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Assessing Air Pollution from Nuclear Power Plants

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Abstract. *The main sources of radioactivity inside a typical nuclear power plant are analyzed. The paper presents the results of case study research of the environmental pollution near the Khmelnytskyi nuclear power plant in Ukraine. Concentrations of radionuclides in air emissions are measured: the largest concentrations are found for Nitrogen-16, Argon-41, Krypton-83m, Xenon-131m, and Tritium. Concentrations of harmful non-radioactive chemicals in the air are found to be below the permissible limit except nitrogen dioxide.*

Keywords: Air Pollution, Nuclear Power Plant, Environment, Radionuclide, Emission

1. Introduction

Reliable electricity sources are indispensable in modern society [1]. The main source of electricity in most countries are thermal power plants. There are many efforts devoted to their improvement [2, 3]. However, their operation is accompanied by many ecological issues. That is why for many countries nuclear power is the priority electricity source. At the same time, nuclear power plants operation results in some kind of environmental pollution as any other manufacture [4]. During the operation of nuclear power plants, gaseous, solid and liquid emissions appear. Usually, they contain radioactive elements [5]. The energy development strategies of many countries include erecting new nuclear power plants. For example, units with a total capacity of 20-22 GW are planned in Ukraine. Similar programs are accepted in such countries as China, India, USA, and Russia. This is the question of energetic safety and independence from electricity import. However, what is the price? Which are the environmental risks? Many investigations show some level of air pollution by radionuclides from nuclear power plants. The danger also exists due to the dissemination of this pollution over big areas. Such pollution was modelled for the Fukushima nuclear power plant in [6], [7]. Morino et al. [8] indicated that approximately 13% of iodine-131 and 22% of cesium-137 were disseminated over 700×700 km2 area after the Fukushima accident. Other authors [9]-[11] also reported about long transportation distances for radionuclides as a result of the operation of nuclear power plants. Besides, different environmental influences and human diseases as a result of air pollution from nuclear power plants are analyzed in [12]. Also, there are studies [13] on the role of nuclear power in protecting the global environment taking into account decreased gaseous emissions in comparison to other energy sources.

2. Materials and Methods

The air pollution with radionuclides from one of the Ukrainian power plants was assessed. The research was carried out in the chemical laboratory of the Department of Environmental Protection at the Khmelnytskyi nuclear power plant (Netishyn, Ukraine). The analysis of air pollution over the territory around the power plant was carried out using high-altitude radio-sensing of the atmosphere at Shepetivka research station – the nearest to the Khmelnytskyi

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nuclear power plant. The content of radionuclides in the emissions from the turbine condenser ejectors of all energy units was measured.

3. Results of the Study

The Sources of Radioactive Emission of the Nuclear Power Plant

In general, the main sources of radioactivity inside a typical nuclear power plant include products of nuclear fuel decomposition, products of constructions corrosion and activation products. Under normal conditions of nuclear power plant operation, any emission out of the nuclear fuel elements or partial destruction of the coverage of nuclear fuel elements results in transportation of some products of the radioactive decay into the heat carrier. Tritium in the heat carrier of the primary circuit is an important component of activation products. Tritium is a radioactive isotope of hydrogen with a half-life of 12.34 years. In nuclear power plant reactor, tritium is formed due to: directly during the fission of nuclei in the fuel; as a result of the neutron interaction with deuterium nuclei; as a result of various reactions of fast neutrons with constructions of the reactor core; as a result of boric acid activation in the heat carrier of the primary circuit. The emission of tritium from the water of the first circuit may occur due to the following: leakages; outflows of the water from the first circuit into the water tanks. The dissolved products of fission and activation are derived from the heat carrier due to the ion exchange processes resulting in the contaminated ion-exchange resin formation at special water treatment equipment. As a result of the periodic replacement of these resins, both liquid and solid radioactive waste are generated. Leakages from the steam generator of the primary circuit to the secondary circuit lead to radioactive contamination of water in the secondary circuit. The gases accumulated in the primary circuit during the operation are taken out from this circuit. This leads to gaseous emissions. Such emissions usually include tritium water vapor, noble gases, aerosols, and other gaseous substances. During the annual reactor shutdown, the cooling system pressure drop is carried out. The reactor lid is removed, and some fuel elements are moved to the storage pool. When extracting spent fuel, liquid radioactive waste and air emissions may be released from the storage pool, construction revision mine, and mine of revision of protective pipes. The main sources of radioactive aerosol emissions into the atmosphere are as follows: ventilation tubes of the reactor room, the height of emission is over 100 m; turbine ejector. Aerosols contain long-lived radionuclides with over 3-hour half-life and short-lived radionuclides with less than 3-hour half-life. The half-life determines the time and the level of possible effects on the human. The intake of radioactive substances related to aerosols comes with water, air, and food. The data on radioactive emissions from the Khmelnytskyi nuclear power plant are presented in Table 1. Suspended aerosol substances in the air may also appear due to the dust and ash transfer. Their concentrations in the air depend on the Earth surface type and the wind. The highest concentrations of suspended particles in the air near the Khmelnytskyi power plant were 3.4–7.7 mg/m3 (Netishyn, 4 km to the north from the plant) and 1.65 mg/m3 (Komarivka, 5 km to the east from the plant).

