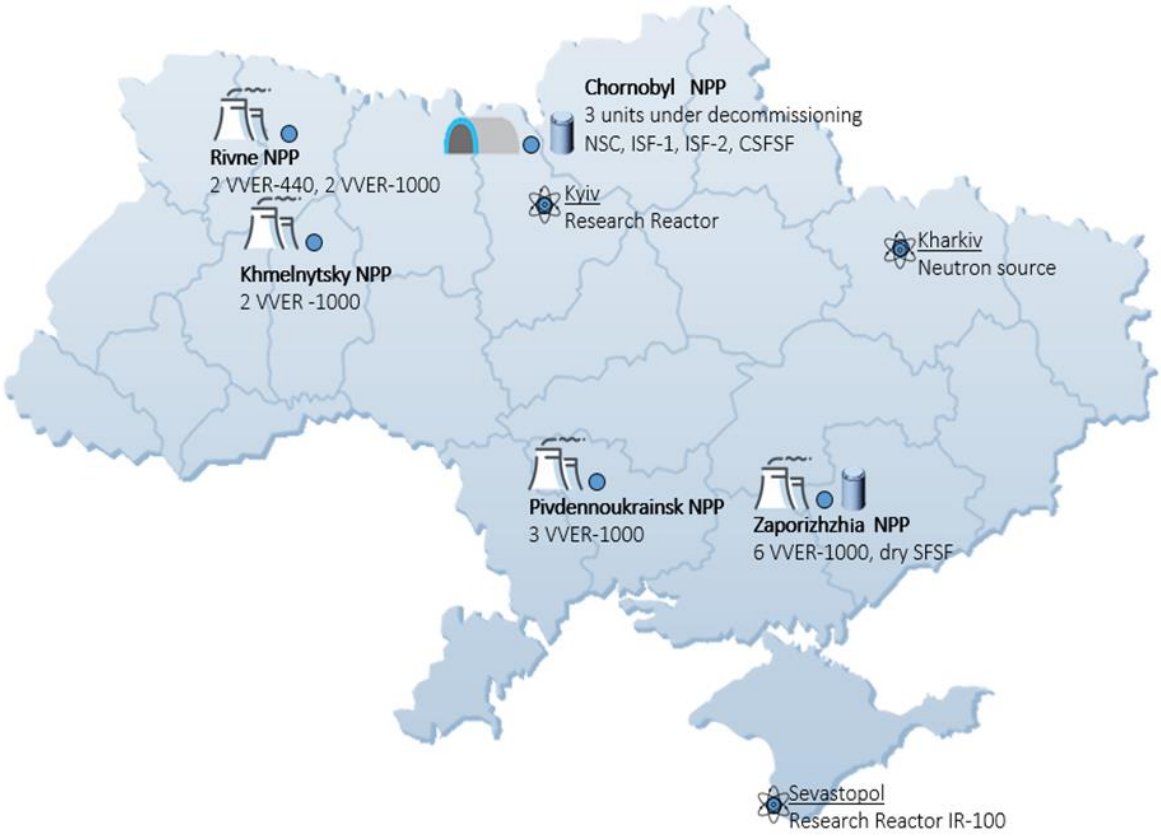

Figure 1.1 – Location of NPPs in Ukraine

NPPs. The State Enterprise "National Nuclear Energy Generating Company Energoatom" (Energoatom) is the sole operator of all operating nuclear power plants in Ukraine. Energoatom includes four NPPs (see Figure 1.2).

Zaporizhzhia NPP

Rivne NPP

Pivdennoukrainsk NPP

Khmelnytsky NPP

Figure 1.2 – Ukrainian NPPs

A stable and safe mode of NPP operation in Ukraine is ensured according to the Law of Ukraine "On Nuclear Energy Use and Radiation Safety" and provisions of the Convention on Nuclear Safety. Measures are being implemented on a systemic basis to increase the safety level of operating NPPs in Ukraine according to the requirements of national nuclear and radiation safety regulations, rules and standards, IAEA standards, and taking into account advanced international practice. The unified system of regulatory documents and branch standards applies to all nuclear facilities in terms of fire protection.

The State Specialized Enterprise "Chornobyl NPP" (SSE ChNPP) performs activities on decommissioning of ChNPP power units according to the license issued by SNRIU through sequential implementation of the following decommissioning stages: operation termination, final closure and safe enclosure, decay storage, dismantling.

SSE ChNPP has completed operation termination stage, during which, in particular, ChNPP units were released from nuclear fuel. SSE ChNPP received permission from SNRIU to implement the next decommissioning stage – final closure and safe enclosure.

The following activities are envisaged at the final closure and safe enclosure stage, in particular:

- dismantling and processing of fuel channels and channels of the control and protection system of ChNPP units;
- safe enclosure of reactors and confinement of safe enclosure areas;
- reconstruction of central hall covers and dismantling of load lifting mechanisms.

According to NP 306.2.141-2008 "General Safety Provisions for Nuclear Power Plants" [3], after complete removal of nuclear fuel from the power unit, the following activities on ChNPP decommissioning shall be performed based on the general safety provisions established for the facilities aimed at radioactive waste management.

Nuclear research reactors. There are two research reactors in Ukraine:

- nuclear research reactor of the Nuclear Research Institute of the National Academy of Sciences of Ukraine in Kyiv (NRI NASU);
- nuclear research reactor (DR-100) and subcritical uranium–water assembly at the Sevastopol National University of Nuclear Energy and Industry (SNUNEI) in Sevastopol.

Due to the occupation of the Autonomous Republic of Crimea in 2014 by russia, Ukraine lost regulatory control over such nuclear facilities as DR-100 research reactor of the Sevastopol National University of Nuclear Energy and Industry and two subcritical low-enriched and natural uranium assemblies. Therefore, License EO 000131 issued by SNRIU to the Sevastopol National University of Nuclear Energy and Industry for the right to perform activities "nuclear facility operation": research nuclear reactor (DR-100) and subcritical uranium-water assembly, was suspended on 16 June 2014.

Nuclear research reactor VVR-M of the Nuclear Research Institute of the National Academy of Sciences of Ukraine was commissioned in February 1960 as a powerful neutron source for fundamental and applied research in different branches of science and technology. The activities on NRI NASU VVR-M operation are performed according to SNRIU license issued on 29 December 2014.

The nuclear subcritical facility "Neutron Source Based on a Subcritical Assembly Driven by a Linear Electron Accelerator" (neutron source) is in the commissioning stage on premises of the National Science Center "Kharkiv Institute of Physics and Technology" (NSC KIPT). The neutron source is designed for scientific and applied research in nuclear physics, radiation materials science, biology, chemistry and for production of medical radioisotopes. The neutron source is constructed and commissioned by operating organization NSC KIPT within the license "to provide activities on the construction and commissioning of the neutron source" issued by SNRIU on 10 October 2013 and according to DDN 39-6-000 Licensing Plan, which specifies the licensing process for the facility in compliance with the requirements of Ukrainian regulations and laws on nuclear and radiation safety.

Spent nuclear fuel storage facilities. At present, there are three storage facilities for temporary storage of spent fuel in operation in Ukraine: one wet storage facility, ChNPP ISF-1, and two dry storage facilities, ZNPP DSFSF and ChNPP ISF-2. Besides, the centralized dry spent fuel storage facility for Ukrainian VVER NPPs (CSFSF), except for ZNPP, is at the stage of commissioning.

ChNPP ISF-1 was constructed in 1983-1986 and was commissioned in 1986 as an interim storage facility for RVPK-1000 fuel assemblies from ChNPP. This facility was not designed for long-term storage of spent fuel (more than 100 years) and its operating lifetime is limited by the term for the transfer of all spent fuel from it to ISF-2.

ISF-2 is designed for acceptance, preparation for storage and direct long-term storage (within 100 years) of all ChNPP spent fuel. The Holtec International (USA) technology is used for spent fuel management. On 26 April 2021, SNRIU approved a decision to provide SSE ChNPP with the license to perform ISF-2 operation activities.

ZNPP DSFSF ensures the storage of ventilated storage containers with spent nuclear fuel (VSC-VVER) during their operation: 50 years. The design is based on the technology of dry ventilated container for the storage of spent fuel assemblies in a vertical position of the US Company Duke Engineering & Services (DE&S). At present, ZNPP DSFSF is operated according to the license issued by SNRIU on 10 August 2004 for the right to perform activities at life stage "operation of Zaporizhzhia NPP" including DSFSF.

CSFSF is designed for long-term storage of spent fuel from RNPP, KhNPP and PNPP. The Holtec International (USA) technology is used for spent fuel management. The completion of CSFSF construction is performed according to the conditions of the license for the right to

perform activities on “construction and commissioning of a nuclear facility – spent fuel storage facility (CSFSF)”, which was issued by SNRIU on 29 June 2017. Within this license, CSFSF received an individual permission of SNRIU to perform activities related to nuclear facility commissioning on 25 April 2022.

1.1 Identification of nuclear installations

Identification of nuclear installations considered in NAR on the second topical peer review at the national level was performed in compliance with the Technical Specification [1] with the definition of candidate installations and represented installations.

A brief description of the national selection of NPP units in operation is presented in Table 1.1 .

Table 1.1 – National selection of NPP units for NAR

NPP	Unit	Installation type	Design Ntherm, MW	Life stage	Decision on inclusion to NAR TPR II
Zaporizhzhia NPP	ZNPP-1	VVER-1000/320	3000	operation	represented installation
	ZNPP-2	VVER-1000/320	3000	operation	represented installation
	ZNPP-3	VVER-1000/320	3000	operation	represented installation
	ZNPP-4	VVER-1000/320	3000	operation	represented installation
	ZNPP-5	VVER-1000/320	3000	operation	represented installation
	ZNPP-6	VVER-1000/320	3000	operation	represented installation
Khmelnytsky NPP	KhNPP-1	VVER-1000/320	3000	operation	represented installation
	KhNPP-2	VVER-1000/320	3000	operation	represented installation
Pivdennoukrainsk NPP	PNPP-3	VVER-1000/320	3000	operation	represented installation
	PNPP-2	VVER-1000/338	3000	operation	represented installation
	PNPP-1	VVER-1000/302	3000	operation	candidate installation
Rivne NPP	RNPP-1	VVER-440/213	1375	operation	represented installation
	RNPP-2	VVER-440/213	1375	operation	candidate installation
	RNPP-3	VVER-1000/320	3000	operation	candidate installation
	RNPP-4	VVER-1000/320	3000	operation	represented installation

Since all units are operated by one operating organization Energoatom, the selection of installations for the inclusion into NAR in the area of fire protection was performed in the view of reactor type and the most complete and relevant analytical justifications of fire safety and

its impact on nuclear and radiation safety. The following installations were selected as candidate ones:

– RNPP-2 (represents VVER-440/213);
– RNPP-3 (represents VVER-1000/320);
– PNPP-1 (represents small series installations VVER-1000/302 and 338).

SSE ChNPP decommissions all units (ChNPP-1, ChNPP-2, ChNPP-3) according to the program and design for the final closure and safe enclosure stage (see Table 1.2).

Table 1.2 – ChNPP units

Unit	**Licensee**	**Installation type**	**Life stage**	**Year of operation termination**
ChNPP-1	SSE ChNPP	RVPK-1000	Decommissioning	30.11.1996
ChNPP-2	SSE ChNPP	RVPK-1000	Decommissioning	11.10.1991
ChNPP-3	SSE ChNPP	RVPK-1000	Decommissioning	15.12.2000

Installations were not under consideration due to the fact that nuclear fuel was fully removed from the units. According to the conclusions of the review of the design for the final closure and safe enclosure stage, fire safety requirements were complied with during the final closure and safe enclosure stage activities. The absence of the risk for potential personnel exposure and additional impact on the environment in case of fire was justified during the analysis of nuclear and radiation safety. The sufficiency of implemented organizational and technical measures to mitigate emergencies with fire was also demonstrated. The impact on the public is eliminated due to ChNPP location in the exclusion zone. In addition, SNRIU recognized ChNPP units as radioactive waste management facilities.

A brief description of the national selection of research facilities is presented in Table 1.3.

Table 1.3 – Research facilities in Ukraine

Installation	**Licensee**	**Type**	**Power, MW**	**Life stage**	**Decision on inclusion to NAR TPR II**
VVR-M of NRI NASU	Nuclear Research Institute of NASU	VVR-M	10	Operation	candidate installation
DR-100 of SNUNEI[1]	Sevastopol National University of Nuclear Energy and Industry	DR-100	0.2	License suspended	excluded installation
Subcritical uranium-water assembly of SNUNEI[1]		Subcritical assembly	-		excluded installation
Physical test bench of SNUNEI[1]		Physical test bench DR-100 (critical assembly)	0.002		excluded installation

Neutron source	National Science Center KIPT	Accelerator driven system (ADS), subcritical assembly	0.36	Commissioning	excluded installation

[1]. Nuclear research reactors of the Sevastopol National University of Nuclear Energy and Industry are currently under russian occupation

Therefore, the scope of TPR II includes VVR-M research reactor of 10 MW, which is at the stage of operation and is located in Kyiv. Nuclear research facilities of the Sevastopol National University of Nuclear Energy and Industry will not be considered due to impossible safety regulation of nuclear facility operation by Ukraine since 2014 related to temporary occupation of the Crimea by russia. The license for their operation was suspended.

The neutron source will not be considered due to the low profile of potential risks for personnel and the public (protection area is limited to the facility building). Insignificant quantity of nuclear fuel in the core, nuclear fuel enrichment does not exceed 19.7%. In addition, the requirements of WENRA reference levels for research reactors do not apply to this type of facilities.

A brief description of the national selection of spent nuclear fuel storage facilities is presented in Table 1.4.

Table 1.4 – Spent nuclear fuel storage facilities

Installation	**Licensee**	**Type**	**Life stage**	**Decision on inclusion to NAR TPR II**
ZNPP DSFSF	Energoatom	Dry spent fuel storage facility (container type)	Operation	excluded installation
ISF-1	SSE ChNPP	Wet spent fuel storage facility (pool type)	Operation	excluded installation
ISF-2	SSE ChNPP	Dry spent fuel storage facility (container type)	Operation	candidate installation
CSFSF	Energoatom	Dry spent fuel storage facility (container type)	Commissioning	excluded installation

The absence of hazardous fire impact on nuclear facilities and NRS was justified for DSFSF and ISF-1. There are no fire sources.

ISF-2 is the most technological spent nuclear fuel storage facility out of all available in Ukraine. Taking this into account, ISF-2 of SSE ChNPP is the most representative facility. The analysis will be performed as related to fire impact on NRS during transport and handling operations and operations using hot cells.

1.2 Key parameters for facilities

Tables 1.5 and 1.6 present key parameters of facilities defined by the national selection and covered by this NAR.

Table 1.5 – Key parameters of NPP units and research reactor

Installation	Licensee	Reactor type	Thermal / electrical power MW	Year the license for operation or first criticality was issued	Date of scheduled termination of design-basis operation / date of long-term operation
RNPP-2	Energoatom	VVER-440/213	1375/415	22.12.1981	22.12.2011/22.12.2031
RNPP-3	Energoatom	VVER-1000/320	3000/1000	21.12.1986	13.12.2018/11.12.2027
PNPP-1	Energoatom	VVER-1000/302	3000/1000	31.12.1982	02.12.2013/02.12.2033
VVR-M NRI NASU	Nuclear Research Institute of NAS of Ukraine	VVR-M	10	12.02.1960	Not defined / 31.12.2026

Table 1.6 – Key parameters of the spent nuclear fuel storage facility

Title	Licensee	Type	Year the license for operation or first criticality was issued	Date of scheduled termination of operation / date of life extension
ISF-2	SSE ChNPP	Dry spent fuel storage facility (container type)	23.04.2021	Not defined

1.3 Approach to developing NAR for the national selection

SNRIU with scientific and technical support of the State Scientific and Technical Center for Nuclear and Radiation Safety (SSTC NRS) arranged and coordinated the development of NAR on the second topical peer review. With this purpose and according to SNRIU Order No. 492 dated 12 August 2022 “On Preparing the National Report on the Second Topical Peer Review according to the requirements of Council Directive 2014/87/Euratom of 08 July 2014 amending Directive 2009/71/Euratom establishing a Community framework for the nuclear safety of nuclear installations”, the coordination group was created and approved to arrange the development of the National Report on the Second Topical Peer Review and consideration of the first and final revisions of NAR, and the working group was created to ensure NAR development and its revision upon comments of the coordination group. The coordination and working group included representatives from the interested central executive authorities, in particular:

- State Nuclear Regulatory Inspectorate of Ukraine,
- Ministry of Energy of Ukraine,
- State Emergency Service of Ukraine,
- State Agency of Ukraine on Exclusion Zone Management,
- National Academy of Sciences of Ukraine,

leading scientific and research establishments on nuclear and radiation safety and fire safety of Ukraine:

- State Scientific and Technical Center for Nuclear and Radiation Safety of Ukraine,
- Institute of Public Administration and Research in Civil Protection,

and licensees:

- Energoatom,
- SSE ChNPP,
- Nuclear Research Institute of the National Academy of Sciences of Ukraine.

The development of NAR TPR II was preceded by self-assessment on the issues defined by the structure and content of NAR [□1] performed by the licensees.

1.4 National legal regulatory framework

Ukrainian legislation has a hierarchic structure. The regulatory document on NRS hierarchical pyramid existing today in Ukraine includes five levels. The highest Level 1 represents the Constitution of Ukraine, the basic law being on top of the hierarchy, as well as the Laws of Ukraine. This level includes also international treaties. Level 2 includes the regulations issued by the Cabinet of Ministers and the President of Ukraine. Level 3 includes the regulations of the Ministries and other executive bodies.

The hierarchical pyramid of NRS legal regulatory framework is presented schematically in Figure 1.3.

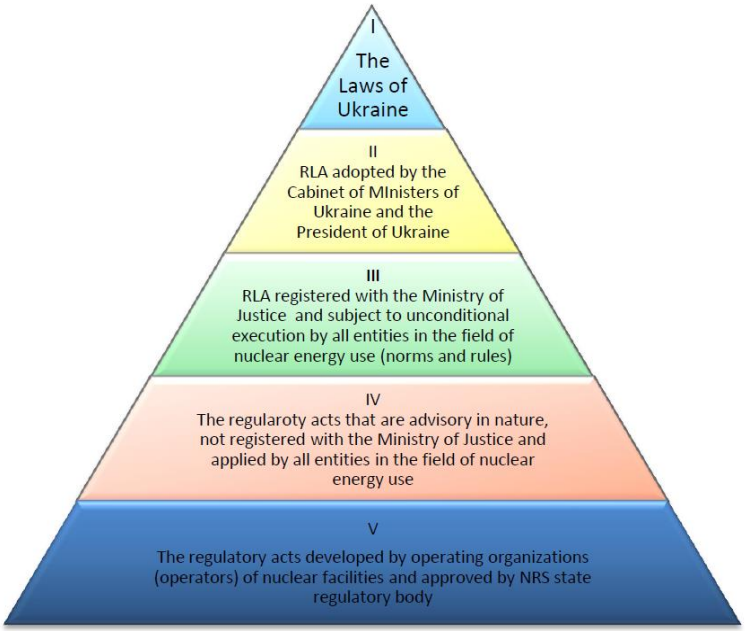

Figure 1.3 Hierarchical pyramid of the regulatory and legal framework on NRS

1.4.1 National regulatory requirements and standards

Laws of Ukraine

Law of Ukraine "On Nuclear Energy Use and Radiation Safety"

The Law is fundamental in the nuclear legislation of Ukraine. It establishes the priority of human and environmental safety, the rights and responsibilities of citizens on nuclear energy use, regulates activities related to the use of nuclear facilities and radiation sources, establishes the legal basis for Ukraine's international obligations regarding nuclear energy use.

Code of Civil Protection

The Code regulates relations with regard to the protection of the public, territories, environment and property from emergencies, response to them, functioning of the unified system of civil protection, and defines the powers of the state authorities, local self-government bodies, rights and obligations of Ukrainian citizens, foreigners and stateless persons, enterprises, institutions and organizations regardless of the form of ownership.

Regulations and rules of nuclear and radiation safety

NP 306.1.190-2012 "General Requirements for the Management System for Nuclear Activities" and ***NP 306.1.182-2012 "Requirements for the Management System Requirements for the Management System for Activities of the Operating Organization (Operator)",*** which establish requirements for the development, implementation, assessment and improvement of the management system for activities of the operating organization (operator) of the nuclear facility at all life stages. In particular, the specified documents establish requirements for the development of the integrated management system for activities, which takes into account the requirements of the laws, other regulatory documents and standards on nuclear and radiation safety, labor protection, physical protection, environmental safety, health protection, civil protection, fire and man-made safety, quality related to the nuclear entity activities.

NP 306.2.141.2008 "General Safety Provisions for Nuclear Plants", which establish the objective, principles and criteria for NPP safety, as well as requirements for implementation of main technical and organizational measures aimed at their implementation and protection of people and the environment against possible radiation impact. In particular, the document establishes requirements for the implementation of defense-in-depth principle for NPP fire protection, general requirements for fire safety at NPPs (use of fire protection systems, use of non-flammable cables, division of NPP premises into firefighting areas, development of firefighting plans, creation of fire depots and fire services, exercises and trainings on fire safety issues).

In 2021-2023, SNRIU revised the General Safety Provisions for Nuclear Plants to consider more than ten years of experience in their application, the need for implementation of the provisions of EU Directives, IAEA documents, WENRA documents. At present, the draft document is under agreement with interested central executive authorities and state registration authorities as envisaged by the legal procedure in Ukraine.

NP 306.2.162-2010 "Requirements for Safety Assessment of Nuclear Power Plants", which establishes the main objectives and components of NPP safety and determine the interconnection between safety assessment reports for different NPP life stages. In particular, the document establishes requirements for the consideration of fire to justify NPP safety using probabilistic and deterministic safety analysis methods.

NP 306.2.214-2017 "Requirements for Periodic Safety Review", which establish general requirements for periodic safety review of NPP units, procedure for the development of periodic safety review reports developed at life stage "nuclear facility operation". In particular, the document establishes requirements for the need to consider impact of fire as an

event to be analyzed within safety factor “analysis of external and internal events” during periodic safety review.

NP 306.2.205-2016 “Requirements for Power Supply Systems Important to Safety of Nuclear Power Plants”, which establish requirements for the arrangement and operation of power supply systems important to NPP safety. In particular, the document contains requirements for:

- consideration of the requirements of fire safety rules and regulations in the design of emergency power supply systems and in-house power supply systems;
- consideration of fire occurrence as an initiating event in the design of emergency power supply systems and in-house power supply systems;
- need for justification of selective operation of protective devices from the point of view of ensuring reliable and logical disconnection in case of short circuits in electrical loops taking into account minimization of cable cross-sections, which are chosen according to the criteria of thermal and fire resistance of cables, in the design of in-house power supply systems;
- need for justification of selective operation of protective devices and thermal and fire resistance of cables in the design of emergency power supply systems;
- need for physical separation of different trains of emergency power supply systems and cable routes of different emergency power supply system trains to prevent common cause failures (including fire), as well as separation of long cable structures by fire partitions into compartments;
- need to equip premises of emergency power supply systems with fire alarm and fire extinguishers.

NP 306.2.204-2016 “Requirements for Systems for Emergency Nuclear Fuel Cooling and Heat Removal to Ultimate Heat Sink”, which establishes requirements for the systems and components of nuclear power plants with pressurized water reactors, which perform functions of emergency cooling of nuclear fuel in the core and spent fuel pool, heat removal from it and its transfer to ultimate heat sink. In particular, the document establishes that the design shall envisage the fire extinguishing system, which performs the functions of protection of systems for emergency nuclear fuel cooling and heat removal to ultimate heat sink, their support, instrumentation and control systems in case of fire, ignition, smoke and explosions. Abnormal operation of fire extinguishing systems or their spurious actuation shall not lead to failure of systems for emergency nuclear fuel cooling and heat removal to ultimate heat sink to perform their functions.

NP 306.2.218-2018 “Rules for Design and Safe Operation of Confining Safety Systems”, which establish general requirements for the structure, characteristics, conditions for operation of such components of the confining safety systems at nuclear power plants, which, in particular, include systems for pressure reduction, heat removal, prevention of explosive and fire hazardous gas concentrations, cleaning of the environment in the accident confinement area.

NP 306.2.202-2015 “Requirements for Nuclear and Radiation Safety for Instrumentation and Control Systems Important to Safety of Nuclear Power Plants”, which

require consideration and implementation of the technical decisions to prevent fire, ensure fast fire detection, prevent its evolution in the design, development, production, operation of NPP instrumentation and control systems and their components. The premises of the power unit, where components of the safety systems are located, shall be equipped with instrumentation for detection and notification of fire (fire alarm systems) and/or automatic fire extinguishing control systems.

NP 306.2.105-2004 "General Safety Provisions for Interim Dry Spent Fuel Storage Facilities", which establish basic principles and criteria for safety of interim dry storage facilities for spent nuclear fuel (ISF), classification of dry ISF systems and components and requirements for ensuring safety at life stages of dry ISF: siting, design, construction, commissioning, operation and decommissioning. In particular, the document establishes the requirement for the need to ensure fire safety of storage facilities and compliance with requirements of fire safety rules and standards.

In 2022, the SNRIU started the review of the General Safety Provisions for Nuclear Power Plants in order to take into account experience of their application, need to implement provisions of EU Directives, IAEA documents, WENRA documents.

OPB IR "General Safety Provisions for Research Reactors in Design, Construction and Operation", which establish general principles and criteria for safety of research reactors regardless of their type and departmental affiliation, as well as organizational and technical requirements, the fulfilment of which is an integral condition for ensuring safety of research reactors. In particular, the document has requirements for the need for consideration of fire as an initiating event that shall be taken into account in the design of systems and components important to safety.

In 2022, the SNRIU started the review of the General Safety Provisions for Nuclear Power Plants in order to take into account experience of their application, need to implement provisions of EU Directives, IAEA documents, WENRA documents.

Fire safety requirements

"Fire Safety Rules in Ukraine" (approved by Order No. 1417 of the Ministry of Internal Affairs of Ukraine on 30 December 2014 and registered in the Ministry of Justice of Ukraine on 05 March 2015 under No. 252/26697), which establish general fire safety requirements for buildings, structures of different purposes and territories adjacent to them, other immovable property, equipment, operated facilities, construction sites, as well as during construction, reconstruction, major repair, technical reequipment of buildings and structures.

"Fire Safety Rules in Operation of Nuclear Power Plants" (approved by Order No. 256 of the Ministry of Fuel and Energy of Ukraine on 30 May 2007 and registered in the Ministry of Justice of Ukraine on 06 September 2007 under No. 1039/14306, which establish fire safety requirements applied to NPP facilities that are under operation, construction, reconstruction, technical reequipment, as well as provisions regulating interaction of NPP administration and personnel, and involved organizations, enterprises or separate workers, who temporarily or permanently function at NPPs, with authorities of the State Fire Protection of Ukraine. In particular, the document contains:

- requirements for the need to implement defense-in-depth concept with regard to fire protection;
- requirements for fire hazard analysis;
- requirements for the need to implement organizational measures on fire safety;
- fire safety requirements for territories, buildings, rooms, structures;
- fire safety requirements for engineering equipment;
- requirements for power facilities and process equipment;
- requirements for maintenance of technical means of fire protection;
- requirements for fire safety in the arrangement of maintenance and reconstruction of buildings, structures and process equipment;
- requirements for the procedure for the case of fire.

"Fire Safety Rules at Companies, Enterprises and Organizations of the Energy Sector of Ukraine" (approved by Order No. 491 of the Ministry of Energy and Coal Industry of Ukraine on 26 September 2018 and registered in the Ministry of Justice of Ukraine on 29 March 2019 under No. 328/33299), which establish general requirements for fire safety of buildings, structures and adjacent territories, other immovable property, equipment, operated facilities of power enterprises, construction sites, as well as for construction works. In particular, the document establishes:

- organizational measures to ensure fire safety;
- main requirements for training of personnel of power enterprises and organizations;
- requirements for the documents on fire safety;
- general fire safety requirements for territories, buildings, premises, structures;
- general fire safety requirements for process equipment;
- requirements for power installations, distribution devices;
- fire safety requirements during maintenance and reconstruction of equipment;
- technical means of fire protection;
- procedure for the case of fire.

Detailed requirements for fire safety and fire protection systems are determined in branch regulatory documents, state building standards, internal regulatory documents of operating organizations.

1.4.2 Implementation/Application of international standards and guidelines

According to the requirements of Article 8 of the Law of Ukraine "On Nuclear Energy Use and Radiation Safety", nuclear and radiation safety regulations and rules are approved taking into account recommendations of international organizations on nuclear energy use.

According to the Procedure for Preparation, Approval, Submission for State Registration and Accounting of Regulatory Documents on Nuclear and Radiation Safety approved by SNRIU Order No. 176 dated 18 October 2016, Nuclear and Radiation Safety Regulations and Rules shall be developed according to the laws of Ukraine, international agreements of Ukraine, consent for the binding nature of which has been given by the Verkhovna Rada of Ukraine, obligations of Ukraine in the area of European integration and compliance with European Union laws, taking into account operational experience, conclusions on safety analysis of operating nuclear facilities, experience in nuclear energy use in Ukraine and other countries, recommendations of international organizations and information on scientific and technical achievements in the sphere of nuclear energy use.

In order to implement these provisions, SNRIU shall take into account Ukraine's obligations in connection with Ukraine's aspirations to become a member of the EU

(EURATOM Directives), IAEA documents, WENRA reference levels, during the development/review/amendments of nuclear and radiation safety regulations and rules.

Within the process of regulatory safety assessment of facilities and activities on nuclear energy use and radiation safety, SNRIU and its technical support organization (SSTC NRS) use IAEA documents and WENRA reference levels as additional criteria in making regulatory decisions.

II. PIVDENNOUKRAINSK NPP UNIT 1

2.1 General information

PNPP Unit 1 was commissioned in 1982. PNPP Unit 1 includes: a VVER-1000 water-cooled water-moderated power reactor (model 302) with a thermal capacity of 3,000 MW and a K-1000-60/1500 turbine unit (installed electrical capacity of 1,030 MW). The operating organization is the State Enterprise "National Nuclear Energy Generating Company Energoatom". Unit 1 was designed in accordance with regulations meeting safety requirements through consistent implementation of the defense-in-depth concept based on the use of physical barriers to prevent the spread of radiation and radioactive releases into the environment. The Unit 1 design is based on the conservative approach. Systems and components important to safety perform their functions in the scope established by the design, both in normal operation and in conditions that may arise as a result of design-basis accidents, with the subsequent impact of natural phenomena (earthquakes, hurricanes, floods). In addition, the design considers the effects of jets, shock waves, missiles, and fires.

A defense-in-depth fire protection system has been implemented at the PNPP, which maintains the functions of systems important to safety, necessary to ensure the NPP nuclear and radiation safety during and after a fire.

2.2 Fire safety analysis

The fire safety analysis of PNPP nuclear installations, including Unit 1, was performed within review of the full range of initiating events (FR IEs) for all states of the reactor and the spent fuel pool (SFP). The fire safety analysis of Unit 1 (both deterministic and probabilistic parts) is an integral component of the probabilistic safety analysis (PSA). Therefore, further review is provided as a single material without additional division into deterministic or probabilistic analyses, in accordance with the requirements for the scope and structure of the National Assessment Report defined in the Technical Specification [1].

The main purpose of deterministic fire hazard analyses is to support the development of the necessary component of the Section "Probabilistic Safety Analysis" of the Safety Analysis Report (SAR) for Unit 1 for identifying fire safety deficits, providing recommendations and proposing corrective measures for their elimination. The deterministic and probabilistic analyses of fire hazards result in assessment of the impact from internal fires on the total core damage frequency (CDF). This assessment complements the results of PSA Level 1 for internal IEs.

2.2.1 Types and scope of fire safety analysis

The analysis of fire safety uses the division of the PNPP site and Unit 1 territory into fire sectors with the establishment of boundaries for these fire sectors for internal fires at full power and LPSS of PNPP Unit 1. The adopted set of fire sectors covers all the main buildings and structures of the PNPP first stage:

- the main building of the PNPP 1st stage, including the reactor compartment, boron unit, turbine hall, deaerator compartment and auxiliary special building;
- unit pumping station of the PNPP 1st stage;

- service water pumping stations of essential loads;
- 330 kV open switchgear;
- standby diesel generators of PNPP 1st stage.

The layout of mutual arrangement of the main buildings and structures of the PNPP first stage is presented below in Figure 1.2.

PNPP Unit 1 was divided into 10 independent fire zones: A – non-sealed part of the reactor compartment and the premise for storage tanks of boron concentrate 1TH; B – building of the boron unit, except for the premises of the boron concentrate storage tanks; C –first stage auxiliary special building; D – deaerator compartment, electrical equipment racks, first stage turbine hall; E – unit pumping station; F – buildings of service water pumping stations; G – standby diesel generator buildings; H – 330 kV open switchgear; I – light yard; K - sealed part of the reactor compartment.

Zones A, B, C, D, and K are structures of the main building of the PNPP 1st stage, which belong to Unit 1 (see Figure 2.2). Zones E, F, G, H and I are separately located buildings and structures, separated by distance and communications, and are completely autonomous.

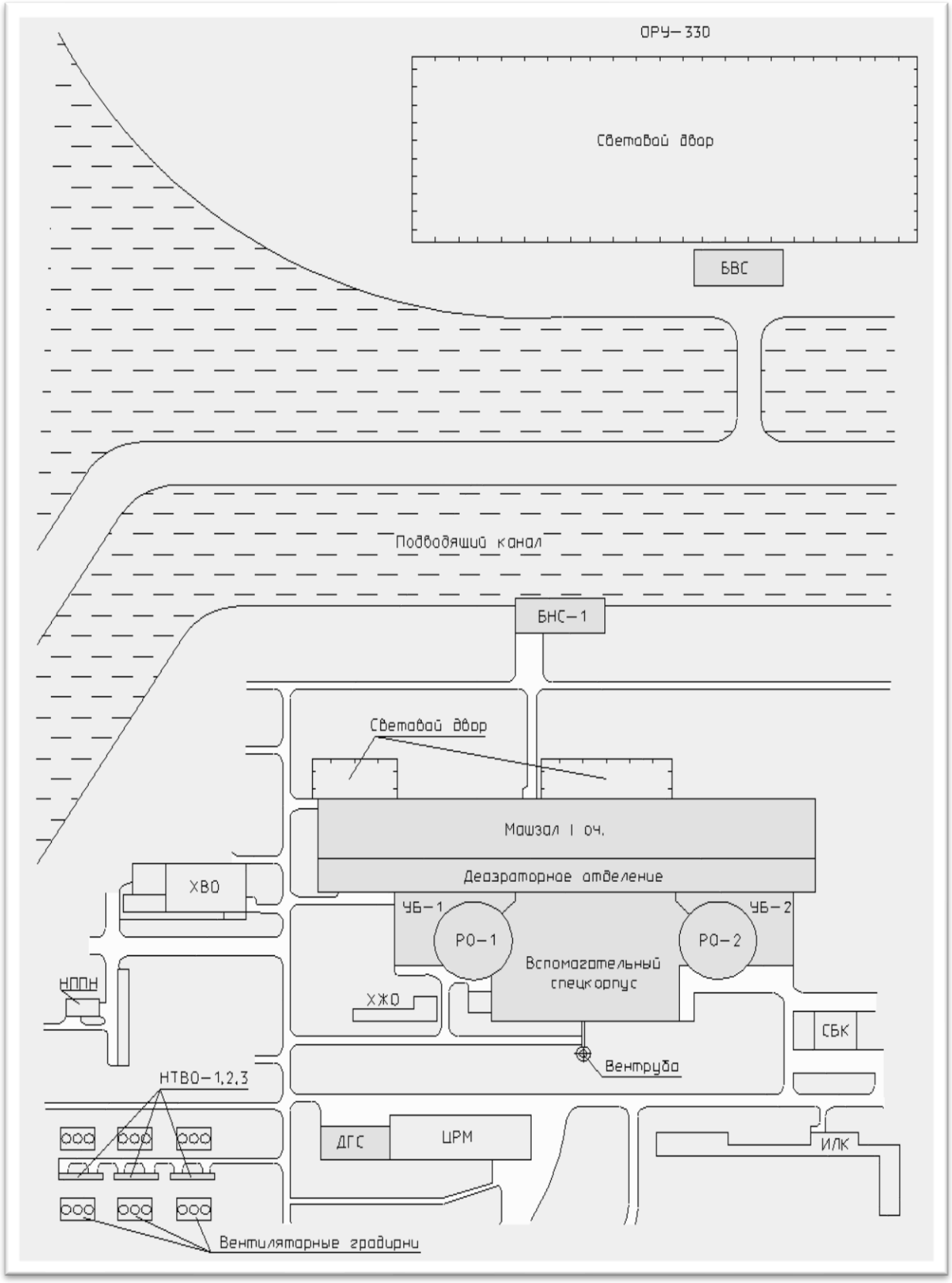

Figure 2.1 – Layout of the main buildings and structures of the PNPP first stage

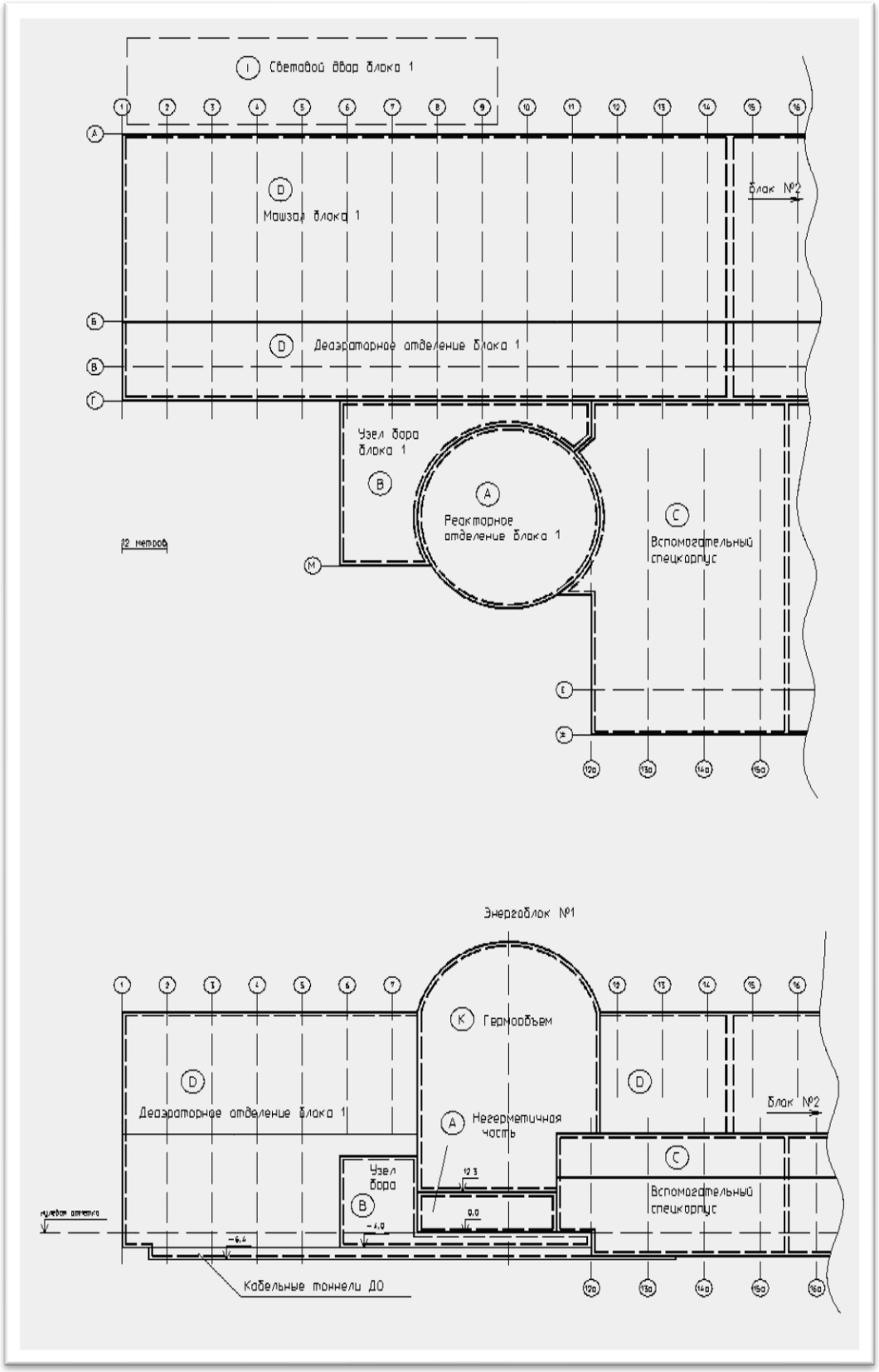

Figure 2.2 – Layout of independent fire zones of the PNPP Unit 1 main building (top and side views)

As part of the fire safety analysis of Unit 1, 14 operational states are considered for the power unit in operation at full power (FP) and in low power and shutdown states (LPSS). In the framework of the in-depth safety analysis of the PNPP Unit 1, the following was performed:

- preliminary assessment of the Unit 1 vulnerability to initiating events associated with internal fires;
- development of a methodology for development of PSA Level 1 concerning internal fires, taking into account the specifics of the power unit;
- collection of data on PNPP Unit 1 cables, including data on location of power, control and instrumental cable connections of the main equipment;
- collection of additional data necessary for probabilistic modeling of internal fires (fire loads, fire protection measures and means, statistical data on initiation of fires and combustion, operation of ventilation systems, etc.);
- targeted walkdowns of the main buildings and structures of the power unit, focused on fire hazard assessment;
- preliminary analysis of emergency scenarios, qualitative and quantitative screening.

As a result of the detailed analysis, 341 fire development trees (FDTs) were built and 957 fire accident sequences were considered. Of these, 397 fire accident sequences did not lead to initiating events (IEs) and were not considered further. Fire accident sequences leading to IEs were screened out according to their frequency. The IE occurrence frequency of 1E-07 1/year was adopted as a criterion for screening. As a result of screening according to the occurrence frequency, 303 fire accident sequences were screened out. Thus, 257 fire accident sequences were left for the final analysis.

The analysis of potential combinations of internal and external hazards for the reactor and SFP is performed as a separate annex within the probabilistic safety analysis (PSA) of the power unit to identify and account for additional components of probabilistic risk indicators (CDF, LERF, FDF) that were not considered during analysis of individual IEs. To make a list of IE combinations, both internal and external hazards, potential combinations of events were analyzed based on the PSA for the full range of initiating events (FR IEs) developed for PNPP Units 1 and 2.

Compiling a list of combinations for internal fires includes:

- screening of fire sectors;
- combining two independent fire events for all possible operational states of the power unit;
- quantitative screening of the combinations according to the occurrence frequency (criterion is the occurrence frequency less than 1.0E-07).

Similar steps are performed for combinations of three or more independent fire events.

