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System of special water purification of spent fuel pool of Beloyarskaya Nuclear Power Plant unit BN-800

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Abstract. The problem of handling of nuclear power plants radioactive waste has a significant impact on the development of the nuclear industry. An effective strategy for radioactive nuclear waste should include all of the components and processing steps since waste formation to final disposal, taking into account emergence of new technologies, changes in the regulatory authority requirements, the duration of the time intervals separating the initial and the final stage of the treatment process [1]. After unloading from the reactor core spent fuel assemblies are placed in spent fuel pools for removing of residual heat and radioactivity decrease. After one year of conditioning radioactivity is reduced by about 10 times, after 5 years radioactivity is reduced by 35 times. After 3-5 years the spent fuel assemblies can be transported to a centralized storage facility or sent for processing. However, the maintaining of necessary conditions for temporary storage is an important task that is carried out by special water treatment systems of the spent fuel pool [2]. This article considers the water purification system of the spent fuel pool of the Beloyarskaya nuclear power plant, which is the flagship of Russian nuclear power industry.

Introduction

The current stage of the development of nuclear power engineering is characterized by an improvement of economical and operational characteristics of nuclear power plants and by an increasing of the safety of all power plant's systems [3]. Nuclear safety of NPP is associated usually with a reactor unit, but the safe operation of the plant involves the appropriate level of nuclear and radiation safety at all stages of the internal fuel cycle from the loading of fresh nuclear fuel into the core and until the irradiated fuel is removed from the plant's territory (when it is provided by the fuel cycle strategy) [4].

When the spent fuel assemblies are removed from the reactor, they are placed into the water that serves as a shield for radiation and as a cooler. Storage in pools is used only as a temporary solution until the place for final disposal is found. As an alternative to storage in pools some of the materials can be stored on the surface in concrete or steel containers, called "dry containers" [9]. This storage is also considered as temporary. Spent fuel assemblies recovered from the reactor core are stored in the spent fuel pool at the power plant for 5-10 years to reduce the heat release and for short-lived fission products decay [5]. This operation, which is mandatory for all nuclear power plants, completes the fuel cycle of the reactor [2].

Sources of radioactive waste generation

During the operation of nuclear power plant various radioactive waste are formed, among the others a large amount of liquid radioactive wastes, which include: low-salt radioactive liquid medium (e.g. water of spent fuel storage pool); liquid radioactive medium from the reactor compartment; liquid radioactive medium from active laundry.

The purposes of cleaning systems of radioactive medium are to protect the environment and to maintain safe and reliable operation of the spent fuel storage pool that is ensured by the correct water chemistry of spent fuel pool [6].

Special water purification system FAL-4 is designed to purify pool water in order to achieve and maintain required water chemistry for unit 4 of Beloyarskaya nuclear power plant. In this system the ion exchange method, which is the easiest in terms of circuit and equipment, is utilized, it has a purification factor of 10^2.

Technical description of the FAL-4 system

As noted above, the FAL-4 system is designed for cleaning spent fuel pool to ensure water transparency, reduce its activity and maintain required water chemistry while storing spent fuel assemblies. The system is designed for cleaning of 60 m^3/h of pool water in order to maintain the quality standards given in Table 1 and also to ensure the reception of 300 m^3 of water from one of the pool compartments when it is taken out for repair.

Table 1. Standards of water quality of the spent fuel pool at unit's work in the nominal mode

Characteristic	Value
Transparency with respect to demineralized water, %	95
pH value	5,6÷7,5
Electrical conductivity, not more than, μs/cm	5,0
Chloride content, not more than, μg/kg	100
Activity, not more than, BK/kg	$3,7\times10^3$

The system consists of mechanical filters, H-cation filters, OH-anion filters, discrete material catchers, pre-repair drain tank of spent fuel pool and its pumps, pipelines, shutoff, nonreturn and safety valves, instrumentation (see Fig .1).

To ensure the maintenance of required water chemistry for storage of spent fuel assemblies the pool water is regularly fed for purification by pool cooling system pumps. Passing in parallel through the mechanical filters the water is purified from mechanical impurities and enters the ion exchange filters: H-cation and OH-anion, where it is cleaned of dissolved impurities and radionuclides, and returns back to the spent fuel pool. The technical characteristics of the filters are shown in Table 2.

