Comparative Assessment of the NPP Risk (on the Example of Rostov and Kalinin NPP). Development of Risk Indicators Atlas for Russian NPPs

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The object of the work is to compare and analyze external and internal exposure doses and assess damage to the population living around nuclear power plants with VVER-type reactors (on the Rostov and Kalinin nuclear power plants), within a certain radius, taking into account the wind rose. There will also be proposed measures for the possible addition and refinement of formulas. The method of calculating the doses of external and internal exposure, as well as damage to the population in the ring segment of rumba. External and internal exposure doses for Kalinin and Rostov NPPs have been considered. An assessment of material damage was conducted. A variant of the format of the atlas of risk assessments is proposed. Initial assumptions have been made regarding the discrepancy in the results obtained for both doses and damage. One of the possible reasons for the discrepancy in the results of calculating the dose and damage to the Kursk and Smolensk NPPs may be the difference in the terrain. We need to take this into account. By relief changes we mean not ravines and slopes, but hills, mountains, fields. Additionally, you can consider the type of terrain: steppes, forests, etc., although all this will contribute to the already quite a long distance from the nuclear power plant. In the future, it is planned to continue work on the atlas of risk assessments and think over its more convenient format.

Keywords*: Irradiation; dose; NPP; damage; population; safety data sheet; risk assessment atlas.*

1. Introduction

The accident at the Chernobyl nuclear power plant was an event of great social and political significance for the USSR. All this left a definite imprint on the course of the investigation of its causes. The approach to the interpretation of the facts and circumstances of the accident has changed over time, and there is still no complete consensus.

But still the most important thing is people. If we learn to accurately assess the damage that a nuclear power plant can cause in the first moments after the accident, we will significantly reduce the number of victims among the population. Comparative risk assessment in an accident at various NPPs gives an idea of the relationship between the amount of damage and external factors (location, climatic conditions, etc.), in this case, the wind rose.

This assessment is relevant, since all nuclear power plants are sources of potential danger. According to the Order of the EMERCOM of Russia of 04.11.2004 No. 506 [1], it is necessary to carry out work on risk assessment at relevant facilities. In this regard, the definition and comparison of the risk of an Emergency Accident (EA) at a nuclear power plant is a relevant topic.

According to Russian legislation (for example, [2]), the development of a facility safety data sheet is a prerequisite for the operation of such facilities as: hydraulic structures, organizations producing, processing, storing or transporting radioactive, fire and explosive, toxic chemical and biological substances (filling stations, thermal power plants, nuclear power plants, industrial enterprises, etc.), as well as those characterized by an increased risk of terrorist actions (crowded places).

This work is based on the study, further comparison and analysis of the estimates obtained in the calculations for two NPPs: Kalinin and Rostov. A comparative assessment has not previously been carried out, but it will help to understand what factors play a key role in the event of an accident. In this connection, two similar nuclear power plants were chosen: Kalinin and Rostov. They are of the same type and can give us a complete Figure for evaluation.

Rostov NPP is located in the Rostov region, 12 km from the city of Volgodonsk on the bank of the Tsimlyansk reservoir.

The electrical capacity of the four existing power units is 4.03 GW.

Kalinin NPP is located in the north of the Tver region, 120 km from the city of Tver. Distance to Moscow - 360 km, to St. Petersburg - 320 km. The NPP site is located on the southern shore of Lake Udomlya and near the city of the same name. The total area occupied by KAES is 287.37 hectares.

The electrical power of the four operating units is 4 GW.

2. Materials and methods

Comparative assessment of risk indicators will be made based on the formulas proposed in [6]. Damage to one person living in the ring segment of rumba:

$$L(R) = \frac{L_\Sigma}{N_\Sigma} \cdot \frac{\int_0^R D_E(r) \cdot N_{\frac{1}{8}}(r) \cdot dr}{D_{E(year)}}, \quad (1)$$

where: L – damage to the population in the rumba ring segment;
R, r – distance from NPP;
L_Σ – total damage from an accident;
N_Σ – total population;
D_E – annual effective radiation dose of the population in the ring segment of rumba, considering the wind rose;
$N_{1/8}$ – number of people in rumba;
$D_{E(year)}$ – annual effective dose to the entire population.