2.2.2 Key assumptions and methodologies

The methodology for safety analysis in relation to internal fires is based on the majority of approaches that were used during development of PSA for internal IEs. At the same time, in the analysis of internal fires, there are a number of peculiarities, including a significant work scope for the identification and screening of the most significant ignition sources and fire

compartments for further assessment. For this purpose, various design features were considered, in particular, the spatial aspects of the PNPP Unit 1 design.

Fire resistance studies of barriers, analysis of automatic fire extinguishing and automatic fire alarm systems, and various types of failures (e.g., direct flame exposure, thermal exposure, and smoke exposure to equipment) are examples of areas under internal fire analysis.

First of all, the most important fire compartments of the power unit were identified. Fire scenarios are defined for each of these compartments. For this purpose, data on the location of cables of the equipment components used in the PSA Level 1 model is collected. Other procedural steps use models and quantitative indicators similar to the PSA Level 1 for internal IEs, with associated modifications and special methods for internal fire analysis.

The main assumptions used in the safety analysis of internal fires for PNPP Unit 1 are presented below. The assumptions are consistent with approaches commonly applied to PSAs for internal initiating events, namely:

- reactor operation at full power is accepted as the initial state of the power unit;
- functions and systems that are necessary and sufficient to achieve a safe end state of the reactor in case of IE have already been defined in PSA Level 1. Additional functions of the systems that will be included in the safety analysis for internal fires are designed to suppress the fire itself;
- the end states of PSA Level 1 remain unchanged. Exceptions are only events that caused new IEs;
- it is assumed that only one independent fire can occur in any fire compartment of the power unit. The possibility of fire propagation to neighboring fire compartments is taken into account, except in cases where it can be demonstrated that the fire can be isolated within the compartment in which it originated with the NPP firefighting means;
- it is assumed that individual internal IEs cannot occur simultaneously with an existing fire, if they were not caused by this fire. It is also assumed that a fire cannot occur at the same time with any IE independent of the fire;
- negative consequences associated with the erroneous operation of the automatic fire extinguishing system (potential flooding) are not considered either in the safety analysis for internal fires. The potential malfunction of the automatic fire extinguishing system is considered in the safety analysis for internal flooding. However, secondary effects caused by operation of the automatic fire extinguishing system during a fire are considered in the analysis for internal fires.

The methodology has been developed based on the recommendations of several guides of the IAEA and U.S. NRC [4] - [9].

2.2.3 Analysis of phenomena accompanying the fire: general overview of the models, data and consequences

A structural diagram for the determination of fire scenarios and their relationship with the information and screening process used during the fire safety analysis is presented in Figure **Ошибка! Источник ссылки не найден.**.

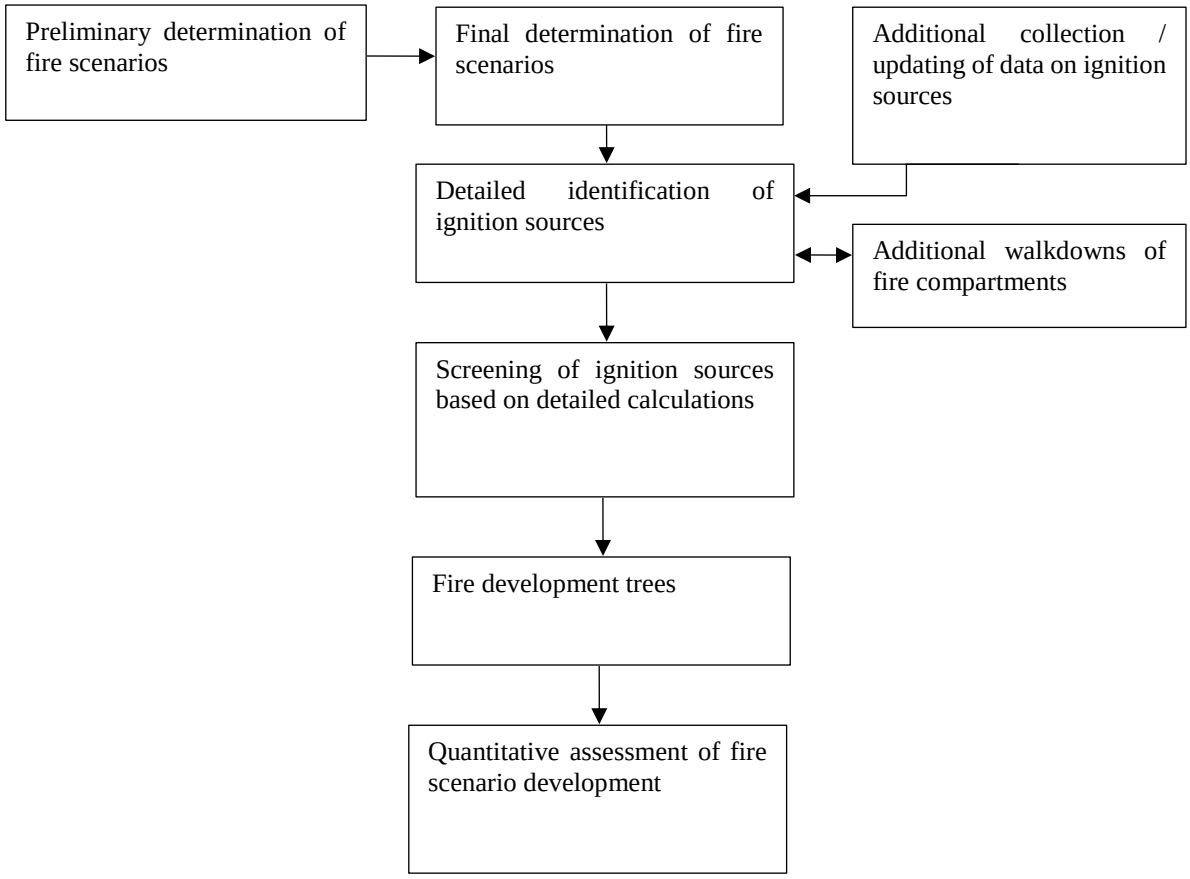

Figure 2.3 – Structural diagram for the determination of fire scenarios and their relationship with the information and screening process

A detailed analysis using deterministic fire propagation calculations is performed for all unscreened fire scenarios. The purpose of this subtask is a detailed assessment of possible fire propagation scenarios from each ignition source located in a separate fire compartment of PNPP Unit 1.

The detailed assessment includes a realistic analysis of the ignition sources, accident progression, measures to detect and suppress the fire, as well as the characteristics of possible objects of ignition. Detailed analysis of fires is performed with the aim to:

- reduce the conservative assumption of complete damage to all equipment during a fire in fire compartments;
- determine critical ignition sources: which cause failure of critical components; which cause secondary ignition;
- determine the probability of successful fire detection and elimination before critical damage;
- specify frequency values for various fire scenarios.

If necessary, an additional walkdown of fire compartments is performed and a detailed description of ignition sources is provided. For a detailed analysis of fire scenarios, the following data shall be collected for all ignition sources:

- source type (electric assembly, transformer, pump);
- configuration (dimensions, information on ventilation);

- amount of heat released during burning of source Q;
- duration of intensive burning, t;
- maximum heat release rate during intensive burning, q;
- location in relation to premise boundaries.

Each ignition source is characterized by two main factors: (1) the total amount of heat released during the source combustion – Q, kJ; (2) the maximum heat release rate during intensive burning – q, kW. The duration of intense burning t depends on the ratio of these factors. All ignition sources are subject to consideration according to the qualitative and/or quantitative screening criteria. Qualitative screening of fire sources is based on expert assessment.

It is assumed that the fire progression does not occur if all the conditions listed below are met:

- the source (electrical cabinet, enclosed equipment, etc.) is isolated, there is no ventilation, hatches, doors, etc. are closed;
- electrical cables, connected to the source, are covered by a non-combustible casing (metal pipe);
- the operating voltage is below 380 V, or the thermal load is very low (separate switches).

The main damage criteria are determined individually for each object (group of objects) of damage based on passport data, other technical documentation, or testing. Damaged objects are analyzed for the impact of the following fire factors: flame; thermal impact; smoke and other combustion products.

Affected objects located directly above the source at a height that does not exceed the height of the flame are affected by the flame.

Under analysis of failures of electrical devices, I&C, short-term deterioration of characteristics when closing circuits and possible failures under the impact of smoke are considered. This effect is temporary and operability can be restored when normal conditions are created.

2.2.4 Main results / dominant events (licensee's experience)

According to quantitative calculations, the CDF contribution in PSA Level 1 for the reactor for fires at FP is 4.6% of the integral CDF, and CDF in PSA Level 1 for the reactor for fires in LPSS is 0.3% of the integral CDF. The FDF for SFP PSA Level 1 for fires has a contribution of > 0.01% to the integral FDF.

The LERF based on the results of PSA Level 2 for the reactor of PNPP Unit 1 is 3.11E-06 1/year. The LERF based on the results of SA Level 2 for the SFP of PNPP Unit 1 is equal to 5.97E 09 1/year.

The CDF, FDF and LERF determined in quantitative calculations fully satisfy the probabilistic safety criteria established in NP 306.2.141 2008 [3] and the IAEA safety criteria for operating NPP units.

Since the main contributor to the CDF from internal fires for PNPP Unit 1 is fire compartment D2, which includes the turbine hall, and the dominant contributors to the CDF are ignitions of the turbine generator (TG) equipment, TG oil inventory and turbine driven

pump (TDP), it was recommended to implement the following measures to reduce the input of these contributors upon the analyses:

1. Consider the possibility of using non-combustible oil in the lubrication system in TG and turbine driven pump (TDP) (by analogy with serial VVER-1000/320 units).

2. Consider a measure to ensure automatic discharge of hydrogen from the generator body. The measure is aimed at improving safety related to the fire hazard of the generator due to the presence of hydrogen in the generator housing (which is used for the generator cooling). The event involves development and implementation of a scheme for automatic discharge of hydrogen from the generator body at the "Fire" signal and its removal outside the turbine hall. This measure is aimed at increasing the fire safety of the turbine hall and the stability of its building structures during a fire.

3. Improve the firefighting training of personnel in view of preventing dependent failure of the critical equipment of the turbine hall (auxiliary feedwater electrical pump (AFEP), stead dump valve to atmosphere, etc.) as a result of a fire.

2.2.5 Periodic analysis and management of changes

In accordance with the requirements of national regulatory documents [11]-[13], the fire safety analysis shall be updated and revised in full scope (both deterministic and probabilistic parts) together with the updating of the PSA every 10 years. The above-mentioned full-scope updating of the analyses shall be carried out in the context of periodic safety reviews, including reviews at the NPP. In addition, the procedure [13] for developing, implementing and updating the living probabilistic safety analysis shall also be used. Two types of updates are established for living PSA - ongoing and complete. The ongoing updating shall be performed every three years for each NPP unit.

The scope of the documentation being developed as part of the ongoing update includes analysis of power unit modifications, modifications in the integral probabilistic model (which also includes analysis of internal fires), update of all related statistical data and their consideration in the integral probabilistic model, as well as the results of quantitative assessments and conclusions on the current safety level of the power unit.

The complete updating of the living PSA shall be carried out within the timeframes established in [11] for periodic safety review, i.e. every 10 years.

2.2.6 Assessment and conclusions on fire safety analysis performed by the regulator

The fire safety analysis as part of the NPP unit safety justification is the subject of the state nuclear and radiation safety review, performed by the SNRIU in accordance with the requirements of the Ukrainian legislation.

The completeness and reliability of the information provided in the reports on the NPP unit safety justification, as well as the implementation status of safety improvement measures, are verified by SNRIU inspectors as part of state oversight measures (inspections and surveys).

The fire safety analysis of PNPP Unit 1 was verified by the SNRIU within the state NRS review of the PNPP Unit 1 Safety Analysis Report, updated for the periodic safety review of PNPP Unit 1, and the Periodic Safety Review Report for PNPP Unit 1, as well as living PSA for PNPP Unit 1 during 2021-2023.

The state NRS review resulted in the following findings:

- the scope and methodology of the safety analysis comply with the regulations and standards on nuclear and radiation safety, as well as IAEA recommendations;
- the computer models consider the current state of the power unit;
- the safety analysis results meet the safety criteria defined by the regulations and standards on nuclear and radiation safety, as well as the design documentation.

The completeness and reliability of the information presented in the Periodic Safety Review Report for PNPP Unit 1 were confirmed by the SNRIU in the framework of the inspection carried out from 21 to 25 August 2023.

2.3 Fire protection concept and its application

The defense-in-depth concept for fires is aimed at performing the following tasks at the PNPP:

– prevention of fire initiation;
– timely detection of a fire, its confinement and mitigation in the shortest possible time with automatic and manual fire extinguishing means; minimization of fire damage;
– protection of systems and equipment important to safety at the level that will make it possible to shut down the reactor during a fire and keep it in a safe condition throughout the fire and its mitigation.

The defense-in-depth concept concerning fires at the PNPP shall be implemented in the following areas:

– performance of fire safety analysis (FSA), development and implementation of associated measures to enhance the PNPP fire safety level;
– development and timely review of documentation on fire safety issues; fire training of personnel; scheduled firefighting exercises for personnel, including with firefighting units;
– a firefighting unit, one common-plant fire technical commission and 19 fire technical commissions in departments were established at the PNPP; a contract for the purchase of firefighting services from State Fire Rescue Team-1 of the SESU Main Department in the Mykolaiv region was concluded;
– PNPP facilities are equipped with external and internal firefighting water mains, fire detection and extinguishing installations, primary fire extinguishing means, a set of measures is ensured to maintain these systems and equipment in constant readiness for action as intended;
– passive fire resistance means of combating the occurrence and spread of fires within standard limits include: fire walls, partitions, doors, fire retardant valves, fire retardant mixtures, cable penetrations and fire retardant belts;
– constant monitoring of compliance with the fire safety regime is carried out at all levels.

2.3.1 Fire prevention

Fire prevention is the first level of defense-in-depth for fire protection.

2.3.1.1 Design features and prevention means

The following requirements for fire protection are implemented in the design documentation and in the operation of PNPP Unit 1:

- reduction of the fire load in NPP premises by reducing combustible substances and materials to the minimum necessary;
- prevention of conditions for generation of gas/air explosive and fire hazardous mixtures;
- organizational and technical measures to prevent the generation of various ignition sources;
- limitation of the mass or volume of combustible substances and materials and their placement in the safest way;
- use of electrical equipment fabricated with the appropriate class of explosion and fire zone in accordance with PUE [14];
- use of materials for civil structures and finishing materials that correspond to the appropriate explosion and fire hazard category of premises [15].

2.3.1.2 General overview of control and monitoring mechanisms for fire loads and ignition sources

The generation of gas/air explosive and fire-hazardous mixtures at the PNPP is prevented by the following measures:

- maintaining a safe concentration of the combustible environment;
- isolation of the combustible environment from the general volume of the premise;
- placement of fire-hazardous equipment in separate premises;
- maximum automation and mechanization of technological processes related to the circulation of combustible substances;
- use of devices to protect process equipment with combustible substances from damage and accidents (automatic disconnection).

The generation of potential ignition sources in the combustible environment is prevented at the PNPP by the following measures:

- use of machines, mechanisms, equipment and devices that does not create ignition sources in their operation;
- use of electrical equipment with the appropriate protection level in fire-hazardous and explosive zones;
- use of fast-action means for protective disconnection of possible ignition sources in the equipment design;
- application of technological process and equipment that meet the requirements of electrostatic electrical safety in GOST 12.1.018 “Occupational Safety Standards. Fire and Explosion Safety of Static Electricity. General Requirements” [16];
- arrangement of lightning protection of buildings, structures and equipment;
- use of spark-free tools when working with flammable liquids and combustible gases;
- compliance with requirements for joint storage of substances and materials;
- reduction in the determining scope of the combustible environment below the maximum allowable flammability level.

The mass or volume of combustible substances and materials at the PNPP is limited by the following measures:

- reduction in the mass or volume of combustible substances or materials located in the premises;
- arrangement of emergency draining of fire-hazardous liquids and emergency discharge of combustible gases from process equipment;
- arrangement of explosion protection systems on process equipment;
- periodic cleaning of premises, communications and process equipment from combustible waste, dust deposits, etc.;
- removal of fire-hazardous industrial waste;
- replacement of flammable and combustible liquids with non-flammable ones.

The electrical systems at the PNPP, including fire protection features, were designed in accordance with the requirements of PUE 2017 “Rules for the Design of Electrical Installations” [14]. All cable products used at PNPP (in safety systems, in systems important to safety, normal operation systems that are not related to safety) do not spread combustion.

Organizational measures to prevent fires at the PNPP and to maintain the appropriate fire protection mode include:

- fire safety briefings are conducted for all PNPP employees;
- fire safety training and subsequent examination are conducted for all PNPP employees, including employees involved in fire-hazardous activities;
- common-plant instruction on fire safety measures was developed;
- instruction on fire safety measures in administrative and service premises was developed;
- instruction on fire safety measures for welding and other hot operations in NPP departments was developed;
- instruction on hot operations at PNPP explosive and fire-hazardous facilities was developed.

In order to detect a fire at an early stage, extinguish a fire with various fire extinguishing systems, and organize the evacuation of people with the help of notification systems, active fire protection systems, which are the second stage of defense-in-depth protection, are installed at the PNPP.

At the same time, it should be noted that effectiveness of active fire protection systems is ensured only in combination with the arrangement of passive fire protection systems, which are the third level of defense-in-depth protection of PNPP.

2.3.1.2.1 Example of implementing fire prevention means

As an example, an implemented measure included the replacement of combustible insulation of the roof over turbine hall No. 1 with non-combustible one. In accordance with the requirements of para. 4.2.3 [17], fire-resistant material (B1) was used as insulation for the roof of turbine hall No. 1, and non-flammable material (RP1) was used as vapor and hydraulic insulation. In order to bring the condition of insulation covering turbine hall No. 1 into compliance with the requirements of para. 4.2.3 [17], C(I)SIP Measure No. 27110 “Replacement of the Combustible Insulation of the Turbine Hall Roof of Unit 1” was

implemented. The objective of this work was to ensure the fire safety of the turbine hall No. 1 roof by replacing the combustible insulation with non-combustible materials. The implementation of this measure increases the operational reliability of the turbine hall building, since it involved the use of non-combustible PAROC insulation and coating from the ZhKM mastic compound, which belong to the materials of flame propagation group RP1 and flammability group G1.

C(I)SIP Measure No. 27110 “Replacement of the Combustible Insulation of the Turbine Hall Roof” at PNPP Unit 1 was completed in full, in accordance with Technical Decision TR.1.0917.1508 “On Roof Repair” of 27 September 2007.

This modification is an effective solution for bringing the building structures of the PNPP Unit 1 turbine hall roof in compliance with the regulatory requirements.

2.3.2 Active fire protection

The active fire protection systems of PNPP Unit 1 include:

- automatic fire alarm system;
- automatic fire extinguishing systems (gas for local and volumetric extinguishing, water);
- notification and evacuation management systems;
- primary fire extinguishing means – fire extinguishers and fire hydrants.

At PNPP Unit 1, active fire protection systems are arranged according to the principles of redundancy (parallel trains that perform the same function), independence, backup and physical separation and the single-failure principle.

The automatic fire-extinguishing installation (AFEI) includes an automatic fire alarm system (AFAS) for fire detection and fire protection automatics (FPA) for AFEI control and monitoring.

2.3.2.1 Fire detection and fire alarm

In accordance with NP 306.2.141-2008 “General Safety Provisions for Nuclear Power Plants” [3], equipment of the automatic fire alarm system (AFAS) for SS premises has a classification mark of 3NO (system important to safety) and that for normal operation premises is denoted by 4N. AFAS is designed to ensure the fire safety of personnel, buildings, structures, and PNPP process equipment through early detection of the fire source, alarming of its occurrence to operational personnel to take the necessary measures, and, if necessary, formation of teams to control fire extinguishing, ventilation, air conditioning installations, notification on a fire.

AFAS is an I&C microprocessor system that implements its functions using information received from fire detectors installed in protected premises and buildings. The AFAS has a modular structure and a self-diagnostic system to ensure prompt identification and elimination of malfunctions without disrupting the AFAS operation. Fault detection is performed with precision to the hardware module or fire detector. The AFAS is designed as an autonomous system, with the organization of communication with other information and I&C systems of firefighting automatics of the power unit. The AFAS collects, displays, documents, and archives information regarding signals generated in case of violations of the AFAS safe operation, protective action commands, and prohibition or disconnection commands.

To detect a fire in the SS cable premises, installation of smoke detectors is envisaged. FACP1 fire alarm boards from the FAS1 system were used as receiving stations. Blocking, control and alarm circuits from the information source to generation of commands in power valve distribution equipment (PVDE) are arranged in a single-channel form in each SS train.

Fire automation means and AFAS are concentrated on special panels of SS trains, located in the MCR and premises of electrical devices of SS trains. AFAS devices ensure constant automatic self-monitoring of readiness for operation and generation of fault signals. The automatic fire alarm system is connected via inverters to storage batteries, which are an emergency uninterruptable power supply source in case of blackout.

Modernization of the AFAS in SS premises equipped with automatic fire extinguishing control (AFEC) systems, which was implemented under C(I)SIP Measure 27101, provides for the arrangement of a three-train AFAS in the protected premises. Two trains of this system directly induce the automatic start of the fire-extinguishing system. The main objective of Measure 27101 was to implement new technical solutions for the AFAS and AFEC systems aimed at replacing obsolete equipment with up-to-date equipment certified in Ukraine that meets special requirements for NPP equipment and devices.

The FAS1 system includes fire alarm control panels (FACP1), fire detectors of various types and modules for various purposes (engineered automation features (EAFs)). FAS1 system. FAS1 is designed to ensure fire safety of personnel, buildings, structures, and NPP process equipment by early detection of a fire, signaling its occurrence to operational personnel for taking necessary measures, and generating commands to control water fire extinguishing installations of premises, disconnect ventilation and air conditioning, provide fire notification, etc. FAS1 is an instrumentation and control system that implements its functions using information received from fire detectors installed in protected premises and structures. In the implementation of Measure 27101, new EAFs were installed to replace the obsolete ones.

To receive signals on actuation of fire detectors, new fire alarm control and indicating devices (FACP1) were installed.

Under the measure, to meet the redundancy principle, three fire alarm loops are envisaged for each SS with water fire extinguishing, two of which are fire extinguishing automation loops and one is an alarm loop. The loops are connected to three different FACP1. FACP1 to which the automation loops are connected are located in the premises adjacent to the protected systems (for example, if the automation loops protect the SS1 premises, then FACP1 to which they are connected are located in the premises of SS2 and SS3. In turn, the power supply of these FACP1 is also arranged from SS2 and SS3). The alarm loop is connected to the FACP1 of its system, which is located in the MCR.

The FACP1 division in adjacent systems allowed further implementation of C(I)SIP Measure 27106 for separate, automatic control of fire extinguishing valves from different SS. The implementation of Measure 27101 allowed bringing the automatic fire alarm system of the SS premises of PNPP Unit 1 into compliance with the requirements of paras 6.1.2 and 6.1.4 of VBN V.1.1-034-03.307-2003 “Fire Protection. Fire Safety Standards for the Design of VVER Nuclear Power Plants”, para. 10.11.5 of NP 306.2.141-2008 “General Safety Provisions for Nuclear Power Plants”, and DBN B 2.5-56:2010. State Construction Standards of Ukraine “Fire Protection Systems”.

C(I)SIP Measure 27105 “Modernization of the Automatic Fire Alarm System for Normal Operation Premises” was implemented for Unit 1 normal operation premises.

The implementation of Measure 27105 was associated with the need to replace the hardware of automatic fire alarm system (AFAS), which is part of the fire automatics of water fire-extinguishing units and control of engineering systems of the main buildings and structures of NPP power units during a fire, with those that meet the special requirements for NPP devices and equipment. The following was performed under the measure:

1. Targeted smoke detectors are installed in the normal operation electrical premises (deaerator compartment-1, turbine hall-1), thermal fire detectors are installed in the process premises of the oil facilities (turbine hall-1, special building), thermal fire detectors are connected to the AFAS loops through intrinsically safe modules. Manual targeted detectors are installed near the process equipment in the premises of the oil facilities (turbine hall-1). ALMAZ-type flame detectors are installed on the columns in the turbine hall-1 premise. The detectors monitor the turbine generator area and are installed on the columns.

2. The AFAS and AFEC of the cable compartments at elevations -6.00, -4.10, and 5.12 are arranged on the basis of FACP1, which is installed on the 6NPE panel, MCR-1. From the 6NPE panel, it is possible to remotely control the valves of these premises. The valves can be remotely controlled from the PVDE assemblies, which allows controlling the valves without FACP1. The 6NPE panel also displays the valve position indication (open, closed).

3. The AFAS and AFEC of the turbine generator oil facilities and fire protection automation of Unit 1 transformers are based on the FACP1 installed in the 7NPE panel. It is also possible to remotely control the valves of these premises from 7NPE panel.

To eliminate the destructive effect of temperature on the fire detector housings, the AFAS of premise 1A203 was arranged using existing thermocouples in combination with existing devices located on the direct current panels 1ShPT-1, 3. Information on temperature increase (setpoint on the control panel ≤ 1000 C) is transmitted from the control panel devices to the FACP1 located in the 7PNE panel, in MCR-1.

4. The AFAS of the premises with normal operation electronic and electrical equipment (electrical premises of deaerator compartment-1, boron unit-1) is based on the FACP1, which is installed in the 8NPE panel.

5. The AFAS of service premises and the AFAS of corridors, stairways (deaerator compartment-1, boron unit-1) is based on the FACP1, which is installed in the panel 9NPE in MCR-1.

For all installed FACP1, a capacity according to the number of connected signal lines with a margin of at least 20% of the available capacity is envisaged.

All fire alarm loops are made of fire-resistant, shielded cable with a fire resistance limit of at least 180 minutes in the mode of direct exposure to flame and at least 90 minutes in the mode of standard temperature conditions. All power supply and control cables are made of fire-resistant, shielded cable with a fire resistance limit of at least 180 minutes in the mode of direct exposure to flame and at least 30 minutes in the mode of standard temperature conditions.

Structures (panels, cabinets) in which FACP1 re installed are made in accordance with the requirements for seismic resistance.

For normal operation premises of Unit 1, C(I)SIP Measure 27105 “Modernization of the Automatic Fire Alarm System of Normal Operation Premises” was implemented to replace obsolete AFAS features with the ones meeting special requirements for NPP devices and equipment, which made it possible to bring the AFAS of normal operation premises (deaerator

compartment, turbine hall, special building) into compliance with [17] (para. 6.1.1, Annex E, para. 1.1.1), [3] (para. 10.11.5), [17], and IAEA recommendations [19] [20].

The reconstruction and modernization of AFAS for the SS and normal operation premises improved the fire safety of both Unit 1 and the PNPP in general. The maintenance of AFAS at the PNPP is organized qualitatively and at a high level and is carried out in accordance with the AFAS maintenance regulations [21].

The AFAS maintenance at the PNPP is carried out in accordance with the "Regulations for the Maintenance of Automatic Fire Alarm Installations at PNPP" (RG.0.0009.0789), which was developed in accordance with the License Conditions approved by Order No. 886 of the State Emergency Service of Ukraine of 25 December 2009.

2.3.2.2 Fire mitigation

To ensure active fire protection, automatic fire extinguishing installations (AFEI) are used to protect premises of safety systems (SS) and normal operation systems. The fire protection automation system includes a production and firefighting pumping station (PFPS) located in a separate building, which is the main water supplier to the AFEI systems. The normal PFPS state is an operating reserve.

The PFPS equipment was manufactured in accordance with NP 306.2.141-2008 [3] and is classified as a system important to safety.

The PFPS includes two water storage tanks with a capacity of 2000 m^3. The PFPS pressure collector is connected to the firefighting water line of the PNPP industrial site by two independent DN500 water pipes. Valves are installed at the connection points of the PFPS pressure collector lines, which can be turned off if necessary. The water storage tanks (WST-1, WST-2) are filled through two DN250 water mains from the pressure collectors of Units 1 and 2.

Both automatic water fire extinguishing and gas fire extinguishing systems are used in Unit 1 premises.

Bellows isolation valves are used as control units for automatic fire extinguishing installations (AFEI) in the fire extinguishing directions of the SS premises.

The reactor compartment (RC) automatic fire extinguishing installation is mounted in the RC cable vaults, in the premises of cable penetrations (A503, A505, A305), in the premises of MCP emergency oil tanks with cable routes.

The turbine hall 1 AFEI is located in the turbine oil piping tunnel, in upper and lower levels, in the premise of the Unit transformer oil coolers, on the equipment of turbine generator oil systems and oil storage facilities of the turbine generator. The AFEI of deaerator compartment-1 (DC) and boron unit-1 (BU) is mounted in the cable premises of DC at elevations: -6.40, -4.00, +5.12, and in the BU premises of the first, second, and third SS at elevations +16.80, +32.00. The AFEI of the standby diesel generators is located in the fuel tank premise, in the process premise at elevation -3.60 and in the diesel generator premises of the turbine halls.

Sprayed water is used to protect the cable ducts of the SS and normal operation premises.

Under normal operation of the power unit and in the event of accidents not related to fire, the fire extinguishing system is in standby mode, and the fire detection (fire alarm), control and monitoring systems are in "standby" mode.

In case of a fire, the fire extinguishing system is automatically actuated by fire detectors installed in the premises. In this case, the fire water supply pump is switched on and the valve in the appropriate direction is opened.

The automatic fire extinguishing installation includes:

- system of underwater, supply and distribution deluge piping;
- manual and electricity driven isolation valves;
- firefighting water pumping station (FWPS).

The motors of fire pumps and electric valves are powered according to category 1 of PUE [14], in case of loss of normal power supply, the electric valves of the fire extinguishing system are powered from the network of the group 2 of reliable power supply (standby diesel generators), pumps with a diesel engine are switched on manually. The isolation valves are powered from the network of group 1 of emergency power supply systems (from a battery via inverters).

The criterion for fulfilling the tasks assigned to the fire extinguishing system is to prevent the failure of more than one SS train due to impact of fire on it.

Estimates of the inertia of the system from the moment of signal receipt to the moment of water supply to the fire epicenter does not exceed 3 minutes. Effective spraying conditions, the speed and sufficiency of the extinguishing agent are ensured by creating a working pressure in before the sprinklers of 0.2 - 0.4 MPa, the estimated spraying intensity of at least 0.12 l/s per m^2 of the building floor and arrangement of sprinklers to ensure spraying of all cable lines, taking into account spraying maps.

When the AFEC equipment operates as intended, its operability should be restored within 24 hours. In case of non-readiness, the restoration of the AFEC performance may be extended up to 72 hours with permission of the PNPP Chief Engineer.

In the FWPS premise (premise 003), 2 FWPS pumps, 2 service water supply pumps (SWSP), a local control board (LCB), automatic load transfer (ALT) panels, PVDE assemblies, PFPS pressure collector, pump piping with isolation valves, ventilation and heating equipment are located. The PFPS building is made of precast reinforced concrete and has three separate premises separated by fire partitions.

The compartment of emergency diesel-driven fire pumps (EDDFP-1, 2) (premise 002) is divided by a fire partition into two isolated cells 002/1 and 002/2. Accordingly, EDDFP-1 and EDDFP-2 are located for both cells, with diesel drives of the D1250-125a type and A2-450M-4 500 kW electric motors. Both cells contain batteries for pumping unit start-up system, ventilation and heating equipment, process piping and valves. Cell 002/1 also contains a rectifier designed to charge the starter batteries.

Similarly, the diesel-driven EDDFP service premise (premise 001) is divided by a fire barrier into two isolated cells, 001/1 and 001/2. Both cells contain the systems that ensure operation of EDDFP-1 and EDDFP-2, respectively: fuel and oil storage tanks, cooling expansion tanks, piping and valves for diesel systems, and ventilation and heating equipment.

The fire partition separating the cells and the fire doors installed in it limit the spread of fire and combustion products. The PFPS building is made of precast reinforced concrete and has three separate premises separated by fire partitions.

On the adjacent territory, on the side of Row "B" of the PFPS building, there are two underground tanks with a capacity of 2000 m^3 each and a wet well for water intake by

firefighting equipment with a capacity of 2 m³. The tanks are connected by suction collectors of fire pumps, divided into sections by manually operated valves. The tanks are made of iron-concrete, rectangular cross-section, covered with a soil layer and are designed to store water in the volume of 4000 m³ for the PNPP fire extinguishing system for three hours of uninterrupted operation of one pump. The bottom of the tanks is sloped to the drainage sump. Each tank has two manholes for repair and maintenance, as well as two roof hatches to provide lighting during work inside the tank. At the top of the tanks there are overflow pipes through which the excess water is poured into the drainage system. The drainage sumps of the tanks are connected to the drainage system by DN150 piping with isolation valves. The water level in the tanks is measured using standard measuring devices of the PVC-01/4BAS type, which are installed on LCB panel 2 of the PFPS. Fire pumps are actuated automatically by the detectors of the fire extinguishing system automation, which protect it, remotely by the "START" key in MCR-1, and manually at the site (PFPS LCB). When the pressure at the pump head drops below 4.0 kgf/cm², the backup fire pump is turned on. In case of an emergency shutdown of the operating fire pump, the backup pump is automatically turned on by ALT.

Maintenance of the AFEI systems at the PNPP is organized qualitatively and at a high level, and is performed in accordance with the Regulations [21].

In accordance with the requirements of para. 1.4.2 of Annex E [17], the premises of the special systems of the main building are subject to equipment with stationary gas fire extinguishing installations. The NFME premises of the first set (1DO830/2), NFME of the second set (1UB902), and ECR (1DO807) of Unit 1 are equipped with non-automatic gas fire-extinguishing installations (NFEI). The NFEI is a system important to safety. The NFEI is designed to detect and extinguish fires in the premises where control boards and electronic and electrical equipment are located. Stationary NFEI are installed in premises without full-time presence of maintenance personnel, with a specific fire load of no more than 200 MJ/m², including cable communications.

The NFEI operation principle is based on the fire extinguishing in a separate premise by forming a fire extinguishing gas concentration throughout the premise. Khladon-125 (HFC-125) is used as the extinguishing gas. To prevent the fire extinguishing gas from flowing into other premises, fire retardant valves (FRVs) are installed at the intersections of ventilation air ducts (except for transit ones) with enclosing structures. FAS1 is the instrumentation system for the NFEI, which ensures automatic fire detection in the protected premises using AFAS. In accordance with NP 306.2.208-2016 [22], FRVs belong to safety class 3 and seismic resistance category 1, and are classified as 3N. FRVs have fire resistance limit of at least 120 minutes.

NFEI equipment includes:

- spray nozzles that ensure uniform distribution of extinguishing gas in a premise;
- feeding piping;
- distribution piping;
- piping collector;
- high-pressure hoses;
- gas fire-extinguishing modules GFEM-65-80-50-(E, P, PK)-01-A and GFEM-65-100-50-(E, P, PK)-01-A equipped with electric start-up (E), pneumatic start-up (P), pneumatic end start-up (PK) with extinguishing agent cylinders provided with lock and release devices (LRDs).

The gas fire-extinguishing modules included in the NFEI (GFEM-65-80-50, GFEM-65-100-50) consist of cylinders filled with the Khladon-125 extinguishing agent and LRDs installed directly on the cylinders. LRD is equipped with a pressure gauge and a pressure transducer of the A-10 type, which is designed to automatically monitor the pressure to detect leaks of the extinguishing gas from the module. The Khladon-125 extinguishing agent is in the cylinder under the pressure of the working gas, nitrogen displacer, whose dew point is not higher than 40 °C, and is released from the cylinder when the LRD working membrane is opened.

The service life of the gas fire extinguishing module (GFEM) is at least 15 years, under the condition of mandatory periodic certification of cylinders for storing the extinguishing gas and replacement of all LRD rubber parts every 10 years.

Annunciators of light and sound warning, alarm and light technological alarms “GAS! DO NOT ENTER!" and "GAS! EXIT!" are installed at each entrance to the protected premise. When the "ALARM" signal appears, the ventilation systems are disabled and the FRVs on the ventilation air ducts are closed within 30 seconds before the extinguishing agent is released into a premise. Limiting switches SQ1, SQ2 are installed in the door frame to control the door position so that the lever roller rests against the door panel when the door is closed.

When one AFAS annunciator is triggered, cell L78 (FIRE, ATTENTION) lights up in the MCR on panel 19PE, and when two annunciators are triggered, cell L33 (FIRE!!!) lights up. The MCR operators identify the premise on the 8NPE panel and give a command to the shift supervisor of the thermal automation and measurement department (TAMD SS) to check the information. Having identified a fire in this premise, the operating personnel, using a remote manual start-up device (a button in the cabinet or a push-button control station near the door at the entrance with a 30-second delay required for personnel evacuation), and provided the doors in the premise are closed, sends a control impulse to open LRDs on the extinguishing gas cylinders. The FRVs close automatically (in case of power outage).

A signal from the remote manual start-up device opens the LRDs on the cylinders of the modules equipped with electric start-up device.

The NFEI is actuated if the following conditions are met:

- the door to the protected room is in the closed position;
- warning signals “GAS! EXIT!” AND “GAS! DO NOT ENTER!” are on;
- no people are present in the protected premise;
- the alarm system is connected to cabinets 01UI11GH003, 01UI11GH004, 01UI11GH005 cabinets and the push-button control station;
- voltage in the power supply circuits;
- activation of the “GAS IS BEING RELEASED” setpoint.

After termination of the NFEI operation in the premise and reduction of the gas mixture temperature to 60 °C, the mobile ventilation unit RSS 10/10-P2 and flexible hoses are manually connected. The delivery hose of the mobile unit is connected to the air duct of the UV52D04-UV52D04a system in the building of the boron unit for the NFME2 premises or to the 1UV57D02 smoke removal system in the deaerator compartment for the ECR and NFME1 premises. The suction hose from the mobile unit is drawn into the lower zone of the premise through the open door. After that, the exhaust system UV52D04-UV52D04a or the exhaust system 1UV57D02 is actuated. After that, the mobile unit is turned on. At the same time,

personnel working with the mobile unit must use personal protective equipment to exclude the possibility of poisoning.

These operations are performed by the TAMD operational personnel. The exhaust systems UV52D04-UV52D04a and 1UV57D02 are put into operation by the personnel of the ventilation and air conditioning department (VACD) by command of the TAMD Shift Supervisor.

After the NFEI is triggered, the first to enter the premises is the fire unit crew accompanied by TAMD representatives, and everyone entering the premises must wear insulating gas masks. After inspecting the fire area, at the request of the TAMD Shift Supervisor, the personnel of the chemical department laboratory analyze the air in the premise for oxygen.

In the absence of combustion products and extinguishing agents in the premise air and in the presence of normal oxygen concentration, the Stage Shift Supervisor (SSS) gives permission for the TAMD personnel and, if necessary, maintenance personnel to enter the premise. The SSS, TAMD SS and Electrical Department SS make a record of the NFEI system actuation in the operational log, draw up a certificate, and inform the management of the NPP, TAMD and Electrical Department.

In accordance with [23], operational and technical maintenance of the NFEI is performed by the TAMD personnel who have undergone training, knowledge testing on NFEI and are familiar with its equipment. During operational maintenance, a visual inspection of the NFEI equipment (pressure gauges, piping, FRVs, doors) is performed on a monthly basis and the following is checked:

- the state of piping fasteners;
- the state of the nozzles for deformations and cleanliness;
- pressure in the gas fire extinguishing modules (if the nitrogen pressure decreases by more than 10% of the nominal value at (20 ± 2) °C, the module must be charged to full capacity or recharged);
- presence of seals on the safety switch for manual start-up;
- integrity of high-pressure hoses;
- the module inflation pressure.

In accordance with the regulatory requirements [24], a separate high-pressure fire water supply system is envisaged at PNPP for external and internal fire extinguishing, for operation of cooling equipment during a fire of building structures and oil tanks, as well as for AFEI, which is not related to safety systems.

Water supply to the fire water supply system of Unit 1 is ensured by the nonessential service water (NSW) system, which includes:

- three NSW pumps located in the building of power unit pumping station 1 (UPS), which ensure operation of the NSW system of Unit 1 (1VG11D01, 1VG12D01, 1VG13D01);
- three water filters FV 800 1VA11 13N01 (two in operation, one in standby) designed to purify coarse particles of cooling water supplied to equipment.

The fire water supply network at the PNPP industrial site and inside the main building is arranged as a ring-type water supply system divided by valves into repair areas. The external

fire water supply system is designed to provide reliable water supply to the internal fire water supply networks to buildings and structures at the NPP site, as well as to allow water intake by firefighting equipment and its supply through laid hose lines from the fire hydrant-mounted fire column to the fire extinguishing location.

The fire water supply system is designed according to the ring-type principle, divided by sectional valves to disconnect individual sections for repair and maintenance without disrupting the water supply to the site facilities, and is equipped with wells with fire hydrants placed in them. In total, 56 fire hydrants are installed at the PNPP industrial site.

Fire water supply system maintenance is performed in accordance with document [25]. Temporary disconnection of fire water supply sections for repair and testing, as well as pressure reduction in the network below the standard value is performed according to the plant application, with the permission of the NPP Chief Engineer, after notification of the 27th State Fire Rescue Unit (SFRU-27) (disconnection duration, boundaries of the disconnected section and numbers of disconnected fire hydrants and inlets to buildings are reported). At the same time, measures to ensure reliable water supply for the entire disconnection period are taken.

In case need to temporary disconnect the building from the fire water supply, compensatory measures for fire protection of the facility are developed and implemented.

Pathways and roads to fire hydrants have solid pavement and are kept clear.

Each fire hydrant is equipped with an indication sign. Manhole covers are closed with standardized lids with hidden handles. A metal manhole pointer (flag) is securely attached to the manhole cover and is used to facilitate the removal of the manhole cover.

Fire hydrant covers shall be painted red and cleaned of dirt, ice and snow in a timely manner. The use of fire hydrants for household needs is prohibited.

Hydrants shall be installed vertically in wells directly on the water supply network. The distance from the hydrant cover to the top of the manhole cover shall not exceed 40 cm and be not less than 15 cm. In this case, the axis of the installed hydrant is located no closer than 17.5 cm and no further than 20 cm from the neck of the well manhole. In turbine hall-1, the main fire water supply network is a ring-type network made of steel DN300 pipes with isolation valves.

Water intake is performed from the collector to the fire extinguishing systems, lubrication systems equipment, unit transformers, cable compartments, fire hose cabinets (FHC) and water cannons.

In the external fire stairway, along row A, axes 9 and 23, there are DN80 dry pipes leading to the turbine hall roof, and along axis 3, row D, to the deaerator compartment roof, equipped with GM-80 heads at the upper and lower ends of the dry pipe.

Water supply to the roofs of the turbine hall and the deaerator compartment has been completed. Fire hoses are located in a metal fire cabinet at the entrance to the deaerator compartment roof from the side of special building-1. The water supply valve to the turbine hall roof is located in the special building-1, at elevation +50.00.

In accordance with the requirements of para. 5.5.10 [17], the following buildings of Unit 1 are provided with an internal fire water supply system with fire hydrants installed on it (188 FHC): turbine hall, special building, standby diesel generator building, deaerator building, boron unit, UPS-1.