Table 2. Technical characteristics of filters

Characteristic	Mechanical filter	H-cationic filter	OH-anionite filter
Operating pressure, MPa	0,6	0,6	0,6
Operating temperature, °C	45	45	45
Productivity, m^3/h	30	60	60
Volume of filter material, m^3	1,8	2,7	2,7
Durability of ion exchangers, years	2	2	2

In the case of carry-over of ion-exchange material due to integrity violation of the drainage system of filters descrete material catchers are provided. The loading of filtering materials is carried out using a mobile hydraulic monitor.

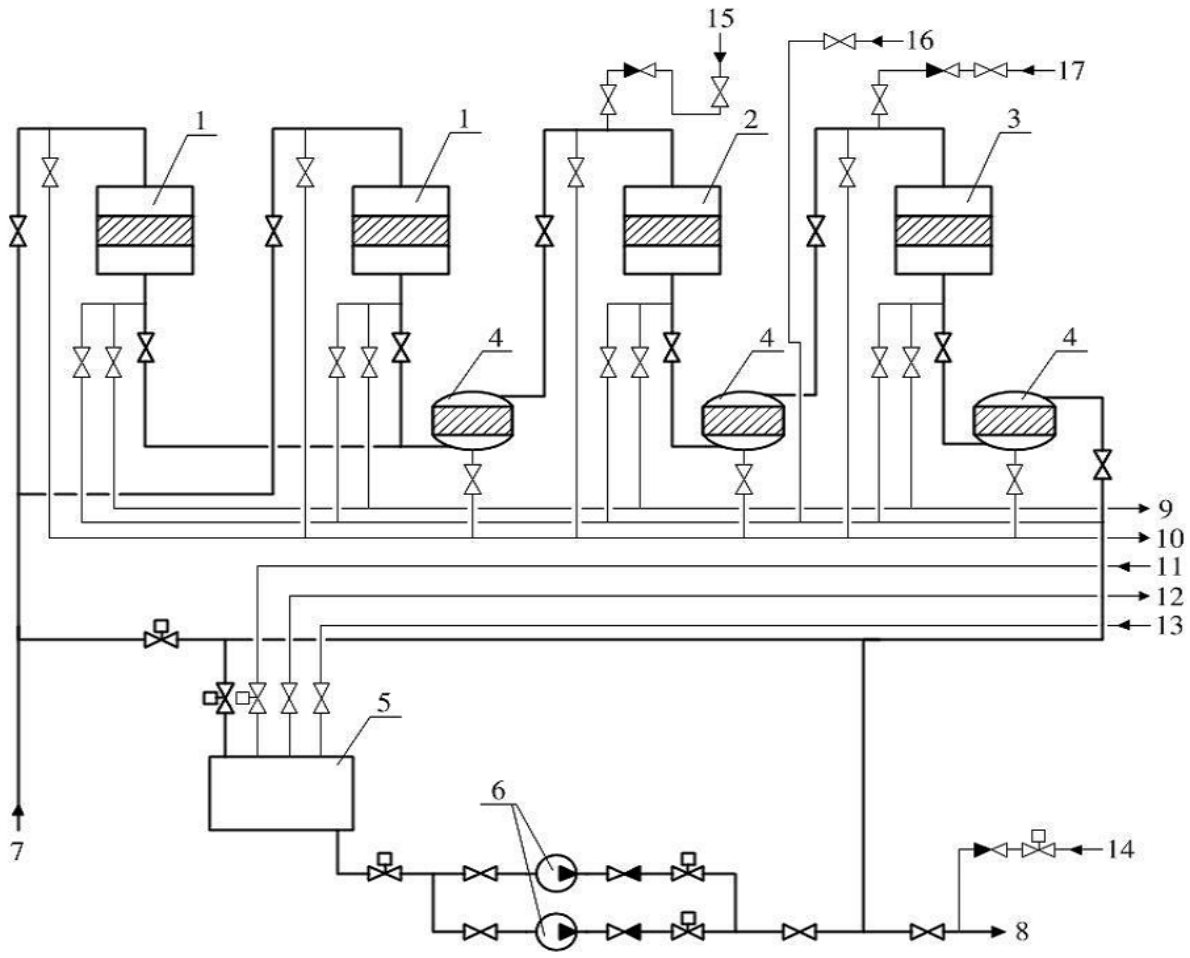

Figure 1. Technological diagram of special water purification of spent fuel pool:
1 – mechanical filter; 2 – H-cation filter; 3 – OH-cation filter; 4 – discrete material catcher;
5 – pre-repair drain tank of spent fuel pool; 6 – pre-repair drain tank of spent fuel pool pump; 7 – from spent fuel pool; 8 – to spent fuel pool; 9 – filter`s emptying to special drain; 10 – to LWR storage;
11 – from trap water filters; 12 – blowing off the tank to special gas treatment system;
13 – decontamination fluids; 14 – from water purification system; 15 – acid solution; 16 – alkali solution; 17 – water for auxiliary needs to filters.