Risk:

$$R = \sum_{i=1}^{n} k \cdot F_i \cdot D_i < R_a, \quad (2)$$

where: Ra - risk acceptable, 1/year;
F - probability (frequency) of dangerous situations;
D - the level of the corresponding dangerous effects on people;
k - coefficient linking the probability (frequency) of death to people with dangerous effects (5,6·10-2 1 / Sv in accordance with [6]).

The annual effective radiation dose of the population in the ring segment of rumba, taking into consideration the wind rose:

$$D_E(R) = P_W \cdot \sum_{i=1}^{k} N_{\frac{1}{8}(i)} \cdot D_{E(year)(i)}, \quad (3)$$

where: DE – annual effective radiation dose of the population in the ring segment of rumba, considering the wind rose;
R – distance from NPP;
P_W – wind direction probability;
$N_{1/8}$ – number of people in rumba;

$D_{E(year)}$ – annual effective dose to the entire population.

3. Literature Review

We have an opportunity to work with the whole point, but priority is given to the directions with the highest probability of the wind. For Rostov NPP: East direction (probability 0.2). For Kalinin NPP: South-West direction (probability 0.18).

Let us calculate the annual effective radiation dose for the Rostov NPP (mSv). The baseline data and the results of calculating the annual effective radiation dose for the Rostov NPP are presented in Table. 1 [7].

Table 1. Baseline data and the results of calculating the annual effective radiation dose of the population for the Rostov NPP

R	P_w	$N_{1/8(i)}$	$D_{E(year)(i)}$	D_E
3	0,2	0	0	0
10	0,2	860	10,5	1806
15	0,2	0	1,91	0
20	0,2	620	1,04	128
30	0,2	512	0,6	61
40	0,2	1044	0,32	66
50	0,2	1342	0,2	54
100	0,2	11186	0,1	234

Let us calculate the annual effective radiation dose of the population for Kalinin NPP (mSv). The baseline data and the results of calculating the annual effective radiation dose for the population of Kalinin NPP are presented in Table 2 [7].

Table 2. Baseline data and the results of calculating the annual effective radiation dose for the population of Kalinin NPP

R	P_w	$N_{1/8(i)}$	$D_{E(year)(i)}$	D_E
3	0,18	16158	34	*98887*
10	0,18	318	13	744
15	0,18	230	4,6	190
20	0,18	598	2,4	258
30	0,18	363	1	65
40	0,18	26349	1	4742
50	0,18	52342	0,61	5747
100	0,18	26511	0,21	1002

It can be seen that the radiation dose for Kalinin NPP is significantly higher than for Rostov. Firstly, this is due, of course, to the number of people who live around the NPP data. If we look at the data for the Kalinin NPP, we note that from the direction of the most possible wind direction at a distance of 3 km from the NPP there is a very large number of people: 16158 people. As for the Rostov NPP, no one lives from the direction of the most possible wind direction at a distance of 3 km from the NPP. Secondly, Kalininskaya and Rostov NPP have approximately the same values for DE (year), but there is a rather large difference in the relief, which can lead to completely different consequences. Most of the territory of the Rostov NPP has a flat and flat relief character. Agricultural production predominates in this area. Arable land is crossed by forest belts of 15-20 m, planted mainly by forest forest strata. Rostov NPP is located in the continental climate zone, with insufficient moisture, hot and dry summers, and relatively long and cold winters. A distinctive feature of the climate is the abundance of sun and heat. Unlike the relief of the territory of the Rostov NPP [7], the territory of the Kalinin NPP has a dissected relief, the prevalence of absolute heights and small relief forms. In the middle part of the region, from the southwest to the northeast, there are uplifts of the Forest Ridge, which is a spur of the Valdai Upland [7]. The forest ridge is divided by two large zandrovaya plains: in the east - Srednemozhskaya nisin with absolute heights of 130-140 m, in the west and south - Vyshnevolotskaya nisin with heights of 150-180 m [4, 5, 9-11].