Fire hose cabinets (FHCs), under proper conditions, are an effective means of extinguishing fires with a permanent water supply source. They are especially important in the

initial stages of a fire and can be used effectively by an untrained person. FHCs have a long service life if properly maintained.

In accordance with the requirements of NAPB 05.026-2010 “Instructions on the Storage and Use of Primary Fire-Extinguishing Features at Enterprises of the Ministry of Fuel and Energy of Ukraine” [26], fire hydrants are equipped with fire hoses and barrels enclosed in cabinets that are sealed. The fire hydrant cabinet door bears the letter index "FHC", the serial number of the fire hydrant, and the telephone number to call the fire department. Fire cabinets have ventilation openings and can be visually inspected without opening them.

Fire hoses are kept dry, well rolled and attached to cranes and barrels. Every six months, the hoses are re-rolled with a change of folding location.

In the turbine hall, at elevations 0.00, +7.20, +8.40, as well as in the deaerator compartment-1 at elevation -4.00 (special buildings-1, 2, 3), the fire hoses used in the FHC are grounded. The grounding has a reliable fastening and must be free of damage.

Maintenance and testing of fire hydrants by means of water injection shall be carried out by the dedicated department’s personnel at least once a year. The procedure for checking fire hose cabinets is specified in [27] and [28]. After the inspection, a record is made in a special logbook.

In accordance with the requirements of para. 10.4.4.2 [29], turbine hall-1 is equipped with water cannons designed to cool the load-bearing metal structures of the turbine hall.

In accordance with para. 4.4.10 [30], a primary firefighting means (PFFM) is a technical means, substance, material, or their combination suitable for human use to localize and (or) eliminate a fire at its initial stage.

In accordance with the requirements of para. 10.5.4 [29] and Section V [31], all buildings, structures, premises, and process equipment are equipped with primary firefighting means - fire extinguishers. A total of 8235 fire extinguishers are in use at the PNPP. At the PNPP, fire extinguishers are operated and maintained in accordance with the requirements of [26], [29], and other regulatory documents of Ukraine on fire safety. Fire extinguishers are inspected during their service life at least once a month by a person responsible for fire safety.

In premises with technological processes that may result in the formation of gas, dust or vapor-air mixtures under an emergency, fire extinguishers are installed outside the premises, by the entrance. In premises with permanent presence of people, fire extinguishers are located inside the premises, preventing the creation of obstacles to the evacuation of people. In premises with temporary occupancy, fire extinguishers are located outside the premises or at the entrance (exit).

Portable fire extinguishers shall be placed by hanging using brackets on vertical structures at a height of no more than 1.5 m from the floor level to the bottom end of the extinguisher and at a distance from the door sufficient to open it completely, or installed in fire hose cabinets, firefighting equipment stands, stands, racks and special cabinets.

To indicate the location of fire extinguishers, there are directional signs in accordance with [32]. The signs are located in prominent places, at a height of 2-2.5 meters from the floor level, both inside and outside the premises.

Examples of improving fire suppression means.

In order to bring the water fire extinguishing installations of the safety systems at Unit 1 into compliance with the requirements of [3] (paras. 10.11.4, 10.11.9), [17] (para. 2.4, last para., 5. 5), recommendations of the IAEA Report [33], to improve fire safety and the safety

level of PNPP Unit 1 in general, C(I)SIP Measure 27106 was implemented to improve the fire safety system, namely to introduce redundancy in the main fire extinguishing units of the safety systems of PNPP Units 1 and 2 [34].

The cable premises of the safety systems located in the reactor compartment (RC) and deaerator compartment (DC) are equipped with an automatic water fire-extinguishing system. Trigger and release valves are grouped into separate units and are located at the 0.000 elevation of the boron solution storage building and the turbine hall of the main building.

The isolation valves were replaced with carbon steel valves for nuclear power plants. The installed valves ensure the supply of extinguishing agent (water) to the dry pipe part of the automatic fire extinguishing system and act as a shut-off device in the closed position of the valves. Since the installed system has a separate redundant power supply, separate routing of communication cable lines, and 2 supply piping with isolation valves for each compartment, in the event of single cause failures of the modified system and due to general cause failures, the system operation will not be disrupted. In addition, the construction part of the premises where the equipment is located is designed to ensure resistance to such factors as earthquake, external shock wave, hurricanes, etc.

The valves on water fire extinguishing piping of the SS cable premises located in the RC and DC, and the premises of the oil equipment of the RC MCP are controlled:

- automatically when the fire alarm is actuated;
- remotely from the MCR;
- at the place of installation of the valve.

Under actuation of a fire alarm in one of the SS trains, automatic actuation of fire extinguishing installations prevents simultaneous water supply in more than one direction of the SS premise.

As a result of this modification, the fire safety of Unit 1 was upgraded, and the safety level of the PNPP as a whole was enhanced.

The implementation of Measure 27106 allowed bringing the water fire extinguishing systems into compliance with the requirements of [3] (paras. 10.11.4, 10.11.9 [17] (para. 2.4, last para., 5.5), recommendations of the IAEA Report [33].

The measure allowed the premises with electrical and electronic equipment for automated process control to brought into compliance with the requirements of [17] (Annex E, para. 2.5).

Under implementation of C(I)SIP Measure 27103 “Provision of NPP Premises Containing Electrical and Electronic Equipment with Stationary Gas Fire-Extinguishing Systems”, the non-automatic gas fire-extinguishing installations (NFEIs) were upgraded. The main objective of Measure 27103 was to introduce fire protection for equipment and cables in the premises with NFME, control cabinets, information computer systems, and ECR. The implementation of Measure 27103 involved the following activities:

- installation of fire detectors, warning units, and path breakers;
- installation of the process part of the NFEI (cylinders, pipe routing, isolation valves, etc.);
- installation of isolation valves for ventilation and air conditioning systems;
- installation of ventilation systems with mechanical inducement to remove extinguishing agent and combustion products;

- sealing (or replacement) of doors, openings (if necessary);
- pre-commissioning of newly installed equipment.

The NFEI operation is based on the principle of protection against fire propagation by creating concentration of gas fire extinguishing agent in the entire volume of the protected premises.

Implementation of the measure (first stage, performed in the framework of the C(I)SIP) allowed bringing the premises with electrical and electronic equipment for automated process control into compliance with the requirements of VBN V.1.1-034-03.307-2003 “Fire Safety Standards for the Design of VVER Nuclear Power Plants” (Annex E, para. 2.5).

The activities performed at Unit 1 increased the reliability of the power unit in terms of timely detection of fires and effective prevention of fire spread and suppression, thereby promoting conditions for ensuring nuclear and radiation safety of the NPP and preserving the integrity of electrical and electronic equipment.

2.3.2.3 Administrative and organizational issues concerning fire protection

Coordination of activities associated with fire safety and their supervision at NPPs is entrusted to the Chief Inspector – Head of the Occupational Health and Fire Safety Service of the PNPP. The Fire Safety Department is a structural unit of the Departmental Oversight and Fire Safety Service (FSD DO&FSS). The Fire Safety Department is managed by the Department Head. The Head of FSD DO&FSS directly supervises the Department personnel according to the staffing list: senior engineer-inspector, 3 engineers-inspectors, category 1 technician.

The organizational structure of the PNPP Departmental Oversight and Fire Safety Service and fire safety oversight functions of FSD DO&FSS personnel are presented in the following documents: PL.0.0037.0052 “Provisions on the Departmental Supervision and Fire Safety Service” [36] and PL.0.3707.0069 “Provisions on the Fire Safety Department” [37].

In accordance with [37], Heads of NPP departments are obliged to: accept the prescriptions (inspection reports) of the FSD DO&FSS for mandatory and unconditional execution and, in case of disagreement with the requirements set forth therein, draw up an appeal to the person authorized to cancel the issued prescription within five days from the date the prescription was delivered;

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- resolve comments of the FSD DO&FSS personnel received during the agreement of operational, maintenance, adjustment and other documentation;
- provide, on a monthly basis, the necessary reporting documentation on the fulfillment of administrative documents of PNPP and Energoatom, prescriptions of state oversight bodies, and prescriptions issued by the FSD DO&FSS;
- take appropriate response measures (within their rights) to violations or non-fulfillment by their employees of the established fire safety regime, requirements of fire safety rules and other regulations in force in this area.

The FSD DO&FSS personnel, jointly with officials responsible for fire safety in the plant departments, fire technical commission members, and SFRT-1 specialists, conduct inspections

of plant departments, as well as walkdowns and inspections of workplaces, equipment, premises, buildings and structures, in accordance with the schedule. During these inspections and walkdowns, compliance with rules, regulations, production and labor instructions, availability and operability of fire-extinguishing and fire protection equipment, availability and condition of technical documentation, etc. are inspected. Based on the inspection results, the heads of departments receive prescriptions with deadlines for eliminating deficiencies; deficiencies of sensitive nature are eliminated immediately or identified comments are registered in the OKO electronic system, setting deadlines for their resolution. If necessary, the identified deficiencies are submitted for consideration at a meeting of the common-plant fire technical commission.

In accordance with the requirements of PL.0.0037.0133 “Provisions on Inspections of Workplaces, Equipment, Rooms, Buildings and Structures” [38], NPP technical managers and heads of departments should conduct periodic inspections and walkdowns of workplaces. Administrative control is established at the plant to minimize hazards; for this purpose, daily, weekly, and monthly inspections of the fire protection state of facilities and equipment are performed, and identified deficiencies are recorded in operational logs and the workplace walkdown log.

The Director General is responsible for overall fire safety at the PNPP. The persons responsible for fire safety of the NPP site, buildings and premises, structures, communications and equipment of individual plant units are appointed by Order of the NPP Director General.

The Director General, authorized heads of departments and other persons perform their duties in accordance with their job descriptions to ensure fire safety. They are obliged to:

- develop comprehensive measures to ensure fire safety, implement advances in science and technology and positive experience;
- ensure compliance with fire safety requirements set forth in standards and rules and compliance with requirements of resolutions (prescriptions), consider proposals of state fire safety oversight bodies;
- organize training of employees on fire safety rules and promote measures to ensure them;
- maintain fire protection and communication equipment, fire appliances, equipment and inventory in good condition, and prevent their misuse, except in cases of natural disasters, accident prevention and for educational purposes;
- take measures to introduce automatic fire detection and suppression equipment;
- conduct internal investigations of fire incidents.

The NPP has an organizational structure [39], which defines the management hierarchy and powers in the field of fire safety assurance and the procedure for interaction with other PNPP departments.

The process of ensuring fire safety at the PNPP is regulated in the document [40].

In accordance with the Fire Safety Rules in Ukraine [42] and the Fire Safety Rules in Operation of Nuclear Power Plants [29], IB.0.3707.0003 “Common-Plant Procedure for Fire Safety Measures” [41] was developed at the PNPP to establish the appropriate fire regime and define:

- places for smoking, procedure for using open flame and household electric heating appliances;

- procedure for temporary hot operations, including welding;
- rules for driving and parking vehicles;
- procedure for cleaning combustible dust and waste, storing oily rags and overalls, and cleaning ventilation ducts from combustible deposits;
- procedure for disconnecting electrical equipment from the network in case of fire;
- procedure for inspection and closure of premises after work;
- procedure for emergency maintenance and inspections of electrical installations, heating, ventilation, process and other engineering equipment, etc.

In addition, each department developed fire safety procedures and instructions for explosive and fire hazardous premises (warehouses, shops, laboratories, sites, etc.) in accordance with the basic requirements for fire safety documentation. Extracts from the instructions with the main provisions on fire safety are posted in visible places near the workplaces in each department.

The entire PNPP territory and buildings are divided into areas of responsibility among the plant departments. Document PL.0.0000.0055 “Distributions of Rooms in Production and Administrative and Service Facilities among Departments at the Pivdennoukrainsk NPP” [43] envisages that the territory, buildings, structures and premises are assigned by an order to sections, shifts, laboratories and other departments with indication of responsible officials. All premises are labeled on the entrance doors in accordance with enterprise standard STP 3.0031.005-2018 “PNPP Premises. Marking Rules” [44], which indicates the person responsible for fire safety and the contact phone number.

The department that owns a premise (including the organization leasing a premise from the PNPP) is responsible for the maintenance and operability of fire extinguishing systems, fire alarms, lighting and communication equipment in the premise, and is obliged to comply with the requirements of explosion and fire safety standards.

Firefighting exercises are conducted at the plant’s facilities in accordance with schedules. The schedules and topics of firefighting exercises are drawn up annually in coordination with an official from SFRU-27 and approved by the head of the enterprise. Firefighting exercises are conducted to prepare personnel for actions in case of fires in accordance with the “Operational Fire Extinguishing Plans of the PNPP”.

The following types of fire exercises are conducted with personnel of the plant departments [45]:

- department-level exercises conducted with personnel of a specific department at workplaces or training fields under supervision of the department head or deputy head;
- unit-level exercises conducted with personnel of several departments under supervision of the Deputy Chief Engineer, Senior NPP Shift Supervisor, and NPP Shift Supervisors;
- plant-level exercises conducted with personnel of all power units under supervision of the Chief Engineer or his Deputies and Senior NPP Shift Supervisor;
- joint facility-level exercises conducted with personnel commonly with SFRT-1 under supervision of a SESU official;
- individual exercises.

Fire exercises may be combined with emergency exercises for personnel. Combined emergency exercises are recorded in general logs, which include comments and suggestions on an exercise, as well as ratings of participants.

An on-site firefighting headquarters was established at the PNPP and approved by PNPP Order [46], which acts under the "Operational Firefighting Plan for the PNPP Main Building of the First and Second Stages" during joint fire exercises and fire tactical exercises. The results of the exercises are discussed at the meetings of the common-plant fire technical commission.

The plant personnel undergoes the necessary fire safety training at the PNPP training center and Ukrainian educational institutions according to relevant programs.

There are full-scale simulators (FSS) of Units 1 and 3 on the plant territory; ECR simulators of Units 1 and 3 allow create situations simulating a fire or inflammation at specific equipment or in NPP premises at a certain stage of training. This is followed by simulation of signals and operation of NPP systems, monitoring the correctness of the MCR personnel actions in eliminating emergencies in accordance with the program for conducting practical exercises at FSSs 1 and 3 on various topics.

The procedure for conducting hot operations at the PNPP is regulated by documents: IB.0.3707.0107 "Instructions on Fire Safety Measures during Welding and Other Hot Operations in Departments" [47] and IB.0.3707.0020 "Instructions on Safe Hot Operations at Explosion and Fire Hazardous Facilities of the Pivdennoukrainsk NPP" [48]. All temporary hot operations are carried out according to special permits, and the places of work execution are agreed upon by SFRT-1 fire safety specialists or FSD DO&FSS personnel.

The hot operations are monitored as follows:

- continuous monitoring - by the work performer;
- periodic monitoring - by the responsible work supervisor and the person authorizing the work;
- selective monitoring - by SFRT-1 specialists, PNPP FSD DO&FSS and other officials specified in para. 2.9 of IB.0.3707.0107 [47].

Prior to the start of hot operations, the process equipment to be used for hot operations shall be brought into an explosion-safe state (existing communications shall be disconnected, explosive and fire hazardous substances shall be removed, cleaning, washing, steaming shall be carried out using safe methods, ventilation and air control shall be ensured).

Combustible substances and materials shall be removed from the areas of hot operations within the radius specified by the rules, depending on the height of the work to the floor level. Building structures located within these radii, finishing materials, as well as insulation and parts of equipment made of combustible materials, shall be protected from sparks by metal screens or blankets made of non-combustible insulating material. Doors of the premises where hot operations are carried out shall be closed (except when cables and hoses of welding equipment are laid).

In order to prevent hot metal particles from entering neighboring rooms, floors, and surrounding equipment, all inspection, process, and other hatches, ventilation, installation, and other openings in the ceilings, walls, and partitions of the premises where fire work is performed shall be covered with non-combustible materials.

It is prohibited to start the work without primary fire-extinguishing equipment.

Visual inspection over the place of hot operations shall be conducted by the duty personnel within two hours after their completion, after which the work permit shall be closed.

For hot operations on fire hazardous equipment and in fire and explosion hazardous areas (if these activities cannot be performed in special places), a work permit shall be issued only by the PNPP Chief Engineer or the deputy person.

If hot operations are conducted in explosion hazardous areas, the air environment is thoroughly monitored through express analyses using gas analyzers.

During examinations and repairs inside the tanks and apparatus of electrolysis installations (where hydrogen is in circulation), explosion-proof portable lamps with a voltage of no more than 12V and a metal mesh are used. It is prohibited to use tools made of steel (including stainless steel) capable of causing sparking in the premises of electrolysis and hydration installations (tools made of non-ferrous metals shall be used).

It is prohibited to use asbestos, activated carbon, cotton wool, yarn, sodium and potassium oxidizers in the premises of hydration installations. To open barrels of nitrocellulose enamel and nitrocellulose paints, tools that do not produce sparks when rubbed and impacted are used.

Temporary connections of electrical equipment at PNPP may be used only during equipment repairs, construction and mounting activities.

Temporary connections to operating equipment are prohibited. If necessary, during repairs, temporary connections of equipment are performed by specially trained personnel of the electrical department. Temporary connections shall be performed in accordance with the requirements of PUE [14] and Rues 29].

The places of possible overheating and oil leaks on equipment shall be periodically monitored by the operators according to a special schedule and route. In places of possible overheating and oil leaks, where access during equipment operation is complicated (reactor compartment containment), video surveillance cameras are installed with a signal output to the MCR.

For personnel conducting walkdowns of fire-hazardous equipment, the departments developed and posted memos at their workplaces for cases of spills of highly-flammable liquids (HFL) and flammable substances (FS).

Special storage facilities are envisaged at PNPP for storing combustible materials, flammable and combustible liquids, and combustible gases. In accordance with the PNPP Order [49], a list of places for storage of HFL and FS on the territory of the PNPP was approved. This Order was agreed with the on-site fire department. This list was compiled taking into account the need for HFL and FS at workplaces in the departments for technological processes. It is forbidden to arrange storage facilities for highly-flammable liquids and flammable substances in the main buildings of the plant. The amount of HFL and FS at the workplace does not exceed the demands of one shift.

Compliance with fire safety requirements in storages of HFL and FS is monitored during walkdowns by heads of departments and by FSD DO&FSS personnel, as well as during fire technical inspections of the fire technical commissions, FSD DO&FSS and SFRT-1.

In accordance with the requirements of regulatory documents, special metal boxes are used to store liquids in unbreakable containers for the daily shift’s needs for HFL and FS. Each box has an extract from the approved list of places for storing HFL and FS on the PNPP territory, signed by the head of department.

Cleaning of PNPP premises using HFL and FS is prohibited. Special detergents shall be used for this purpose. Non-flammable detergents are also used to degrease large equipment during repair of components and assemblies. Oil-filled equipment that uses combustible lubricants shall be hermetically isolated from ignition sources. Electrical equipment in fire and explosion hazardous areas shall be explosion-proof.

In accordance with the requirements of the Civil Protection Code of Ukraine [2] and in accordance with para. 3.3 [17], State Fire Rescue Team-1 (SFRT-1) was established to protect the PNPP facilities from fires, which includes two state fire rescue units: SFRU-27 and SFRU-28. SFRU-27 is located at a distance of 150 m from the PNPP perimeter and SFRU-28 is located at a distance of 2 km from the PNPP perimeter. These units provide fire protection services under an agreement concluded annually between the PNPP and the Main Directorate of the State Emergency Service of Ukraine in Mykolaiv Region and are equipped with the necessary equipment to perform fire extinguishing tasks and provide assistance in emergency response and rescue operations. The personnel of these units are fully equipped with protective clothing, boots, gloves, and helmets. They are also equipped with special means of communication (radio stations) and lighting (portable lanterns). The units possess 24 basic and special fire trucks with a full set of extinguishing agents (water, foam, powder), as well as the necessary equipment for firefighting, emergency response, and rescue operations. All available equipment is designed to be used to extinguish fires at NPPs.

To train personnel of SFRU-27 and SFRU-28 to work in gas masks in an unbreathable environment and to adapt to heavy work in conditions of high temperature and limited visibility, a heat and smoke chamber and a psychological training ground with all necessary equipment were built. The SFRU-27 and SFRU-28 personnel dealing with the protection of PNPP facilities have the necessary qualifications and training to carry out fire prevention and fire extinguishing activities at the plant facilities.

The on-site fire units participate in fire drills, exercises, fire safety briefings, psychological training of NPP firefighters and operational personnel, special training and testing of knowledge on fire safety. A group of fire safety specialists was established under SFRT-1 to monitor compliance with the fire regime at the PNPP facilities, conduct introductory fire safety briefings, and selectively monitor the implementation of active and passive protective equipment.

-Activities of the SFRT-1 specialists and their interaction with the heads of PNPP departments is organized in accordance with the Procedure for Performing Preventive Activities at PNPP Facilities.

The SFRU-27 and SFRU-28 personnel dealing with the protection of PNPP facilities have the necessary qualifications and training to carry out fire prevention and fire extinguishing activities at the plant facilities.

State fire rescue units are equipped with the necessary firefighting vehicles and equipment.

In accordance with the requirements of para. 3.3 of NAPB 03.005-2002, a heat and smoke chamber was built and equipped on the SFRU-27 territory on premises of the Gas and Smoke Protection Service (GSPS) to train personnel to work in gas masks in an environment unsuitable for breathing and to adapt them to performing heavy work in conditions of high temperature and limited visibility.

The smoke chamber is equipped with a gas and smoke detector tracking system with elements of sound and light effects simulation.

The GSPS headquarters, which is located on the SFRU-27 territory, is equipped with tools and supplies in accordance with the standards and is intended for repairing and refueling equipment using compressed air.

All personnel of the duty teams are on duty around the clock and have sufficient firefighting training and knowledge of the operation area and the specifics of firefighting at NPPs.

SFRU-28 has a psychological training ground for PNPP firefighters and operational personnel, where firefighters and PNPP staff are trained and master ways and methods to extinguish possible fires.

The State Fire Rescue Units (SFRU-27 and SFRU-28), in accordance with the training programs approved by the Main Directorate of the State Emergency Service of Ukraine in Mykolaiv Region, conduct daily training sessions to improve the level of operational preparedness of their personnel.

According to the plan, fire and tactical exercises are held quarterly to practice fire and emergency response actions at the facility, and to practice interaction with the facility firefighting headquarters, emergency crews, and facility administration.

The SFRU-27 and SFRU-28 personnel are trained at the training center on radiation safety and dose monitoring and have the necessary qualifications and preparedness to extinguish fires and carry out preventive work to prevent fires at the plant's facilities. The personnel of the units undergo periodic training in specialized educational institutions of Ukraine.

Scenarios for fire and tactical exercises are developed based on the previously learned firefighting experience. The exercises are conducted at different areas of the facility, taking into account their fire hazard and importance for safe NPP operation.

During the drills, the ability of firefighting unit to perform the assigned tasks is checked.

After each training session, the results are summarized, the actions of the participants are assessed, and an assessment is given to determine whether the training objectives have been met.

The experience gained is used to modify the training program (if necessary) or to update firefighting plans and cards.

All personnel of the units constantly and regularly improve their training and practical skills in the basics of firefighting and equipment, rescue, and are in constant operational preparedness for assigned actions.

In accordance with the requirements of para. 6.3 of NAPB B.01.014-2007 "Fire Safety Rules in Operation of Nuclear Power Plants" [29], the following documents were developed at the PNPP: "Operational Plan for Fire-Extinguishing of the Main Building of the PNPP First Stage", "Operational Plan for Fire-Extinguishing of the Main Building of the PNPP Second Stage" and fire extinguishing cards for fire-hazardous premises and equipment. The operational fire-extinguishing plans are the main documents that define actions of the enterprise personnel in the event of a fire, the interaction procedure with the SESU units, the directions for deployment of manpower and means to extinguish the fire, taking into account safety measures and rational deployment of fire equipment, etc. They are developed by the SESU specialists jointly with the energy company's specialists and approved by the enterprise head and the

SESU territorial body. The fire-extinguishing plans are kept in the MCRs of Units 1, 2, 3 and SFRU-27, and fire-extinguishing cards are kept at workplaces of the plant's operational personnel.

Operational fire-extinguishing plans include:

- actions of the plant personnel in the event of a fire before arrival of fire rescue units;
- procedure for interaction with the arrived fire rescue units;
- procedure for authorization to extinguish fires in powered electrical installations and in conditions of ionizing radiation;
- rational deployment of fire equipment and location of the firefighting headquarters;
- peculiarities of fire extinguishing in storage facilities for fresh and spent nuclear fuel and radioactive waste;
- notification, alarm and communication scheme;
- layouts and plans of facilities;
- conditions for deploying forces and means to extinguish the fire, taking into account the requirements of nuclear and radiation safety and technical safety for participants in fire extinguishing and mitigation of consequences.

The main provisions of the fire-extinguishing plan and fire-extinguishing cards are communicated to the NPP employees during fire and emergency exercises.

In accordance with the requirements of para. 6.3 of NAPB B.01.014-2007 [29], a list of the most fire-hazardous premises and equipment of the PNPP (213 premises) was compiled and approved by the PNPP Chief Engineer. Operational cards for the main actions of the operating personnel in case of fire were developed for them, as well as for the premises (electrical installations) where it is impossible to quickly disable the electrical equipment for safety reasons.

The plan of interaction between the plant's department and fire rescue units is set out in the document "Instruction on Interaction and Information Exchange between SFRT-1 and PNPP Departments in the Event of Emergencies (Fires) at PNPP Facilities and Mitigation of Their Consequences". The document was approved by the joint Orders of the PNPP and SFRT-1 No. 1311/58 of 24 September 2020 and Order of the SESU in Mykolaiv Region No. 285 of 27 March 2021 "On Organization of Garrison and Guard Service".

2.3.3 Passive fire protection

Passive fire protection is one of the defense-in-depth levels aimed at preventing the spread of fire in case of possible failure of the fire-extinguishing system and possible increase in response time of fire units.

The main objectives of passive fire protection systems are to limit the spread of fire, to ensure and maintain the safe state of the NPP by performing safety functions, and limiting the amount of radioactive materials that may fall into the fire epicenter or be released during a fire.

The passive fire protection systems implemented at the PNPP include:

- fire barriers (walls, partitions, fire doors, fire retardant valves);
- smoke exhaust systems;
- lightning protection;
- fire protection mixtures, plasters, boards.

2.3.3.1 Prevention of the propagation (barriers)

In accordance with the requirements of [17], buildings and structures on the PNPP territory are located with consideration of the prevailing wind direction and meet the requirements for safe operation in the event of possible fires.

The design envisages arrangement of fire breaks at the location of buildings and structures, entrances, and division of the PNPP industrial site into fire protection zones to reduce the risk of fire propagation and damage from chemically active gaseous combustion products, as well as to reduce the degree of radioactive contamination.

In accordance with the requirements of para. 3.4 [17], free passage of fire trucks to all buildings and structures and conditions for safe evacuation of personnel are ensured on the PNPP territory. In addition to the main entrance, there are three other entrances to the PNPP industrial site, which are scattered around the perimeter.

In accordance with the design documentation, the PNPP industrial site includes safety and normal operation premises in reactor compartment (RC), deaerator compartment (DC), turbine hall (TH), and boron unit (BU) of Unit 1, with enclosing structures that shall have a standardized fire resistance level.

As an example, the enclosing structures of premises with safety and normal operation systems located in DC-1 at elevation 0.00 (switchgear premises, direct current board and relay panels) were upgraded to a higher fire resistance level under C(I)SIP (Measure 27113). To bring the fire resistance limit of enclosing structures of the switchgear, direct current board and relay panel premises to the standardized value, fire protection was implemented using PYRO-SAFE AESTUVER T fireproof boards manufactured by Brandschutz, Germany. The material is certified in Ukraine and meets the requirements of DBN V.1.1-7:2016 “Fire Safety of Construction Sites” [15] and DSTU B.V. 1.1-4-98 “Fire Protection. Civil Structures. Fire Resistance Testing Methods. General Requirements” [50]. To ensure the required fire resistance limit of the enclosing structures, the doors and gates in the openings were replaced with fireproof ones. The implementation of this measure made it possible to bring the fire resistance limit of the enclosing structures of switchgear, direct current board and relay panels to the standard value in accordance with the requirements of NP 306.2.141-2008 [3], VBN V 1.1-034-03.307-2003 [17] and IAEA recommendations.

In accordance with the requirements of para. 4.2.1 [17], the enclosing structures of fire compartments that physically separate the premises of different trains of the safety systems are of type I, with a fire resistance limit of REI 90 and a fire propagation limit of M0.

The fire resistance level of NPP buildings and structures was determined by calculations and meets the requirements of Annex D [17]:

- reactor compartment (RC) of Unit 1 - fire resistance class I;
- turbine hall (TH) of Unit 1 - fire resistance class III;
- deaerator compartment (DC) - fire resistance class IIIa;
- boron unit (BU) - fire resistance class IIIa;
- special building (SB) - fire resistance class II;
- standby diesel generators (SDGs) - fire resistance class I.

The premises located in the RC, DC, and BU, where equipment of different safety system trains is located, are separated from each other and from the normal operation premises by fire barriers with a fire resistance limit of 90 minutes.

The places where process communications (cable ducts, piping, air ducts, cables, etc.) pass through the enclosing structures and partitions are sealed with non-combustible materials. The fire resistance limit of penetrations through structures with a standardized fire resistance limit or fire barriers is not less than the standardized fire resistance limit of this enclosing structure or fire barrier according to the EI.

In order to fulfill the requirements of paras. 2.5 and 5.4.2 of VBN V.1.1-034-03.307-2003 [17], under (C(I)SIP) Measure 27108, in accordance with design documentation PO-800-PPR79, the standardized fire resistance limit was brought to EI 30 for removable non-combustible structures of cable channels and raised floors of PNPP Unit 1 premises.

In accordance with the requirements of para. 4.2.3 of NAPB 03.005-2003 [17] and DBN V.1.1-7-2016 [15], metal trusses with horizontal and vertical connections between them in the turbine hall of Unit 1 have fire resistance level R 45.

In 2021, in order to resolve comments and deviations from the current fire safety standards and regulations, as well as to implement technical decision No. TP.1.0004.4674 of 15 September 2021 “On Extension of the Service Life of Fireproof Coating of Metal Structures of the Turbine Hall of Power Unit 1”, the following activities were performed:

- replacement of the existing fire fireproof coating on the surfaces of metal structures of trusses and horizontal connections of the lower and upper belts with fire protection material "PYRO-SAFE FLAMMOPLAST SP-2";
- additional application of fire protection coating on the surface of metal structures of trusses and horizontal connections of the lower and upper belts with fire protection material "PYRO-SAFE FLAMMOPLAST SP-2";
- application of the protective coating on the surface of the metal structures of the trusses and horizontal connections of the lower and upper belts with PYRO-SAFE DECORLACK SP2 decorative varnish.

In accordance with the requirements of NAPB B.01.012-2019 “Fire Protection Rules” and NPP Order No. 825 of 17 June 2021, the acceptance commission inspected the quality of fire protection activities.

2.3.3.2 Ventilation systems

Ventilation systems for 6 kV integrated switchgears, 0.4 kV integrated switchgears, 0.4 kV switchgears, direct current board, storage batteries, control and protection systems, shafts, and tunnels are designed to remove excess heat and create the required temperature in these premises. Air is extracted from the above premises by the following systems: 1UV81D24 - 1UV81D40 (V24-V40), 1UV81D57 (V40), 1UV81D66 (V66), 1UV81D67 (V67), 1UV81D68 (V68), 1UV81D77 (V77), 1UV81D86-1UV81D88 (V86-V88), 1UV81D44-1UV81D56 (V44-V56), 1UV81D69-1UV81D71 (V69-V71) interlocking with unified air electrically operated dampers/fire retardant valves (FRVs), through which the supply air equal to the exhaust volume is supplied from the turbine hall due to the vacuum created by the exhaust fans. The natural inflow units are equipped with electrically operated air valves that are interlocked by the corresponding exhaust units.

On the supply and exhaust ventilation systems of the premises with 6 kV integrated switchgear, 0.4 kV integrated switchgear, 0.4 kV switchgear, direct current board, storage batteries, control and protection systems 1UV81D09-D16 (B9-B16), 1UV81D18-D23 (B18-B23), 1UV81D76 (B76), 1UV81D83 (B83) 1UV81D84 (B84), PE7-14, PE17, PE18, PE59,

PE74, PE83 are equipped with valves of KPU-2A type, with fusible inserts and return spring, on the ventilation systems 1UV81D17 (B17), PE6, PE15, PE16, PE19, PE20, PE21, PE22, PE23, PE76, PE84 FRVs with an electric drive with a built-in return spring and a fuse in the circuit, the electric drives are interlocked with fire alarm detectors in the serviced premises. In valve actuation as intended, it is replaced with a new valve, no fuse replacement is envisaged. The fire resistance limit of the valves is 2 hours, the melting point of the fusible insert is 72 °C.

In the event of a fire (when smoke appears), the fire extinguishing system detectors send a signal to disconnect the operating fans and close the process-related FRV (for FRV non-blocked with fans, closing occurs when the fire extinguishing system is activated). In the event of a fire extinguishing system failure, thermal sensors are installed inside the FRVs, which, when the temperature rises above 72 °C, disconnect power and release the actuator spring, which closes the FRV. The FRVs at Unit 1 are equipped with both individual and group control panels.

To prevent the spread of fire from fire hazardous premises, automatic closing of dampers on the inflow of air to these premises is envisaged, as well as disabling of fans in these premises.

Also, for fire hazardous premises, it is possible to close FRVs on the supply and exhaust air ducts.

To fulfill the conditions of para. 4.4 of VBN V.1.1-034-03.307-2003 [17], para. 2.14 of Tables 1, 2 and 3, DBN V.1 .1-7-2002 [15], and para. 10.11.1 of NP 306.2.141-2008 [3], Technical Decision No. TP.1.0018.2845 of 12 December 2012 was developed to install fire retardant valves (FRVs) with fire resistance limit corresponding to the fire resistance limit of the fire barrier at the PNPP. Based on the technical decision, the premises of PNPP Unit 1 were inspected to determine the locations of the fire barrier installation.

In accordance with the YuAT-661-1621-OV.PZ design, stainless-steel, explosion-proof, manually operated FRVs with fusible insert and limit switch were installed in the places where the supply and exhaust ventilation ducts cross the fire barriers of the battery premises.

In accordance with the AOAYa 42 5 1 1 P.0728-PZ design, electrically operated FRVs of various dimensions are installed in places where supply and exhaust ventilation ducts cross fire barriers in premises containing electrical and electronic equipment and cable structures. The FRVs have fire resistance limit EI120.

Fire dampers were installed in the SDG building in 2013 during the reconstruction of the air conditioning systems of the 0.4 kV switchgear and local control panel in accordance with the YuAT 663-909-OV.PZ design.

In accordance with the requirements of VBN V.1.1-034-03.307-2003 [17] (para. 5.6.2.1), NP 306.2.141.-2008 [3] (para. 10.11.5), and YuAT-661-1605-OV.PZ design [52], a smoke removal system was installed. The smoke removal system (SRS) 1UV57D01 (SRS-1), 1UV57D02 (SRS-2), 1UV57D03 (SRS-3), 1UV57D04 (SRS-4), 1UV57D05 (SRS-5) provides for the removal of smoke at the initial stage of the fire through smoke valves located in the DC corridors at elevations +8.40 and +17.40.

The stairway air support systems 1UV33D01 (PShL-1) and 1UV33D04 (PLK-2) are designed to prevent combustion products from entering the stairways during a fire by creating a pressure difference between the stairways (evacuation routes) and smoke-filled premises.

As equipment for smoke removal systems, certified radial fans of the VRDV-287-46.1 type, smoke removal roof fans of the VDRDV-6.3.2-01 type, manufactured by Interkondytsioner PJSC, Kharkiv, smoke valves of KD EV type with electric drive and control

panel manufactured by PJSC "Plant Equator" (Mykolaiv) were used. To increase the fire resistance limit, the air ducts of the smoke removal system are covered with the Conlit-150 fire protection system.

In accordance with IE.1.0018.0028 [53], the following control types of smoke removal systems 1UV57D01 (SRS-1), 1UV57D02 (SRS-2), 1UV57D03 (SRS-3), 1UV57D04 (SRS-4), 1UV57D05 (SRS-5) are envisaged:

- automatic, control from fire alarm detectors installed in evacuation corridors at elevations +8.40, +17.40;
- remote control, control from automation cabinets installed in a separate premise of the VACS operational personnel (1DO1701);
- manual (remote), by control buttons installed at the entrance to the stairways SB-1 and SB-2 at elevations +8.40, +17.40;
- local control of smoke valves 1UV57S01, 1UV57S02, 1UV57S03, 1UV57S04, 1UV57S05, 1UV57S06, 1UV57S07, 1UV57S08, 1UV57S09, 1UV57S10, 1UV57S11 from the control panels supplied together with the valves.

2.3.4 Licensee's experience in applying the fire protection concept

The experience in implementing the fire protection concept was gained upon the conclusions and recommendations of experts in various fields, including fire safety, during various missions and inspections of the PNPP, in particular:

- mission to assess the design safety of the PNPP Unit 1, 2-9 February 2009;
- WANO peer review from 12 to 23 April 2010;
- WANO peer review from 13 to 29 November 2014;
- WANO peer review from 19 to 23 September 2016;
- WANO peer review from September 28 to October 02 2020;
- comprehensive inspection of the fire safety of the PNPP by representatives of the Energoatom from 13 to 18 June 2021.

According to the results of one of the inspections, the IAEA representatives concluded that the design of the PNPP Unit 1 fully complies with most of the IAEA NS-R-1 requirements. The IAEA representatives emphasized several important positive aspects of the PNPP Unit 1 design.

The introduction of new active and passive fire protection means, measures to prevent fire at the PNPP facilities, is carried out in accordance with the analysis of events at other nuclear facilities in the world and is implemented at the State level.

Resolution of the Cabinet of Ministers of Ukraine No. 1270 of 7 December 2011 approved the Comprehensive (Integrated) Safety Improvement Program for NPPs (C(I)SIP).

In accordance with the C(I)SIP, 12 fire protection measures were implemented to improve the safety level of Unit 1, namely:

- 27101 "Modernization of the Automatic Fire Alarm System of NPP Safety System Premises";
- 27102 "Implementation of Smoke Removal System in DC Evacuation Corridors";
- 27104 "Provision of the Main NPP Electricity Generation Circuit with Automatic Control Units for Power Oil-Filled Equipment";

- 27105 “Modernization of the Automatic Fire Alarm System of DC, TH and SB Premises”;
- 27106 "Implementation of Redundancy for Water Fire-Extinguishing Units of Safety Systems";
- 27107 “Installation of Fire Retardant Valves with a Standardized Fire Resistance Limit at Intersections between Supply and Exhaust Ventilation Air Ducts and Fire Barriers of Battery Premises and Premises Containing Electrical and Electronic Equipment”;
- 27108 “Bringing the Fire Resistance Limit of Removable Non-Combustible Structures of Cable Ducts and Raised Floors of NPP Premises Containing Electrical and Electronic Equipment to the Standardized Value”;
- 27109 “Introduction of Automatic Fire Extinguishing System in Premises of Standby Diesel Generators”;
- 27110 “Replacement of Combustible Insulation of the Turbine Hall Roof”;
- 27111 “Bringing the Fire Resistance Limit of the DC Load-Bearing Metal Structures to the Standardized Value”;
- 27113 “Bringing the Fire Resistance Limit of Enclosing Structures of Premises with Switchgears, Direct Current Boards and DC Relay Panels to the Standardized Value”;
- 26203 “Development and Implementation of Measures to Reduce Hydrogen Concentration in the Containment for Beyond Design-Basis Accidents at PNPP Unit 1”;

Two measures were partially implemented:

- 27103 “Provision of NPP Premises Containing Electrical and Electronic Equipment with Stationary Gas Fire-Extinguishing Units”;
- 27112 “Bringing the Fire Resistance Limit of Transit Air Ducts and Process Piping Passing Through the Premises of Safety Systems and Normal Operation Systems to the Standardized Value”.

According to the second WANO peer review, which took place at the PNPP from 28 September to 2 October 2020, two positive practices No. 27/109 and No. 27/99 were identified and recommended by WANO experts for dissemination to other NPPs:

SERGI TR system (No. 27/99):

The purpose of installing a passive mechanical explosion prevention system on the oil-filled power equipment of the main power output circuit of a nuclear power plant is to:

- reduce the pressure in the transformer tank (within a few milliseconds);
- remove explosive gases from the transformer tank without contact with air (oxygen);
- separate gases from oil;
- remove explosive gases to a remote area;
- complete the release of explosive gases in the tank by nitrogen supply.

No other technical and economic results are expected from the installation of a passive mechanical explosion prevention system on oil-filled power transformers.

In 2016, the 330/150 kV 1AT communication transformer was repaired with the installation of the passive mechanical explosion prevention system TRANSFORMER

PROTECTOR (TP) SERGI. The SERGI TP system was also installed on the 2AT autotransformer.

A conceptual technical solution was developed to provide for equipping all oil-filled PNPP transformers and reactors with a passive mechanical explosion prevention system.

TRANSFORMER PROTECTOR (TP) is a transformer explosion and fire prevention system suitable for installation on oil-filled transformers, voltage regulators under load (RPN device).

In the event of a short circuit, the TP system is activated by the first dynamic pressure front from the shock wave within a few milliseconds, preventing tank deformation and transformer explosion before the static pressure begins to build up.

As a passive protection, the TP system uses rupture disks that open completely within a period of time up to several milliseconds, depending on the energy transferred to the oil by the short circuit arc.

As a result of the implementation of the positive practice “Provision of Transformers with an Additional Explosion and Fire Prevention System”, the following results were achieved:

- improving the operational safety of power units;
- improving the operational reliability of oil-filled power equipment.

Using a combination of the PLS-60 water cannon and NRT turbine type spray nozzle (No. 27/109). The purpose of using the combination of the PLS-60 water cannon and the NRT turbine type spray nozzle for extinguishing fires at NPP facilities is to:

- effectively extinguish fires in powered electrical installations, tanks with flammable liquids, transformers, and open switchgears;
- ensure the supply of a large volume of extinguishing agents from a safe distance when extinguishing electrical installations under high voltage, in conditions of dense heat flow and in conditions of radiation hazard;
- ensure the ability to use one device to supply both sprayed water and air-mechanical foam.

The development was based on the experience of extinguishing a fire at power transformers due to the impossibility of supplying extinguishing agent under the impact of powerful thermal radiation from the spread fire.

2.3.5 Regulator’s assessment of the fire protection concept and conclusions

The fire protection concept is subject to SNRIU assessment and oversight as one of the areas of NPP safety assurance. The SNRIU monitors the implementation of the fire protection concept in the framework of the following processes:

- Comprehensive safety assessment of PNPP Unit 1, during the state nuclear and radiation safety review of the Safety Analysis Reports and amendments thereto and Periodic Safety Review Reports;
- Regulatory assessment of modifications to structures, systems and components important for safety, including those related to the implementation of the fire protection concept;

- Assessment of the status and completeness of compliance with the terms of licenses and other permits before issuing individual permits for the start-up of a nuclear power unit after outage;
- Review of applications of the operating organization and relevant safety justifications for amending licenses in connection with long-term operation.