In the case of taking one of the compartments of spent fuel pool out of service for repair, the water of the compartment to be disposed into the pre-repair drain tank of spent fuel pool. The water can be discharged into the tank through the cleaning system or bypassing it. After checking and confirming the required quality of water in the pre-repair drain tank the filling of the pool compartment after repair is carried out by the pre-repair drain tank pumps.

Apart it should be noted that in order to provide a long service life and high reliability of the equipment, fittings and pipelines when selecting their structural materials the influence of the following factors was taken into account: the influence of the chemical composition of the contacting media on the corrosive destruction of structural materials, working medium parameters (pressure, temperature), environmental parameters, as well as the practicability of the technology of manufacturing of equipment and pipelines without defects and in accordance with the requirements of technical conditions. Based on these factors, the main material used in the manufacture of equipment is austenitic stainless steel [7].

Features of the 4 FAL system operation

The equipment of the FAL-4 system is located in a special building. This system operates periodically when it is necessary to adjust the chemical parameters of spent fuel pool water. Prior to the start-up of the pool water treatment system, it is necessary to check the initial state of the system and its elements. Before switching on the filters must be loaded with sorbents, cleaned of small items; in its turn sorbents should be washed from regeneration solutions. While filters of FAL-4 system are operating, the following readings are inspected: flow of water to be cleaned, water temperature and pressure, pressure drop across the mechanical and H and OH filters, and the pressure drop across discrete material catchers.

The main indicators that determine the operational limits in the FAL-4 system are the maximum value of temperature of the spent fuel pool water, which is fed to the filters, the maximum value of the pressure drop across the operating filters, the minimum value of the pressure in the discharge manifold of the centrifugal pumps; the minimum value of the level in the pre-repair drain tank of spent fuel pool as well as its maximum value and of course the chemical parameters of water.

If the maximum temperature of water before the filters reaches more than 60 ℃ an alarm is triggered to automatically close the valve at the spent fuel pool water supply to the filters and open the valves on the bypass. The functioning of the FAL-4 system is stopped until the pool water temperature drops to the nominal value, thereby preventing the deterioration of the performance properties of the filter materials and the production of purified water of unsatisfactory quality. Similar interlocks up to the complete stopping of the system operation in the cleaning mode are triggered when the pressure rises above 0.1 MPa.

However, the most difficult is to adjust the parameters of the water chemistry. If the above mentioned parameters are rejected from the standardized values, the system filters should be removed from working and operations on backwashing and washing of the filters, regeneration of the filtering material and post-regeneration washing should be performed.

After backwashing the filtering material is regenerated with 5% HNO_3 solutions for filters loaded with cation exchangers and 5% NaOH for anionic once. Then it is necessary to perform post-regeneration washing with water for auxiliary needs. Discharge of regeneration and washing water is carried out through the drain collector, which is disconnected from the system of special canalization and switched to the collector of hydraulic discharge into the tank of medium-radioactive sorbents. As a result of the regeneration, the dynamic exchange capacity of the filter media is restored, the washed filters can be put into operation and the functioning of the system can continue.

It should be noted that when the resource of the sorbent is exhausted and if it is not possible to restore the dynamic exchange capacity of the filter during regeneration, the filter load is hydraulically discharged to the medium-radioactive sorbent tank and the filters are loaded with fresh sorbent using hydrotransport [8].

The factors that may result in malfunction of FAL-4 system are failures of pre-repair drain tank of spent fuel pool pump, depressurization of the tank, violation of the integrity of the drainage system of the filters and de-energization of the system.

The system provides redundancy of the pumping equipment and manual duplication of the electric drives of the shutoff valves, therefore, the failure of the active elements does not lead to the failure of the system's functions.

Conclusion

The control system of FAL-4 special water purification system provides high operation stability and serves to protect the system during operation irregularities and in emergency situations. All components, as well as the system itself, belong to the class of repairable, recoverable items. The service life of the system is 40 years.

The technical and organizational decisions taken to ensure the safety of the operation of the FAL-4 system have been approved by previous design experience, testing, research, and confirmed by the operating experience of such systems at Russian NPPs [9].

The water purification system of the spent fuel pool meets the principles and criteria of radiation safety, prescriptions and rules in the field of nuclear energy.

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