In more detail this issue will be considered later.

4. Comparative damage assessment for Kalinin and Rostov NPPs

For damage assessment, as well as for comparative assessment of external and internal exposure doses, we will consider the most dangerous accident. These data additionally give an idea of the situation around the Kalinin and Rostov NPPs.

The calculation will be made by the formula (1). As can be seen from the formula, we will need the data obtained earlier in the calculation of doses using formula (3) and presented in Table 1 and 2 [7].

Immediately, we note that the damage for Kalinin NPP, presented in [5], is significantly higher than for Rostov [4], which partially confirms our formula and conclusions made on the basis of a comparative assessment for doses of external and internal exposure.

First, perform the calculations for the Rostov NPP.

L (for the Rostov NPP at a distance of 10, 30 and 100 km from the NPP):

L(10) = 0,04 million rubles

L(30) = 0,84 million rubles

L(100) = 5,87 million rubles

L (for Kalinin NPP at a distance of 10, 30 and 100 km from the NPP):

L(10) = 7,66 million rubles

L(30) = 100,14 million rubles

L(100) = 531, 59 million rubles

Again, we get an excess of the Kalinin NPP. This excess has a logical explanation. The population is one of the main indicators for damage. Since the main costs fall on the people and property that these people possess. Of course, errors are permissible, since For the Kalinin and Rostov nuclear power plants, calculations were made taking into account the most probable wind direction, but these errors do not change the overall Figure.

5. Formation risk indicators assessments atlas of Russian NPP units

Calculation of damage to the population in the ring segment of rumba, as a result of exposure to radioactive substances, was carried out according to formula (1) [6-11].

The calculation of the annual effective radiation dose of the population in the ring segment of rumba, taking into account the wind rose, was carried out according to the formula (3) [6-11].

In [10], an example of an atlas format of risk indicator estimates is proposed.

For power units with RBMK-1000 type reactors (Kursk and Smolensk NPP) - Table. 3-14, fig. 1-6.

Table 3. Indicators of radiation risk for the population from accidents at the Kursk NPP

Average individual effective dose for population Ei, Sv	Individual risk of death of the population (long-term effects) rc, (for 1 accident)	Individual risk of the population death rci, 1/year (considering EA frequency)
$2.5 \cdot 10^{-4}$	$1.25 \cdot 10^{-5}$	$8.75 \cdot 10^{-13}$

Table 4. Indicators of the economic risk to the population from accidents at the Kursk NPP

Population, people	Collective dose for population, people · Sv	Damage to the population, mln. rub.
1 365 132	339	102

Table 5. Probability of the direction of propagation of radioactive substances in the cardinal directions at the Kursk NPP

Rumb	Wind direction repeatability, %
North	5,5
Northeast	4,9

Rumb	Wind direction repeatability, %
East	16,5
Southeast	9,1
South	15,9
Southwest	10,4
West	28,7
Northwest	9
Total	100

Figure 1 is a diagram of the frequency of wind direction at the Kursk NPP [10].