In the course of state oversight activities, fire safety and implementation of measures to improve fire safety are among the areas of comprehensive inspections and surveys conducted by the SNRIU on a scheduled basis.

The results of the regulatory control for the fire protection concept indicate that the fire protection concept implemented at PNPP Unit 1 generally complies with nuclear and radiation safety and fire safety standards.

Measures to improve the safety of PNPP Unit 1, including measures to improve fire protection based on operating experience, recommendations of international organizations, results of inspections and surveys, and introduction of new safety requirements, are implemented by the operating organization taking into account their impact on safety within the timeframes agreed with the SNRIU.

III. RIVNE NPP UNITS 2 AND 3

3.1 General information

The Rivne Nuclear Power Plant (RNPP) consists of four power units using two different types of reactors: Units 1 and 2 are VVER-440/213 and are the only units with such reactors in Ukraine. Units 3 and 4 are large-series VVER-1000/320, which are operated at all other Ukrainian NPPs. The RNPP operating organization is the State Enterprise "National Nuclear Energy Generating Company Energoatom". This NAR considers Unit 2 as a VVER-440 reactor and Unit 3 as a VVER-1000/320 reactor.

RNPP Unit 2 was commissioned in 1981. RNPP Unit 2 includes a VVER-440 reactor (model 213) with a thermal capacity of 1375 MW and 2 K-220-44 turbine units (each with installed electrical capacity of 220 MW) with a total electrical capacity of 415 MW. The power unit is operated under a license for nuclear facility operation No. EO 000943 dated 10 December 2010. The license was granted by reissuing the previous license for operation based on the safety justification for long-term operation of RNPP Unis 1 and 2. The license is valid until 31 December 2031.

RNPP Unit 3 was commissioned in 1986. RNPP Unit 3 includes a VVER-1000 reactor (model 320) with a thermal capacity of 3000 MW and a K-1000-60/3000 turbine unit (installed capacity of 1000 MW). The power unit is operated under a license for nuclear facility operation No. EO 000944 dated 10 December 2010. The license was reissued on a new form with the changes of 17 July 2018. The license is valid until 11 December 2037.

Units 2 and 3 were designed in accordance with regulations meeting safety requirements through consistent implementation of the defense-in-depth concept based on the use of physical barriers to prevent the spread of radiation and radioactive releases into the environment. The design of the units is based on the conservative approach. Systems and components important to safety perform their functions in the scope established by the design, both in normal operation and in conditions that may arise as a result of design-basis accidents, with the subsequent impact of natural phenomena (earthquakes, hurricanes, floods). In addition, the design considers the effects of jets, shock waves, missiles, and fires.

A defense-in-depth fire protection system has been implemented at the RNPP, which maintains the functions of systems important to safety, necessary to ensure the NPP nuclear and radiation safety during and after a fire.

3.2 Fire safety analysis

Given that all nuclear power plants in Ukraine are operated by a single operating organization acting under a unified policy, safety (including fire safety) is analyzed using a unified approach, considering the specific features of each site and its facilities. Therefore, the fire safety analysis of RNPP nuclear installations, like PNPP, was performed within review of the full range of initiating events (FR IEs) for all states of the reactor and the spent fuel pool (SFP). The fire safety analysis of Units 2 and 3 (both deterministic and probabilistic parts) is an integral component of the probabilistic safety analysis (PSA). Hence, further review is provided without additional division into deterministic or probabilistic analyses, in accordance

with the requirements for the scope and structure of the NAR defined in the Technical Specification [1].

3.2.1 Types and scope of fire safety analysis

The main purpose of deterministic fire hazard analyses is to support the development of the necessary component of the Section “Probabilistic Safety Analysis” of the Safety Analysis Report (SAR) for Units 2 and 3 for identifying fire safety deficits, providing recommendations and proposing corrective measures for their elimination. The deterministic and probabilistic analyses of fire hazards result in assessment of the impact from internal fires on the total core damage frequency (CDF). This assessment complements the results of PSA Level 1 for internal IEs.

The fire probabilistic safety analysis of RNPP Units 2 and 3 was carried out within the development of the Section “Probabilistic Safety Analysis” of Safety Analysis Reports and is presented in Reports [54]-[57].

The analysis uses the division of the site territory into fire sectors with the establishment of boundaries for these fire sectors for internal fires at full power and LPSS of RNPP Units 2 and 3.

For RNPP Unit 2, the adopted set of fire sectors covers all the main buildings and structures:

- main building of Unit 2, including the reactor compartment, turbine compartment and electrical equipment racks;
- unit pumping station UPS-1;
- diesel pump unit building;
- Unit 2 DGS.

The layout of mutual arrangement of the main buildings and structures of RNPP Unit 2 is presented below in Figure 3.1.

RNPP Unit 2 was divided into 6 independent fire zones: RB – reactor compartment; BE – electrotechnical premises of the main building; PB – UPS building; GB – diesel pump unit building; DB – diesel generator building; TB – turbine compartment.

Zones RB, BE and TB are structures of the RNPP Unit 2 main building. Zones PB, GB and DB are separately located buildings and structures, separated by distance and communications, and are completely autonomous.

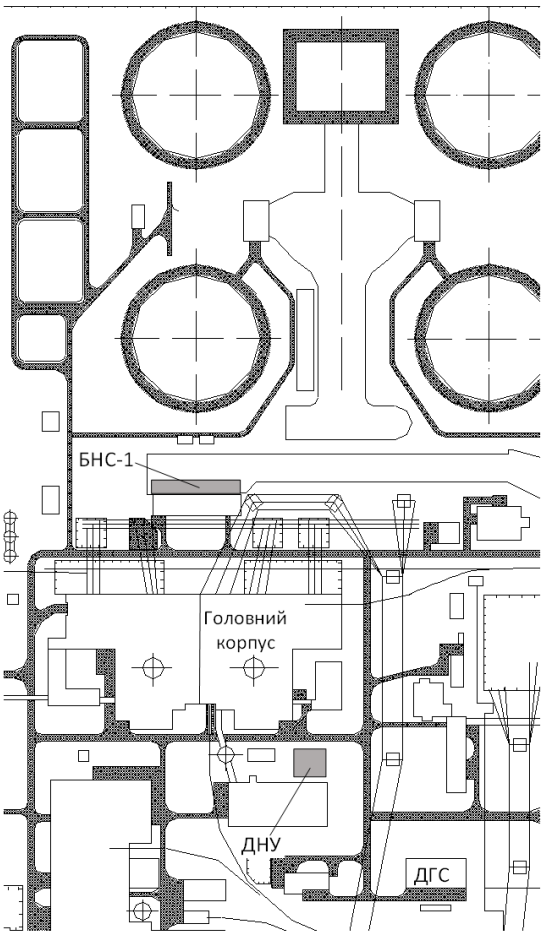

Figure 3.1 – Layout of the main buildings of RNPP Unit 2

For RNPP Unit 3, the adopted set of fire sectors covers all the main buildings and structures:

- main building of Unit 3, including the reactor compartment, turbine compartment and electrical equipment racks;
- unit pumping station UPS-2;
- SDGs of Unit 3 (SDG-31, SDG-32, SDG-33);
- pumping station of service water for nonessential loads of Unit 3 (NSW).

The layout of mutual arrangement of the main buildings and structures of RNPP Unit 3 is presented below in Figure 3.2.

RNPP Unit 3 was divided into 4 independent fire zones: RB – reactor compartment; DB – diesel generator building; BNS – UPS building; TB – turbine compartment.

Zones RB and TB are structures of the RNPP Unit 3 main building. Zones DB and BNS are separately located buildings and structures, separated by distance and communications, and are completely autonomous.

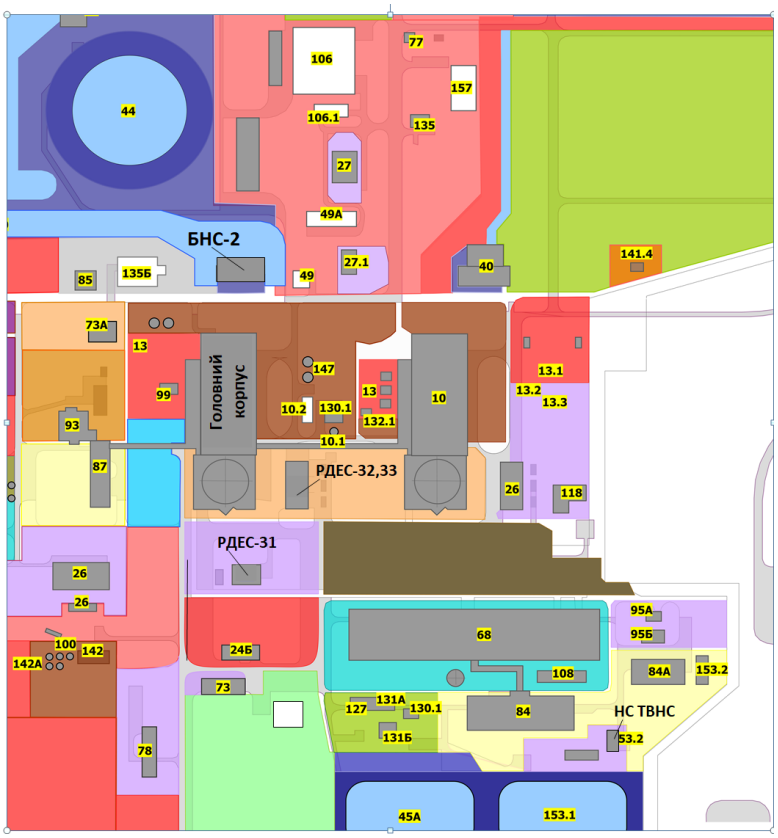

Figure 3.2 – Layout of the main buildings of RNPP Unit 3

As part of the fire safety analysis of RNPP Units 2 and 3, 14 operational states are considered for the reactors at full power (FP) and in low power and shutdown states (LPSS) and 2 operational states are considered for the SFP. Within the PSA of internal fires at RNPP Units 2 and 3, the following activities were performed by NPP personnel and contracting organizations:

- collection of initial data required for the internal fire PSA;
- identification of fire sectors;
- qualitative screening of fire sectors;
- quantitative screening of fire sectors;
- detailed fire analysis;
- quantitative analysis, analysis and interpretation of results;
- identification of aspects that require improvement in terms of reducing the risk of NPP operation and development of a list of the main safety improvement measures based on fire PSA result;
- recording work results.

Within the fire PSA for

- Unit 2, 93 fire sectors were identified;
- Unit 3, 122 fire sectors were identified.

In qualitative screening of fire sectors, sectors that met a set of criteria were screened out from further consideration:

- fire sector does not contain equipment included in the Level 1 PSA model and cable connections to this equipment;
- fire in the sector does not result in IEs of the Level 1 PSA for internal initiators;
- fire in the sector does not result in new and more severe IEs than those considered in the Level 1 PSA.

Based on the qualitative analysis results, 23 fire sectors were screened out for Unit 2 and 33 fire sectors were screened out for Unit 3.

Fire accident sequences leading to IEs were screened out according to their frequency. For this purpose, occurrence frequency of each fire accident sequence was determined for each operational state. The duration of operational state, presence and condition of ignition sources were considered, taking into account temporary ignition sources and fire activities.

As part of quantitative screening, sectors that met at least one of the following conditions were screened out from further consideration:

- initial frequency of IE caused by fire in the sector is less than 10-7 1/year;
- contribution of an individual fire sector to the CDF/FDF from IEs caused by fires in the analyzed sector is less than 10-8 1/year.

Based on the quantitative screening results, another 52 and 60 fire sectors for Units 2 and 3, respectively, were screened out from further consideration.

Thus, for 18 and 29 fire sectors of Units 2 and 3, respectively, a detailed analysis of fire progression was performed, based on whose results a final list of fire progression scenarios leading to IEs was developed.

The analysis of potential combinations of internal and external hazards for the reactor and SFP is performed as a separate annex within the probabilistic safety analysis (PSA) of the power unit to identify and account for additional components of probabilistic risk indicators (CDF, LERF, FDF) that were not considered in analysis of individual IEs. Compiling a list of combinations for internal fires includes:

- screening of fire sectors;
- combining two independent fire events for all possible operational states of the power unit;
- quantitative screening of the combinations according to the occurrence frequency (criterion is the occurrence frequency less than 1.0E-07).

Similar steps are performed for combinations of three or more independent fire events.

3.2.2 Key assumptions and methodologies

The key assumptions and methodology are similar to those described in 2.2.2 of this NAR.

3.2.3 Analysis of phenomena accompanying the fire: general overview of the models, data and consequences

The analysis of phenomena accompanying the fire: see 2.2.3 of this NAR for an overview of models, data and consequences.

3.2.4 Main results / dominant events (Licensee’s experience)

The results from the quantitative assessment of the fire PSA for RNPP Unit 2 are presented in the report [55] and for RNPP Unit 3 in [64].

3.2.4.1 Impact of internal fires on integral CDF upon results of Level 1 PSA:

The contribution of the considered PSAs to the integral CDF of RNPP Units 2 and 3 is presented in Tables 2.1 and 2.2.

Table 2.1 – Contribution of the considered PSAs to the integral CDF of RNPP Unit 2

PSA	**% of CDF**
PSA for internal IEs at FP	37.57
PSA for internal IEs in LPSS	28.19
fire PSA at FP	3.55
fire PSA in LPSS	26.07
Flood PSA at FP	0.99
Flood PSA at LPSS	0.01
PSA for external extreme hazards at FP	3.18
PSA for external extreme hazards at LPSS	0.45
Integral CDF	100

Table 2.2 – Contribution of the considered PSAs to the integral CDF of RNPP Unit 3

PSA	**% of CDF**
PSA for internal IEs at FP	18.90%
PSA for internal IEs at LPSS	58.80%
Fire PSA at FP	1.01%
Fire PSA at LPSS	0.08%
Flood PSA at FP	5.90%
Flood PSA at LPSS	12.63%
PSA for external extreme hazards at FP	0.77%
PSA for external extreme hazards at LPSS	1.90%
Integral CDF	**100.00%**

3.2.4.2 Impact of internal fires on integral CDF upon results of Level 1 PSA

The contribution of the considered PSAs to the integral FDF of RNPP Units 2 and 3 is presented in Tables 2.3 and 2.4.

Table 2.3 – Contribution of the considered PSAs to the integral FDF of RNPP Unit 2

PSA	**% of FDF**
FDF for internal IEs	47.48
Fire FDF	0.72
Flood FDF	0.03
FDF for external extreme hazards	51.77
Integral FDF	100.00

Table 2.4 – Contribution of the considered PSAs to the integral FDF of RNPP Unit 2

PSA	% of FDF
FDF for internal IEs	99.14%
Fire FDF	<0.01%
Flood FDF	0.15%
FDF for external extreme hazards	0.70%
Integral FDF	**100.00%**

The CDF, FDF and LERF determined in quantitative calculations fully satisfy the probabilistic safety criteria established in NP 306.2.141 2008 “General Safety Provisions for Nuclear Power Plants” [3] and the IAEA safety criteria for operating NPP units [65].

Upon PSA results for Unit 2, the following measures were recommended in connection with the high contribution of fires in electrotechnical device premises to the integral CDF:

- modernization of the automatic fire alarm system for the electrotechnical device premises,
- equipping of NPP premises containing electrical and electronic equipment with stationary non-automatic gas fire-extinguishing units.

Relevant safety improvement measures were developed based on the recommendations. The contribution of internal fires to the integral FDF is insignificant, so there was no need to develop special measures upon the results of PSAs for SFP fires.

For Unit 3, the contribution of internal fires to the integral CDF and integral FDF is insignificant, so there is no need to develop special measures upon the results of fire PSAs

3.2.5 Periodic analysis and management of changes

In accordance with the requirements of national regulatory documents [11]-[13], the fire safety analysis shall be updated and revised in full scope (both deterministic and probabilistic parts) together with the updating of the PSA every 10 years.

The full-scope updating of the analyses shall be carried out in the context of periodic safety reviews, including reviews at the NPP.

In addition, procedure [13] is in force in the industry. It establishes the process for organization of activities according to the procedure of living PSA (LPSA), requirements for the frequency of updating the integral probabilistic model and its documents, as well as regulates approval of materials of living probabilistic safety analysis in the Company and in the SNRIU.

Two types of updates are established for living PSA - ongoing and complete. Ongoing updating shall be performed every three years for each NPP unit. Complete updating of the living PSA shall be carried out within the timeframes established in [11] for periodic safety review, i.e. every 10 years.

3.2.6 Assessment and conclusions on fire safety analysis performed by the regulator

The fire safety analysis as part of the NPP unit safety justification is the subject of the state nuclear and radiation safety review, performed by the SNRIU in accordance with the requirements of the Ukrainian legislation.

The fire safety analysis of RNPP Unit 2 was verified by the SNRIU within the state NRS review of the RNPP Unit 2 Safety Analysis Report, updated for the periodic safety review, and the Periodic Safety Review Report for RNPP Unit 2, as well as living PSA for PNPP Unit 2 during 2018-2021.

The fire safety analysis of RNPP Unit 3 was verified by the SNRIU within the state NRS review of the PNPP Unit 3 Safety Analysis Report, updated for the periodic safety review, and the Periodic Safety Review Report for RNPP Unit 3 during 2015-2018, as well as living PSA for RNPP Unit 3 in 2019.

The state NRS review resulted in the following findings:

- the scope and methodology of the safety analysis comply with the regulations and standards on nuclear and radiation safety, as well as IAEA recommendations;
- the computer models consider the current state of the power unit;
- the safety analysis results meet the safety criteria defined by the regulations and standards on nuclear and radiation safety, as well as the design documentation.

The completeness and reliability of the information presented in the Periodic Safety Review Report for RNPP Unit 2 were confirmed by the SNRIU in the framework of the inspection carried out from 24 to 28 May 2021.

The completeness and reliability of the information presented in the Periodic Safety Review Report for RNPP Unit 3 were confirmed by the SNRIU in the framework of the inspection carried out from 4 to 8 June 2018.

3.3 Fire protection concept and its application

The defense-in-depth concept for fires is aimed at performing the following tasks both at the PNPP and RNPP:

– prevention of fire initiation;
– timely detection of a fire, its confinement and mitigation in the shortest possible time with automatic and manual fire extinguishing means; minimization of fire damage;
– protection of systems and equipment important to safety at the level that will make it possible to shut down the reactor during a fire and keep it in a safe condition throughout the fire and its mitigation.

The defense-in-depth concept concerning fires at the RNPP shall be implemented in the following areas:

– performance of fire safety analysis (FSA), development and implementation of associated measures to enhance the RNPP fire safety level;
– development and timely revision of fire safety documents (instructions, provisions, operating plans and firefighting cards, enterprise standards, etc.)
– a fire safety department and a common-plant fire technical commission were established at the RNPP;
– a contract was concluded for the purchase of fire protection services for RNPP facilities from State Fire Rescue Team-2 of the SESU Main Department in the Rivne region;
– fire safety training of personnel was provided;

- fire training of personnel, including joint training with SFRU, is conducted in accordance with the schedules,
- RNPP facilities are equipped with external and internal firefighting water mains, fire detection and extinguishing installations, primary fire extinguishing means, a set of measures is ensured to maintain these systems and equipment in constant readiness for action as intended;
- passive fire resistance means of combating the occurrence and spread of fires within standard limits include: fire walls, partitions, doors, fire retardant valves, fire retardant mixtures, cable penetrations and fire retardant belts;
- constant monitoring of compliance with the fire safety regime is carried out at all levels, immediate measures are taken to eliminate the identified incompliance with fire safety requirements and rules.

3.3.1 Prevention of fire occurrence

Fire prevention is the first level of defense-in-depth for fire protection.

3.3.1.1 Design features and prevention means

The following requirements for fire protection are implemented in the design documentation for construction and in the operation of RNPP Units 2 and 3:

- reduction of the fire load in NPP premises by reducing combustible substances and materials to the minimum necessary;
- prevention of conditions for generation of gas/air explosive and fire hazardous mixtures;
- organizational and technical measures to prevent the generation of various ignition sources;
- limitation of the mass or volume of combustible substances and materials and their placement in the safest way;
- use of electrical equipment fabricated with the appropriate class of explosion and fire zone in accordance with PUE [□14];
- use of materials for civil structures and finishing materials that correspond to the appropriate explosion and fire hazard category of premises and to state construction standards.

3.3.1.2 General overview of control and monitoring mechanisms for fire loads and ignition sources

Organizational measures performed at the RNPP to prevent fires and maintain the relevant fire safety regime:

- fire safety briefings are conducted for all RNPP employees in compliance with [66];
- special fire safety training is conducted for all employees of the RNPP who perform activities with increased fire hazard in accordance with the program [67];
- fire safety training of RNPP officials is carried out in accordance with the program [68];
- common-plant instruction on fire safety measures was developed [69];

- notes (instructions) on fire safety measures in administrative, production and warehouse premises were developed;
- RNPP Order on organization of fire activities was issued [70]

The generation of gas/air explosive and fire-hazardous mixtures at the RNPP is prevented by the following measures:

- maintaining a safe concentration of the combustible environment;
- isolation of the combustible environment from the general volume of the premise;
- placement of fire-hazardous equipment in separate premises;
- maximum automation and mechanization of technological processes related to the circulation of combustible substances;
- use of devices to protect process equipment with combustible substances from damage and accidents (automatic disconnection).

The generation of potential ignition sources in the combustible environment is prevented at the RNPP by the following measures:

- use of machines, mechanisms, equipment and devices that does not create ignition sources in their operation;
- use of electrical equipment with the appropriate protection level in fire-hazardous and explosive zones;
- use of fast-action means for protective disconnection of possible ignition sources in the equipment design;
- application of technological process and equipment that meet the requirements of electrostatic electrical safety in GOST 12.1.018 [16];
- arrangement of lightning protection of buildings, structures and equipment;
- use of spark-free tools when working with flammable liquids and combustible gases;
- compliance with requirements for joint storage of substances and materials;
- reduction in the determining scope of the combustible environment below the maximum allowable flammability level.

The mass or volume of combustible substances and materials at the RNPP is limited by the following measures:

- reduction in the mass or volume of combustible substances or materials located in the premises;
- arrangement of emergency draining of fire-hazardous liquids and emergency discharge of combustible gases from process equipment;
- arrangement of explosion protection systems on process equipment;
- periodic cleaning of premises, communications and process equipment from combustible waste, dust deposits, etc.;
- removal of fire-hazardous industrial waste;
- replacement of flammable and combustible liquids with non-flammable ones.

The electrical systems at the RNPP, including fire protection features, were designed in accordance with the requirements of PUE [□14]. At the same time, power supply to the loads of NPP safety systems is provided in accordance with the [□83].

In accordance with the requirements of para. 5.3.2.2 [17], all cable products used at RNPP (in safety systems, in systems important to safety, normal operation systems that are not related to safety) do not spread combustion.

3.3.1.2.1 Example of implementing fire prevention means

To prevent damage of roof structures caused by excessive loads and to restore watertightness of the roof, refurbishment of the roofing carpet was conducted. The objective of this work was to ensure the fire safety of the turbine hall No. 2 roof by replacing the combustible insulation with non-combustible materials. During roof refurbishment for the turbine hall No. 2, the following activities were performed: obsolete layers of roofing were dismantled; vapor barrier made of fiberglass cloth impregnated with ZhKM mastic compound was laid; heat insulation was laid; three layers of fiberglass cloth waterproofing were laid with ZhKM mastic compound applied to each layer; reflective powder was applied. The measure at Unit 1, 2 was implemented in full. The implementation of this measure increases the operational reliability of the turbine hall building, since it involved the use of non-combustible PAROS insulation and coating from the ZhKM mastic compound, which belong to the materials of flame propagation group RP1 and flammability group G1 in accordance with para. 4.2.3 [17].

A similar measure was implemented for RNPP Unit 3: replacement of combustible insulation of the turbine hall No. 3 roof with non-combustible one. The following activities were performed during roof refurbishment for the turbine hall No. 3: obsolete layers of roofing were dismantled; vapor barrier with 2 layers of bituminous-polymer material was laid; heat insulation was laid; waterproofing layer of bituminous-polymer material was laid; protective layer of bituminous-polymer material was laid. Measure 17110 “Replacement of Combustible Insulation of the Turbine Hall Roof” of the Comprehensive (Integrated) Safety Improvement Program for Nuclear Power Units at RNPP Unit 3 was implemented in full, according to the design.

These modifications are performed in accordance with the requirements [3], comply with the standards and rules for modifications of nuclear facilities and procedure of their safety assessment [35], and are an effective solution for bringing the civil structures of the turbine hall roof at RNPP Units 1, 2 and 3 into compliance with the requirements of regulatory documents.

3.3.2 Active fire protection

In order to detect a fire at an early stage, extinguish a fire with various fire extinguishing systems, and organize the evacuation of people with the help of notification systems, active fire protection systems, which are the second stage of defense-in-depth protection, are installed at the RNPP.

At the same time, it should be noted that effectiveness of active fire protection systems is ensured only in combination with the arrangement of passive fire protection systems, which are the third level of defense-in-depth protection of RNPP.

The active fire protection systems include:

- automatic fire alarm system;

- automatic fire extinguishing systems (gas for local and volumetric extinguishing, water);
- notification and evacuation management systems;
- primary fire extinguishing means – fire extinguishers and fire hydrants.

At RNPP, active fire protection systems are arranged to form parallel trains that perform the same function in accordance with the principles of redundancy, independence, backup and physical separation and the single-failure principle.

The automatic fire-extinguishing installation (AFEI) includes an automatic fire alarm system (AFAS) for fire detection and fire protection automatics (FPA) for AFEI control and monitoring.

AFAS and FPA are intended for:

- alarm on the main control room (MCR) of fire occurrence in the main building premises, indicating the room where the fire occurred;
- control of valves necessary for water supply to the respective premise;
- automatic disconnection of ventilation systems in the premises where the fire occurred;
- automatic connection of ventilation systems in stairwells;
- formation of generalized information on fire in the main building of the power unit in the central dispatch room;
- automatic water supply only in one direction (where the fire occurred), and closure of gate valves in other directions;
- generation of position information and light and sound signals related to fire occurrence and its extinguishing, as well as in case of malfunction (e.g. “valve jammed” and “fire alarm malfunction”);

AFEI elements are controlled automatically or remotely from the MCR, or locally, at the place of installation of pumps and stop valves.

3.3.2.1 Fire detection and fire alarm

Automatic fire alarm system is designed for early detection of fire and generation of alarm signal to take necessary measures (e.g.: evacuation of people, calling fire and rescue units, starting smoke suppression systems, control of fire dampers, disconnection or blocking (unblocking) of other engineering systems and equipment upon the fire signal).

Equipment of the automatic fire alarm system (AFAS) is classified in accordance with [3]:

- for safety system premises – 3N;
- for normal operation premises important to safety, main building – 3N;
- for normal operation premises of auxiliary buildings – 4N.

AFAS is an I&C microprocessor system that implements its functions using information received from fire detectors installed in protected premises and buildings. The AFAS has a modular structure and a self-diagnostic system to ensure prompt identification and elimination of malfunctions without disrupting the AFAS operation. Faults are detected with the accuracy of the hardware module or fire detector. The AFAS is designed as an autonomous system, with

the organization of communication with other information and I&C systems of firefighting automatics of the power unit. AFAS jointly with targeted and non-targeted peripheral devices ensures the fulfillment of its functions in accordance with the technical specifications established in [71]. The AFAS collects, displays, documents, and archives information regarding signals generated in case of violations of the AFAS safe operation, protective action commands, and prohibition or disconnection commands.

AFAS has a multi-level control system that eliminates the possibility of unauthorized access to the software, as well as to the database of the system. The design of casings for AFAS FACPs, special equipment set (SES) (for safety systems) and FACP1, RS1 (for normal operation systems important to safety) envisage devices that prevent unauthorized access to the AFAS controls and interlocks. Fire alarm panels FACP-01f from the FAAS system and FACP1 from the FAS1 system are used as receiving stations. Blocking, control and alarm circuits from the information source to formation of commands in power valve distribution equipment (PVDE) are arranged in a single-channel form in each SS train.

Fire automation means and AFAS are concentrated on special panels of SS trains, located in the MCR and

- in PPRV premise (AE-357) for Unit 2
- in premise (AE-340) for Unit 3.

AFAS devices ensure constant automatic self-monitoring of readiness for operation and generation of fault signals. The automatic fire alarm system is connected via inverters to batteries, which are an emergency uninterruptible power supply source in case of blackout.

Example of implementing solutions for fire detection at RNPP Unit 2

The main objective of the measure 37101 was to implement new technical solutions for the AFAS and AFEC systems aimed at replacing obsolete equipment with up-to-date equipment certified in Ukraine that meets special requirements for NPP equipment and devices. The AFAS system is being brought into compliance with the requirements of [17], reliability and informativeness are being improved.

Modernization was carried out for the AFAS and AFEC systems of water fire extinguishing installations of the SS1, SS2 and SS3 premises, as well as DGS-21, DGS-22 and DGS-23 cells by replacing worn-out and obsolete existing equipment and technical means with up-to-date, certified FAAS and FAS1 equipment meeting special NPP requirements.

In accordance with [72], the FAAS system includes fire control panels FACP-01f, fire detectors of various types and modules for various purposes (engineered automation features (EAFs)). The FAS1 system includes fire control panels FACP1, fire detectors of various types and EAFs. They are instrumentation and control systems that implement their functions using information received from fire detectors installed in protected premises and structures. FAA" has a modular structure and a self-diagnostic system.

In the implementation of the measure 37101, new EAFs were installed to replace the obsolete ones:

- targeted smoke detectors - for premises with electrical equipment, cable rooms and structures, in which the occurrence of fire may be accompanied by smoke;
- non-targeted smoke detectors - for cable premises of the containment;
- non-targeted smoke detectors - for premises of oil facilities;
- manual fire detectors - on escape routes and stairwells.

To receive signals on actuation of fire detectors, new fire alarm control and indicating equipment FACP-01f was installed.

To meet the redundancy principle, three fire alarm loops are envisaged for each SS with water fire extinguishing, two of which are fire-extinguishing automation loops and one is an alarm loop. The loops are connected to three different types of fire alarm control and indicating equipment FACP1. FACP1 to which the automation loops are connected are located in the premises adjacent to the protected systems (for example, if the automation loops protect the premises of the first SS, then FACP1 to which they are connected are located in the premises of SS 2 and SS 3. In turn, the power supply of these FACP1 is also arranged from SS 2 and SS 3). The alarm loop is connected to FACP1 of its system, which is located in MCR-2.

Before the modification, the AFAS equipment, which was used for the normal operation systems of NPP units, did not meet the requirements of the current regulations, standards and rules of Ukraine in terms of resistance to external factors, interference protection, self-diagnostics and configuration. In this regard, it was necessary to replace the AFAS with an instrumentation and control system that implements its functions using information from fire detectors installed in premises and structures. This system had to be certified in Ukraine and meet special requirements for NPP equipment and devices. Cable communications (loops, power and control cables), which were laid before the modification, did not meet the current requirements of regulatory documents in terms of fire resistance.

When the measure is implemented for non-system rooms, the following is performed:

1. Targeted smoke detectors are currently installed in the normal operation electrical premises (electrical equipment rack and turbine hall), thermal fire detectors are installed in the technological premises of the oil facilities (turbine hall, special building 1). Thermal fire detectors are connected to AFAS loops through intrinsically safe modules.

Flame detectors are installed in the turbine hall premise, on the wall on row A. The detectors monitor the turbine generator area.

2. AFAS and AFEC of electrical equipment rack and turbine hall cable rooms are based on FACP1, which is installed in the 2AP-2 panel of the PPRV (premise E-357). Remote control of gate valves is possible from panel 2AP-2. The gate valves can be remotely controlled from the PVDE assemblies, which allows controlling the valves without FACP1. In addition, gate valve position (open, closed) is indicated on the 2AP-2 panel.

3. Fire protection automatics of the Unit 2 transformers is based on the relay circuit installed in panel 2AP-4 of the PPRV (premise E-340). In addition, remote control for gate valves of these premises is possible from panel 2AP-4.

The valves can be remotely controlled from the PVDE assemblies, which allows controlling the valves without automatic fire-extinguishing circuit. In addition, gate valve position (open, closed) is indicated on the 2AP-4 panel.

4. AFAS and AFEC of reactor compartment premises is based on FACP1 installed in panel 2AP-1 of the PPRV (premise E- 357).

For all installed FACP1, a capacity according to the number of connected signal lines with a margin of at least 20% of the available capacity is envisaged. All fire alarm loops are made of fire-resistant, shielded cable with a fire resistance limit of at least 180 minutes in the mode of direct exposure to flame and at least 30 minutes in the mode of standard temperature conditions. All power supply and control cables are made of fire-resistant, shielded cable with

a fire resistance limit of at least 180 minutes in the mode of direct exposure to flame and at least 30 minutes in the mode of standard temperature conditions.

Structures (panels, cabinets) in which FACP1 are installed are made in accordance with the requirements for seismic resistance. For all installed FACP1, a capacity according to the number of connected signal lines with a margin of at least 20% of the available capacity is envisaged.

The implementation of Measure 37101 (taking into account the completion of activities in normal operation premises) will bring the automatic fire alarm system of safety system (SS) premises and normal operation premises at RNPP Unit 2 into compliance with the requirements of para. 6.1.2, 6.1.4 [17], para. 10.11.5 [3] and construction standards [17].

Maintenance of the AFAS systems at the RNPP is organized qualitatively and at a high level, and is performed in accordance with [73].

Example of implementing solutions for fire detection at RNPP Unit 3

Similar Measure 17101 "Modernization of Automatic Fire Alarm System for NPP Safety System Premises" was implemented at RNPP Unit 3 within the C(I)SIP. Modernization of the AFAS in the SS premises equipped with AFEC systems provides for a three-train AFAS in the protected premises. Two trains of this system directly induce the automatic start of the fire-extinguishing system.

The main objective of Measure 17101 was to implement new technical solutions for the AFAS and AFEC systems aimed at replacing obsolete equipment with up-to-date equipment certified in Ukraine that meets special requirements for NPP equipment and devices. Modernization was carried out for the AFAS and AFEC systems of water fire extinguishing installations of the SS1, SS2 and SS3 premises, as well as DGS-21, DGS-22 and DGS-23 cells by replacing worn-out and obsolete existing equipment and technical means with up-to-date, certified "FAAS" and "FAS1" equipment meeting special NPP requirements. Measure 17101 "Modernization of the Automatic Fire Alarm System of NPP Safety System Premises" of the Comprehensive (Integrated) Safety Improvement Program for Nuclear Power Plants was implemented in full scope at RNPP Unit 3.

C(I)SIP Measure 17105 "Modernization of the Automatic Fire Alarm System for Reactor Compartment, Turbine Hall, Deaerator Compartment, Electrotechnical Device and Special Building Premises" was implemented for normal operation premises of RNPP Unit 3.

The implementation of Measure 17105 was associated with the need to replace the hardware of automatic fire alarm system (AFAS), which are part of the fire automation of water fire extinguishing units and control of engineering systems of the main buildings and structures of NPP power units during a fire, with those that meet the special requirements for NPP devices and equipment.

Before the modification, the AFAS equipment, which was used for the normal operation systems of NPP power units did not meet the requirements of the current regulations, standards and rules of Ukraine in terms of resistance to external factors, interference protection, self-diagnostics and configuration.

In this regard, it was necessary to replace AFAS with an instrumentation and control system that implements its functions using information from fire detectors installed in premises and structures. This system had to be certified in Ukraine and meet special requirements for NPP equipment and devices. Cable communications (loops, power and control cables), which

were laid before the modification, did not meet the current requirements of regulatory documents in terms of fire resistance.

The following was performed under the measure:

1. Targeted smoke detectors were installed in the normal operation electrical premises and turbine hall, thermal fire detectors are installed in the process premises of the oil facilities, thermal fire detectors are connected to the loops of the automatic fire alarm system through intrinsically safe modules.

Flame detectors are installed in the turbine hall premises. The detectors monitor the turbine generator area and TG oil-filled equipment.

2. AFAS and AFEC of electrical equipment rack and turbine hall cable premises are based on FACP1, which is installed in the HZ16/1 panel (electrical equipment rack) and HZ16/2 panel (turbine hall, deaerator compartment) (AE-340). Remote control of gate valves is possible from the panels. The valves can be remotely controlled from the PVDE assemblies, which allows controlling the valves without FACP1. In addition, gate valve position (open, closed) is indicated on the panel.

3. Fire protection automatics of the Unit 3 transformers is based on the relay circuit installed in panel 37P of the AE-340 premise. In addition, remote control for transformer fire extinguishing valves is possible from the panel.

The valves can be remotely controlled from the PVDE assemblies, which allows controlling the valves without AFE circuit. In addition, valve position (open, closed) is indicated on the panel.

4. The AFAS and AFEC of the reactor compartment premises is based on FACP1 installed on the HZ12/1, HZ12/2, HZ12/3 panels in premise AE-340.

For all installed FACP1, a capacity according to the number of connected signal lines with a margin of at least 20% of the available capacity is envisaged.

All fire alarm loops are made of fire-resistant, shielded cable with a fire resistance limit of at least 180 minutes in the mode of direct exposure to flame and at least 30 minutes in the mode of standard temperature conditions. All power supply and control cables are made of fire-resistant, shielded cable with a fire resistance limit of at least 180 minutes in the mode of direct exposure to flame and at least 30 minutes in the mode of standard temperature conditions.

Structures (panels, cabinets) in which FACP1 are installed are made in accordance with the requirements for seismic resistance.

Implementation of measure 17105 allowed the AFAS in normal operation premises (reactor compartment, electrotechnical device rack, deaerator compartment, turbine hall) to be brought into compliance with [17] (para. 6.1.1, Annex E, para. 1.1.1), [3] (para 10.11.5), and State Construction Standards [10].

The AFAS reconstruction and modernization for the SS and normal operation premises allowed improving the fire safety of both Unit 3 and the fire safety of the RNPP in general.

3.3.2.2 Fire mitigation

To ensure active fire protection, automatic fire extinguishing installations (AFEI) are used to protect premises of safety systems (SS) and normal operation systems.

The fire protection automation system includes a foam firefighting pumping station (FFPS) located in a separate building, which is the main water supplier to the AFEI systems of Units 1 and 2.

The external fire water supply networks of the facilities of Units 1 and 2, which are powered by the foam firefighting pump system (FFPS), and the facilities of Units 3 and 4, which are powered by UPS-2 and 3, are disconnected from each other by isolation valve that is in closed position. The above-mentioned networks operate independently of each other. If necessary, Units 1, 2 can be powered from UPS-2, 3 by opening the isolation valve.

Power Unit 2. In accordance with [75], the FFPS water fire extinguishing supply network of the NGF is under a pressure of 6-7 kgf/cm^2. At the FFPS, 4 fire pumps are installed to supply water to the fire-extinguishing water supply network to power units 1 and 2:

- SWP-1 is a diesel-driven service water pump;
- SWP-2, SWP-5 - pumping units for service water pumping;
- SWP-3 - pumping unit for pumping service water or foam forming agent solution;

Normal condition of the FFPS equipment means that one of the pressure pumps SWP-2, SWP-3, and SWP-5 is constantly in operation (the rest of the pumps are in standby mode ready for operation). Systematic control over the technical condition of the equipment is ensured by means of routine inspections, equipment examination, routine testing operations and transitions in accordance with approved programs and on time according to approved schedules.

In the turbine hall, pressure gauges are installed on the pressure piping in front of the check valve of each pumping unit (SWP-1, 2, 3, 5) to monitor the pumping station operation. Pressure gauges (operating and control ones) are installed on the pressure piping DN-400 at the outlet of the pumping station to control the pressure in the fire water supply pipelines.

The level in the fire service water tanks (FSWT-1, FSWT-2) is determined by the OBM1-160 device installed in the pumping station's turbine hall on the suction line of the SWP-1. The control panel of the starting backup boiler (panel No. 28) contains the keys for controlling the pumping units SWP-2, 3, 4 and valves 3VN, 3VV, 4VN, 4VV, 3V-3, ZV-4; a switch for blocking the pumping units SWP-2, 3 to select the operating mode.

The pressure control in the fire water supply pipelines is controlled by the pressure control value (PCV) RD-1 installed on the FFPS recirculation line. RV-1, RV-2 and a bypass line with valves RV-3 are also installed on the recirculation line. The pressure in the fire-extinguishing water supply piping should be maintained within 6.0-7.0 kgf/cm^2.

Both automatic water fire-extinguishing and gas fire-extinguishing systems are used in the Unit 2 premises. The water fire-extinguishing system includes a water supply system, piping with sprinklers, fire detection and isolation valves control units. Distribution pipelines with sprinklers are installed in each protected premise. When the water supply is finished, the pipelines are drained through drainage valves.

Manual and electrical gate valves are used as isolation valves.

In accordance with [3], the AFEI valves have a classification f 3N for the SS premises and 4N for the normal operation premises.

The RNPP-2 reactor compartment (RC) AFEI system is mounted in: cable shafts and corridors; premises of BMP oil systems; premises of MCP oil systems; Arrangement of RNPP-2 turbine hall (TH) AFEI: in cable floors under TH; in TH oil facilities; on damping and pressure oil tanks; on unit transformers, auxiliary transformers, and standby transformers. The RNPP-2 DGS AFEI system is located in the fuel tanks premises; in the process premise at elevation -3.900;

In case of a fire, the fire-extinguishing system is actuated automatically by the fire detectors installed in a premise. At the same time, the valve opens in the appropriate direction.

At RNPP Unit 3, the fire automation system includes UPS-2, which is located in a separate building and which is the main water supplier to the Unit 3 AFEI systems, and the automatic stationary fire-extinguishing system (3UJ11, 12, 13, 14) designed to extinguish fires with spray water installations in protected premises and is referred to a normal operation systems important to safety. The RC automatic fire-extinguishing system consists of three trains 3UJ11, 3UJ12, 3UJ13. Each train consists of fire water supply pump 3UJ11D01 (3UJ12D01, 3UJ13D01); fire water storage tank 3UJ11B01 (3UJ12B01, 3UJ13B01); pipelines and valves; I&C.

Automatic fire extinguishing for non-system process premises 3UJ14 from the main fire water supply line includes: pipelines and valves; I&C equipment.

The automatic fire-extinguishing system 3UJ11 (3UJ12, 3UJ13) ensures fire extinguishing in cable premises belonging to safety systems, as well as in the premise of MCP oil systems.

Three automatic input fire-extinguishing pipelines are connected to the containment from the fire-extinguishing distribution point at elevation 28.800. Each pipeline is equipped with an electrically driven gate valve 3UJ11,12,13S12 from the auxiliary building side and a check valve from the containment side. To ensure reliable operation of the fire-extinguishing system in the containment area, to prevent false alarms and water flooding of the premises, the 3UJ11,12,13S12 valve is in the closed position, the section of the fire pipeline between the 3UJ11,12,13S12 valve and the valve in the containment area in the direction of the protected premises is drained. The opening of the valve 3UJ11,12,13S12 is performed when automatic fire-extinguishing starts in automatic mode with the simultaneous opening of the fire valve in the direction of the protected premise, as well as in remote mode from the control panel HZ13, HZ14, HZ15 (MCR-3).