Other (Non-Radioactive) Emissions of the Nuclear Power Plant

The sources of non-radioactive emissions to the atmosphere include objects and equipment, where technological processes are accompanied by the release of harmful gaseous substances. At the Khmelnytskyi nuclear power plant, 85-90% of chemical air emissions are related to the boiler room. Emissions from other equipment are relatively low due to the low capacity and gas treatment devices. Concentrations of harmful chemicals in the surface air around the Khmelnytskyi nuclear power plant are presented in Table 2.

Table 1. Average annual emissions of radionuclides from ventilation tubes of the Khmelnytskyi nuclear power plant, 2010-2015.

Isotope	Half-life time	Emission [Ci/day]	Isotope	Half-life time	Emission [Ci/day]
Tritium	12,33 y	3,22E-01	Zirconium-95	64,02 d	4,76E-07
Carbon-14	5730 y	1, 12E-07	Niobium-95m	3,61 d	8,04E-11
Nitrogen-16	7,13 s	2,14E+00	Molybdenum-99	66,02 h	5,88E-10
Nitrogen-17	4,17 s	2,98E-04	Niobium-101	7,1 s	3,04E-08
Sodium-24	14,97 h	3,34E-07	Technetium-101	14,2 m	9,84E-07
Argon-41	1,82 h	1,05E+00	Ruthenium-103	39,25 d	2,06E-09
Potassium-42	12,36 h	1,00E-05	Rhodium-103m	56,114 m	1,87E-07
Chrome-51	27,7 d	6,72E-08	Antimony-129	4,4 h	1,25E-08
Manganese-54	312,2 d	1,66E-09	Tellurium-129m	33,6 d	1,55E-10
Ferrum-55	2,68 y	2,34E-09	Tin-130	3,7 m	9,44E-08
Cobalt-60	5,27 h	4,68E-09	Iodine-131	8,01 d	1,91E-04
Selenium-83	22,4 m	2,76E-08	Xenon-131m	11,97 d	8,28E+00
Bromine-83	2,39 h	3,34E-06	Cesium-137	30,20 y	2,74E-06
Krypton-83m	1,83 h	2,66E+00	Barium-137 m	2,552 m	1,02E-05
Rubidium-88	17,8 m	7,96E-02	Lanthanum-141	3,92 h	2,14E-07
Strontium-89	50,62 d	3,68E-08	Cerium-143	33,0 h	2,36E-08
Ittree-90	64,26 h	4,12E-11	Praziodim-144m	7,2 m	1,62E-11

Table 2. The maximum concentrations of harmful chemicals in the surface air around the Khmelnytskyi nuclear power plant.

Compound	Limit, [mg/m^3]	Concentration at the border of the protecting area [mg/m^3]
sulfur dioxide	0.5	0.22
carbon monoxide	5	0.03
nitrogen dioxide	0.2	0.21
Ash	0.15	0.015
inorganic dust	0.3	0.05
sawdust	0.1	< 0.01
abrasive-metal dust	0.4	< 0.01
Toluene	0.6	< 0.05
butyl acetate	0.1	0.05

To protect the air from the harmful influence of the emissions, the monitoring of meteorological and aerial characteristics of the atmosphere is provided. These characteristics directly affect the dissemination of radionuclides. Some climate factors reduce the natural self-cleaning mechanism of the atmosphere and contribute to the accumulation of chemicals in the air. These factors include: the direction and speed of wind; temperature stratification of the atmosphere; regime of clouds, precipitation, fogs, probability of meteorological phenomena appearance.

4. Conclusions

Nuclear power plants have air emissions from the main and auxiliary facilities. These emissions contain radionuclides and non-radioactive chemicals, causing harmful effects on the environment. Most gas emission sources operate periodically. Therefore, the total emission is relatively small. The concentrations of chemical compounds in the air around the Khmelnytskyi nuclear power plant are below the permissible limits. Only nitrogen dioxide has minor exceeding. The largest concentrations of radionuclides are found for Nitrogen-16, Argon-41, Krypton-83m, Xenon-131m, and Tritium. For the case of an accident, people living in the area near nuclear power plants (where air pollution may occur) should be familiar with the rules of behavior in emergency situations. Despite the low level of air pollution under normal conditions, the risks of nuclear power plant operation should be carefully assessed.

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