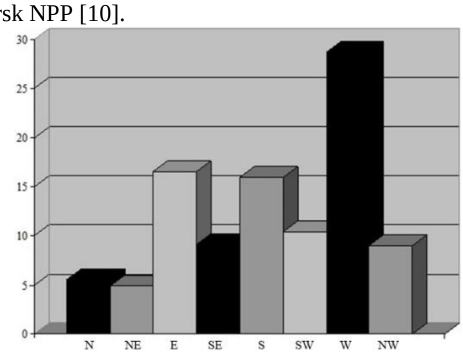

Figure 1. Diagram of the frequency of wind direction at the Kursk NPP

Table 6. Population distribution in the 100-km zone of the Kursk NPP

Rumb	Distance from NPP, km							
	3-5	5-10	10-15	15-20	20-30	30-40	40-50	50-100
North	467	224	184	755	1 661	7 700	9 880	82 432
Northeast	–	636	600	2 303	4 853	7 700	9 880	82 432
East	–	2 471	941	1 953	20 631	7 700	408 000	82 432
Southeast	46 500	120	649	3 114	5 695	7 700	9 880	82 432
South	–	3346	321	1 260	1 352	7 700	9 880	82 432
Southwest	–	10 552	371	2 010	6 900	7 700	9 880	82 432
West	–	435	330	1 303	29 779	7 700	9 880	82 432
Northwest	685	124	238	1 808	12 345	7 700	9 880	82 432
Total	47 652	17 908	3 634	14 506	83 216	61 600	477 160	659 456
TOTAL	1 365 132							

Table 7. The results of the calculation of the annual effective radiation dose of one person and the entire population living in the ring segment of rumba, taking into account the wind rose, at a distance of 3-30 km from the nuclear power plant for Kursk NPP with an RBMK-1000 type reactor

Rumb	Annual effective dose of one person taking into account wind rose (Sv)	Number of people	Collective radiation dose of the population in the ring segment of rumba (man-Sv)
3-10 km			
South	$2.3\cdot10^{-4}$	3346	0.76
Southwest	$2.0\cdot10^{-4}$	10552	2.14
West	$6.8\cdot10^{-4}$	435	0.30
Northwest	$3.8\cdot10^{-4}$	809	0.30
North	$6.6\cdot10^{-4}$	691	0.45
Northeast	$4.3\cdot10^{-4}$	636	0.27
East	$1.2\cdot10^{-3}$	2471	2.93
Southeast	$3.7\cdot10^{-4}$	46620	17.34
10-15 km			
South	$3.0\cdot10^{-5}$	321	0.01
Southwest	$2.0\cdot10^{-5}$	371	0.01
West	$8\cdot10^{-5}$	330	0.02
Northwest	$4\cdot10^{-5}$	238	0.01
North	$7\cdot10^{-5}$	184	0.01
Northeast	$5\cdot10^{-5}$	600	0.03
East	$1.3\cdot10^{-4}$	941	0.12
Southeast	$4\cdot10^{-5}$	649	0.03
15-20 km			
South	10^{-5}	1260	0.02
Southwest	10^{-5}	2010	0.02
West	$4\cdot10^{-5}$	1303	0.05
Northwest	$2\cdot10^{-5}$	1808	0.04
North	$4\cdot10^{-5}$	755	0.03
Northeast	$3\cdot10^{-5}$	2303	0.06
East	$7\cdot10^{-5}$	1953	0.14
Southeast	$2\cdot10^{-5}$	3114	0.07
20-30 km			
South	10^{-5}	1352	0.01
Southwest	10^{-5}	6900	0.05
West	$2\cdot10^{-5}$	29779	0.72
Northwest	10^{-5}	12345	0.17
North	$2\cdot10^{-5}$	1661	0.04
Northeast	$2\cdot10^{-5}$	4853	0.07
East	$4\cdot10^{-5}$	20631	0.87
Southeast	10^{-5}	5695	0.08

Figure 2 shows a graphical representation of the results of calculating the annual effective doses of exposure of one person and the entire population living in the ring segment of rumba, taking into account the wind rose, for Kursk NPP [10].