In the protected premises of each SS train, two fire automation beams from the other two trains and one alarm beam with a command for disconnection of the ventilation unit (under actuation of one detector) are mounted. The signals from the detector are sent to the control panels installed at the elevation 20.400 in premises AE-609/1-3. In case of a fire in the protected premise of the SS train, the "FIRE" signal shall be actuated on FACPs of the other SS trains, the 3UJ12,13(11) D01 pumps shall be actuated and the corresponding valves 2,3(1) of SS trains shall be opened. If the "FIRE" signal is actuated in several premises of the 1st SS train at the same time, the valve opens only to one premise (direction) and the prohibition of opening the valves to other directions is actuated.

The main pipelines are used to transport fire-extinguishing water from the ring fire pipeline of the TH and RC of Units 2 and 3 to the distribution point. Fire-extinguishing distribution points (FEDPs) are premises where distribution pipelines - dry pipes extend to the protected premises from the ring fire-extinguishing water collector fed by two main pipelines.

The power supply of fire pump motors and electric valves is carried out according to the first category in accordance with the PUE [□14]. In case of loss of normal power supply to the electric valves of the fire-extinguishing system, the power supply should be provided from the network of the 2nd group of reliable power supply (SDG). The isolation valves are powered from the network of the 1st group of emergency power supply systems (from a battery via inverters).

The criterion for fulfilling the tasks assigned to the fire-extinguishing system is to prevent the failure of more than one SS trains due to the fire impact.

Estimates of the facility inertia from the moment of signal receipt to the moment of water supply to the fire epicenter, not exceed 3 minutes. Effective irrigation conditions, the rate and sufficiency of the extinguishing agent are ensured by creating an operating pressure in front of the sprinklers of 0.2 - 0.4 MPa, the estimated irrigation intensity of at least 0.12 l/s per m² of the building floor and the placement of sprinklers based on the irrigation of all cable lines, taking into account irrigation maps.

When the AFEI equipment is actuated as intended, the performance must be restored within 24 hours. In case of non-readiness, it is allowed to continue work to restore the AFEI performance up to 72 hours with the permission of the RNPP Chief Engineer.

The protection and alarm system shall be checked according to the schedule approved by the Chief Engineer, at least once a week. The inspection is performed by the personnel of the Thermal Automation and Measurement Department (TAMD) and the operational personnel of Thermal and Underground Communications Department (TUCD).

Withdrawal of FFPS equipment for repair is performed according to an application submitted to the Chief Engineer - First Deputy Director General of RNPP, with a record in the "Station Shift Supervisor's Application Log".

Maintenance of the RNPP AFEI systems is performed in accordance with [76], which was developed according to the License Terms approved by the Cabinet Resolution No. 852 dated 23 November 2016 (as amended by the Cabinet Resolution No. 1190 dated 02 December 2020).

In accordance with the requirements of para. 1.4. of Annex E [17], premises with electronic and electrical equipment must be equipped with stationary automatic gas fire extinguishing systems.

The Automatic Gas Fire-Extinguishing System of Module Type (AGFES) is designed to protect against fire in the premises of power units 2 and 3, where electrical and electronic equipment is located and where water cannot be used as a fire extinguishing agent. The AGFES operation is based on the principle of volumetric fire extinguishing in a separate premise by creating a concentration of gas extinguishing agent in the entire volume of the premise.

The AGFES equipment belongs to class 3N (normal operation system, important to safety according to [3]. The module type automatic gas fire extinguishing system is part of the common Fire Automatics and Alarm System (FAAS) of the power unit. In accordance with [78], each protected AGFES premise is equipped with an autonomous modular volumetric gas fire-extinguishing unit consisting of technological and electrical parts.

The technological AGFES part consists of: nozzles (gas sprayers); supply pipelines; pipeline manifold; high-pressure hose; module (extinguishing gas cylinders) of the MGP-50-100 type.

The electrical AGFES part is made in a two-level version and consists of upper and lower level equipment.

The upper level equipment consists of three redundant sets of special equipment of the computer system (SES), which are installed at RNPP 2 MCR-2 in premise E-355, at RNPP 3 MCR-3 in premise AE-341 (two sets of SES-1 "Main", SES-3 "Backup" at each power unit) and at RNPP 2 ECR-2 in premise E-336, at RNPP 3 ECR-3 in premise AE-052 (one set of SES-2 "Backup" at each power unit). In case of power loss of SES-1 "Main", the control is

automatically transferred to SES-3 "Backup", if SES-3, SES-1 are de-energized, the control is automatically transferred to SES-2 "Backup", but the information on the units' AGFES will not be complete. SES-3 is used for communication (via Ethernet channel) between SES-1 and SES-2. If SES-1 is disconnected, there will be no communication between SES-1 and SES-2, which means that the monitoring of the AGFES will not be synchronized, and the information will not be complete.

As a gas extinguishing agent, the liquefied gas "Khladon-125HP" pentafluoroethane (C2F5H) is chosen, and as a displacing gas, nitrogen (N2) with a dew point not exceeding -40°C is used.

The FACPs ensure receiving and processing input signals of various types, issuing control signals to warning devices and process equipment, and information output to higher-level equipment via RS-485 communication line. The FACPs operate in the programmed mode of receiving, processing input and output signals according to the algorithm that realizes their functioning in the installations. Programming is performed at the manufacturing plant. The FACPs are designed on a modular principle.

The warning units BOP-03F (units) are designed to provide light and sound alarms under supply of direct current to them. The units are designed to operate as part of fire alarm and fire-extinguishing systems in closed stationary facilities.

All FACPs are connected by separate cable lines of RS-485 interfaces with mutually redundant SES cabinets.

The FACP has two control modes: manual and automatic.

The main control mode for protected premises without permanent service personnel is manual mode. In this case, the AGFES performs all the functions of interlocks, warning alarms "Gas! Get out!", "Gas! Do not enter!" and "Automation is disabled", as well as determines the location of the fire when fire detectors are actuated in the controlled premise.

Under FACP operation in automatic mode, the transition to manual mode occurs: at the operator's command; at the signal from the end switch on the door "Door open" or at the command from the upper level equipment (MK01, MK02, MK03). The automatic mode of the FACP is set at the operator's command from the device, and at the command from the upper level in the absence of the "Door open" signal.

In the automatic mode, the automatic start of the AGFES is performed only when one fire detector in each of the two fire alarm loops protecting the given premise is actuated, i.e., when the "Fire" signal is received. In the manual mode, the AGFES actuation is controlled by a command from the FACP, as well as by a command from the upper level cabinet keyboard (MK01).

SES cabinets receive, process and display on the monitor screens all the information coming from FACP.

The upper level software of the gas fire-extinguishing system (UL GFES) used in SES ensures execution of the following functions:

- permanent centralized control of the readiness of automated means of the gas fire extinguishing system (GFES) (control of FACP readiness and readiness of fire-extinguishing equipment);
- permanent centralized control of the fire condition in protected premises and notification of personnel about violations;
- centralized task and change of operation modes of GFES means;

- registration of fire incidents at controlled facilities, of the operator actions and provision of information for further analysis;
- centralized management and issuance of appropriate commands to GFES means.

Each premise where gas fire extinguishing is implemented is served by supply and exhaust ventilation. In addition, fire retardant valves (FRVs) are installed in places where ventilation ducts cross the fencing of the premise protected by gas fire extinguishing. The fire retardant valves are equipped with automatic (from the AFAS included in the AGFES system), remote and local control.

After the combustion products and extinguishing gas are removed by a portable fan, the FRVs are set to the "open" position from the valve control panels or manually (at the valve installation place). In absence of a fire, the system should be in the "standby" mode, the safety of the extinguishing agent and operability of the automation and power supply system should be monitored. Remote and on-site start-up devices shall be protected against accidental actuation and sealed.

Disconnection of ventilation systems and closing of valves on ventilation air ducts at the "Fire" signal should be carried out within 30 seconds before the extinguishing agent (refrigerant) release into the protected premises.

The command impulse for controlling the ventilation systems and FRV is generated by the electronic key module (EKM) of the FACP, which is programmatically linked to the FACP fire alarm loops and is initiated after the actuation of two fire detectors connected to different loops.

To remotely control the valves of the ventilation systems of the protected premise, it is provided to install control panels with position indicators and buttons for controlling the valve actuator "Open" and "Close" outside the premise at its outlet. Local valve control is used to adjust the valve and is executed from the button mounted on the valve body.

In order to ensure safety when performing works related to visiting the premises equipped with the AGFES units, the owner department is obliged to ensure mandatory implementation of the following organizational and technical measures:

- warning posters with brief instructions to personnel on the procedure for entering and leaving the premises, as well as on the notification procedure in case of fire in a premise protected by the AGFES, are installed on the doors to the premises equipped with the AGFES;
- visits to the premises are carried out for inspections, testing, maintenance, scheduled and emergency repairs, and operational switching;
- operational personnel visit the premises based on job descriptions in accordance with the assigned equipment and service area in the course of routine operation;
- maintenance personnel visit the premises based on work permits and work orders;
- personnel of third-party organizations shall visit premises equipped with the AGFES only accompanied by an employee of the owner department of the premises who has the right for AGFES operation, after conducting a targeted briefing on the peculiarities of work in premises equipped with AGFES. When the personnel of a third-party organization perform work in the premises, a supervisor from among the employees who have the right to operate the AGFES shall be mandatorily assigned by the owner department of the premises;

– department shift supervisors shall control the number of personnel in the premises with the AGFES by registering them in the work order logs, as well as in the operational log at the time of the shift turnover.

The AGFES start-up procedure is as follows:

– the Unit Shift Supervisor calls up a video frame of the protected premise on the SES-1 screen;
– on the video frame, the cursor shall be moved on the active "START" button, the button shall be pressed for confirmation, and then an electronic key shall be placed on the reader within the time allotted by the system (the protected premise is in "Manual" mode, the sealed key is located near the SES monitor).

The remote start-up of the AGFES shall be carried out from the control panel installed outside at the entrance to the protected premises or by the MCR-2 operator. (For premises with FACPs installed inside the premises, the remote AGFES start-up shall be carried out by the MCR-2 operator).

The conditions necessary for the AGFES activation are:

– disconnection of all ventilation (air conditioning) systems servicing the given premise and isolation of the premise from adjacent premises by fire protection valves through the ventilation system air ducts (operator shall make sure that the ventilation systems are disabled and the fire retardant valves are closed);
– closure of all doors of the given premise (if one of the doors of the premise equipped with AGFES is not closed, the "Automatic" mode will not be set).

Upon AGFES actuation in any premise, the ventilation systems servicing that premise are disabled and the fire retardant valves are closed.

In accordance with [78] and [79], the operational and maintenance of the AGFES shall be performed by the personnel of the thermal automation and measurement department (TAMD) and electrical department (ED) who have undergone training, knowledge testing and are instructed on the AGFES equipment use.

During the operational maintenance, a visual inspection of the AGFES equipment state (pressure gauges, pipelines, FRVs, doors) and control of the condition of piping fasteners, the condition of nozzles for deformations and cleanliness shall be carried out on a monthly basis, pressure presence in the gas fire-extinguishing modules (if the nitrogen pressure decreases by more than 10% of the nominal value at (20 ± 2) °C, the module must be loaded to full capacity or recharged), the presence of seals on the safety check for local start-up, the integrity of the high-pressure hoses and presence of module inflation pressure.

During the AGFES operation, it is necessary to carry out maintenance in accordance with [76]. The works shall be performed by trained personnel.

External fire water supply networks are designed to provide uninterrupted and reliable supply of the required amount of water to the RNPP industrial site facilities for fire-extinguishing purposes. External fire water supply networks should provide the required water flow rate and pressure according to the standards. Operation and maintenance of fire water supply networks shall be performed in accordance with [75]. Main tasks of utilization of external fire water supply networks are to:

- supervise the technical condition of networks, structures, devices, and equipment on them, maintain them in proper technical condition, remove clogging, and freezing effects;
- set operating modes of the networks and control their operation;
- ensure presence of the required water pressure at the inlets to the facilities and distribution of water flows in accordance with water consumption standards;
- perform routine and major repairs on the networks, eliminate malfunctions and emergencies, and monitor the absence of leaks;
- keep industrial and technical documentation;
- prepare perspective plans for the reconstruction and development of networks.

The system of external fire water supply networks includes:

- external fire water supply networks of power units 1 and 2;
- external fire water supply networks of power unit 3;
- external fire water supply networks of power unit 4.

Fire water supply piping is laid in the ground at a depth that prevents water from freezing. To protect the piping from corrosion, a protective coating is used: enhanced corrosion protection in accordance with DSTU B D.2.4-16:2014 [□76].

In accordance with the requirements of regulatory documents, two independent sources of fire water supply are provided for external fire extinguishing at RNPP: FFPS startup and standby boiler, which is used for the needs of external facilities of power units 1, 2 and UPS-2, UPS-3 for facilities of power units 3, 4 and open switchgear-750.

The FFPS is designed for firefighting water supply to auxiliary facilities of units 1, 2, the startup and standby boiler complex, structures for treatment of additional water, industrial and laboratory complex, IAEA, SFRU-22, 23 by means of two DN300 pipelines with operating pressure of 7.0 kgf/cm^2, as well as for foam fire-extinguishing with a 6% foam forming solution of cable ducts and cable semi-floor of the startup and standby boiler, turbine hall of the fuel oil pumping station, fuel oil overpass and fuel oil storage facility. The service water pumping unit SWPU-2 (3, 5) is in constant operation at the FFPS, which maintains pressure (P=7.0 kgf/cm^2) in the fire water supply piping of the auxiliary facilities of units 1, 2 with the RC-3 valve permanently open on the recirculation line located in the turbine hall. When one pumping unit is shut down for repair or transferred into standby mode, the backup pumping unit is put into operation. Pressure increase in the fire water supply networks of the auxiliary facilities of units 1 and 2 above P>7.0 kgf/cm^2 is possible in exceptional cases by order of the Plant Shift Supervisor.

UPS-2 is designed for fire water supply to the facilities of Unit 3 and the main building of Units 1 and 2. Pumping units 3UJ10D01.02; 3UJ20D01.02 intake service water from the circulation system inlet channel and, with an operating pressure of P=10.0 kgf/cm^2, supply it to Unit 3 fire water supply piping system.

UPS-3 supplies fire water to the Unit 4 facilities and to the open switchgear-750. Pumping units 4UJ10D01.02; 4UJ20D01.02 intake service water from the circulation system inlet channel and, with an operating pressure of P=10.0 kgf/cm^2, supply it to the fire water supply piping system of Unit 4 and open switchgear-750.

For interconnection of fire water supply networks of Units 1, 2 and Units 3, 4, isolation valves are installed on the piping.

The standard position of the isolation valve is closed. The valves are opened by the order of the station shift supervisor in case of emergency shutdown of fire pumping units at UPS-2, UPS-3, FFPS according to approved form programs (No. 1/02-TUCD, No. 2/02-TUCD, No. 3/02-TUCD, No. 4/02-TUCD).

If it is necessary to disconnect sections of the fire water piping and fire hydrants, or reduce the pressure in the network below the nominal pressure, the Shift Chief Engineer shall submit an application, which shall be preliminarily agreed with the deputy chief engineers (Meeting of the Council of Deputy Chief Engineers), SFRU, DO&FSS, and immediately report after the work completion.

The fire water supply system is designed according to the ring-type principle, divided by sectional valves to disconnect individual sections for repair and maintenance without disrupting the water supply to the site facilities, and is equipped with wells with fire hydrants placed in them. In total, 143 fire hydrants are installed at the RNPP industrial site. Hydrants shall be installed vertically in wells directly on the water supply network. The distance from the hydrant cover to the top of the manhole cover shall not exceed 40 cm and be less than 15 cm. In this case, the axis of the installed hydrant is located no closer than 17.5 cm and no further than 20 cm from the well hatch. Passageways and roads to fire hydrants have solid pavement and are kept clear. Fire hydrant covers shall be painted red and cleaned of dirt, ice and snow in a timely manner. The use of fire hydrants for household needs is prohibited. Signs shall be installed near the locations of fire hydrants and tanks with reflective coating, with the following information on them:

- for a fire hydrant: letter index FH, numerical designation, distance in meters from the sign to the hydrant, internal diameter of the piping in millimeters and type of water supply network;
- for a fire reservoir: letter index FR, numerical designation of the water stock in cubic meters.

Fire hydrants are opened and closed using a hydrant stand pipe by screwing it onto the hydrant nipple so that the square of its key fits into the seat. The fire hydrant valves shall be closed.

Operability of fire hydrants shall be checked by the SFRU personnel during the daytime with the permission of the Chief Engineer, with the mandatory presence of a TUCD representative. The state of all fire hydrants shall be checked once a year including water discharge in preparation for the autumn-winter period. In preparation for the spring-summer period, visual examination of the FH shall be carried out.

during the inspection including water discharge the following activities are performed to:

- check the operation of the hydrant rod with a caliper;
- check the operation of the hydrant rod with a gauge;
- install a hydrant stand pipe on the hydrant with water discharge;
- clean the drain opening;
- remove cork previously clogged into the drain opening, if the groundwater level in the well is below the fire flange.

In case of pressure decrease in startup and boiler room below 4.8 kgf/cm², the shift supervisor of the heat and underground utility shop immediately informs the NPP shift

supervisor about the deviation, reports to the management of the heat and underground utility shop, and takes immediate measures to restore normal water supply at Units 1 and 2.

If it is necessary to disconnect water mains on which fire hydrants are installed, for the performance of activities, the heat and underground utility shop shift supervisor shall notify SFRT-2 in advance. If extended period is required to repair fire hydrants or replace them, additional measures should be developed to ensure water supply in the event of a fire.

According to the maintenance results for the fire hydrants and fire water supply system, the relevant documents are drawn up.

The internal fire protection water supply system of the turbine hall at Units No. 1 and 2 is connected to the main piping by three valves (inlets):

- row A-B, axis 1, level -3.6, gate valve PZh-1;
- row A, axis 13÷14, level 0.0, gate valve PZh-24;
- row A-B, axis 24, level 0.0, gate valve PZh-42.

A comb of eight fire riser dry pipes with half-nuts for connecting fire equipment to the internal fire water supply is at a level of 0.000, row A-B, axis 24 (beyond the building). Internal fire hydrant cabinets in the turbine hall of Units 1 and 2 are located at the following levels: -3.600; 0.000; 9.600; 28.000. The following is provided to extinguish the roof of the turbine hall at Units 1 and 2:

- water supply to the roof of the turbine hall in axes 7, 17, row A from the fire piping along row A;
- water supply to the roof of the turbine hall at Units 1 and 2 through dry pipes in axes 1, 11 and 23 on the outside of the turbine hall from firefighting vehicles.

The internal fire protection water supply system at Unit 3 is connected to the main piping by three valves (inlets):

- row A axis 2÷3, level 0.000 - valve 3UJ20S01;
- row A÷B axis 12, level 0.000 - valves 3UJ20S02, 3UJ20S0.

For partial repair, the fire water supply system is divided into sections by sectional valves 3UJ20S04÷3UJ20S12. Internal fire hydrant cabinets in the turbine hall at Unit 3 are located at the following levels: -3.600; 0.000; 15.000; 19.800; 27.000.

The fire dry pipe of the turbine hall at Unit 3 is connected to the internal fire water supply system by valve 3UJ30S04 and supplies fire extinguishing agent to the roof of the turbine hall (there are 10 fire hydrants); deaeration rack (there are 4 fire hydrants); roof of the reactor compartment (there are 8 fire hydrants).

In warm season, dry pipes are connected to internal fire water piping of Unit 3 through the 3UJ30S04 valve. In cold season, dry pipes are disconnected and drained to prevent freezing.

Maintenance of fire dry pipes is provided according to the schedule approved by the Chief Engineer of the shift, but at least once a year.

Fire hose cabinets (FHCs), under appropriate conditions, are effective firefighting means with a permanent water supply source. They are particularly important at the initial stage of a fire. In accordance with the requirements of para. 5.5.10 [17], the following buildings of Unit 2 (122 FHCs) and Unit 3 (294 FHCs) are provided with internal firefighting water supply system with installed fire hydrants: turbine hall; reactor compartment; deaerator compartment;

electrical equipment rack; special building; DGS-21, 22, 23; SDG-31, 32, 33; transverse and longitudinal racks of electrical equipment; UPS-1; UPS-2.

In accordance with the requirements of the instruction [26], fire hydrants are equipped with fire hoses and barrels encased in cabinets, which are sealed. The letter index “FHC”, serial number of the fire hydrant and number for calling the fire department are indicated on the door of the fire hydrant cabinet.

In accordance with regulatory documents [□26], fire cabinets have ventilation openings and can be visually inspected without opening them.

Fire hoses are stored dry, folded in a double fold or accordion and attached to the cranes and barrels. Every six months, the hoses are re-rolled with a change of folding location.

Maintenance and testing of fire hydrants by means of water injection shall be carried out by the dedicated department’s personnel at least once a year. After checking, a record is made in the fire hydrant cabinet accounting software.

The procedure for checking fire hose sets is specified in [□79].

In accordance with para. 4.4.10 of DSTU2272:2006 [□30], a primary firefighting means (PFFM) is a technical means, substance, material, or their complex suitable for human use to localize and (or) eliminate a fire at its initial stage.

In accordance with the requirements of para. 10.5.4 [29] and Section V [82], all buildings, structures, premises, and process equipment are equipped with primary firefighting means - fire extinguishers.

In total there are 6287 fire extinguishers in operation at the RNPP, of which:

- carbon dioxide fire extinguishers - 2834;
- powder fire extinguishers - 2712;
- water aerosol fire extinguishers - 971.

Fire extinguishers are operated and maintained in accordance with the requirements of [26], [29], [82] and other regulatory documents of Ukraine on fire safety.

Before placing fire extinguishers at the facility, the person responsible for fire safety in the structural subdivision should inspect the fire extinguisher. After the inspection, accounting (inventory) numbers should be assigned to fire extinguishers according to the numbering system accepted at the facility. Fire extinguishers are inspected during their service life at least once a month by a person responsible for fire safety. During the inspection of fire extinguishers, after acceptance from maintenance, the person responsible for fire safety checks the availability of RNPP maintenance department label on the extinguisher casing, whose form and content meet the requirements of Annex 3 of the Rules [82]. The inspection results are recorded in the software of the fire extinguisher logbooks. Fire extinguishers are maintained by the RNPP maintenance department having the license to provide services and perform firefighting activities.

In premises with technological processes that may result in the formation of gas, dust or vapor-air mixtures under an emergency, fire extinguishers are installed outside the premises, by the entrance. In premises with permanent presence of people, fire extinguishers are located inside the premises, preventing the creation of obstacles to the evacuation of people. In premises with temporary occupancy, fire extinguishers are located outside the premises or at the entrance (exit).

Portable fire extinguishers shall be placed by hanging using brackets on vertical structures at a height of no more than 1.5 m from the floor level to the bottom end of the

extinguisher and at a distance from the door sufficient to open it completely, or installed in fire hose cabinets, firefighting equipment stands, stands, racks and special cabinets.

To indicate the location of fire extinguishers, there are directional signs in accordance with [□32]. The signs are located in prominent places, at a height of 2-2.5 meters from the floor level, both inside and outside the premises.

As part of C(I)SIP measures 37103 and 17103 “Provision of NPP Premises Containing Electrical and Electronic Equipment with Stationary Automatic Gas Fire-Extinguishing Systems” for RNPP Unit 2 and RNPP Unit 3, the automatic gas fire-extinguishing systems (AGFES) were upgraded. The implementation of the measure allowed bringing the premises with electrical and electronic equipment for automated process control into compliance with the requirements of [17] (Annex E, para. 1.4).

Upon the activities performed, the reliability of the power units increased in terms of timely detection of fires, as well as effective prevention of fire spread and mitigation, thereby creating conditions for nuclear and radiation safety of NPP and preserving the integrity of electrical and electronic equipment.

3.3.2.3 Administrative and organizational issues concerning fire protection

Coordination of activities associated with fire safety and their supervision at NPPs is entrusted to the Head of the RNPP Departmental Oversight and Fire Safety Service. The Fire Safety Department is a structural unit of the Departmental Oversight and Fire Safety Service (FSD DO&FSS). The Fire Safety Department is managed by the Department Head. The Head of FSD DO&FSS directly supervises the Department personnel according to the staffing list: Deputy Head of Department, Chief Inspector, 2 Inspectors, Leading Engineer, Category 1 Engineer.

The organizational structure of the RNPP Departmental Oversight and Fire Safety Service by FSD DO&FSS personnel is set forth in the following documents: [84] and [□85].

In accordance with [84], Heads of RNPP Departments are obliged to:

- accept for mandatory and unconditional implementation the FSD DO&FSS (inspection reports) prescriptions, and appeal the prescription by RNPP Chief Inspector within 3 days in disagreement with the requirements set out in them;
- eliminate comments of the FSD DO&FSS personnel received in the agreement of operational, repair, adjustment and other documentation;
- provide, on a monthly basis, the necessary reports on the fulfillment of organizational and administrative documents of RNPP and Energoatom, as well as prescription of state oversight bodies;
- take appropriate response measures (within their rights) to violations or failure to fulfill the established fire safety regime, requirements of fire safety rules and other regulations in force in this area by their employees.

The FSD DO&FSS personnel, jointly with officials responsible for fire safety in the departments, fire technical commission members, and SFRT-1 specialists, conduct inspections of structural units, as well as walkdowns and inspections of workplaces, equipment, premises, buildings and structures, in accordance with the schedule. During these inspections and walkdowns, compliance with rules, regulations, production and labor instructions, availability and operability of fire-extinguishing and fire protection equipment, availability and condition

of technical documentation, etc. are inspected. Based on the inspections, the heads of departments receive prescriptions with deadlines for eliminating deficiencies, deficiencies of sensitive nature are eliminated immediately, or the comments are registered in the electronic system “Walkdowns and Surveys” setting deadlines for their elimination. If necessary, the identified deficiencies are submitted for consideration at a meeting of the common-plant fire technical commission.

According to the requirements of document [84], periodic walkdowns and surveys of workplaces are conducted. The Director General is responsible for overall fire safety at the RNPP. The persons responsible for fire safety of the NPP site, buildings and premises, structures, communications and equipment of individual plant units are appointed by Order of the NPP Director General [86].

The Director General, authorized Heads of Departments and other persons perform their duties in accordance with their job descriptions to ensure fire safety. They are obliged to:

- develop comprehensive measures to ensure fire safety, implement advances in science and technology and positive experience;
- ensure compliance with fire safety requirements of standards, rules, as well as fulfillment of requirements of resolutions (prescriptions), consider proposals of state fire safety oversight authorities;
- organize training of employees on fire safety rules and promote measures to ensure them;
- maintain fire protection and communication equipment, fire appliances, equipment and inventory in good condition, and prevent their misuse, except in cases of natural disasters, accident prevention and for educational purposes;
- take measures to introduce automatic fire detection and suppression equipment;
- conduct internal investigations of fire incidents.

The NPP has an organizational structure [87], which defines the management hierarchy and powers in the field of fire safety assurance and the procedure for interaction with other structural RNPP units.

The process of ensuring fire safety at the RNPP is regulated in [88].

According to the requirements of Rules [42] and [29], RNPP developed a document [69] establishing appropriate fire protection regime and specifying the following:

- possibility and places for smoking, the procedure for using open flame, household electric heating appliances;
- procedure for temporary hot activities, including welding;
- rules for driving and parking vehicles;
- the procedure for cleaning combustible dust and waste, storing oily rags and overalls, and cleaning ventilation ducts from combustible deposits;
- procedure for disconnecting electrical equipment from the network in case of fire;
- procedure for inspection and closure of premises after work;
- procedure for conducting maintenance and inspections of electrical installations, heating, ventilation, process and other engineering equipment, etc.

In addition, RNPP departments developed fire safety instructions and instructions for explosive and fire hazardous premises (warehouses, shops, laboratories, sites, etc.) in accordance with the basic requirements for fire safety documentation.

The entire RNPP territory and buildings are divided into areas of responsibility among the departments. The territory, buildings, structures and premises are assigned to the structural subdivisions at Rivne NPP in accordance with provisions [90]. All premises on the entrance doors are marked in accordance with provision [91], which indicates the name of the person responsible for fire safety and a contact telephone number.

The unit that owns the premises (including the organization renting the premises from at Rivne NPP) is responsible for the preservation and good condition of fire protection systems, and is also obliged to comply with the requirements of fire safety rules and regulations.

Fire exercises are conducted at the plant's facilities in accordance with schedules. The schedules and topics of fire exercises are annually drawn up in coordination with SFRT-2 and approved by the head of the enterprise.

The main tasks of staff fire exercises are:

- acquiring the skills to independently and quickly make the right decision on arranging fire extinguishing at the initial stage;
- practicing clear actions to prevent possible accidents, equipment damage and personnel injuries during a fire;
- arranging an immediate call to fire and rescue units when automatic fire protection systems are actuated, identifying signs of a fire;
- personnel training and examining of their skills to identify the beginning of events that caused NPP operational events;
- ensuring the necessary professional and psychophysiological training of personnel and determining the degree of their preparedness during activities aimed at mitigating an accident or suppressing fire;
- practicing the interaction of enterprise employees with personnel of fire and rescue units in accordance with operational firefighting cards and operational fire extinguishing plan;
- arranging of rescue and evacuation of people and material assets;
- determination of safe and efficient methods for extinguishing fires on equipment, especially in energized electrical installations, and acquiring skills in the use of primary firefighting means;
- acquisition of skills in relatively clear and quick actions to switch process equipment in order to prevent fire spreading and accident progression;
- checking compliance with safety requirements and coordinated joint actions with fire and rescue units in difficult fire conditions at the facility;
- acquisition of skills in providing first aid to fire victims.

Firefighting exercises are divided into:

- department exercises are carried out with department (plant subdivision) personnel;
- landfill exercises;
- on-site training is carried out with personnel of several departments (plant subdivisions);

- unit exercises are carried out with operational personnel of several departments (plant subdivisions) operating at one power unit;
- joint exercises with fire and rescue units;
- individual exercises are carried out with newly hired employees when checking the fire safety condition in the structural subdivisions.

All maintenance personnel in each department (plant subdivisions) take part in department exercises at least twice a year. All employees of the non-production (non-industrial) personnel in each department (plant subdivisions) and operational personnel ensuring production participate in department fire exercises at least once a year. On-site fire exercises are carried out with the periodicity of at least three exercises per year with each shift. The periodicity of unit exercises can be at least twice a year with each shift. Joint fire exercises are held according to the schedules at least once a quarter.

Fire exercises may be combined with emergency personnel exercises.

The on-site fire extinguishing headquarters approved by the RNPP order [92] have been constructed at RNPP. The operational fire extinguishing headquarters practice operational firefighting plans for the main building at RNPP during the joint firefighting exercises and fire-tactical training. The results of the exercises are discussed at operational meetings after their completion.

Nuclear power plant personnel should pass fire safety exercises. Fire safety exercises are divided into:

- fire safety exercises for officials;
- special exercises for workers engaged in activities related to increased fire hazard (the fire technical fundamentals).

Fire safety exercises are conducted at territorial courses in the educational and methodological centers of civil protection and life safety or in other enterprises, institutions and organizations that have the approved fire safety training programs, as well as in the RNPP training center. Fire safety exercises are conducted by experts having appropriate education in the knowledge field of “Civil Security” (in the specialties of “Civil Security”, “Fire Safety”), who have at least three years of work experience in the civil protection bodies and subdivisions and have passed special training at territorial courses, in the educational and methodological centers of civil protection and life safety.

The schedule of fire safety exercises is an integral part of the general schedule of professional training of RNPP personnel for the calendar year at the RNPP training center and in the educational institutions of Ukraine according to relevant programs.

The procedure for hot activities at RNPP is regulated by the common plant instructions on fire safety measures [69] and the RNPP order [70]. All temporary hot activities are carried out under special work orders agreed with SFRT-2. SFRT-2 fire safety experts provide daily access to the site of temporary fire work.

The hot activities are monitored as follows:

- continuous monitoring - by the work performer;
- periodic monitoring - by the responsible work supervisor and the person authorizing the work;
- selective monitoring - by SFRT-2, RNPP management.

Prior to the start of hot activities, the process equipment to be used for hot activities shall be brought into an explosion-safe state (existing communications shall be disconnected, explosive and fire hazardous substances shall be removed, cleaning, washing, steaming shall be carried out using safe methods, ventilation and air control shall be ensured).

Combustible substances and materials shall be removed from the areas of hot activities within the radius specified by the rules, depending on the height of the work to the floor level. Building structures located within these radii, finishing materials, as well as insulation and parts of equipment made of combustible materials, shall be protected from sparks by metal screens or blankets made of non-combustible insulating material. Doors of the premises where hot activities are carried out shall be closed (except when cables and hoses of welding equipment are laid).

In order to prevent hot metal particles from entering neighboring rooms, floors, and surrounding equipment, all inspection, process, and other hatches, ventilation, installation, and other openings in the ceilings, walls, and partitions of the premises where fire work is performed shall be covered with non-combustible materials.

It is prohibited to start the work without primary firefighting means.

Visual inspection over the place of hot activities shall be conducted by the duty personnel within two hours after their completion, after which the work permit shall be closed.

If hot activities are conducted on fire hazardous equipment and in fire and explosion hazardous areas (if these activities cannot be performed in special places), the work permit shall be issued by the RNPP Chief Engineer or a substituting person.

If hot activities are conducted in explosion hazardous areas, the air environment is thoroughly monitored through express analyses using gas analyzers.

During examinations and repairs inside the tanks and apparatus of electrolysis installations (where hydrogen is in circulation), explosion-proof portable lamps with a voltage of no more than 12 V and a metal mesh are used.

Temporary connection of electrical equipment at RNPP may be used only during equipment repairs, construction and mounting activities.

Temporary connections to operating equipment are prohibited. If necessary, during repairs, temporary connections of equipment are performed by specially trained personnel of the electrical department. Temporary connections shall be performed in accordance with the requirements of PUE [14] and Rues 29].

Only non-combustible materials are used on thermal-mechanical and electrical equipment in areas where surfaces may be heated. Thermal monitoring devices that display information on control panels and unlocking automation are installed on important equipment in places of possible overheating (bearings, housings). Special pallets, borders and oil receivers are installed on lubricant-filled equipment in places of possible leaks. There are also systems for monitoring the lubricant level in the equipment. The places of possible overheating and oil leaks on equipment shall be periodically monitored by the operators according to a special schedule and route.

Special storage facilities are envisaged at RNPP for storing combustible materials, flammable and combustible liquids, and combustible gases. It is forbidden to arrange storage facilities for highly-flammable liquids (HFL) and flammable substances (FS) in the main buildings of the plant. The amount of HFL and FS at the workplace does not exceed the demands of one shift.

Compliance with fire safety requirements in the places of storage of HFL and flammable substances is monitored during walkdowns by Heads of Units and by FSD DO&FSS personnel, as well as during fire and technical inspections by fire technical commissions, FSD DO&FSS and SFRT-2.

In accordance with the requirements of regulatory documents, special metal boxes are used to store liquids in unbreakable containers for the daily shift's needs in HFL and flammable substances.

Cleaning of the premises at the RNPP with using HFL and flammable substances is prohibited. Special detergents shall be used for this purpose. Oil-filled equipment that uses combustible lubricants shall be hermetically isolated from ignition sources. Electrical equipment in fire and explosion hazardous areas shall be explosion-proof.

In accordance with the requirements of [2] and in compliance with para. 3.3 [17], the state fire rescue team No. 2 was formed that includes two fire rescue units of SFRU-22 and SFRU-23 to protect RNPP facilities from fire. SFRU-22 is located 100 m away from the RNPP security perimeter and SFRU-23, which is placed 800 m away from the RNPP perimeter. These subdivisions perform fire protection services based on an agreement concluded annually between RNPP and SFRT-2. RNPP fire protection units (SFRU-22 and SFRU-23) are equipped with the necessary devices that allows them extinguishing fire and assisting in mitigation of emergency situations, as well as carrying out rescue operations. The personnel of the subdivisions are fully provided with overalls and special footwear. They are also equipped with special means of communication (radio stations) and lighting (portable lanterns). The units possess 24 basic and special fire trucks with a full set of extinguishing agents (water, foam, powder), as well as the necessary equipment for firefighting, emergency response, and rescue operations. All personnel of the duty teams are on duty around the clock and have sufficient firefighting training and knowledge of the operation area and the specifics of firefighting at NPPs.

To train the personnel of SFRU-22 and SFRU-23 to work in gas masks in an unbreathable environment and to adapt to heavy work in conditions of high temperature and limited visibility, a heat and smoke chamber and a psychological training ground with all necessary equipment were built. The SFRU-22 and SFRU-23 personnel involved in the protection of RNPP facilities have the necessary qualifications and passed necessary training for fire prevention and fire extinguishing activities at the plant facilities.

The SFRU has a psychological training ground for RNPP firefighters and operational personnel, where firefighters and RNPP staff are trained and master ways and methods to extinguish potential fires.

The following fire strip shells were installed at the landfill, according to the project taking into account the main criteria for the psychophysiological training of personnel: labyrinth; cable manifold; metal platform of the overpass with damaged process equipment; transition bridge; metal frame of the transformer; open overpass with burning liquid; target.

The training objective is:

- practicing and improving skills in the use of primary firefighting means, checking the preparedness to extinguish fires by SFRT-2 and RNPP personnel;
- independently, quickly and correctly orientate and make the right decision in fire conditions;
- taking correct measures for fire mitigation;

– correctly use firefighting means.

State Fire Rescue Units, in accordance with the training programs approved by the Main Directorate of the State Emergency Service of Ukraine in Rivne Region, conduct daily training sessions to improve the level of operational preparedness of their personnel.

According to the plan, fire and tactical exercises are held quarterly to practice fire and emergency response actions at the facility, and to practice interaction with the facility firefighting headquarters, emergency crews, and facility administration.

The SFRU-22 and SFRU-23 personnel are trained at SESU training facilities on radiation safety and dose monitoring and have the necessary qualifications and preparedness to extinguish fires and carry out preventive work to prevent fires at the plant's facilities. The personnel of the units undergo periodic training in specialized educational institutions of Ukraine.

Scenarios for fire and tactical exercises are developed based on the previously learned firefighting experience. The exercises are conducted at different areas of the facility, taking into account their fire hazard and importance for safe NPP operation. During the drills, the ability of firefighting unit to perform the assigned tasks is checked. After each training session, the results are summarized, the actions of the participants are assessed, and an assessment is given to determine whether the training objectives have been met. The experience gained is used to modify the training program (if necessary) or to update firefighting plans and cards.

In accordance with the requirements of para. 6.3 [29], RNPP developed an operational fire-extinguishing plan [94] and fire-extinguishing cards for fire hazardous premises and equipment. The operational fire extinguishing plan is the main document that defines actions of the enterprise personnel in the event of a fire, the interaction procedure with the SESU units, the directions for deployment of manpower and means to extinguish the fire, taking into account safety measures and rational deployment of fire equipment, etc. They are developed by SFRT-2 jointly with the energy company's specialists and approved by the enterprise head and the department of the SES territorial body. The main provisions of the fire-extinguishing plan and fire-extinguishing cards are communicated to the NPP employees during fire and emergency exercises.

The operational fire extinguishing plans include:

– actions of the plant personnel in the event of a fire before arrival of fire rescue units;
– procedure for interaction with the arrived fire rescue units;
– procedure for authorization to extinguish fires in powered electrical installations and in conditions of ionizing radiation;
– rational deployment of fire equipment and location of the firefighting headquarters;
– peculiarities of fire extinguishing in storage facilities for fresh and spent nuclear fuel and radioactive waste;
– notification, alarm and communication scheme;
– layouts and plans of facilities;
– conditions for deploying forces and means to extinguish the fire, taking into account the requirements of nuclear and radiation safety and safety measures for participants in fire extinguishing and mitigation of consequences.

Firefighting cards for the main actions of operating personnel in fire initiation are developed for explosion- and fire-hazardous premises and equipment, as well as for premises

(electrical installations) where it is impossible to safely de-energize electrical equipment, premises in which 6 kV cable routes are laid. Firefighting cards are developed by the plant departments and agreed with the ZGIE -1,2 and ZGIE -3,4 chief engineers, SGD service, DO&FSS, electrical department and SFRT-2 and approved by the Shift Chief Engineer. The cards are stored by the Shift Supervisors of NPPs, units and departments.

According to the schedule, practical exercises are periodically carried out related to actions of fire and rescue units to practice operational fire extinguishing plans with on-site visits.

The joint order of RNPP and SFRT-2 [95] established the procedure for interaction between SFRT-2 of the SESU Main Department in Rivne Region and RNPP Services with RNPP services when mitigating fires, the consequences of accidents, natural disasters and emergencies at RNPP facilities.

3.3.3 Passive fire protection

Passive fire protection is one of the defense-in-depth levels aimed at preventing the spread of fire in case of possible failure of the fire-extinguishing system and possible increase in response time of fire units.

The main objectives of passive fire protection systems are to limit the spread of fire, to ensure and maintain the safe state of the NPP by performing safety functions, and limiting the amount of radioactive materials that may fall into the fire epicenter or be released during a fire.

The passive fire protection systems implemented at the RNPP include:

- fire barriers (walls, partitions, fire doors, fire retardant valves);
- smoke exhaust systems;
- lightning protection;
- fire protection mixtures, plasters, boards.

3.3.3.1 Prevention of fire propagation (barriers)

In accordance with the requirements of Section 3 [17], buildings and structures on the RNPP territory are located with consideration of the prevailing wind direction and meet the requirements for safe operation in the event of possible fires.

The design envisages arrangement of fire breaks at the location of buildings and structures, entrances, and division of the RNPP industrial site into fire protection zones to reduce the risk of fire propagation and damage from chemically active gaseous combustion products, as well as to reduce the degree of radioactive contamination.

In accordance with para. 3.4 [17], free passage of fire trucks to all buildings and structures and conditions for safe evacuation of personnel are ensured on the RNPP territory. In addition to the main entrance, there are two other entrances to the RNPP industrial site, which are scattered around the perimeter.

At RNPP, in compliance with design documentation, the supporting metal structures in turbine hall rooms and rooms with electrical equipment racks, which include premises with normal operation systems important to safety, must meet the standardized fire resistance limit.

In accordance with para. 4.2.1 [17], the enclosing structures of fire compartments that physically separate the premises of different trains of the safety systems are of type I, with a fire resistance limit of REI 90 and a fire propagation limit of M0.

The fire resistance level of NPP buildings and structures was determined by calculations and meets the requirements of Annex D [17]:

- reactor compartment - fire resistance class I;
- turbine hall – fire resistance class IIIa;
- deaerator compartment - fire resistance class IIIa;
- electrical equipment rack – fire resistance class IIIa;
- special building - fire resistance class II;
- standby diesel generator - fire resistance class I.

The premises where the equipment of different safety system trains is located are separated from each other and from the normal operation premises by fire barriers with a fire resistance limit of 90 minutes.

The places where process communications (cable ducts, piping, air ducts, cables, etc.) pass through the enclosing structures and partitions are sealed with non-combustible materials. The fire resistance limit of penetrations through structures with a standardized fire resistance limit or fire barriers is not less than the standardized fire resistance limit of this enclosing structure or fire barrier according to EI.

3.3.3.1.1 Assurance of efficiency within the operation life

In compliance with [17] and [10], the supporting metal structures in turbine hall rooms and rooms with electrical equipment racks, which include premises with normal operation systems important to safety, must meet the standardized fire resistance limit.

As an example, in the framework of C(I)SIP for Unit 2 the following measures were implemented: 37105 – the fire resistance limit for the turbine hall columns erected in places of cable route arrangement was brought in compliance with regulatory requirements; 37111 – the fire resistance limit of the metal structures supporting the electrical equipment rack was brought in compliance with the standardized value; 37113 – the fire resistance limit of the turbine hall roof trusses was brought in compliance with standardized value. During implementation of these measures, Feniks STV fireproof finish was used to bring the fire resistance limit of the metal structures in compliance with the standardized value. The material is certified in Ukraine and complies with the requirements of [10] and DSTU B.V. 1.1-4-98. The Unit 2 turbine hall metal trusses with horizontal and vertical connections between them are brought to the specified fire resistance limit R 45 in compliance with the requirements of para. 4.2.3 [17] and [10]. These measures were implemented to comply with the requirements [35].

To fulfill the requirements of paras. 2.5 and 5.4.2 of [17], in the framework of (C(I)SIP) measure 17108, in accordance with the design documentation, the standardized fire resistance limit was brought to EI 30 of removable non-combustible structures of cable channels and raised floors of the RNPP Unit 3 premises.

According to the measure implementation concept and considering the Letter No. 26-12348/261 of the State Emergency Service of Ukraine dated 31 August 2017, the measure 17108 was implemented at Unit 3 in the framework of C(I)SIP for the following measures: 14103 “Modernization of the power unit I&C with integration of ARMS and SPDS”; 14301 “Modernization of safety control systems with replacement of the unified complex process protection”; 14404 “Modernization of the control system of the standby diesel generators”.

To comply with the comments and eliminate the deviations from current fire safety standards and rules the following measures were implemented in Unit 3 turbine hall:

- in 2005, the surfaces of metal trusses with horizontal and vertical connections between them were covered with PYRO-SAFE FLAMMOPLAST SP-2 fireproof finish;
- in 2017, the columns erected in places of cable route arrangement were covered with FLAMMOPLAST SP-A2 fireproof finish.

The Unit 2 and Unit 3 fire safety, as well as RNPP safety, was improved as a result of these works.

In compliance with the requirements of [96] and [97], the Inspection Boards are created and responsible persons are appointed by the orders of the Heads of the structural subdivisions to perform the annual inspection of the technical state of the fireproof coating. In compliance with [96], the results of the annual inspection are recorded in the fireproof coating technical state reports drawn up according to the separate form.

3.3.3.2 Ventilation systems

At RNPP Unit 2, the ventilation systems, arranged in the rooms with Control and Protection Systems, Instrumentation and Control Systems, Control Safety System hardware and software, in Reactor Building rooms with normal operation system hardware and software, auxiliary relay of non-system mechanisms, balance-of-plant switchgears (0.4 kV switchgear, 6 kV switchgear), uninterrupted power supply units, cable shafts and penetrations, are designed for residual heat removal and creation of the required temperature in these rooms. The air to the above-mentioned rooms is supplied by the following forced ventilation systems: 2K-2, 2K-5, 2P-4, 2P-12 and natural ventilation systems: 2PE-2÷9, 2PE-10÷13, 2PE-14÷20, 2PE -21÷26, 2PE-27÷34, 2PE-35÷38, 2PE-39÷43, 2PE-44÷47. The abovementioned rooms are ventilated by the exhaust ventilation systems: 2V-4, 2V-17÷20, 2V-22÷29, 2V-30÷36, 2RK-2, 2RK-5.

At RNPP Unit 3, the ventilation systems, arranged in the rooms with the storage batteries, switchgears (0.4 kV switchgear, 6 kV switchgear), uninterrupted power supply units, cable shafts, are designed for residual heat removal and creation of the required temperature in these rooms. From the abovementioned rooms the air is exhausted by the by the following exhaust ventilation systems: 3UV21D01-D02, 3UV22D01-D02, 3UV23D01-D02, 3UV29D01-D02, 3UV30D01-D02, 3UV31D01-D02, 3UV24D01, 3UV25D01, 3UV26D01, 3UV33D01, 3UV34D01, 3UV57D01-D06, 3UV93D01, 3UV91D03-D10, 3UV91D12-D34 interlocked with motor-driven air dampers/fire retardant valves through which the air is supplied by the supply ventilation systems 3UV41D01-D02, 3UV42D01-D02, 3UV43D01-D02, 3UV44D01, 3UV45D01, 3UV46D01, 3UV50D01-D02, 3UV53D01, 3UV54D01, 3UV56D01-D06, 3UV70D02 and due to the turbine hall air depressurization. The natural ventilation facilities are equipped with motor-driven air dampers 3UV49S01-S02, 3UV51S01-S02, 3UV69S03-S34 interlocked with corresponding exhaust ventilation facilities.

The BF230-T drive (with counter spring) combined with thermoelectric switching device BAE 72-S is used as valve executive mechanism.

The valve controls and alarms (open-shut) are arranged on the control panel. If the solenoid is energized, the valve is open (the blade is perpendicular to the air flow). In the absence of the control panel, the valve's operability is checked by valve energization and de-energization. The appropriate position of the valve ("OPEN", "SHUT") are checked with the help of the valve indicator.

In the event of a fire, the drive mechanism is de-energized as a result of generation and transmission to the control panel of the control impulse by the fire detector (fire interlock) or

thermoelectric breaker, installed on the valve and consisting of two thermal switches: Tf1 is actuated when the ambient air temperature exceeds 72ºC; Tf2 is actuated when the temperature in the air duct exceeds 72ºC. At the same time, drive counter spring shuts the valve (the blade is parallel to the air flow). The drive should be de-energized upon transfer of the signal of fire detectors at disconnection of their contacts. It is impossible to restart the drive without replacement of Tf2 thermal switch.

The air ducts of the supply and exhaust ventilation systems, arranged in cable shafts and penetrations, are equipped with KO.014.11(VxN) 1.5 and KO.014.21(VxN) 1.5 valves designed for automatic shut off of the supply and exhaust air ducts crossing the fire barriers to isolate the rooms at risk for fire.

The supply and exhaust ventilation systems of the abovementioned rooms are equipped with KO.VxNE valves envisaged for automatic shut off of the supply and exhaust air ducts crossing the fire barriers to isolate the rooms at risk for fire. In the event of detection of fire or smoke in the power unit rooms, the AFAS fire detectors installed in these rooms generate a signal on de-energization of corresponding ventilation system and closure of the fire-retardant valves.

In the initial position the valve is open. At the same time, the air damper is perpendicular to the air flow. Keeping the damper in open position is ensured by fixation (through the lever slot arranged on the damper axis) with the help of spring retainer. The valve is closed remotely with the help of the solenoid or automatically with the help of the heat effect when the temperature reaches +72°C ± 3°C and manually.

Closure with the help of the solenoid takes place as follows: the solenoid core is picked up upon generation of the signal on solenoid energization (voltage) by the fire alarm systems or from the control room or directly by means of the button installed on the valve. At the same time, the solenoid rod connected to the retainer turns the retainer arranged on the axis and in the process of turning the retainer is disconnected from the lever. After disconnection of the retainer, the damper is full turned for 90° with the help of the counter spring, at the same time the limit switch is actuated and alarm generates the signal on valve closure and transmits this signal to the control room.

The valve closure with the help of the heat flow takes place as follows: when the temperature in the air duct reaches +72°C ± 3°C, the thermal lock disappears. The lever is turned by the spring, the retainer is disconnected and the damper is closed.

The ventilation system maintenance is carried out by the operating personnel of Electrical Service, Instrumentation Service and Air Conditioning Service in compliance with equipment distribution between RNPP structural subdivisions. Instrumentation Service personnel performs post-repair and comprehensive testing of safeguards and interlocks of Instrumentation Service ventilation system equipment. Testing of the control circuit and automatic load transfer circuit is carried out by the Instrumentation Service personnel together with Electrical Service operating personnel during system commissioning.

At RNPP Unit 2, the following exhaust ventilation systems of the rooms for 0.4 kV and 6 kV balance-of-plant switchgears and uninterruptible power supply unit: 2V-22, 2V-23, 2V-24, 2V-25, 2V-26, 2V-27, 2V-28, 2V-29, which are installed directly in the service rooms, are equipped with interlocks with motor-operated valves for 2PE10÷13, 2PE-27 and 2PE30÷34 natural air supply ventilation.

Unit 2 Reactor Building Ventilation System	
2P-4, 2V-4 supply and exhaust ventilation systems	Operation of ventilations systems is carried out during maintenance. Maintenance systems 2V-4, 1P-4 are equipped with one operable ventilation installation. The electrical part of ventilation equipment and fittings are energized by normal operation bus.
2V-17	The exhaust system removes the air from the Reactor Building cable ducts at elevation -2.8. The system includes 2 units – operable and standby. The system is constantly under normal operation. The fan is interlocked with fire detectors of cable ducts. At actuation of detectors, the fan is tripped and valves are closed.
Ventilation Systems of Unit 2 electrical equipment rack	
Supply-exhaust ventilation systems 2PE-2, 2PE-3, 2PE – 5, 2PE-6, 2PE-8, 2PE-9, 2V-19, 2V-20,	Natural air supply and exhaust (from turbine hall) of Unit 1 and Unit 2 cable rooms with II, III SS. The air supply and exhaust ducts of cable rooms are equipped with fire valves, as well as with fireproof insulation which fire resistance limit makes 1.5 hour.
2PE-14 ÷ 2PE-16, 2PE-20, 2PE-35 ÷ 2PE-42	Natural air supply to Unit 1 and Unit 2 cable rooms
2PE-21 ÷ 2PE-26, 2V-18	Natural air supply to Unit 1 and Unit 2 cable rooms with I SS. The air supply and exhaust ducts of cable rooms are equipped with fire valves, as well as with fireproof insulation which fire resistance limit makes 1.5 hour.
2PE-44 ÷ 2PE-46	Natural air supply to Unit 1 and Unit 2 auxiliary relay rooms
2V-30÷2V-33, 2V-35, 2V-36	The air exhaust from the rooms with transformers of CPS, 6 kV Balance of plant Switchgear, Normal Operation System Instrumentation and Control, Control Safety System Instrumentation and Control. Exhaust fans are actuated when temperature in the rooms with BOP Switchgear reaches +35ºC and tripped at the temperature of - (+20ºC).
2P-12	Air supply to the rooms with BOP Switchgear and auxiliary relay. 2P-12 system fans are interlocked with the dampers which supply the turbine hall air to electrical room. At fan actuation the dampers are closed and at actuation of two fans the dampers are opened.
2K-2, 2RK-2	The 2K-2, 2RK-2 air conditioning and recirculation system is designed to ensure and maintain the required temperature of +22 ± 2 °C and relative humidity of 55 ± 5% in Unit 1 rooms: CPS (E307), In-core Instrumentation System (E306) and Unit 2 rooms: CPS (E338), In-core Instrumentation System (E337) in compliance with the requirements of current regulatory documents.
2K-5, 2RK-5	Air conditioning in Unit 1 and Unit 2 ICS rooms

At RNPP Unit 3, the supply ventilation systems which supply the pressurized air to the elevator shaft and stairwells for smoke exhaust through the smoke valves at the initial fire stage are arranged in corridors and lobbies and equipped with pressurizing valves designed for the air supply to Unit 3 Reactor Building stairwells No. 1, 2, 3,4, halls, corridors at actuation of 3UV58, 3TL44 smoke protection system.

Unit 3 Reactor Building Ventilation System	
Supply and exhaust ventilation systems 3UV21D01-D02, 3UV22D01-D02, 3UV23D01-D02. 3UV41D01-D02, 3UV42D01-D02, 3UV43D01-D02	Continuous operation at the air temperature from + 20ºC up to +35ºC in the rooms with 6 kV and 0.4 kV switchgears and uninterruptible power supply unit (UPSU), at the same time one of the fans is operable, the other one is standby. The fan is actuated and tripped by control switch. In case of fire in the rooms with 6 kV and 0.4 kV switchgears and UPSU, the ventilation systems are automatically tripped.
supply and exhaust ventilation systems 3UV29D01-D02, 3UV30D01-D02, 3UV31D01-D02. 3UV49S01-S02, 3UV50D01-D02, 3UV51S01-S02	Continuous operation when SS I, SS II and SS III cable floors are used, at the same time one of the fans is operable, the other one is standby. In case of fire on SS I, SS II and SS III cables floors, the ventilation systems are automatically tripped, the dampers are automatically closed.
Supply and exhaust ventilation systems in the rooms AE-407/1. 3UV24D01, 3UV44D01	Continuous operation at air temperature from +20ºC up to + 45ºC in SS I Storage Battery rooms. The fan is actuated and tripped by control switch. In case of fire in SS I Storage Battery rooms, the ventilation systems are automatically tripped.
Supply and exhaust ventilation systems in the rooms AE-407/2. 3UV25D01, 3UV45D01	Continuous operation at air temperature from +20ºC up to + 45ºC in SS II Storage Battery rooms. The fan is actuated and tripped by control switch. In case of fire in SS II Storage Battery rooms, the ventilation systems are automatically tripped.
Supply and exhaust ventilation systems in the rooms AE-407/3. 3UV26D01, 3UV46D01	Continuous operation at air temperature from +20ºC up to + 45ºC in SS III Storage Battery rooms. The fan is actuated and tripped by control switch. In case of fire in SS III Storage Battery rooms, the ventilation systems are automatically tripped.
Supply and exhaust ventilation systems in the rooms AE-738/2. 3UV33D01, 3UV53D01	Continuous operation at air temperature from +20ºC up to + 45ºC in the rooms with Storage Battery Direct Current Board. The fan is actuated and tripped by control switch. In case of fire in the rooms with Storage Battery Direct Current Board, the ventilation systems are automatically tripped.
Supply and exhaust ventilation systems in the rooms AE-732. 3UV34D01, 3UV54D01	Continuous operation at air temperature from +20ºC up to + 45ºC in the rooms with Storage Battery of Control and Protection System. The fan is actuated and tripped by control switch. In case of fire in the rooms for Storage Battery of Control and Protection System, the ventilation systems are automatically tripped.

Supply and exhaust ventilation systems in the rooms 3UV57D01-D06, 3UV56D01-D06	Continuous operation at air temperature from +20ºC up to + 35ºC in the rooms with 0.4 kV switchgear, at the same time one of the fans is operable, the other one is standby. The fan is actuated and tripped by control switch. In case of fire in the rooms with 0.4 kV switchgear, the ventilation systems are automatically tripped.
Supply ventilation systems of rooms 3UV58D01-D08, D13-D16	Continuous operation during fire to ensure pressure in the elevator shaft and stairwells No. 1, No. 2 to prevent smoke condition in these rooms.
Smoke exhaust systems 3UV58D09, D11 equipped with smoke valves 3UV58S13, S19, S24, S29, S29/1, S32, S38, S39, S45, S46, S52, S52/1	Smoke exhaust from the stairwells No. 1 and No. 2 through the smoke valves arranged in corridors and lobbies at elevation from -4.20 up to +41.40 at the first stage of fire.
Supply ventilation systems 3TL44D01-D08	Continuous operation during fire to ensure pressure in the elevator shaft and stairwells No. 3, No. 4 to prevent smoke condition in these rooms.
Air supply valves in corridors and lobbies at elevation from -4.20 to +41, 40, 3UV58S14-S18, S20-S23, S25-S28, S30-S31, S33-S37, S40-S44, S47-S51, S53-S54	Operation at the first stage of fire to ensure safe evacuation of personnel. Smoke exhaust through the smoke valves arranged in corridors and lobbies at elevation from -4.20 up to +41.40 at the first stage of fire.
Ventilation Systems of Unit 3 electrical equipment rack	
Supply and exhaust ventilation systems 3UV93D01, 3UV70D02	Continuous operation at air temperature from +20ºC up to + 45ºC in SAB-5 rooms. The fan is actuated and tripped by control switch. In case of fire in SAB-5 rooms, the ventilation systems are automatically tripped.
Exhaust ventilation systems 3UV91D03-D10, 3UV91D12-D34 and air supply valves (from turbine hall) 3UV69S03-S34.	Continuous operation at operation of cable shaft, 6 kV and 0.4 kV switchgears and UPSU, at the same time one of the fans is operable, the other one is standby. In case of fire in cable shaft, 6 kV and 0.4 kV switchgears and UPSU rooms, the ventilation systems are automatically tripped and the dampers are automatically closed.
Supply and exhaust ventilation systems in rooms with ICS and CFG (control functional group) at elevations +12.00 and +16.80, 3UV14D01-D04	Continuous operation at air temperature from +15ºC up to +27ºC in ICS and CFG rooms at elevations +12.00 and +16.80. The fan is actuated and tripped by control switch. In case of fire in ICS and CFG rooms at elevations +12.00 and +16.80, the ventilation systems are automatically tripped.

To fulfill the conditions specified in para. 4.4 [17], para. 2.14, Tables 1, 2 and 3 [10], para. 10.11.1 [3] which relate to the installation in the openings of the fire barriers of the fire-retardant valves (FRV) which fire resistance limit complies with RNPP Unit 3 fire resistance limit, the certified in Ukraine FRV (KO.VkE) of various sizes equipped with electric drive, manufactured by JSC "PLANT "EKVATOR" in Mykolaiv, which fire resistance limit makes

EI120, are installed in places where the supply and exhaust ventilation system air ducts cross the fire barriers of the rooms containing electrical and electronic equipment and cable structures.

The certified in Ukraine explosion-proof stainless steel FRV of KO.VkhN E type equipped with the fuse link and limit switch, manufactured by JSC "PLANT "EKVATOR" in Mykolaiv, which fire resistance limit makes EI120 are installed in places where the air ducts of supply and exhaust ventilation system cross the fire barriers of the storage battery rooms.

The RNPP Unit 2 and Unit 3 FRV are equipped both with individual and group control panels. The FRV position alarm (closed/open) is arranged on the front panel.

In case of fire (smoke), the fire extinguishing system generate a signal on de-energization of operating fans and closure of interlocked FRV (for not interlocked FRV, the FRV are closed at actuation of the fire extinguishing system).

In case of failure of the fire extinguishing system, the flame detector switches installed inside FRV de-energize the FRV when the temperature rises above 72 °C and release the solenoid spring as a result of what the FRV is closed. There is no fuse link. The control panels are installed outside the room protected by FRV.

At RNPP Unit No. 2, 2TL98 ventilation system is designed to supply the pressurized air to the Reactor Building stairwells in case of smoke during the fire. The system includes two fans: one is operable, the other one is standby. The fans are arranged in the ventilation chamber rooms E-148, E-152 and lobby at the elevation +3.60. The check valves which is opened by the air pressure are installed on the fan delivery ducts. When the air is not supplied, the blades are returned to the initial position and the valve is closed.

The 2TL99 ventilation system is designed to supply the pressurized air to the Reactor Building stairwells in case of smoke during the fire. The system includes four fans combined in groups of 2 in each: one fan is operable, the other one is standby. The fans are arranged near the stairwells at the elevation +37.40. The sealed valves with electric drives interlocked with fans are installed on the fan delivery ducts.

The 2VPP1001÷1002, 2VPP1003÷1004 ventilation systems are designed to supply the pressurized air to the lobby of the elevator and stairs of Unit 2 basement with electrical equipment rack in the event of smoke during the fire. The air supply from the outside prevents the penetration of smoke to the escape routes which allows to ensure safe evacuation of power unit personnel. The system includes two fans, one is operable, the other one is standby. The fans are arranged in E-171/1, E-152 rooms.

The 2VPP1001÷1004 smoke exhaust system is controlled remotely from Unit 2 stairwells with the help of SBC1, SBC2 control switches; SAB1, SAB2 control switches arranged in E-171/1 and E-152 rooms and A-14 control panel. At actuation and tripping of fans (1, 2) the warning lights appear on the control panel. The automatic load transfer is actuated at failure of the operating fan after that the standby fan is put into operation. The fans are interlocked with fire automatics which actuates the separate system.

At RNPP Unit 3, the 3UV58D09, D11 smoke exhaust system removes the smoke at the initial stage of the fire through the smoke valves arranged in Reactor Building corridors at elevations from -4.20 up to +41.40.

The pressurized air supply systems of the stairwells No. 1,2 - 3UV58D01-D16 and No. 3,4 - 3TL44D01-D08 prevent the penetration of combustion products to the stairwells during

the fire due to creation of the difference in pressure in the stairwells (escape routes) and smoke-filled rooms.

The certified UKROS91-063-DUV400-N-015000/4F(2128)-UKhL radial fans, manufactured by LLC “VEZA”, KD.VkhN type smoke valves with electric drive and control panel, manufactured by JSC “Plant “EKVATOR” in Mykolaiv, are accepted as equipment of the smoke exhaust systems. To increase the fire resistance limit, the air ducts of the smoke exhaust system are covered with Conlit-150 fire protection system.

In compliance with 173-22-E-TsVtaK “Operation Manual. Reactor Building Ventilation Systems. Systems Important to Safety and Normal Operation Systems. Unit 3” the following is envisaged:

- automated control by fire alarms installed in the escape routes at elevation from -4.20 up to +41.40;
- remote control from the control cabinets arranged in separate rooms of the Air Conditioning and Ventilation Service (AV-1039, AV-1023/2);
- manual (remote) control by control switches installed in Rector Building stairwells No. 1, 2 at the elevation from -4.20 up to +41.40;
- local control of the smoke valves from the control panels completed with valves and installed in stairwells No. 1, 2 and stairwells No. 3, 4 at the elevation from -4.20 up to +41.40.

3.3.4 Licensee's experience in applying the fire protection concept

The experience in implementing the fire protection concept was gained upon conclusions and recommendations of experts in various fields, including fire safety, during various missions and inspections of the RNPP.

New active and passive fire protection means and measures to prevent fires at the RNPP facilities are implemented at the national level in accordance with the analysis of events at other nuclear facilities in the world.

The safety improvement program was developed in compliance with Presidential Decree No. 585 on 12 May 2011 for implementing the resolution of the National Security and Defense Council of Ukraine and considering prospects for the development of nuclear energy in Ukraine in the light of the Fukushima-1 NPP events.

The program is intended to:

- enhance the safety and operational reliability of nuclear power plants;
- reduce the risk of accidents at nuclear power plants during natural disasters or other hazards;
- improve the efficiency of managing design-basis and beyond-design accidents at nuclear power plants and minimize their consequences.

Resolution of the Cabinet of Ministers of Ukraine [98] approved the Comprehensive (Integrated) Safety Improvement Program for NPPs (C(I)SIP).

In accordance with the C(I)SIP, 49 measures are planned to be implemented to improve the safety of Unit 2, of which eight measures are included in Section 7.1 “Fire Protection”, specifically:

- 37101 “Modernization of the Automatic Fire Alarm System for the Reactor Compartment, Turbine Hall, Deaerator Compartment, Electrical Equipment Rack and Special Building Premises”;

- 37104 “Provision of the Main NPP Electricity Generation Circuit with Automatic Control Units for Power Oil-Filled Equipment”;
- 37105 “Bringing the Fire Resistance Limit of Columns near the Cable Routes in Turbine Halls to Regulatory Requirements”;
- 37106 “Provision of NPP Premises Containing Electrical and Electronic Equipment with Stationary Non-automatic Gas Fire-Extinguishing Units”;
- 37107 “Installation of Fire Retardant Valves with a Standardized Fire Resistance Limit at Intersections between Supply and Exhaust Ventilation Air Ducts in the Standby Diesel Generator Building”;
- 37111 “Bringing the Fire Resistance Limit of the Electrical Equipment Rack Load-Bearing Metal Structures to the Standardized Value”;
- 37112 “Bringing the Fire Resistance Limit of Transit Air Ducts Passing Through the Premises of Safety Systems and Normal Operation Systems of the Electrical Equipment Racks of Units 1 and 2 to the Standardized Value”;
- 37113 “Bringing the Fire Resistance Limit of the Turbine Hall Roof Trusses to the Standardized Value”;

Five measures were implemented fully (37105, 37107, 37111, 37112, 37113) and the reports were agreed with the SESU. Three measures (37101, 37104, 37106) are at different stages of implementation. Measure 37101 was scheduled for implementation in the 2023 refueling outage at Unit 2. Measures 37104 and 37106 are planned in accordance with the C(I)SIP 2023 schedule to be implemented in 2024 (2024 refueling outage).

C(I)SIP Measure 37102 “Implementation of a Fire Water Supply Network from Steel Pipes with Steel Valves” and Measure 37103 “Provision of Premises Containing Electrical and Electronic Equipment of Automated Control Systems with Stationary Automatic Gas Fire-Extinguishing Units” were implemented at Units 1 and 2 under activities for long-term operation of these units in the period of 2008-2010.

For Unit 3, 70 measures are planned to be implemented, of which 8 are included in Section 7.1 “Fire Protection”, specifically:

- 17102 “Development and Implementation of Smoke Protection System in RC Premises and Evacuation Corridors without Restrictions on Communication with the Environment”;
- 17104 “Provision of the Main NPP Electricity Generation Circuit with Automatic Control Units for Power Oil-Filled Equipment”;
- 17105 “Modernization of the Automatic Fire Alarm System of Reactor Compartment, Deaerator Compartment, Electrical Equipment Rack, Turbine Hall and Special Building Premises”;
- 17106 “Provision of NPP Premises Containing Electrical and Electronic Equipment with Stationary Non-automatic Gas Fire-Extinguishing Units”;
- 17107 “Installation of Fire Retardant Valves on Air Ducts in Fire Partitions of Ventilation Centers, Storage Battery Premises, Cable Structures, and Premises Containing Electrical and Electronic Equipment, Separating Them from Premises”;
- 17108 “Bringing the Fire Resistance Limit of Removable Non-Combustible Structures of Cable Ducts and Raised Floors of NPP Premises Containing Electrical and Electronic Equipment to the Standardized Value”;

- 17109 “Provision of NPP Auxiliary Transformers with Automatic Fire-Extinguishing Units”;
- 17110 “Replacement of Combustible Insulation of the Turbine Hall Roof”;
- 17201 “Ensuring the Operability of the Main Steam Isolation Valve for Resistance to Internal and External Events”.

All eight measures were implemented in full scope.

C(I)SIP Measures 17101 “Modernization of the Automatic Fire Alarm System of NPP Safety System Premises”, 17103 “Provision of NPP Premises Containing Electrical and Electronic Equipment with Stationary Automatic Gas Fire-Extinguishing Units” and 17109 “Provision of NPP Auxiliary Transformers with Automatic Fire-Extinguishing Units” were implemented at Unit 3 under activities for long-term operation of this unit in the period of 2008-2012.

From 2001 to 2023, WANO conducted nine peer reviews a the RNPP (the peer reviews are listed in Table 3.5).

Table 3.5– Peer Reviews

Year	Peer review	RNPP installation
2001	Main operational WANO MC	Unit 1
2012		Units 1-4
2016	Exchange project-oriented WANO PC	Units 1-4
2004	Pre-startup WANO MC	Unit 4
2014	Follow-up operational WANO MC	Units 1-4
2018		Units 1-4
2015	Main corporate WANO MC - Energoatom	RNPP
2018	Follow-up corporate WANO MC - Energoatom	RNPP
2021	Main operational WANO MC	Units 1-4

Based on the main peer reviews, WANO made observations and provided assessments of fire protection (areas for improvement (AFIs)), which are presented in Table 3.6.

Table 3.6– Results of the main WANO peer reviews

Year	AFI	Brief description	Level
PR November 2012	FP.6-1	The condition of individual components and devices of passive fire protection, and in some cases their absence, does not prevent the spread of fires	B
PR October 2016	FP.1-1	There are shortcomings in fire separation, and fire protection systems are not installed in all premises where equipment important to safety is located. This increases the risk and potential severity of fire damage to equipment important to safety	B (Repeated from PR 2012)

A scale is used to assess the current state of AIFs:

Level B - there are clear improvements in this area, but there is still some room for further improvement. A part of the developed corrective measures has been implemented and the remaining planned measures are expected to fully address the issue identified as AFI.

3.3.5 Regulator’s assessment of the fire protection concept and conclusions

The fire protection concept is subject to SNRIU assessment and oversight as one of the areas of NPP safety assurance. The SNRIU monitors the implementation of the fire protection concept at RNPP Units 2 and 3 in the framework of the following processes:

- Comprehensive safety assessment of RNPP units, during state nuclear and radiation safety reviews of the Safety Analysis Reports and amendments thereto, and Periodic Safety Review Reports;
- Regulatory assessment of modifications to structures, systems and components important for safety, including those related to ensuring the implementation of the fire protection concept;
- Assessment of the state and completeness of fulfillment of the terms of issued licenses and other permits before issuing individual permits for the start-up of a nuclear power unit after outage;
- Review of applications of the operating organization and relevant safety justifications for amending licenses in connection with ensuring long-term operation.

In the course of state oversight activities, fire safety and implementation of measures to improve fire safety are among the areas of comprehensive inspections and surveys conducted by the SNRIU on a scheduled basis.

The results of regulatory control over the fire protection concept indicate that the fire protection concept implemented at RNPP Units 2 and 3 generally complies with nuclear and radiation safety and fire safety standards.

Measures to improve the safety of RNPP Units 2 and 3, including measures to improve fire protection based on operating experience, recommendations of international organizations, results of inspections and surveys, and introduction of new safety requirements, are implemented by the operating organization taking into account their impact on safety within the timeframes agreed with the SNRIU.

IV. VVR-M NUCLEAR RESEARCH REACTOR AT THE NUCLEAR RESEARCH INSTITUTE OF THE NATIONAL ACADEMY OF SCIENCES OF UKRAINE

4.1 General information

VVR-M nuclear research reactor (NRR) of the Nuclear Research Institute (NRI) of the National Academy of Sciences of Ukraine (NASU) is a pool-type research reactor with a thermal capacity of 10 MW and no electrical power. The NASU NRI site is located in the south-eastern part of Kyiv on the territory of the Holosiivskyi district. The total area of the institute's territory is 450,000 m^2 (45 hectares). The control area of the reactor with a radius of 300 m and the observation area (zone with a radius of 5 km away from the reactor vent tube) are located on the territory of the Holosiivskyi and Pechersk districts in Kyiv.

The site of the institute is primarily built up with administrative and scientific buildings; it houses the Kytaivska electrical substation, by which the institute's facilities, including VVR-M, as well as nearby residential buildings are powered. There are two charged particle accelerators on the territory (main site) of the institute: the U-240 cyclotron and the EPG-10K electrostatic accelerator. The Institute of Physics of the National Academy of Sciences of Ukraine (at a distance of 600 m from the reactor), the Institute of Semiconductor Physics of the National Academy of Sciences of Ukraine (distance - 700 m), and part of the divisions of the Institute of Cybernetics of the National Academy of Sciences of Ukraine (distance - 950 m) are located near the institute site. In addition to the institutes of the National Academy of Sciences of Ukraine, there are other enterprises in the observation zone. All enterprises and organizations surrounding the reactor territory do not pose a potential hazard to NRR. The most intense traffic on the streets adjacent to the reactor is on the Nauky Avenue, the distance to which is about 600 m. The distance to the railway is 1500 m (a branched railway line). The distance to Dnipro River is 3000 m. The shortest distance to the glide path of the Kyiv airport (formerly Zhuliany) is 2.0 km. The straight-line distance between the Kyiv airport and the reactor site is 8 km. The nearest metro station is 2 km away from the reactor [99].

From the very beginning of the reactor operation, the systems and equipment were subject to modernization to improve operational safety of the systems and bring them to compliance with the requirements of the regulations, replace faulty components with new ones, and implement the systems that have not been provided for in the design. The replacement, modernization or implementation of the new systems were carried out in accordance with the requirements of the current rules and regulations taking into account the IAEA recommendations.

4.1.1 Fire safety improvements considering the experience gained

Over the years of operation, the VVR-M systems, equipment and components have been upgraded or replaced with new ones. Modernization and replacement designs were developed in accordance with the requirements, rules, standards and regulations in force in the nuclear energy industry of Ukraine taking into account the IAEA recommendations. The implemented measures to improve fire safety taking into account the operating experience and inspection comments include, but are not limited to:

- fences and bearing structures (walls, partitions, plates, doors, manholes) in the premises and buildings separating the safety system channels from each other are made of non-combustible materials with a fire resistance limit not less than the permissible one established in the standards and regulations (at least 1.5 hours);
- the emergency control room has been implemented at the reactor in a different premise than the main control room;
- the fire resistance limits of the doors in the reactor building comply with the fire resistance standards of the fence structures whose openings they block. The doors of the control panel, emergency control room, and corridors at the exits to the interfloor stairs have devices for self-closing and sealing in porches;
- the plastic floor in the reactor hall was replaced with a fire-resistant flood floor;
- fire-retardant treatment of wooden structures of the attic was completed;
- emergency lighting is envisaged in the reactor premises.

Cable channels and laying of cables in them were performed in compliance with the requirements of the rules and regulations: in 2002-2008, the power and control cables were replaced with copper core cables and those whose insulation is flame retardant (VVGng):

- cables were laid on the structures in cable channels and niches;
- cables were laid to individual power consumers and startup equipment in the floors in pipes, partly on the walls;
- cable shafts provide communication between the floors;
- cables leading to the device and to the reactor hall are laid on the structures in the bridge and in a box on the device case;
- cables from CPS equipment at the reactor to the cabinets of the software and hardware complex of automatic regulation, control, management and protection system are laid separately from other cables in three iron boxes covered with a fire-retardant solution and closed with iron covers;
- space for laying control cables from bundle laboratories to horizontal channels of the device is provided in the box, channels and shafts;
- the cross-section of the cables is selected so that operating current not over 60% of the maximum permissible current during normal operation of such a cable goes through them.

Laying of electrical cables meets the requirements of the nuclear safety rules for research reactors (PBYa-03-75) [100] and the fire safety requirements. The multi-train (3 trains) principle is applied to mitigate fire consequences on the safety systems, the safety systems are protected against fire so that if one train of the safety systems fails, the backup train can perform its functions taking into account the single failure principle (each of the three trains for monitoring and protection of capacity and period is physically separated and has appropriate fire barriers - cable insulation does not spread fire, partitions are installed on their pathway).

The automatic fire detection and warning system for immediate detection of fire signs at the nuclear research reactor was upgraded in 2011.

4.2 Fire safety analysis

4.2.1 Types and scope of fire safety analysis

The deterministic fire safety analysis was carried out for VVR-M research reactor in accordance with the established regulatory requirements. The probabilistic safety analysis, including the Fire PSA for VVR-M has not been performed and is not required by the national regulatory requirements.

The main functions of the NRR safety system under fire conditions are to ensure reliable reactor transfer to subcritical state, maintain it in this state during the required period, actuate and control the fire protection installations, actuate other safety systems and obtain reliable information on the reactor condition. Failure of the normal operation systems during fire should not affect the ability of the reactor safety systems to perform their functions. The systems important to fire safety should be sufficiently protected to enable the performance of their functions considering the single failure principle [101].

Thus, the deterministic fire safety analysis for the VVR-M research reactor includes identifying possible ignition sources and the impact of fire on the ability of the safety systems to perform their functions. The fire safety analysis of the VVR -M research reactor is given in the Technical Safety Justification [99] and Periodic Safety Review Reports [101]. During the fire safety analysis at the VVR-M research reactor, special attention is paid to identifying possible sources and causes of fire and analyzing fire impact on the operability of individual systems and components of the reactor.

According to the analysis results, the causes of fire in the nuclear reactor premises may be the following:

- failure of electrical equipment (short circuit);
- negligence in handling open flame during equipment repair (e.g., during welding);
- non-compliance with the fire safety instructions;
- external hazards (lightning, man-made explosions, sabotage) with subsequent initiation and further fire progression.

4.2.2 Analysis of phenomena accompanying the fire: general overview of the models, data and consequences

The list of the postulated initiating events in assessing fire at the research reactor was selected according to the IAEA recommendations. The analysis of these postulated initiating events involved expert review and operating experience of the VVR-M research reactor to determine the possibility of reactor transfer into subcritical state and maintaining it in this state during the required period. Thus, the fire analysis at VVR-M was carried out taking into account the possibility of the reactor transfer to a safe state during its operation at rated power (10 MW) and fire initiation in areas of the reactor where the most vulnerable reactor safety systems are concentrated, in particular:

- fire in the premise of the reactor control panel (premise No. 213);
- fire in the premise of the power distribution panel for reactor loads (premise No. 113);
- fire in the cable channel of the reactor hall (bridge from the balcony of the 2nd floor in the reactor hall to the reactor pressure vessel);
- fire in the cable channel of the reactor basement;
- fire in the reactor hall;
- fire in the fresh and spent nuclear fuel storge facilities.

The fire safety analysis considers the following:

- personnel are always staying at the reactor during its power operation: at least one regular shift (five persons of the operating personnel plus 2-7 experimenters), and personnel guarding the reactor building;
- timely fire detection is ensured by the automatic fire alarm system and visually by personnel of the next shift and security personnel (physical protection);
- under timely detection of a fire source at the initial stage, the duty shift personnel are able to extinguish fire on their own. In this case, personnel actions are regulated by the procedure for accident and fire mitigation at the VVR reactor [102] and by the Emergency Plan in [103].

Fire in the premise of the reactor control panel (premise No. 213, building No. 17). In accordance with the operating procedures, the reactor is tripped by the emergency scram button in the event of a fire in building 17: all scram rods and manual control rods are immersed into the core. In this case, it is necessary to remove residual energy release from the core, which is ensured by water circulation through the core. If it is impossible to access the buttons located on the control panel for reactor scram because of fire, the reactor can be shut down from the premise of the emergency control room (premise No. 303) and the reactor hall - the reactor scram button in the reactor hall is located on the bridge at the entrance to the upper part of the reactor. As a backup option, the reactor can be shut down from premise No. 113 (power distribution panel), in order to do this, it is necessary to remove 48 V DC voltage with an automatic circuit breaker, which will lead to de-energization of the servo drive couplings for control of the rods (tension will be removed from the coils of the emergency immersion couplings of the scram rods, which in turn will lead to the immersion of other rods into the core).

Cooling of the core to safe values will be carried out according to a usual scheme, but monitoring of the primary coolant parameters will be impossible in the reactor control panel premise due to fire: in this case, it is possible to monitor the coolant temperature at the emergency control room. Cooling is performed in accordance with the operating procedures. *Conclusion*: In case of fire in the control room, if access to reactor monitoring and control equipment is impossible due to the fire, there are other possibilities to trip the reactor and transfer it into a safe state, as can be seen from the readings of the relevant parameters at ECR in accordance with Art. 54 [99].

Fire in premise No. 113 (power distribution panel). Fire in premise No. 113 where two sections of the power distribution panel of 400 V (50 Hz) are located and where the special load panel (SLP) and two sections of DC switchboards of 110 V and 48 V are placed can lead to the following consequences: fire will lead to automatic switching off 400 V (50 Hz) voltage and limit access to the control panels in the control room or will only limit access to the control rooms without switching off the voltage. In these both cases, the reactor is shut down by the scram button located on the control panel.

Under DC 400 V (50 Hz), 48 V and 110 V voltage failure, the reactor will shut down automatically with the corresponding alarm signals (AS). The rods in the core will reach the lower position by their own. The control rods (1RR, 2RR, PR, AR) can be inserted into the core manually, for which the shift personnel lower the suspension of each rod from the boxes where the rod drives are located to the lower mark. In such cases, the core is cooled by draining part of the primary system water through the core to a special sewerage system. To do this, the duty personnel open drainage valves No. 2 and 3 on the heat exchangers. This will ensure water

flow through the core of up to 10 m^3/h. Water should be replenished into the tank of the device from the backup distillate tanks. It has been experimentally demonstrated that it is enough to cool the reactor core to a safe temperature within 20 minutes. In the case where voltage will not automatically switch off due to fire, there are almost no problems with transferring the reactor into a safe state: the reactor is tripped with the scram button, and subsequent actions are determined by the operating procedures.

Conclusion: in case of fire in the switchboard power distribution room (No. 113, building No. 17), provided that the reactor was operating at rated power, it is possible to transfer its systems into a safe state from other rooms in accordance with Articles 54-55 [99].

Fire in a cable channel passing along the bridge in the reactor hall. In case of fire in the cable channel passing along the bridge in the reactor hall, there is a possibility of damage to the cables laid to the drives and ionizing chambers of the reactor control and protection system. The reactor should be shut down by pressing the scram button (if it does not shutdown automatically) located on the control panel. If it is not possible (due to damage to the cables due to a fire) to control the position of the scram rods and control rods remotely from the control panel, one should verify this by the position of the cables on the drive drums of each rod. If it turns out that the rod is not in the lower position, then the personnel lower the rods in the same way as in the situation described in case of fire at the distribution panel. The core during such a fire can be cooled according to the usual scheme.

Conclusion: in case of fire in the cable channel on the bridge in the reactor hall, it is possible to transfer the reactor into a safe state from other premises and locations of the reactor system equipment in accordance with Art. 55 [99].

Fire in the cable channel of the basement floor. Power cables for energization of the primary system pumps pass through the cable channel in the basement floor. Therefore, in the event of a fire in them, there is a risk that the primary system pumps will be de-energized and there will be no water circulation through the core. When the primary system pumps are disconnected, the reactor will automatically trip (pressure drop and water flow decrease in the primary system will lead to automatic trip). If this does not happen, the personnel will trip it by pressing the scram button on the control panel. It will be possible to control the position of the rods according to the usual scheme, and the core should be cooled similarly as by the method described for the case of fire in premise No. 113 (distribution panel). Thus, the initial event “fire in the cable channel of the basement floor” does not lead to emergency progression and the reactor is transferred into a safe state by means of an available design equipment Art. 54 [99].

Fire in the reactor hall. In the reactor hall, there is a reactor pool with biological shielding and the control and protection system (control rod drives, control cabinets for drives and rods, equipment and tools of experimental devices), horizontal experimental channels (nine items and a thermal column) with process (biological) protection (metal tanks with water and metal impurities) against neutron and other types of radiation that can enter the reactor hall during the reactor power operation through an open gate. The hall stores tools and equipment for working with the reactor (in the core and on the reactor tank cover) as well as spent fuel storage (SFP-1), which is located in the basement floor, the reactor hall has access to its pool only through an opening that is closed by a protective metal lid. A bridge crane with the carrying capacity of 10 tons has been installed in the reactor hall to transfer cargo (parts of rotating steel covers of the device, steel plugs for closing the holes in the reactor cover and in

the steel cover of the spent fuel storage (SFP-1), large-sized protection units for each horizontal experimental channel, unloading containers with spent FA, other large-sized cargo). The reactor hall includes: radiation monitoring equipment; sensors of the physical protection system; sensors of the automatic fire alarm system; fire extinguishing equipment - hydrants, fire extinguishers, sand boxes, panels with fire extinguishing equipment. The reactor hall has video surveillance devices - video cameras whose monitors are located on the reactor control panel and in the room where the physical protection equipment is located. All entrances to the reactor hall are hermetically sealed. According to the list of equipment located in the reactor hall, the most vulnerable by fire are the bridge crane control cables and cables of experimental devices. Cables of the CPS equipment that go from CPS cabinets in premise No. 213 (control panel) to the device, pass through the cable channel and are located in the bridge between the upper deck of the device and the balcony of the 2nd floor in the laboratory building.