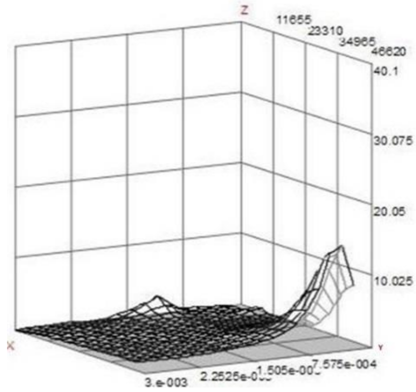

Figure 2. Graphic representation of the results of calculating the annual effective doses of exposure to one person and the entire population living in the ring segment of rumba, taking into account the wind rose, for the Kursk NPP

Table 8. The results of the calculation of damage to one person living in the ring segment of rumba, at a distance of 3-30 km from the nuclear power plant for Kursk NPP

Rumb	Number of people	Damage to one person in the ring segment of rumba, rub.
3-10 km		
South	3346	2.7
Southwest	10552	2.4
West	435	8.2
Northwest	809	4.5
North	691	7.9
Northeast	636	5.2
East	2471	14
Southeast	46620	4.5
10-15 km		
South	321	2.7
Southwest	371	2.4
West	330	8.2
Northwest	238	4.5
North	184	7.9
Northeast	600	5.2
East	941	14
Southeast	649	4.5
15-20 km		
South	1260	2.8
Southwest	2010	2.4
West	1303	8.3
Northwest	1808	4.5
North	755	7.9
Northeast	2303	5.1
East	1953	14
Southeast	3114	4.5
20-30 km		
South	1352	2.7
Southwest	6900	2.4
West	29779	8.2
Northwest	12345	4.4
North	1661	7.8
Northeast	4853	5.1
East	20631	0.1
Southeast	5695	4.4

Figure 3 shows a graphical representation of the results of calculating the damage caused to one person and the entire population living in the ring segment of rumba, at a distance of 3-30 km from the NPP for Kursk NPP [10].

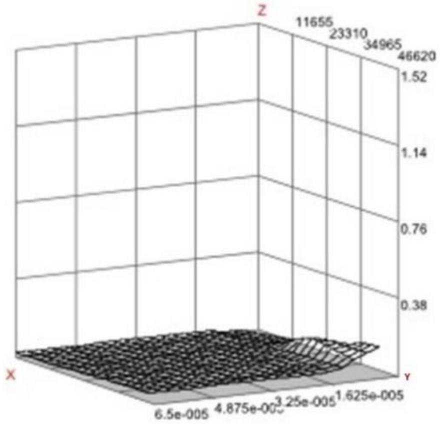

Figure 3. Graphic representation of the results of calculating the damage caused to one person and the entire population living in the ring segment of rumba, at a distance of 3-30 km from the NPP for Kursk NPP

Table 9. Indicators of radiation risk from accidents at Smolensk NPP

Average individual effective dose of the population Ei, Sv	Individual risk of death of the population (long-term effects) rc, (for 1 accident)	Individual risk of the population death rci, 1 / year (including EA frequency)
$1.3 \cdot 10^{-3}$	$6.4 \cdot 10^{-5}$	$4.5 \cdot 10^{-12}$

Table 10. Indicators of the economic risk from accidents at Smolensk NPP

Population	Collective dose of the population, people · Sv	Damage to the population, mln. rub.
257 412	330	99

Figure 4 is a diagram of the frequency of wind direction at Smolensk NPP [10].

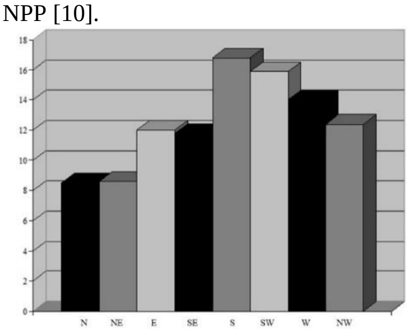

Figure 4. Diagram of the frequency of wind direction at Smolensk NPP

Figure 5 shows a graphical representation of the results of calculating the annual effective doses of exposure to one person and the entire population living in the ring segment of rumba, taking into account the wind rose, for the second stage of the Smolensk NPP [10].