Among the locations in the reactor hall, the most likely fire centers would be the locations of crane control cables and experimental devices. The ignition of these cables will not lead to the safety with the release of radionuclides into the reactor hall because such cables are located beyond the reactor core. In this case, the reactor is shut down by the scream button; and the core is transferred to a safe state according to the usual methodology. There will be no smoke in the laboratory premises because the entrances to the reactor hall are hermetically sealed. A fire in the reactor hall can be extinguished by the operational personnel of the reactor by means of available extinguishing equipment, or by personnel of the special fire department vehicle called to extinguish fire in accordance with Art. 56 [99].

Fire in the fresh and spent fuel storage facilities. Spent nuclear fuel is stored in “wet” temporary storage pools SFP-1 and SFP-2. Schematically, both storages have the same structure: a metal tank in a concrete box. The tanks of the both storages are filled with distillate. SFP-1 is located in the basement floor with access to it through a hole in the metal cover on the side of the reactor hall. SFP-2 is located in premise No. 102 (the entry of the reactor hall). Fire in the storage has not been considered due to its impossibility. The fresh nuclear fuel storage facility is located in a separate premise in building 17A. It meets the requirements of Class 2 storage facilities.

The storage facility contains metal casks containing hermetically sealed nuclear fuel in the form of VVR-M2 fuel assemblies. The casks are installed on racks made of steel. The walls of the storage facility are brick, plastered with cement mortar. The door is armored steel. There are fire alarm sensors and SCFR sensors inside. Due to the low probability, a fire in the premise is not considered as an emergency in accordance with Art. 57 [99].

4.2.3 Main results

Combinations of events at the VVR-M nuclear research reactor are not considered. The main valid fire safety document for the VVR-M nuclear research reactor is NAPB-02-01-2000 (IR) General Provisions for Fire Safety of the VVR-M Nuclear Research Reactor (OPPB IR)” [104].

There are no containers where flammable materials are stored on the territory of the industrial site and the nuclear research reactor building. The deployment of a fire brigade on the industrial site territory is not envisaged. The nearest fire station in Kyiv to the nuclear research reactor is SDPCH-8 (independent state fire station No. 8).

Based on the analysis results of the fire resistance conditions of the systems and components and their effectiveness under fire conditions, the following conclusions were drawn:

– fire affecting nuclear fuel is impossible: fuel assemblies are in water in the core and in spent FA storage facilities, and fresh nuclear fuel is stored in sealed metal factory containers and in a premise where combustible materials are absent and a fire alarm is installed;
– fire in individual systems and components of the reactor allows it to be extinguished using standard means and the reactor to be transferred into a safe state.

4.2.4 Regulator's assessment and conclusions on fire safety analysis

The fire safety analysis as part of safety substantiation of the VVR-M nuclear research reactor is the subject of the state NRS review conducted by the SNRIU in accordance with the requirements of the Ukrainian legislation.

The current fire safety analysis of the VVR-M nuclear research reactor was revised by the SNRIU as part of the State NRS Review of the Technical Safety Justification of the VVR-M Nuclear Research Reactor [□99] updated based on the periodic safety review results of the VVR-M nuclear research reactor in 2017.

The following was established based on the state NRS review results:

- the scope and methodology of the safety analysis performed meets the requirements of the standards and regulations on nuclear and radiation safety, and considers the IAEA recommendations for the research reactors;
- the analysis results consider the current condition of the VVR-M nuclear research reactor and the periodic safety review results of the VVR-M nuclear research reactor;
- the safety analysis results comply with the safety criteria established in the standards and regulations of nuclear and radiation safety, as well as in the design documents.

The completeness and validity of the information contained in the safety justification documents of the VVR-M nuclear research reactor is checked during the inspections and surveys that are periodically conducted by SNRIU state inspectors on a scheduled basis.

4.3 The fire protection concept and its application

The main objective of fire protection of the VVR-M nuclear research reactor is to prevent the impact of fire and its consequences on nuclear and radiation safety of the nuclear research reactor, resistance of its building structures and sealing barriers, operability of the monitoring systems of nuclear and radiation safety and protection of the nuclear research reactor personnel against hazardous impact of fire and its consequences; exclusion of loss of material assets. The arrangement of NRR fire protection is based on the following principles:

– analysis of NRR fire resistance impact of internal and external causes and potential sources of fire on it including natural events and man-made factors (the principle of fire hazard analysis);
– implementation of fire and ignition prevention measures (prevention principle);
– timely detection and mitigation of fire (principle of early detection);

- impact and isolation of the most hazardous areas and implementation of measures to prevent the spread of fire and combustion products (zoning principle);
- equipping NRR with fighting means and minimizing fire consequences (principle of technical preparedness);
- constant preparedness to implement administrative measures to mitigate fire and minimize its consequences (fire management principle);
- development of a regulatory framework for fire safety of NRR considering its features, primarily the increased radiation hazard (standard regulation principle).

The comprehensive implementation of these principles forms a concept of defense-in depth fire protection. [99]

4.3.1 Fire prevention

Fire prevention at the industrial site of the VVR-M research reactor of the NASU NRI and directly in the VVR-M buildings is ensured by design/construction features and administrative measures.

The main building of the VVR-M reactor is compositely designed in form of two connected parts - the reactor hall, where the VVR-M reactor itself with auxiliary devices is located, and the laboratory and service building in form of a three-story building of usual type. In plan, the building has a T-shape. The reactor hall is a one-story structure, it has metal columns, trusses and crane beams. The walls of the reactor hall are made of grade 75-100 brick, grade 25 mortar, and wall thickness is 510 mm. The outer walls in the basement floor under the reactor hall are concrete to the height of the ground surface up to ±0.00, they are lined with brick outside, the walls of the basement floor in the laboratory building to the ground level are rubble concrete and are made of grade 200 stone on grade 70 concrete, and above they are made of red brick. The massive walls between the reactor hall and the laboratory building are reinforced concrete, monolithic, with a volumetric weight of 2300 kg/m3. Interfloor ceilings and attic floors are prefabricated reinforced concrete two-cavity large-panel flooring supported by brick walls and partly by reinforced concrete prefabricated beams. The massive ceiling between the basement premises and the reactor hall is monolithic reinforced concrete, 800 mm ÷1400 mm thick. The reactor building meets the requirements of fire resistance level 1:

- fences and load-bearing structures (walls, partitions, slabs, doors, manholes) in the premises and structures separating the safety systems channels from each other are made of non-combustible materials with a fire resistance limit of not less than the one permissible in the standards and regulations (at least 1.5 hours) ;
- emergency control room has been arranged in the reactor, which is located in a different premise than the main control room;
- the fire resistance limits of the doors in the reactor building meet the fire resistance standards for the fence structures whose openings they block. The doors of the control panel, emergency control room, and corridors at the exits to the interfloor stairs have devices for self-closing and sealing in porches;
- emergency lighting is envisaged in the reactor premises;
- old control cables were replaced with copper core cables and those whose insulation is flame retardant (VVGng). When replacing cables, the following fire safety measures were taken: fire-resistant belts made of non-combustible materials with a

fire resistance of at least 0.75 hours were installed every 30 m along the entire length of the cable route; sealing of cable passages through walls and ceilings; fire-resistant belts and sealing of cable passages were made of mineral plates treated with fire-retardant material.

Cable channels and the laying of cables in them are carried out in compliance with the requirements of the rules and regulations, the insulation of which does not spread fire (VVGng). The laying of electrical cables meets the requirements of the nuclear safety rules for the research reactors (PBYa-03-75) [100] and the fire safety requirements [104]: to mitigate fire consequences for the safety systems, the multi-channel principle (three channels) was applied, the safety systems are protected against fire so that if one safety system channel fails, the backup channel can perform its functions taking into account the single failure principle (each of three channels for capacity monitoring and protection and period is physically separated and has appropriate fire-prevention interference - cable insulation does not spread fire, partitions are installed on their paths).

A typical feature of the reactor premises in comparison with other facilities is the possibility of placing radioactive waste and fissile materials (FM) in them, and this imposes specific conditions regarding fire and its extinguishing. The fire progression character, the possibility of fire center progression into local or large fire is determined by fire hazard level of the premises and equipment in it. Namely: the structural and planning characteristics of the premise (volume, total floor area, premise height, the size of openings in height and their location relative to the floor), fire resistance of the ceiling and walls in the premises (thickness of the floor, walls, columns, beams, reinforcement class, thickness of the protective concrete layer on top, reinforcement, etc.), the level of fire load (the character and quantity of combustible materials and their unloading), as well as possible actions of personnel and fire services to localize the fire source. The fire load in all reactor premises is represented by hard combustible materials, which may contain the following materials:

- wooden packaging of externally supplied products;
- enamel coating of walls and ceilings;
- electrical insulation in electrical cable and wiring harnesses;
- electric windings of different type drives in devices and equipment (vacuum pumps, electrified gates, electric drives of gate valves in horizontal experimental devices and other electrical equipment of the reactor systems).

Products made of wood, polyethylene, and plexiglass are not used or stored in the reactor hall. [101]. Only the following combustible materials (CM) can be used as a fire load: products and equipment made of polyethylene; wooden products; graphite; paper; construction garbage.

Fire in the reactor building and on its industrial site can mainly arise as a result of careless and negligent handling of fire by personnel, malfunction of scientific and production equipment, violation of the rules for installation and operation of electrical equipment, sparks resulting from electric and gas welding. In order to prevent fire, reactor personnel should strictly follow the production and technological discipline, internal labor regulations including refueling outage of electrified equipment and tools, ventilation systems, energy sector, heating and gas supply systems, timely inspection of electric drives, and testing of electrical networks for insulation resistance.

All fire hazardous activities related to the use of open flame (electric and gas welding, electric gas cutting, etc.) may only be conducted with written permission of the Chief Engineer of the reactor. The most hazardous places for a fire to occur are the main reactor hall, the reactor control panel, as well as the radiation monitoring and power supply panels in accordance with Art. 31 [102]. The components of emergency prevention measures at the VVR-M nuclear research reactor are:

- high qualifications and preparedness of all personnel;
- operability of all equipment and process systems;
- explosion and fire safety;
- compliance with safety regulations and protection of personnel against radiation exposure [102].

4.3.2 Active fire protection

4.3.2.1 Fire detection and fire alarm

The early fire detection principle implemented at the VVR-M research reactor of the NASU NRI is ensured by the automatic fire alarm system. In 2011, the equipment of the automatic fire detection system was replaced with a new one with an established service life of 20 years. The fire alarm system meets the requirements of regulatory and technical documents. The fire protection system is operated in accordance with the requirements of the passport data, technical specifications, operational procedures and process regulations. The address automatic fire alarm installation includes:

- Polon 4900 fire alarm control panel;
- combined (smoke-heat) linear, thermal and manual sensors;
- light and sound detectors;
- remote indication and control panels;
- fire monitoring system;
- interlocking with fire warning systems and turning off ventilation systems;
- distribution cable network;
- reliable power supply system [108].

The ignition character and fire progression process, temperature increase, smoke concentration in different places in the premise and the possibility of initiation of an increased radioactivity in the premises should be considered when choosing detectors (sensors). Each surface point to be protected should be monitored by at least two automatic address detectors of the same type in order to increase fire detection reliability (according to para. 1.6.2 [17]). The selected fire detectors most closely correspond to the initial fire progression and provide fire alarm at an early stage of fire. The maximum level of electromagnetic interference for combined address detectors reaches 70 V/m in the frequency range of 15-1000 MHz.

The main hall (height up to 20 m) is protected by linear smoke optical detectors installed in two rows. The operating principle of the detectors is based on sending a beam from the transmitter to the receiver (installed in one detector case). All detectors are combined into loops using the “loop” system and the fire alarm control panel is switched on. The POLON-4900 control panel provides capacity redundancy and 10% detector redundancy. Redundancy of the indication and monitoring systems for the fire alarm system is provided; panels are installed in

the premises of the main control room (2nd floor is the main) and the emergency control room (3rd floor is backup). The design provides for blocking the address fire alarm system with the fire warning systems, fire monitoring systems and disconnection of the ventilation systems in case of fire.

Sound detectors are installed in all premises where people may stay. Loudspeakers without volume controls installed above the entrance door are envisaged. Microphone consoles for installation control are installed in the (main) control room and the (backup) emergency control room. The design provides for redundancy for notification zones. Automatic fire alarm and fire warning systems ensure operability during abnormal operation. Startup and shutdown of the equipment and its systems do not affect the operation of the fire extinguishing systems. [108].

Firefighting equipment belongs to power supply category 1 according to the PUE and DBN. Power supply is provided from two independent power supply sources: input No. 1 – 220 V (50 Hz); input No. 2 – 24 V from built-in batteries. The batteries are recharged automatically. When connecting equipment, the existing ground loop was is in accordance with the PUE [108].

4.3.2.2 Fire mitigation

The principle of technical preparedness implemented at the VVR-M research reactor of the NASU NRI is ensured by the available fire extinguishing means (location, quantity) provided for in the design. According to the VVR-M design, firefighting water consumption for internal fire extinguishing is 5 l/s for simultaneous action of two fire extinguishing jets of 2.5 l/s each. The required water supply pressure to ensure the operation of internal taps is 25.7 m of water column. A total of 14 fire hydrant sets and one fire hydrant are installed in the building. Three hydrants are envisaged on the territory beyond the building. Laboratory building No. 17 includes 12 fire hydrant sets on three separate risers, three fire hydrant sets per one floor. Fire hydrants with a diameter of 50 mm are used. Fire hydrant sets are located on the landings of the stairwells (2 pcs.) and in the middle of the corridor. The fire hydrant sets consist of a hose holder, a manual inlet shut-off valve, a hose with connecting heads, a shut-off barrel and a hose cassette. The fire hydrant sets located in the reactor hall are similar. In damage or rupture of the fire extinguishing system pipelines, there is the possibility to shut off water supply to the reactor building through the fire extinguishing system using shut-off valves. To mitigate the consequences of a failure of the fire extinguishing system, there is portable fire extinguishing equipment and the possibility to supply water from the cooling tower to the fire site using a motor pump.

In addition to fire hydrants, there are fire extinguishers (4 pcs.) on each floor in the corridors at the exits to the interfloor stairs, and there are six fire extinguishers in each niche (one niche for each floor) in the corridors of the basement floor, the first, second and third floor in the middle part. There are 2-5 fire extinguishers in the premises where the normal operation systems and the systems important for operation are located, depending on the area of the premise. Two types of fire extinguishers are used: VVK-3.5 carbon dioxide and VP-3 powder fire extinguishers. The total number of fire extinguishers in building No. 17 (reactor) is 55 pcs. Fire protection panels are equipped in front of the entrance to the attic, as well as in the basement floor (on both sides of building No. 17) in the premises of the ventilation center and the pumping station in the secondary system. The set of fire extinguishing equipment placed

on these panels includes: hook - 1 pc., fire extinguishers - 3 pcs., a box of sand with a volume of 0.08 m3, shovels - 2 pcs., axes - 1 pc., bucket - 2 pcs.

The boxes with sand related to the crane sets (in total, 15 boxes with sand with a volume of 0.08 m3) are installed in building No. 17 on each floor in the corridors and in the reactor hall according to [99].

4.3.2.3 Administrative and organizational issues concerning fire protection

Administrative and organizational issues related to fire protection at VVR-M are ensured by an effective management system, personnel and relevant documents. In particular, fire safety and personnel actions in the event of possible fire at the VVR-M research reactor of the Institute for Nuclear Research at the National Academy of Sciences of Ukraine are regulated by the provisions of the following documents.

Instruction No. 2 VVR-02-097-18 on the prevention of accidents and fires and mitigation of their consequences at the VVR-M research nuclear reactor of the NASU NRI. This Instruction considers emergencies at the research reactor that are possible in failure of equipment or systems in violation of instructions and personnel error. In accordance with the IAEA recommendations, measures to mitigate accident consequences are determined, the responsibilities and actions of reactor personnel in these situations are established and their coordination with the activities of other departments of the Institute for Nuclear Research of the National Academy of Sciences of Ukraine and external organizations involved in the mitigation of accident and fire consequences are indicated.

Emergency plan in case of accidents at the VVR-M research nuclear reactor of the NASU NRI. The emergency plan is intended for the preparation and implementation of coordinated actions to mitigate the consequences of nuclear and radiation accidents (accidents) at the VVR-M nuclear research reactor of the Institute of Nuclear Research at the National Academy of Sciences of Ukraine in order to prevent or reduce radiation exposure on personnel, the public and the environment.

I-KhS instruction on personnel actions in the event of emergencies (accidents) in the storage facility for "fresh" fuel assemblies of the VVR-M nuclear research reactor. 1-KhS-10 Instruction establishes reactor personnel actions when light and sound alarms are triggered in the initiation of emergencies in the premise of the storage facility for "fresh" fuel of the VVR-M nuclear research reactor. Such emergencies can be: self-sustaining chain reaction; fire; water in the premise.

Instruction No. AS-2-109-08/14/20 on extinguishing fire at the NASU NRI research nuclear reactor in possible exposure of reactor personnel and fire department personnel. This instruction considers reactor personnel actions during fire extinguishing at the nuclear research reactor by own forces, as well as interaction with fire department personnel.

The instruction for fire safety measures in the premises of the departments, laboratories, structures, workshops in building 17 (nuclear research reactor) of the NASU NRI. This instruction regulates personnel actions regarding the maintenance of workplaces, production premises, and the use of primary fire extinguishing means.

Instruction No. 43 on fire safety measures in the chemical laboratory in premise. No. 306 of building No. 17. This instruction describes the actions of personnel and features when extinguishing fire in the chemical laboratory.

General Provisions for Fire Safety of the VVR-M Nuclear Research Reactor. NAPB-02-01-2000 (IR). It establishes fire protection requirements to ensure nuclear and radiation safety of the nuclear research reactor.

Personnel actions in case of fire in the reactor are managed in accordance with the above documents. The primary actions of personnel staying in the premises of the reactor services and experimentation laboratories where a fire (ignition) occurred are set out in the Fire Safety Instructions available in these premises and approved by the chief engineer of the reactor [102]. In all cases of fire initiation in the building, the reactor should be immediately shut down by the "scram" button at the control panel, and if access to the control panel is impossible, it should be tripped by the button located on the reactor process site.

Fire extinguishing activities are carried out under continuous radiation monitoring in places of fire (ignition) with the mandatory use of radiometric devices for measuring beta contamination of overalls and the body [102]. Personnel should interact with personnel of the arriving fire department. Access roads for fire trucks are provided on an asphalt road built around the reactor complex having the width of 3-4 m. Arrival is envisaged through specially equipped entrances in the physical protection system from the left and right part of the reactor building.

In addition, reactor personnel training regarding activities in case of emergency (fire) consists of training according to the special programs, passing exams for the workplace, periodic knowledge examination of safety regulations and radiation safety, as well as practicing skills in servicing systems and mechanisms ensuring the prevention and mitigation of emergencies. Training of reactor shift personnel regarding activities in case of an emergency (including fire) at the reactor should be carried out at least once a quarter. Training of all reactor personnel regarding activities in case of emergency (fire) at the reactor in interaction with other departments and services of the Institute should be conducted at least once per year in accordance with Art. 31 [102].

4.3.3 Passive fire protection

4.3.3.1 Prevention of fire propagation (barriers)

Prevention of fire spread if it is impossible to extinguish it is ensured by the construction barriers envisaged in the design. The fire barriers at the VVR-M nuclear research reactor are the reactor building premises. The reactor building meets the requirements of fire resistance level 1. The estimated fire resistance of the reactor hall floors is 6-12 hours. The main building was constructed in the form of two connected parts - the reactor hall, where the reactor itself with auxiliary devices is located, and the laboratory and service building in the form of a three-story building. According to the layout, the building has a T-shape. The reactor hall is one-story, has metal columns, trusses and crane beams. The walls of the reactor hall are made of grade 75-100 red brick, grade 25 mortar with wall thickness of 510 mm.

The outer walls in the basement floor under the reactor hall are concrete to the height of the ground surface up to ±0.00, they are lined with brick outside, the walls of the basement floor in the laboratory building to the ground level are rubble concrete and are made of grade 200 stone on grade 70 concrete, and above they are made of red brick. The massive walls between the reactor hall and the laboratory building are reinforced concrete, monolithic, with concrete density of 2300 kg/m3. Interfloor ceilings and attic floors are prefabricated reinforced concrete two-cavity large-panel flooring supported by brick walls and partly by reinforced

concrete prefabricated beams. The massive ceiling between the basement premises and the reactor hall is monolithic reinforced concrete, 800 mm ÷1400 mm thick.

During the entire period of operation, the following measures were taken to improve passive fire safety:

- fences and bearing structures (walls, partitions, plates, doors, manholes) in the premises and buildings separating the safety system trains from each other are made of non-combustible materials with a fire resistance limit not less than the permissible one established in the standards and regulations (at least 1.5 hours);
- the fire resistance limits of the doors in the reactor building comply with the fire resistance standards of the fence structures whose openings they block. The doors of the control panel, emergency control room, and corridors at the exits to the interfloor stairs have devices for self-closing and sealing in porches;
- cables from CPS equipment at the reactor to the cabinets of the software and hardware complex of automatic regulation, control, management and protection system are laid separately from other cables in three iron boxes covered with a fire-retardant solution and closed with iron covers;
- old cables were replaced with copper core cables whose insulation is flame retardant (VVGng). When replacing cables, the following fire safety measures were taken: fire-resistant belts made of non-combustible materials with a fire resistance of at least 0.75 hours were installed every 30 m along the entire length of the cable route; sealing of cable passages through walls and ceilings; fire-resistant belts and sealing of cable passages were made of mineral plates treated with fire-retardant material.

4.3.3.2 Ventilation systems

According to the design, the VVR-M research reactor of the NASU NRI includes a special ventilation system. Special ventilation ensures ventilation of volumes where radioactive gases and aerosols can accumulate; therefore, the main components are duplicated in all four systems for reliability: the systems include (V-1A, V-1B), (V-2A, V-2B), (V-3A, V-3B), (V-4A, V-4B). All four pairs of ventilators are mounted in a special premise (ventilation center) located next to the reactor hall. V-1 system provides ventilation for premises No. 016 (cabinet with the primary measurement tools of process parameters), No. 030 (the space under the reactor), No. 031 (pumping room in the primary system). B-2 System ensures ventilation in premises No. 028 (spent nuclear fuel storage facility), No. 101 (space between the upper level of the tank and the metal movable reactor cover), No. 108 (space within the biological shielding of the deaerator tank (scrubber). B-3 system ensures ventilation in premise No. 101 (reactor hall) and the premises in the basement floor, where different purpose laboratories, checkpoint, and operator rooms of hot cells are located. B-4 system ensures ventilation for “hot” chambers (boxes). Four air duct pipes from the air exhaust points to the ventilators lay underground and have different diameters. In case of fire in the strict access area, these four systems can be turned off separately depending on a premise where fire occurred [99].

4.3.4 Licensee’s experience in applying the fire protection concept

All equipment of the nuclear research reactor is located at a safe distance to minimize the fire load to prevent fire in NRR; generation or accumulation of hydrogen as an explosive substance has not been detected for the entire period of operation since 1960; combustible

materials are not used or stored during NRR operation. The reactor building meets the requirements of level 1 fire resistance taking into account the implemented measures to improve fire safety.

An automatic fire detection and warning system for immediate detection of signs of fire was installed at the nuclear research reactor in 2011. Each premise in the reactor building where personnel stays is equipped with loudspeakers to notify about a fire. Each premise and cable networks are equipped with fire detectors. A fire signal is issued to the security post and duplicated to the reactor control panel. The operating organization developed instructions for personnel actions when detecting and extinguishing fire at the nuclear research reactor, as well as interaction between reactor shift personnel and fire brigade personnel arriving to help extinguish the fire. In addition, since VVR-M reactor commissioning, key measures have been taken that impact fire safety improvement:

- power and control cables were replaced with new ones whose insulation is flame retardant;
- the spent fuel management system was modernized and additional spent fuel storage facility was constructed as part of this modernization;
- the emergency autonomous power supply system was modernized, at the same time, new components such as battery, emergency generators were replaced and an additional power supply source was implemented, namely a diesel power plant;
- four ventilators of the special ventilation system were replaced with new ones (one from each four pairs);
- a new fresh nuclear fuel storage facility was put into operation;
- an emergency air purification system was constructed and implemented for air released into the environment through a ventilation center pipe from the space above the water surface in the reactor tank.

Peer reviews on fire protection have not been conducted by the international organizations at the nuclear research reactor. Internal inspections of the NASU NRI were carried out (the last one in 2022), for which appropriate certificates were drawn up. 15 fire hydrants located on the ring network on the territory of the institute (Certificate dated 04 October 2022) [105] were tested. Fireproof cover (seepage, cladding) of the wooden structures of the attic in building No. 17 with a total area of 1400 m2 was tested (Certificate dated 05 January 2022) [106]. Fire hydrants were tested for completeness and the presence of pressure in the network located in building No. 17 (Certificate dated 22 August 2022) [107]. There have been no emergency situations involving fire during the entire operation of the nuclear research reactor since 1960.

4.3.5 Regulator's assessment of the fire protection concept and conclusions

The concept of fire protection is the subject of assessment and oversight by the SNRIU as one of the areas for ensuring safety of nuclear research reactors. The implementation of the fire protection concept at the VVR-M nuclear research reactor is supervised by the SNRIU under the processes of:

- comprehensive safety assessment of RNPP units during the state nuclear and radiation safety review of the Technical Safety Justification of the VVR-M nuclear research reactor and amendments to it, the periodic safety review reports;

- regulatory assessment of modifications to the structures, systems and components important to safety including those related to the implementation of the fire protection concept;
- consideration of applications from the operating organization and relevant safety justifications for amending licenses related to long-term operation.

During state oversight activities, fire safety and the state of implementation of measures to improve fire safety are one of the areas of comprehensive inspections and testing carried out by the SNRIU periodically on a scheduled basis.

The results of regulatory oversight of the fire protection concept indicate that the fire protection concept implemented at the VVR-M nuclear research reactor generally complies with the nuclear and radiation safety and fire safety standards.

Measures to improve the safety of the VVR-M nuclear research reactor including measures to improve fire protection, developed on the basis of operating experience, recommendations of international organizations, the results of inspections and testing, the entry into force of new safety requirements are carried out by the operating organization taking into account their impact on safety within the timeframe agreed with the SNRIU.

V. INTERIM SPENT FUEL STORAGE FACILITY-2 (ISF-2)

5.1 General information

The French FRAMATOME company developed the ISF-2 Project in 1999 within the framework of the international financial and technical assistance provided to Ukraine on the basis of the Memorandum of Understanding concluded on 20 December 1995 between the governments of the G7 countries, the Commission of the European Community and the Government of Ukraine on the closure of the Chornobyl NPP, and the Grant Agreement (Chornobyl NPP Nuclear Safety Project) signed on 12 November 1996 by the European Bank for Reconstruction and Development, the Government of Ukraine and the Chornobyl Nuclear Power Plant. In accordance with the Project, a dry storage system in sealed containers (canisters) placed in the ventilated concrete modules (NUHOMS®) was selected for ChNPP spent fuel. HOLTEC International (USA) conducted Project modifications and construction completion.

The ISF-2 consists of two main parts, namely:

- spent fuel processing facility (SFPF) designed for receiving and packaging spent fuel assemblies (SFAs) for storage during one hundred years in accordance with the requirements of the Technical Specification. This facility is also used for solid radioactive waste generated during ISF operation;
- spent nuclear fuel storage area (SFSA) intended for storing spent nuclear fuel in the form of fuel rod bundles for a hundred years.

The design of the facility provides for an annual capacity for processing and transport of 2,500 spent fuel assemblies for storage from ISF-1. Spent fuel assemblies are delivered to SFPF in a container car designed for transport of spent fuel assemblies/limited permission for connection of RVPK-1000 type reactors at Chornobyl NPP.

The storage system includes horizontal reinforced concrete storage modules and dry shielded canisters (DSC), into which sealed cartridges with fuel rod bundles are placed for storage in a horizontal position. The natural ventilation system of the CSM ensures removal of heat generated during residual energy release in spent fuel. The canister manipulation and transport system (CMTS) is used for DSC transport between SFPF and CSM.

Construction activities under the Project “Construction Completion of the Dry Spent Fuel Storage Facility (ISF-2) at ChNPP Site” were carried out from October 2014 to December 2019, after which a certificate was issued based on the certificate of facility preparedness for operation dated 20 December 2019 of IU series No. 163200101342. the Chornobyl nuclear power plant received SNRIU license EO 001091 dated 23 April 2021 for the right to carry out activities at the life cycle stage “nuclear facility operation ” in the spent nuclear fuel storage facility (ISF-2).

5.2 Fire safety analysis

5.2.1 Types and scope of fire safety analysis

ISF-2, as a facility where fires can lead to harm to people and the surrounding area due to secondary manifestations of hazardous fire factors, primarily when radioactive substances

and materials release beyond the protective structures, should have fire safety systems that ensure minimum possibility of fire initiation. This condition is achieved due to the fire prevention and fire protection measures implemented in the ISF-2 Project:

- architectural and planning decisions of the SFPF and CSM buildings;
- technological process;
- electrical installations;
- room ventilation systems in SFPF.

Despite the fact that the technological process inside the SFPF building does not use combustible and flammable liquids and combustible gases, there is such a source of fire hazard at the ISF-2 site as a diesel generator station that has a diesel generator and a diesel fuel tank containing 0.7 tons of fuel. A fire event is postulated that is caused by the spill and ignition of 880 liters of flammable fuel from a vehicle of the canister manipulation and transport system (CMTS) during the transport of a HI-TRAC on-site transport container (OTC) with loaded double-walled dry shielded canister (DWSC) on the way for placement to the CSM. This estimated amount of fuel corresponds to the volume of a diesel generator tank, but it is significantly higher than the capacity of a fuel tank of the 120 l CMTS transporter. [109].

The postulating fire event belongs to group IV; its potential consequences are a design basis accident, during which the following may occur:

- exceeded temperature limit and violated integrity of fuel rod cladding;
- exceeded temperature limits of the HI-TRAC and DWSC containment materials, which can lead to their damage. In this case, the destruction of DWSC structures can lead to the criticality and the release of radioactive materials, and the loss of HI-TRAC biological shielding can lead to emergency exposure of personnel above established limits.

5.2.2 Main results/dominant events (licensee's experience)

According to the assessment results given in [110], all process premises of the SFPF are classified to category D taking into account the fire load (condition - specific fire load does not exceed 180 MJ/m^2 [10]). Classifying premise No. 501 to category D provides for a low fire load, sufficient distance between equipment with a fire load to prevent the spread of fire. Thus, when assessing fire load in premise No. 501 (Main Building (MB)), electrical equipment was considered as the main source of load – electric drives of lifting and process equipment, namely: crane in premise No. 501; cutting device; sliding holder; TC double cover systems; tables for damaged fuel, etc. In accordance with the technical specifications for the stated MB equipment, the equipment designs take into account the requirements for minimizing fire loads, namely:

- cables and parts made of non-flammable materials that do not spread fire are used;
- the number of units/components filled with petroleum products, oil and lubricants is minimized;
- lifelong lubrication is used;
- preventing leakage of oil and lubrication;
- power supply provides for phase protection;

– grounding is carried out in the power cable routing in addition to the protective grounding wire.

Other materials in premise No. 501 corresponding to the characteristics of materials [10] defined for category D premises are made of non-combustible or non-flammable materials [111].

The probability of a fire in (from) an electrical product is an integral indicator that takes into account both the reliability (failure rate) of the product itself and its protective (thermal and electrical) equipment, and the probability of ignition (reaching a critical temperature) by the product parts, supporting structural materials or substances and materials located in the zone of its radiation exposure or in the zone affected by an electric arc or hot parts (flying particles) of the product.

Ignition in SFPF electrical and technical equipment is minimized by the following design decisions based on the above requirements of the regulatory documents:

– electrical equipment and networks in the MB are made in accordance with the requirements of the PUE (chapter 3.1, chapter 5.3) [14] for protection equipment against overload currents and short circuits;
– automatic circuit breakers are used for protection; the automatic protective shutdown time does not exceed 0.4 sec;
– redundancy of protection equipment against short circuit currents and overloads has been implemented;
– the connection points of wires and cables, as well as connecting and branch terminals have a minimum transition resistance to avoid their overheating and damage to joint insulation;
– electrical and technical equipment has a cladding protection degree of at least IP44;
– cables and parts of electrical equipment are made of flame retardant materials with low smoke and gas emissions.

Failures of electrical equipment associated with the initiation of short circuit currents, overloads and overheating of contacts/connections in electrical equipment, which can lead to ignition, are prevented by periodic inspections and maintenance of the MB equipment in accordance with regulations [113], [114]. At the same time, in the event of short circuit currents and overloads taking into account the actuation of automatic protection equipment, fire resistance of cables and parts of electrical equipment, as well as operation of the main building ventilation system in the normal mode (the premises served by the ventilation systems in the main building are not equipped with an automatic fire alarm system, the signal of which turns off the MB ventilation system [14]), the following conclusions can be drawn:

– fire will not initiate in/from electrical equipment;
– in case of ignition of a separate component, the MB ventilation system continues to operate and necessary exhaustion in the MB will be ensured;
– technological process can be safely stopped using backup equipment;
– damaged electric drives can be shut down for repair according to the procedures provided for in the Technical Specification.

Taking into account the fire prevention and fire protection measures described above and implemented in the ISF-2 Project, the probability of fire initiation and spreading associated

with explosion and fire hazard sources in the SFPF building, particularly in the hot chamber, is minimum and meets the regulatory requirements.

Fire accident analysis results of HI-TRAC OTC.

The parameters, conditions and conservative assumptions for a fire accident were accepted in accordance with the requirements of PBPRM-2006 [115]. According to the mentioned above, a hypothetical ignition event was considered for 880 liters of diesel fuel poured in a form of a 1 m wide ring around the HITRAC container, that is in a horizontal position with the loaded double wall dry shielded canister (DWSC) with a maximum thermal load of 10 kW. Fire duration corresponds to the time sufficient for combustion of all flammable liquid; the minimum combustion rate is considered conservatively. The purpose of the fire analysis is to determine the temperature value, to which the temperature of fuel located in DWSC and the temperature of the confining barriers in the HI-TRAC-H and DWSC will increase due to a short-term increase in temperature of the environment around the HI-TRAC-H.

The analysis results of CSM fire accident. Fire probability is considered extremely low due to the absence of flammable materials in the CSM storage area. The only possibility of accident initiation is associated with ignition of fuel and hydraulic fluid in the OTC transporter, which causes the outer layers of the CSM to heat up to high temperatures. Cables installed on the CSM do not affect fire intensity and are considered destroyed during a postulated fire. The following parameters and assumptions were adopted to analyze the envisaged fire in accordance with the regulatory document of Ukraine [115] on the transport:

- with the exception of a free support surface, a container should be completely engulfed in flames. Full coverage of the CSM by flame corresponds to the maximum heat transfer surface covered by fire;
- average flame emissivity coefficient is taken into account, which should be equal to at least 0.9 during the entire fire;
- average flame temperature should be at least 8000 °C. Typically, an open flame also covers a significant amount of air, causing the average flame temperature to decrease. This same temperature is applied to all surfaces of the container that are exposed to fire, which is a very conservative assumption given the size of the CSM. Therefore, using a temperature of 8000 °C is conservative;
- the source of fire load should have a horizontal extension of at least 1 m, but it cannot exceed more than 3 m beyond the outer surface of the container. Using a minimum flame ring width of 1 m increases the size of the flame area, thereby conservatively resulting in a maximum fire duration.

In addition, the following assumptions were made during thermal mode calculations:

- the coefficient of convective thermal conductivity should have a value justified for fire with the specified parameters. Based on experimental studies of fire in a large tank [116], a conservative coefficient of forced convection heat transfer of 25.5 W/m2-oK (4.5 BTU/ft2-h-OF) is applied to exposed CSM during a short-term fire);
- it was conservatively assumed during the fire analysis that air temperature of CSM, inlet and outlet ventilation openings corresponds to flame temperature.

Given the volume of fuel and hydraulic fluid spillage of 880 l [117], the size of the CSM and the spill ring of 1 m, the area of the spill around the CSM is 5.04 m^2 with a depth of 17.46 cm. Taking into account the specified depth and the minimum fuel burnout rate (0.381 cm/min, the Sandia report on burning of a large spill of combustible substances [116]), the maximum estimated fire duration is 45.8 minutes. The value assumed to be 880 liters corresponds to tank capacity of a diesel generator [117] and significantly exceeds tank capacity of the OTC transport platform of about 120 liters [118]. In the interests of conservativeness, fire duration of 46 minutes is assumed.

The thermophysical mode of a loaded CSM under fire conditions is determined by the FLUENT computer program. The three-dimensional model of CSM concrete was developed to perform the analysis. It is assumed that the side and top surfaces of the CSM are exposed to fire, while the CSM base is isolated. An analysis of the corresponding non-stationary mode lasting 46 minutes was carried out. The results indicate that a fire does not have a significant impact on the CSM. Only a few local areas of concrete show temperature limit exceeding for the short-term conditions. In addition to fire impact on the CSM, its impact on the double-walled dry shielded canister (DWC) and the fuel rod bundles stored inside it is also considered. The analysis of fire impact on DWC and its content was carried out in accordance with the instructions of document NUREG-1536 (4.0,V,5.b) [119], which states: “the US Nuclear Regulatory Commission allows calculation of fuel temperature increase for short -term fire (less than 10% of the thermal constant for the container casing) taking into account the adiabatic inner wall of the container. Therefore, fuel temperature increase should be determined by dividing spent fuel heat release during the fire exposure time by heat capacity of the “fuel basket-spent fuel” system.

CSM time constant is determined by the following formula:

$$\tau = (C_p \times \rho \times L_c^2)/k$$

where: C_p = specific heat capacity (J/kg-K)

ρ = CSM density (kg/m3)

L_c = CSM characteristic length (m)

k = CSM thermal conductivity coefficient (W/m-K)

The main part of CSM mass and volume is represented by concrete; therefore, the specific heat capacity (Table 5.1), density (Table 5.1) and thermal conductivity coefficient (Table 5.1) of concrete are taken to calculate CSM time constant. The characteristic length of the CSM corresponds to its wall thickness and is 1.325 m. Based on the values indicated in the equation, the time constant of the CSM is determined in form of:

$$\tau = (653 \times 2200 \times 1.3252) / 1.09 = 642.7 \text{ hours}$$

Table 5.1 Thermophysical properties of concrete

Parameter	Value		
Temperature	50°C	100°C	300°C
Thermal conductivity coefficient [Note 1] [120], W/m-K	1.51	1.37	1.09

Density [Note 2], kg/m^3	2200
Specific heat capacity [Note 3], J/kg-oC	653
Note 1: the most conservative thermal conductivity from reinforced concrete sources [121], [122], [123]. Note 2: the lower value for the CSM concrete grade and the most conservative one from [121], [120], [124] for B40 concrete grade were accepted. Note 3: the lower value of specific heat capacity from American sources [125] is more conservative than the one in the Ukrainian reference books and standards [121], [122]	

One-tenth of the specified time constant is about 64.3 hours, this is significantly less than the fire duration of 46 minutes, thus, the analysis of the double-walled dry shielded canister (DWC) is performed for adiabatic boundary conditions. Therefore, DWC temperature increases only due to the ongoing residual heat release and its increase is calculated using the expression:

$$T_{rise} = (Q \times t) / I$$

where: T_{rise} = temperature increase (K)
Q = DWC total heat release (W)
t = fire duration (sec)
I = thermal inertia (J/K)

The lower value of DWC thermal inertia with fuel rod bundles located with it is 5.5x106 J/K; taking into account the maximum heat release of 6.816 kW and fire duration of 46, the heating of fuel rod bundles will be 3.45°C. This increase in fuel temperature is insignificant. Accordingly, the impact on helium pressure inside DWC will also be very low. The distribution of temperature fields in the CSM casing is shown in Figure 5.1. Taking into account the conservative analysis of CSM response to a hypothetical fire event, one may conclude that fire does not have a significant effect on temperature of the DWC or spent fuel in it. In addition, the CSM ability to ensure spent fuel cooling after a fire following the design permissible temperature limit is maintained.

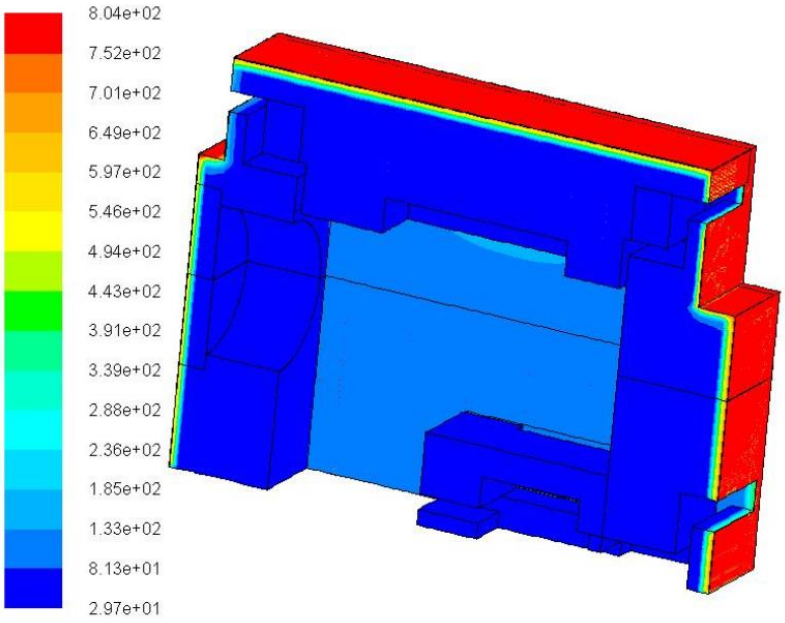

Figure 5.1 Distribution of temperature fields in CSM casing

Transport communications and forest plantations around the ISF-2 site (probable sources of external fire) are located at distances ensuring the absence of temperature impact and/or efficient counteraction to fire spread towards ISF-2 by means of regular measures and by personnel, as well as due to calculations of fire and rescue units (the tank – the outlet channel at Chornobyl NPP units is located 50 meters from the perimeter of the ISF-2 fence). In addition, in accordance with the requirements of the administrative procedures, the ISF-2 site has been cleared of any uncontrolled vegetation.

5.2.3 Regulator's assessment and conclusions on fire safety analysis

Fire safety analysis as part of the safety justification for ISF-2 is the subject of the State Nuclear and Radiation Safety Review carried out by the SNRIU in accordance with the requirements of the legislation of Ukraine.

The fire safety analysis of ISF-2 was revised by the SNRIU as part of the State Nuclear and Radiation Safety Review of the Final Safety Analysis Report of ISF-2 in 2021. The State Nuclear and Radiation Safety Review of the Final Safety Analysis Report of ISF-2 in 2021 was carried out by the SNRIU as part of the consideration of ChNPP application for issuing a license for the right to carry out activities at the operation life cycle stage of the ISF-2 nuclear installation.

The following was established based on the results of the State Nuclear and Radiation Safety Review:

- the scope and methodology of the safety analysis performed will meet the requirements of the standards and regulations for nuclear and radiation safety, as well as consider the IAEA recommendations for the spent nuclear fuel storage facilities;
- the analysis results consider the current ISF-2 condition;
- the safety analysis results comply with the safety criteria defined in the standards and regulations for nuclear and radiation safety, as well as the design documents.

The adequacy and validity of the information in the Final Safety Analysis Report of ISF-2 was confirmed by the SNRIU under the inspection survey conducted from 22 March to 02 April 2021.

5.3 Fire protection concept and its application

The defense-in-depth fire protection system was implemented in ISF-2 designing; this will help preserving the functions of the fire protection system necessary to ensure NPP nuclear and radiation safety during and after a fire, as well as provide the following:

- fire prevention by:
    - bringing the amount of combustible substances and materials to the minimum required by the manufacturing conditions;
    - preventing conditions for generation of gas-air explosive mixtures;
    - administrative and technical measures to prevent generation of different ignition sources;
    - use of electrical and technical equipment produced in accordance with the class of explosive or fire hazardous zone according to the PUE;
    - use of materials for the building structures and finishing materials that meet the category of premises according to explosion and fire hazard [6];
- timely and targeted detection of ignition and further fire extinguishing at the initial stage of its spreading up to complete fire suppression.
- preventing the spread of fire and combustion products by isolating the systems important to safety, localization of fire sources.

The following is prohibited in the structures, buildings and premises, as well as in the open areas where nuclear fuel and radioactive waste is stored and/or managed:

- storage of combustible and explosive substances and materials in any type, form and quantity, which are not related to the technology of handling nuclear fuel/radioactive waste;
- placement of any containers and pipelines, including transit ones, with combustible and/or explosive media;
- laying of electrical cables, including transit ones, not related to power supply to the equipment used when handling nuclear fuel;
- use of fire extinguishing agents for fire suppression, which can lead to violation of nuclear safety conditions due to their neutron-absorbing and/or reflective properties;
- use of fire extinguishing agents for fire suppression, which can lead to unacceptable chemical, mechanical, thermal or other effects on fuel assemblies and their components, as well as on racks, frames, tubes, shipping and storage casks.

5.3.1 Fire prevention

ISF-2 belongs to the group of facilities where fires can lead to harm to people and the surrounding area due to secondary manifestations of hazardous fire factors, primarily when radioactive substances and materials release beyond the protective structures. The specificity of the fire safety of ISF-2 is that the fire safety systems of the facility are targeted and ensure

the radiation and nuclear safety of the facility. The ISF-2 fire safety system performs fire prevention and fire protection functions.

Fire protection is achieved by a combination of the following methods:

- use of automatic fire alarm and fire extinguishing systems;
- use of fire extinguishing means and appropriate types of fire equipment;
- use of non-combustible building structures and materials with standardized fire hazard indicators;
- use of space-planning decisions and devices that limit the spread of fire: dividing the building into fire sections, installing fire barriers, fire-resistant components in equipment, emergency shutdown of equipment, etc.;
- timely notification and evacuation of personnel with the help of space-planning decisions and equipment;
- use of collective and individual protection means for people (personnel, fire departments) against hazardous factors of fire and radiation exposure;
- use of smoke protection equipment.

General overview of the management and monitoring mechanisms of fire load and ignition sources. Generation of flammable environment is prevented by a combination of the following methods:

- maximum possible use of non-combustible and highly flammable substances and materials;
- limiting the mass of compactly located flammable substances and materials by placing them in the safest way;
- isolation of a fire area;
- installation of fire hazardous equipment in isolated premises;
- maximum isolation and automation of technological process with spent nuclear fuel;
- use of devices to protect production equipment with flammable substances against damage and accidents.

Limiting the mass of combustible substances and materials and the safest way of their placement is achieved by a combination of the following methods:

- reducing the mass of combustible substances located simultaneously in the premises;
- maximum possible replacement of combustible liquids in equipment with non-combustible ones.

5.3.2 Active fire protection

The active fire protection of ISF-2 includes [126]:

- fire alarm system (FAS) in the SFPF and checkpoint building;
- gas fire extinguishing system (GFES) in the SFPF and checkpoint building;
- firefighting water supply to SFPF buildings and cartridge storage.

FAS is an integral part of fire protection in the SFPF and checkpoint buildings for ISF-2 personnel. ISF-2 FAS is mounted on the FlexES control series equipment manufactured by ESSER by Honeywell, whose operation is based on the use of the address-analog technologies. A hardware complex of active fire protection based on FlexES control ensures early fire

detection in the controlled premises of the SFPF and checkpoint buildings and ISF-2 ARMS point, sending signals to alert personnel about a fire in the control room and generating automatic control commands:

- FAS in the SFPF and checkpoint buildings;
- GFES in the SFPF and checkpoint buildings;
- firefighting water supply to the SFPF buildings and cartridge storage;
- GFES actuation;
- interlock (for disconnection) for the operation of the supply and exhaust ventilation systems;
- connection of the ventilation systems for air pressurization in the smoke protection systems for SFPF staircases;
- closing fire-retarding valves on the supply and exhaust ventilation ducts;
- the fire alarm system and management of people evacuation.

5.3.2.1 Fire detection and fire alarm

AFAS is an integral part of the fire protection of the ISF-2 SFPF (structures according to DP-01) and personnel checkpoint buildings (structures according to DP-05.1). AFAS includes fire protection equipment providing early detection of fire, sending a signal about fire initiation to the fire alarm control panel in the premise with on-duty personnel and generating command impulses to control the engineering firefighting equipment in the building that allows creating conditions for safe evacuation and suppression of a fire outbreak or limiting the spread of fire. In terms of impact on safety, AFAS refers to normal operation systems that do not affect facility safety (the system not affecting safety in accordance with the principles set out in Report HI2094357 “Safety Classification of ISF-2 Structures, Systems and Components). AFAS in the SFPF and personnel checkpoint building has been developed on the basis of the addressable analogue fire detection systems certified and approved in Ukraine. The lists of the protected premises in the SFPF and checkpoint buildings were determined on the basis of VBN V.1.1-034-03.307-2003 (Annex D) [17] and taking into account their categories of explosion and fire hazard, as well as materials stored or handled in these premises. Installing automatic smoke and heat addressable fire detectors (IQ8Quad series) is planned to detect a hot spot of fire in the protected premises.

Addressable manual fire detectors (I8Q series) are located on evacuation routes. Remote indicators are installed in places accessible for visual monitoring to monitor detectors installed in the false bed space. Installation of transponders with relay outputs is provided to actuate the automatic fire protection system. Power supply of transponders intended for inclusion into the fire alarm loops, “Exit” annunciators and direction indicators is provided through power supply units from an alternating current network, 220 V voltage, 50 Hz frequency.

Installation of two fire detectors that monitor the same point on the surface subjected to protection is provided to generate an impulse to control automatic alarm systems such as CO4, gas fire extinguishing systems, and FAS systems in the premises of the SFPF building. The above systems will be turned on only after two detectors protecting one premise are actuated. The type of a fire detector (heat, smoke, etc.) was selected in accordance with the characteristics of combustible substances and stored and/or handled materials during the technological process performed in this premise. The type of fire detectors for each premise was selected according

to probable primary signs (heat, smoke, flame) of an incipient fire in order to detect it at an early stage of spreading. The design of fire detector cases meets the environmental conditions.

Fire detectors in the protected premises and on evacuation routes are placed on the basis of the requirements of DBN V.2.5-56:2014 [17]. Smoke fire detectors are installed in the gateways of staircases C.A and C.B equipped with the air pressurization systems to ensure monitoring of the protected surface by at least two detectors. Separation of AFA signal lines in free- and strict-access premises is envisaged.

The fire alarm control panels (FACPs) of the targeted analogue fire detection system were accepted to monitor fire alarm signal lines and receive signals from fire detectors. Fire alarm receivers are installed:

- in the SFPF building (structures according to DP-01) in the premise of physical protection system local control board (premise 130) –FX-10 fire control panel;
- in the personnel checkpoint (structure according to DP-05.1) in the operator's premise (premise 202) - FX10(5) control panel.

AFAS FACPs are installed in premises for permanent staying of operating personnel.

The capacity of automatic fire alarm devices ensures reception of all fire alarm loops associated with the automatic fire alarm system of the designed facility structures with a reserve of signal lines of at least 10%.

FACPs of the AFAS targeted system have a control panel with a liquid crystal display and LED indication. Information on the liquid crystal display of the remote control is displayed in Russian. Monitoring receiver installed in premise No. 130 in the SFPF building is the major one and provides the ability to connect remote control or the alarm panels that fully or partially duplicate the functions of the main panel.

AFAS FACPs have microprocessor control, which allows programming the functions of each of the monitoring and control modules connected to the system signal line, and develop a multi-zone alarm system with different response algorithms. Fire alarm loops are made of KOVEVng -FRHF-FE180/E30 – 2x2x0,8 fire-resistant cable according to the ring principle with connection to fire alarm devices. Fire detectors are connected to the signal line (loop) of receivers by separate cables.

Cables of AFAS signal lines are laid on walls, ceilings and metal structures openly with fastening with staples or on walls, ceiling on mesh cable trays laid for low-current networks with a voltage of not over 60 V, and, if necessary, an increased level of protection against mechanical impact. Requirements for wires and cables in signal lines and internal communication lines (AFA loops) are determined in accordance with the requirements of DBN V.2.5-56:2014 [17].

In a container type structure of ARMS post (structure according to DP-07), an automatic fire alarm is provided by the manufacturer and is included into the delivery package. "Fire", "Failure" signals generated by the AFA equipment of this structure and transmitted to the inputs of SFPF AFAS FACPs via connecting lines that are made independently and laid at the site in the communication cable channel.

The Project envisaged and carried out the formation and output of general "Fire", "Failure" signals from AFAS FACPs for their transmission via designed and existing communication lines to the first detachment of the volunteer brigade for ChNPP fire protection.

According to the requirements of VBN V.1.1-034-03.307-2003 [17], power supply of automatic fire alarm devices is carried out according to the requirements of a special group of reliability category 1 in compliance with the PUE. The built-in power supply units with 7 Ah, 12 V batteries that ensure operation of the main devices of the fire alarm system for 24 hours in standby mode and 3 hours in "Fire" mode are used as a backup power supply source.

The automatic fire alarm in the SFPF building has functional relations with the engineering systems, such as:

- power supply system of 220 V, 50 Hz alternating current;
- system for notification and management of people evacuation during a fire;
- fire protection automatics (FPA).

The fire alarm equipment accepted in the Project is certified in the UkrSEPRO system. The equipment provided for in the Project was mounted by 2015.

The hardware complex of active fire protection based on "FlexES Control" ensures early detection of a fire hot spot in the controlled premises in the SFPF and checkpoint buildings and ARMS point in ISF-2, sending signals to notify personnel about a fire at the control panel and generating automatic control commands [126]:

- actuation of the automatic fire extinguishing system (gas);
- interlock (for disconnection) for the operation of the supply and exhaust ventilation systems;
- closing fire-retarding valves on the supply and exhaust ventilation air ducts;
- inclusion of air pressurization ventilation units, smoke protection systems for staircases in the SFPF building;
- the fire alarm system and management of people evacuation;
- sending alarm messages to the fire communication control room.

Impulse to control automatic notification systems, gas fire extinguishing systems, and automatic fire protection systems at ISF-2 is generated at two fire detectors. The above systems will be turned on only after two detectors protecting one premise are actuated.

The SFPF building is equipped with the supply smoke control ventilation systems to supply outside air in case of fire to smoke-free staircases C.A and C.B, premise No. 610 and firefighting airlocks.

Axial fans without soft inserts are installed to create air supply and excess pressure and prevent smoke of staircases and airlocks. The air pressurization system (APS) for smoke-free staircases and fire-protection airlocks are assumed to be separate. The equipment in the supply smoke control ventilation systems is located on the roof.

Smoke protection valves with a fire resistance limit of EI 90 are installed to create backup in case of a fire in the airlocks at staircases C.A and C.B in premise No. 610, which are designed as smoke-free staircases of H4 type. The valve on the fire floor opens with a time delay in actuation of FAS and appropriate smoke protection system (SPS).

The air intake devices of the supply smoke protection ventilation systems are equipped with smoke SL to prevent smoke from entering the building through the supply duct in case of external smoke.

The notification system (NS) is provided to notify personnel staying in the buildings and structures of ISF-2 about fire initiation and to create conditions for their timely evacuation. The

following NS types are provided in accordance with the regulatory requirements, as well as taking into account the specifics of the facility:

- in the SFPF building– NS -4 type;
- in the personnel checkpoint building – NS -3 type.
- NS provides for:
- transmission of light and sound signals;
- broadcasting of voice messages in case of fire;
- turning on “Exit” light indicators;
- inclusion of traffic direction signs (only in the SFPF building) with inclusion separately for each zone;
- transmission of alarm messages to the central control room CCR-1.

IQ8Alarm light alarms with a siren and a strobe lamp (Honeywell addressable signaling devices) are installed in the premises of the strict access zone in the SFPF building. Light and sound alarms of “Shmel-2” type are installed on the facades of the SFPF and checkpoint to alert personnel.

Light and sound alarms are installed in such a way as to ensure necessary audibility in all places of permanent or temporary staying of personnel.

FlexES Control FACPs are installed in premises with permanent staying of OP. In order to prevent personnel errors, fire alarm equipment has a multi-level access protected by passwords and mechanical keys, without which the access to the functioning of the fire alarm system is impossible (protection against unauthorized access).

In order to control fire alarm signal lines and receive signals from signaling devices (SD), a hierarchical system for constructing FAS has been adopted, the center of which is the FlexES Control addressable analogue fire control panel. The FlexES control panel of the FAS targeted system has a control panel with a liquid crystal display and LED indication. Information on the liquid crystal display of the remote control is displayed in russian. FAS equipment received at the facility exchanges data with the central control room and internally and provides the following information to the central station:

- identification of any FAS subordinate device in “Fire” and “Failure” mode;
- identification of any failure on the line leading to the FAS subordinate device.

Fire alarm receivers are installed:

- in the SFPF building on the central control panel of the fire protection systems (FPS CCP) (premise No. 130), the FlexES Fire Control panel and a computer with WINMAG Plus software monitor the FAS state and are an additional backup information and control component;
- IQ8Control M panel in the personnel checkpoint building in the operator’s premise (prem. No. 202).

ISF-2 FAS includes FlexES Control addressable analog fire control panel with 8 ring address lines with software consisting of:

- IQ8Quad addressable optical smoke SD;
- IQ8Quad address thermal maximum SD;
- IQ8 address manual signal device (MSD);

- remote addressable power sources;
- address control modules (transponders);
- 8010 remote display and control panel.

FlexES Control FACPs have microprocessor control, which allows programming the functions of each monitoring and control module connected to the system signal line, and developing a multi-zone alarm system with different response algorithms.

FlexES Control FACP during its operation in a standby mode and alarm mode ensures the following:

- receiving and displaying the information (type of event, address, etc.) from SD and the monitoring and control modules on a liquid crystal alphanumeric display;
- priority of displaying the “Fire” signal over the “Warning (Attention)”, “Failure” signals and other process signals of the system operation;
- checking the received alarm signal;
- possibility of periodic self-testing of the main system units;
- disconnecting a part of the signal line in failure while maintaining the operability of other undamaged sections of the line;
- generation of command impulses, general or the ones from each zone, to control FPA engineering systems;
- generation of general signals on fire and failures for transmission behind the controlled lines to other control rooms, if necessary;
- the possibility to display information on events stored in non-volatile memory on the display and, if necessary, on paper media using a connected printer;
- a backup central control module (FX808328.RE) is installed in the fire alarm device that operates in a “hot” standby mode and ensures 100% reliability as a result of failure of the main control module in order to prevent system failure resulting from the failure in one of the systems, personnel error, internal or external action.

The signal loops (lines) are the two-wire information buses including addressable SD and MSD, sound annunciators, control modules (transponders) with relay outputs and other devices.

In order to increase reliable functioning, the loops are made according to a closed ring circuit; short circuit modules built into the detector allow disconnecting the damaged section in the circuit in case of damage or a short circuit and ensure functionality of other SL, which enables maintaining the operability of the ring signal loop, if a short circuit or break occurs in it. Two detectors maximally subjected to damage isolate (disconnect) the section in the damaged loop on the both sides. In this case, the devices are connected to FACP via radial dead-end sections of the loop. Information on short circuit and actuation of insulators is transmitted to FACP.

When the operating power supply disappears in the emergency mode and when switching to the emergency backup power supply from the built-in accumulators, FAS control panels generate a “Fault” warning signal that corresponds to the standard operating algorithm and the design decision. The built-in accumulators provide FACP with the ability to operate in a standby mode for up to 24 hours and up to 3 hours in emergency mode; the power supply addresses of the devices are given in Table 3.1. All alarm (fire) and warning (failure, accident

or operational occurrences) messages generated on the FlexES Control are duplicated on the FX-10 remote control and display panel installed in the checkpoint building (prem. No. 202).

5.3.2.2 Fire mitigation

Installing water and foam fire extinguishing systems has not been provided for at the ISF-2 site. Due to the transfer of the physical protection system local control board (PPS LCB) from the SFPF to the second floor in the checkpoint building that has been already constructed, the operator's premise (prem. No. 202), hardware premise in the central physical protection point (CPPP) (prem. No. 203), changing room (101), security room (107), as well as the space under the raised floor in premises No. 202 and No. 203 will be equipped according to the Project with the automatic gas fire extinguishing systems (GFES). Cable networks behind suspended ceilings should be additionally coated with a certified fire-retardant compound.

In accordance with VBN V.1.1-034-03.307-2003 [17] (Annex E), paras. 1.4.1, 1.4.2, 2.4, 2.5, in order to protect premises containing electronic and electrical equipment, the Project provides for the use of non-automatic volumetric gas fire extinguishing installations with decentralized storage of fire extinguishing agent, since the specific fire load in these premises does not exceed 200 MJ/m2.

Each premise has a separate gas fire extinguishing system. Khladon-125 HP gas was used as a fire extinguishing agent. The Project provides for the implementation of the requirements [17] to ensure personnel safety in GFES actuation and fire extinguishing gas supply to the premises:

- delay in the supply of fire extinguishing gas (for a period of 30 sec) since actuation of GFES and the warning light and sound alarm;
- actuation of “Gas - Exit!” warning sound and light alarms in the protected premises and “Gas – Do not Enter!” light alarm at their entrances;
- interlock of startup when opening the doors to the protected premises.

The GFES operating principle is based on the principle of volumetric fire extinguishing in a separate premise by creating a fire extinguishing concentration of a gas fire extinguishing agent in the entire volume of this premise, including the space behind the suspended ceiling and raised floor. Standby cylinders are also provided for replacement. In addition, a reserve of fire extinguishing agent is provided to test the installation of gas fire extinguishing when protecting the premises of the smallest volume. The reserve of fire extinguishing agent is stored in the storage in charged cylinders along with the standby cylinders.

The premises in the central control and management panel (CCMP) (No. 308), server room (No. 203, No. 308A), communication room (No. 118C) located in the SFPF building are equipped with the automatic gas fire extinguishing systems. Similar basic equipment specified for the checkpoint premises with Freon 125 HP fire extinguishing agent is envisaged. The amount of Freon 125 HP gas to maintain the required concentration of the fire extinguishing agent in premises No. 118C, No. 203, No. 308, No. 308A in the SFPF building will be 185 kg.

The automatic fire extinguishing system ensures [126]:

- actuation within a period shorter than the initial stage of fire spreading;
- estimated supply intensity and required concentration of fire extinguishing substance;

– fire localization during a period necessary for the deployment of operational forces and means, or its suppression.

The use of non-automatic volumetric gas fire extinguishing systems of a modular type with decentralized storage of fire extinguishing agent is provided to protect the premises containing electronic and electrical equipment. A separate gas fire extinguishing installation and gas Khladon-125 HP fire extinguishing agent is envisaged for each premise.

Automated GFES with manual electric startup are provided for fire protection of CCMP premise (No. 308) in the SFPF building, as well as the switchboard premise (with electronic equipment) (No. 201), operator's (No. 202) and server premise (No. 203) in the checkpoint building. Remote and local actuation of GFES is provided for the server (No. 203) and electrical switchboard (No. 201) premises in the checkpoint building, and a local mode of manual automated actuation of GFES is envisaged (the indicated premises are staffed 24 hours a day by duty personnel) in the operator's premise (No. 202) of the checkpoint and the central control and monitoring panel (No. 308) in the SFPF building. Equipment for warning alarms and electrical interlocks is installed in the premises protected by the automatic fire (gas) extinguishing system.

The gas fire extinguishing system in the remote and local (manual) control modes is actuated after visual checking that there are no people in the protected premise and all doors are tightly closed. Control levers at the shut-off device in the gas modules are used for local control of the gas fire extinguishing systems. The automatic fire (gas) extinguishing system was designed based on the principle of a distributive hierarchical structure.

Forced ventilation of the premises is ensured after the gas fire extinguishing system is actuated, not earlier than in 10 minutes, in order to completely dissipate hazardous environment and prevent it from entering other premises. The operation principle of the system in fire initiation, fire alarm equipment actuation, or pressing remote start button of the system in the protected premise is that the sound and light warning alarm is actuated, and a signal is generated to turn off the ventilation. In 30 sec after the warning alarm is turned on, an electrical impulse is sent to the electromagnetic actuator that opens the shut-off device. In this case, the shut-off device valve opens and fire extinguishing substance under the influence of operating pressure is supplied from the module to the protected area. When the pressure in the module tank decreases, the pressure alarm sends a signal to FACP that the module has been actuated.

5.3.2.3 Administrative and organizational issues concerning fire protection

Coordination of activities related to fire safety and its oversight at ISF-2 is entrusted to the head of the spent fuel management department. A range of administrative measures has been adopted to ensure ISF-2 fire safety and establish an appropriate fire safety mode, namely:

"Fire Safety Instruction for Chornobyl NPP Radioactive Waste Management Department", 1E-Ts00YAT establishes the basic requirements for fire safety in the buildings, structures, as well as in the production, storage and office premises. It determines the basic fire safety requirements and responsibilities of managers, experts and workers, establishes the fire safety procedure and methods, responsibilities and actions of workers in case of fire, the procedure for notifying people and reporting it to the fire and rescue unit, requirements for the maintenance and use of fire extinguishing equipment;

The relevant ChNPP orders define: the presence of (smoking areas), the possibility of (places of use of) household electric heating devices, the procedure for driving and parking

vehicles, the procedure for inspecting and closing premises after the end of the working day, the procedure for examination of personnel knowledge on fire safety, measures for preparing the enterprise for work during the spring-summer and autumn-winter fire hazardous periods;

" Instruction for Arranging Safe Hot Operations at ChNPP Facilities" 34E-S defines the procedure for hot work at permanent and temporary sites. Temporary hot work is carried out according to special work permits, the work locations are agreed upon with experts of the fire safety group at the institutional oversight department;

"Provisions on the Procedure for Training and Knowledge Examination of ChNPP Employees on Labor Protection, Fire Safety, Civil Protection and Emergency Actions, Radiation Safety, Technical Operation Rules", 13P-S defines the procedure for officials to pass training and knowledge examination on fire safety, the procedure to conduct fire safety instructions and training on the basic fire safety standards for employees;

"Instruction for the Operation of the System of Integrated Household, Drinking, Industrial and Fire Water Supply at ChNPP Industrial Site", 35E-TsTPK established the procedure for arranging and maintenance of the integrated household, drinking and fire water supply system, as well as fire pumping stations;

"Instructions for Emergency and Fire Protection Exercises at Chornobyl NPP, 31E-S establish the procedure for practicing the interaction of operational, production and administrative and technical personnel with the staff of the fire and rescue units, arranging a call to the fire and rescue units when a fire is detected, rescuing and evacuating people;

The Regulations of the "Fire Safety" Process, RP 2.2.6-01, establish the procedure for arranging the Fire Safety Day at the enterprise, the principles of allocation of equipment and service areas of the fire protection systems between ChNPP divisions, establish goals, main tasks, composition, and operational procedure of the ChNPP fire and technical commission;

"Instruction for Internal Investigation, Primary Accounting and Analysis of Fire That Occurred at ChNPP", 29E-C, establishes the procedure for arranging an internal investigation, primary accounting and analysis of fires and ignitions that occurred at ChNPP facilities;

The Operational Fire Extinguishing Plan for the Spent Nuclear Fuel Storage Facility defines the procedure for notifying people in case of fire; actions of ISF-2 personnel in fire initiation; the procedure for extinguishing fire in energized electrical installations; the procedure for interaction between ChNPP personnel and the staff of the fire and rescue units arriving at the fire place;

Plans (Schemes) for Evacuation of People in Case of Fire (developed for buildings with two or more floors) determine the procedure for the safe evacuation of people and material assets in case of fire;

Operating Instructions of the Workshop establish the procedure for operating and maintaining the fire protection systems;

According to the standard technological processes of charging in compliance with the technical specifications, the primary fire extinguishing equipment (fire extinguishers) is serviced at the RMS fire extinguisher charging area. The fire safety signs are installed in accordance with the requirements of DSTU EN ISO 7010:2019 on the territory of ISF-2 in the production premises and workplaces, when it is necessary or desirable to provide publicly available information on the location and (or) nature of fire warning and manual control means, evacuation routes, fire extinguishing devices, equipment for preventing fire spread, zones or materials of increased fire risk.

Fire safety signs informing on location of the primary fire extinguishing equipment are installed when placing (fire extinguishers, fire hydrant sets) in closed cabinets and stands. When placed outside the line of sight, the signs are positioned so that they are clearly visible. The placement of fire safety signs, as well as the procedure for applying inscriptions to signs should be agreed with the institutional oversight department.

A special firefighting corner has been arranged directly on the territory of ISF-2 in order to conduct firefighting agitation and propaganda and ensure the most effective training of workers and employees. Signs indicating the telephone numbers for calling units of the civil protection operational rescue service (CPORS) are posted in the premises near the telephones. ISF-2 personnel undergo necessary fire safety exercises at ChNPP training center and educational institutions of Ukraine according to the relevant programs. The use of materials and substances that do not have fire hazard indicators is prohibited during production.

Cleaning ISF-2 premises with flammable and combustible liquids is prohibited. Special detergents should be used for these purposes. Non-flammable detergents are also used to degrease large equipment when repairing units and assemblies. Electrical equipment in fire hazardous areas is fireproof.

Instructions for guards have been developed, which define their responsibilities for monitoring compliance with the fire safety mode, FPS actuation, inspection of the territory and premises, the operational procedure in case of fire, as well as indicate a person among facility officials who should be called at night in case of fire.

Employees when hired and staying at their work places should pass fire safety training in accordance with the procedure established in Provision 13P-S. Persons hired for work associated with increased fire hazard should pass special exercises according to the fire-technical minimum program before starting independent work, as well as should further annually pass knowledge examination in accordance with 13P-S. The head and deputy head of the spent fuel management department should pass training and knowledge examination on fire safety before starting their duties and periodically (once per three years) at the life safety educational institution of the State Emergency Service of Ukraine in the Kyiv region. Persons who have not passed the exercises, special training and knowledge examination on fire safety are not allowed to work.

Workers from operational, production, maintenance, administrative and technical personnel take part in fire safety exercises. According to the plan (twice a year), fire-tactical exercises are conducted to practice actions aimed at fire suppression and accident mitigation at the site, options for interaction with the site firefighting headquarters, emergency teams, and the facility administration are worked out. Fire exercise scenarios are developed taking into account previously studied fire extinguishing experience. Exercises are carried out in different areas of the facility taking into account their fire hazard and significance for ISF safe operation. After each training session, the results are summed up, the participants' actions are evaluated, and an assessment is given to determine whether the exercise goals have been achieved.

The experience gained is used to change the training program (if necessary) or amend the fire extinguishing plan. The main provisions of the fire extinguishing plan are brought to the attention of ISF workers during the fire and emergency exercises. In accordance with the requirements of NAPB B.01.014-2007 para. 6.3 [29], a list of the most fire-hazardous premises has been drawn up at the ISF and approved by the head of the enterprise.

5.3.3 Passive fire protection

5.3.3.1 Prevention of fire propagation (barriers)

Fire protection decisions are made according to the general plan (firefighting trenches, construction of roads, driveways). The ISF-2 site is located in the northern part of the Kyiv region in the exclusion zone at the distance of 1.8 km in the south-east direction from ChNPP site, approximately 110 km away from the city of Kyiv, 12 km northwest from the city of Chornobyl, and 44 km southwest from the city of Slavutych. The site is bordered on the north-eastern side by the existing road leading to ChNPP plant area and the cooling water drainage channel, on the south-western side it is bordered by a railway line, and on the north-western side by the territory of the concrete plant.

According to process requirements, the site has two railway entrances from the Yaniv station and two access roads. The distances between the existing buildings and structures meet the regulatory requirements for distances between the buildings and structures depending on their fire resistance degree and explosion and fire hazard category according to SNiP II-89-80 [127]. The designed on-site passages provide a rational connection between the facilities and the possibility of access for firefighting vehicles.

The buildings and structures at the ISF-2 site are located within a 4-km radius of maintenance of the ChNPP fire protection department. The distance from the fire station to the ISF-2 site along the public roads is up to 4 km, fire trucks on standby are: fire tanker ATs-40 (130) 63b on ZIL chassis - 2 pcs., air foam extinguishing vehicle on KAMAZ chassis - 1 pc. The fire station is located 2 km away.

In accordance with R&D reports [128]-[131], the SFPF building corresponds to fire resistance degree I, the CSM building corresponds to fire resistance degree II, the checkpoint building corresponds to degree II, the ammunition storehouse building and the mobile (inventory) container type building for ARMS corresponds to fire resistance degree IIIa.

The fire resistance degree, fire resistance limits of the main building structures meet the requirements of DBN V.1.1-7-2016 [10], SNiP 2.09.02-85*, SNiP 2.09.03-85. The categories of the buildings for explosion and fire hazards are adopted according to DSTU B V.1.136:2016 [132].

The fire resistance limit of the building structures (in minutes) and the maximum values of the fire limit are designed according to the accepted fire resistance degree of the buildings. Load-bearing components such as the structures ensuring overall and geometric stability of the buildings and structures in case of fire are load-bearing walls, frames, columns, beams, crossbars, stiffening diaphragms, etc., made of non-combustible construction materials (flammability group: non-combustible). The fence construction structures of the buildings are also accepted as non-combustible (flammability group: non-combustible).

When technological processes with different explosion and fire hazards are located in one building or premise, measures are provided to prevent explosion and fire spread - technological processes with different explosion and fire hazards are located in separate premises, while category B premises are separated from category D premises and corridors by type 1 fire resistant partitions (EI 45) and type 3 fire resistant floors (EI 45). Type 2 fire resistant doors (EI 30) are installed in type 1 fire resistant partitions (EI 45).

5.3.3.2 Ventilation systems

In arranging SFPF ventilation, fire prevention measures are provided in accordance with the requirements of DBN V.2.5-67:2013 [133], namely:

- installation of fire dampers is provided to prevent the penetration of combustion products (smoke) into the room during a fire. In this case, fire dampers are installed directly near the obstacle in accordance with the manufacturer's documents. The section of the air duct from the obstruction to the valve is insulated with a fire-retardant coating, which ensures a standardized fire resistance class;
- sealing with non-combustible materials the places where air ducts pass through the fence structures in the (SFPF and checkpoint) building ensuring a standardized fire resistance class of the crossed fence.

The fence structures (partitions) in the premises for ventilation equipment are type 1 fireproof with EI 45 fire resistance class, the doors are type 2 fireproof with EI 30 fire resistance class.

The supply smoke protection ventilation systems are designed to supply outside air during a fire into smoke-free staircases and fire protection airlocks at the staircases.

Axial ventilators without soft inserts are installed to create air pressure, exceeding pressure and to prevent smoke entering to staircases and airlocks. Air pressurization systems for smoke-free staircases and fire protection airlocks are made separately. Fire protection valves with EI 90 fire resistance class are installed in the airlocks at staircases C.A and C.B made as H4 type smoke-free staircases to create pressure in case of fire. The valve on the fire floor opens with a time delay in actuation of AFAS and corresponding smoke protection system.

All transit air ducts in fire-hazardous premises after crossing the ceiling or fire barrier throughout the entire length to the ventilation equipment premise, as well as air ducts of the smoke protection systems are made of non-combustible materials of EI 90 fire resistance class with installation of fire protection valves with EI 90 fire resistance class.

Air ducts in evacuation staircases are laid in compliance with the following conditions:

- the air duct within the volume of the staircase has a fire resistance class of at least EI 45;
- when the air duct crosses the fence structures in the staircase, fire protection valves with a fire resistance class of at least EI 45 are installed in the air duct, which automatically close in case of fire;
- air ducts of the CAVS-S-1 and NCAVS-S systems passing through the NC.B staircase are air ducts transporting the outside air. Air duct sections within the staircase volume have a fire resistance class of at least EI 60;
- fire protection valves are not installed when air ducts cross the CAVS-3 system of the fence structures in the C.B staircase at elevations +5.500 and +9.000. Air duct sections within the staircase volume have a fire resistance class of at least EI 60;
- air ducts do not interfere with the process of people evacuation (the required width and height of evacuation passages are met). Forced-down sections of air ducts in the volume of evacuation staircases and on evacuation routes are marked with a "zebra" using luminescent and reflective paints in accordance with the general technical requirements of GOST R 12.4.026-2001, para. 8;
- air duct in premise 105 is laid at the height of 1.9 m from the floor;

- local lowering of the NCAVS-S system air duct was carried out to a level of 1.9 m from the floor in the corridor of the 1st floor in axes 201-201/1÷2F-2F1;
- local lowering of the NCAVS-S system air duct was carried out to a level of 1.95 m from the floor in the corridor of the 2nd floor in axes 201/1-201/2÷2E-2E/2;
- local lowering of the NCAVS-E system air duct was carried out to a level of 1.95 m from the floor in premise 302A;
- the air duct in C.A staircase is laid at a height of 1.91 m from the floor and 1.79 m from the stairs;
- CAVS-S-2 and CAVS-E-2 system air ducts in C.B staircase is laid at a height of 1.8 m from the floor;
- NCAVS-4 system air duct in C.B staircase at the level of +2,800 is laid at a height of 1.85 m from the floor.

After laying air ducts, the remaining holes are filled with cement-sand mortar.

According to DBN V.2.5-67:2013, para. 11.4 [132], interlock of the ventilation systems with fire alarm systems is provided for their automatic disconnection during a fire (except for the systems that provide air supply to the staircases and fire protection airlocks).

The ventilation systems are actuated and monitored from the central control and management panel (CCMP) or from local control panels, depending on the purpose of the system.

The following scope of automation and control of the heating and ventilation systems is envisaged in terms of the fire safety requirements:

- actuation of standby equipment when the main one fails;
- shutdown of the ventilation systems in case of fire;
- actuation of the smoke protection systems.

5.3.4 Licensee's experience in applying the fire protection concept

ISF-2 operation was started on 07 June 2021 on the basis of the received SNRIU license No. EO 001091 for the right to carry out activities at the life cycle stage “operation of a nuclear installation - dry spent fuel storage facility (ISF-2). In order to evaluate the adequacy, effectiveness and reliability of fire protection equipment, more operating time of a given facility is required. ISF-2 fire safety of is ensured by the fire prevention and fire protection subsystems, including administrative and technical measures. The specificity of ISF-2 fire safety is that the fire safety systems of the facility are addressed and should ensure first of all the radiation and nuclear safety of the facility. The designed fire safety system for ISF-2 performs the functions of fire prevention and fire protection.

Fire prevention is achieved by preventing generation of combustible environment and preventing generation of an ignition source in the combustible environment (or entering into it).

Measures to ensure ISF-2 fire safety are developed in accordance with the fire safety regulations, as well as based on the fire hazard assessment of substances, technological processes, materials, products, buildings and structures.

These measures include a set of forces and means, as well as legal, administrative, scientific, technical, economic and social measures aimed at fire suppression.

The measures are aimed at preventing fire, ensuring the facility safety and protecting personnel and equipment in case of fire. Fire protection materials and equipment are certified in the UkrSEPRO Certification System by the State Certification Center of the SESU.

The operational fire extinguishing plan for ISF-2 operation has been developed [134], which contains the following information:

- operational and tactical characteristics;
- number and types of necessary fire rescue equipment and firefighting means;
- arrangement of forces and means;
- locations of water sources and their characteristics;
- operating procedure for the fire and rescue units;
- necessary graphic materials.

The operational fire extinguishing plan was drawn up in two copies, one copy of which is stored in the fire and rescue unit, and the second is in the premises of the ISF-2 shift supervisor.

During hot work (gas welding, gas cutting, electric welding, heating (boiling) of bitumen and resins), painting, activities with mastics, adhesives and other flammable materials, ISF-2 personnel are guided by the requirements of the relevant sections in NAPB B. .01.014-2007 [29], Fire Safety Rules for the Operation of Nuclear Power Plants and Instructions on ChNPP Fire Safety Measures (22E-S).

In case of fire, officials take measures to immediately call fire and rescue units, inform immediate supervisor on fire, arrange extinguishing with primary fire suppression equipment and evacuate personnel. They ensure gathering of ISF-2 personnel according to the established evacuation schemes.

ISF-2 personnel and persons responsible for fire safety should pass special fire safety exercises in accordance with the Provision on the Procedure for Training and Knowledge Examination of ChNPP Workers on Labor Protection, Fire Safety, Civil Protection and Emergency Actions, Radiation Safety, and Technical Operation Rules (13P-S). ISF-2 personnel take part in fire protection exercises at least once a year (arranging evacuation, using fire extinguishers, etc.) for skill development related to activities during a fire. Exercises related to activities in case of fire are carried out with all ISF-2 personnel in accordance with the requirements of the Instructions for Emergency and Fire Exercises at ChNPP (31E-S) [43]. Responsibilities regarding fire safety of authorized persons and personnel are established in the relevant job descriptions.

Training, knowledge examination and instructions on fire safety are arranged and conducted in accordance with the requirements of the Provision on the Procedure for Training and Knowledge Examination of ChNPP Workers on Labor Protection, Fire Safety, Civil Protection and Emergency Actions, Radiation Safety, and Technical Operation Rules (13P-S).

Periodic inspections of technical condition of the fire protection engineering systems and process equipment are carried out in the buildings, structures, premises and at ISF-2 site in compliance with the schedule approved according to the established procedure. Scheduled outage of the fire protection engineering systems and process equipment is carried out in compliance with the schedule approved according to the established procedure, taking into account manufacturers' recommendations.

The buildings and structures on the ISF-2 territory are marked with safety signs in accordance with NAPB B.01.014-2007 [29], Fire Safety Rules for the Operation of Nuclear Power Plants. Safety signs meet the requirements of DSTU ISO 6309:2007 [VII].

The ISF-2 site is systematically cleaned of any vegetation that may have a certain fire load.

5.3.5 Regulator's assessment of the fire protection concept and conclusions

The concept of fire protection is the subject of assessment and oversight of the SNRIU as one of the areas for ensuring the safety of spent nuclear fuel storage facilities. The SNRIU monitors the implementation of the fire protection concept at ISF-2 within the framework of the following processes:

- RNPP comprehensive safety assessment during the state NRS review of the ISF-2 safety analysis report;
- regulatory assessment of modifications to the structures, systems and components important to safety, including those related to the implementation of the fire protection concept;
- considering the statements of the operating organization and relevant safety justifications in order to issue authorizing documents.

During the state oversight, the fire safety and the implementation state of measures to improve fire safety is one of the areas of comprehensive inspections carried out periodically by the SNRIU on a scheduled basis.

The results of regulatory control of the fire protection concept indicate that the fire protection concept implemented in ISF-2 generally complies with the nuclear and radiation safety standards and fire safety regulations.

VI. GENERAL ASSESSMENT AND GENERAL CONCLUSIONS

The main objectives of the Second Topical Peer Review (TPR II) process are to:

- enable participating countries to review their provisions for fire protection to identify strengths and weaknesses;
- undertake a European peer review to share operating experience and identify findings: common issues or challenges at EU-level, good practices, areas of good performance and areas for improvement;
- provide an open and transparent framework for participating countries to develop appropriate follow-up measures to address areas for improvement.

The National Assessment Report of Ukraine has been developed in line with the requirements for the structure and contents of national assessment reports presented in [□1].

According to the national selection of nuclear installations for the purposes of TPR II, PNPP Unit 1, RNPP Unis 2 and 3, VVR-M nuclear research reactor, and ISF-2 were identified as candidate installations and ZNPP Units 1-6, RNPP Units 1 and 4, KhNPP Units 1 and 2, PNPP Units 2 and 3, and CSFSF were identified as represented installations.

The national assessment has demonstrated the following:

1. Fire safety of nuclear installations is an integral part of nuclear and radiation safety of nuclear installations in Ukraine.

2. The Ukrainian legislation pays special attention to fire safety of nuclear installations. The requirements of regulations and standards on nuclear and radiation safety and fire safety were developed considering operating experience, conclusions from safety analysis of operating nuclear facilities, experience in the use of nuclear energy in Ukraine and other countries, recommendations of international organizations, and information on scientific and technical advances in nuclear energy and are revised on a systematic basis. In order to improve the legislative framework on nuclear and radiation safety, including fire safety of nuclear installations, the SNRIU takes measures to revise:

- NP 306.2.141-2008 “General Safety Provisions for Nuclear Power Plants”;
- NP 306.2.105-2004 “General Safety Provisions for Interim Dry Spent Fuel Storage Facilities”;
- OPB IR “General Safety Provisions for Research Reactors in Design, Construction and Operation”.

3. Fire safety analysis is performed by the operating organization on a systematic basis, The methodology and scope of the analysis generally comply with the requirements of Ukrainian legislation and takes into account recommendations of international organizations such as the IAEA and WENRA.

4. The fire protection concept for nuclear installations is implemented using the defense-in-depth principle, which involves organizational and technical measures to protect human life and health, prevent, detect, extinguish, confine, and mitigate fires, minimize potential consequences, and promote conditions for effective work of fire rescue units.

5. The results of the fire safety analysis and implementation of the fire protection concept for nuclear installations are subject to state oversight conducted by the SNRIU through state nuclear and radiation safety reviews of safety justifications for nuclear installations and through inspections and surveys of nuclear installations.

6. Measures to improve fire protection developed on the basis of operating experience, recommendations of international organizations, findings of inspections and surveys, and introduction of new safety requirements are implemented by the operating organizations considering their impact on safety within the timeframes agreed with the SNRIU.

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