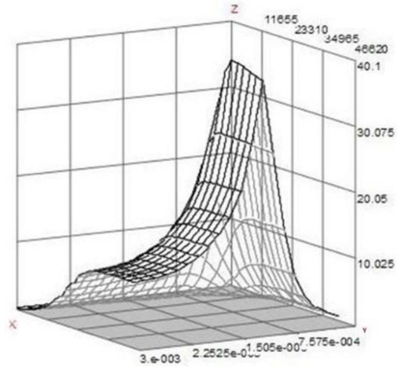

Figure 5. A graphic representation of the results of calculating the annual effective radiation doses of one person and the entire population living in the ring segment of rumba, taking into account the wind rose, for Smolensk NPP

Table 11. The results of the calculation of damage to one person living in the ring segment of rumba, at a distance of 3-30 km from the nuclear power plant for Smolensk NPP

Rumb	Number of people	Damage to one person in the ring segment of rumba, mln. rub.
3-10 km		
South	0	0
Southwest	0	0
West	0	0
Northwest	0	0
North	0	0
Northeast	0	0
East	0	0
Southeast	33000	$4.6 \cdot 10^{-5}$
10-15 km		
South	294	$3.3 \cdot 10^{-5}$
Southwest	294	$3.3 \cdot 10^{-5}$
West	294	$4.6 \cdot 10^{-5}$
Northwest	294	$4.6 \cdot 10^{-5}$
North	294	$6.3 \cdot 10^{-5}$
Northeast	294	$6.0 \cdot 10^{-5}$
East	294	$5.3 \cdot 10^{-5}$
Southeast	294	$4.9 \cdot 10^{-5}$
15-20 km		
South	412	$3.3 \cdot 10^{-5}$
Southwest	412	$3.3 \cdot 10^{-5}$
West	412	$4.6 \cdot 10^{-5}$
Northwest	412	$4.6 \cdot 10^{-5}$
North	412	$6.5 \cdot 10^{-5}$
Northeast	412	$6.1 \cdot 10^{-5}$
East	412	$5.4 \cdot 10^{-5}$
Southeast	412	$4.8 \cdot 10^{-5}$
20-30 km		
South	1176	$3.3 \cdot 10^{-5}$
Southwest	1176	$3.3 \cdot 10^{-5}$
West	1176	$4.6 \cdot 10^{-5}$
Northwest	1176	$4.6 \cdot 10^{-5}$
North	1176	$6.5 \cdot 10^{-5}$
Northeast	1176	$6.2 \cdot 10^{-5}$
East	1176	$5.4 \cdot 10^{-5}$
Southeast	1176	$4.7 \cdot 10^{-5}$

Figure 6 shows a graphical representation of the results of calculating the damage caused to one person and the entire population living in the ring segment of rumba, at a distance of 3-30 km from the NPP for Smolensk NPP [10].

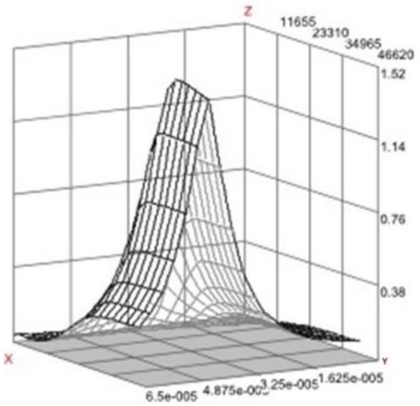

Figure 6. Graphic representation of the results of calculating the damage caused to one person and the entire population living in the ring segment of rumba, at a distance of 3-30 km from the NPP for Smolensk NPP

6. Results

At present, external and internal exposure doses for Kalinin and Rostov NPPs have been considered. An assessment of material damage was conducted. A variant of the format of the atlas of risk assessments is proposed. Initial assumptions have been made regarding the discrepancy in the results obtained for both doses and damage.

7. Thanks

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