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*Physics*

# AZIMUTHS RADIATION RISK DEGREE APPRAISAL FOR THE POPULATION LIVING IN AREA OF THE NUCLEAR POWER PLANTS LOCATION

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The data of radioactive emission from the Armenian NPP in atmosphere in a mode of normal operation and in emergency situations are presented.

The technique of the azimuths (sectors) radiation risk calculation for the population, living in area of nuclear power plants location, is proposed. The values of azimuths radiation risk for area of the Armenian NPP location are calculated. The analysis of the obtained values is carried out.

The azimuths, most significant from the point of view of radiation monitoring organization in area of the Armenian NPP location are determined, as well as concentration of forces and means for the population protection in case of possible accidents.

***Keywords***: monitoring, emission, radiation, protection, accident, azimuth.

The nuclear power plants (NPP) in a mode of normal operation do not represent danger for the population and an environment. Long-term operation of the NPPs in different countries has shown that radioactive emissions from the plants, working in a normal mode, are much less than the admissible values, noted in regulations, and do not represent danger for the population and an environment. For example, data on emissions of radioactive aerosols during the operation period of the Armenian NPP are presented in Table 1.

However the sad experience of accidents on nuclear power plants «Three-Mile-Island», at other stations and, especially, at Chernobyl NPP has shown that radiation consequences of major accidents represent a great danger to the population and an environment. In the case of the over-project accidents the uncontrollable emission of radioactive substances can become the reason of formation of the population irradiation great dozes, much exceeding the normative values.

The Russian Centre of science «Kurchatov Institute» has modeled and performed the calculations of emissions of radioactive substances and irradiation dozes of the population, living in area of nuclear power plants with reactors

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PWR-440 (B-270) accommodation, for the various over-project accidents [1]. Some results of calculations are represented in Tables 2 and 3.

*Table 1*

*The nuclide composition (the basic nuclides) and values of emissions during the operation period of the Armenian nuclear power plant [$10^7$ Bq/year]*

| Year of operation | The nuclides | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | *LTN | $^{137}$Cs | $^{131}$I | $^{110m}$Ag | $^{60}$Co | $^{90}$Sr | $^{134}$Cs | $^{54}$Mn | $^{51}$Cr |
| 1978 | 16,9 | 0,1 | 276 | 6,4 | 7,8 | 0,03 | 0 | 5,6 | 20 |
| 1979 | 633 | 17,2 | 579 | 202 | 31 | 1,4 | 5,1 | 19,1 | 313 |
| 1980 | 428 | 48,6 | 777 | 40 | 18,1 | 0,3 | 46,7 | 13,6 | 70 |
| 1981 | 214 | 22,4 | 735 | 30,3 | 26,9 | 0,6 | 15,5 | 10,7 | 11,6 |
| 1982 | 341 | 9,5 | 230 | 48,5 | 62,8 | 0,37 | 10,0 | 22,3 | 11,5 |
| 1983 | 884 | 5,0 | 70 | 4,8 | 20,6 | 0,06 | 1,7 | 5,8 | 0,7 |
| 1984 | 1785 | 66,3 | 228 | 37 | 28,2 | 0,04 | 51,0 | 4,9 | 4,6 |
| 1985 | 754 | 60,6 | 151 | 71,6 | 17,2 | 0,11 | 33,1 | 4,0 | 16,2 |
| 1986 | 794 | 25,0 | 44 | 73,4 | 21,7 | 0,25 | 12,8 | 8,4 | 0 |
| 1987 | 259 | 13,4 | 103 | 122 | 34,7 | 0,08 | 5,6 | 7,2 | 17,2 |
| 1988 | 338 | 14,9 | 602 | 142 | 128 | 0,06 | 24,0 | 26,8 | 10,2 |
| 1989 | 181 | 10,1 | 110 | 56,6 | 29,4 | 0 | 0 | 0 | 0 |
| 1990 | 113 | 8,8 | 0 | 16,1 | 12,3 | 0,09 | 0 | 0 | 0 |
| 1991 | 46,0 | 6,2 | 0 | 11,8 | 8,9 | 0 | 4,0 | 1,3 | 0 |
| 1992 | 24,0 | 4,1 | 0 | 4,3 | 5,8 | 0 | 0 | 0 | 0 |
| 1993 | 19,4 | 2,2 | 0 | 0 | 3,9 | 0 | 0 | 0 | 0 |
| 1994 | 82 | 0 | 0 | 0 | 60,1 | 0 | 0 | 0 | 0 |
| 1995 | 193 | 23,3 | 9,7 | 0 | 83,7 | 0,15 | 0 | 0 | 0 |
| 1996 | 121,1 | 6,46 | 23,5 | 13,4 | 15,5 | 0,12 | 0,8 | 0,8 | 11,6 |
| 1997 | 278,1 | 11,6 | 36,71 | 7,24 | 9,0 | 0,36 | 1,27 | 0,33 | 0 |
| 1998 | 238,4 | 9,35 | 28,8 | 7,72 | 18,4 | 0,29 | 1,32 | 1,89 | 21,6 |
| 1999 | 238,5 | 10,2 | 25,77 | 10,82 | 11,94 | 0,44 | 0,89 | 1,22 | 0 |
| 2000 | 30,7 | 4,2 | 26,0 | 22,5 | 17,70 | 0,38 | 5,97 | 8,78 | 0 |
| 2001 | 22,0 | 13,1 | 18,8 | 17,0 | 23,7 | 0,27 | 5,36 | 3,42 | 2,24 |
| 2002 | 9,9 | 7,9 | 59,6 | 2,50 | 6,6 | 0,20 | 2,28 | 0,16 | 0 |
| 2003 | 29,3 | 26,7 | 38,1 | 25,0 | 22,1 | 0,23 | 5,0 | 3,23 | 0 |
| 2004 | 28,5 | 5,59 | 97,1 | 11,3 | 14,6 | 0,035 | 0,38 | 1,35 | 2,53 |
| 2005 | 20,9 | 6,98 | 3,04** | 1,35 | 5,10 | 0,03 | 0,83 | 0 | 0 |
| 2006 | 18,3 | 5,12 | 3,65** | 1,77 | 9,45 | 0,032 | 0,54 | 0 | 0 |

* LTN – the radionuclides with a half-life period > 24 hours.

** Since 2005 the new more exact technique of measurement and accounts of emissions $^{131}$I was input at ANPP.

As follows from the calculations, represented in Table 3, in case of over-project accidents, during short time intervals, the high doze loadings on the population in area of nuclear power plants accommodation are formed. For protective actions efficiency they should be adequate to real radiation condition, which is formed in area of the NPP accommodation as a result of accident. In paper [1] it is underlined that in case of correct protective actions acceptance, the inhalation doze of an irradiation decreases in 10–100 times and a doze of an external irradiation decreases in several times.

Table 2

*Emission of radionuclides from the NPP station with the reactor PWR-440 (B-270), depending on time at over-project accident with the leak (equivalent diameter of 200 mm) and its deenergized position, operation $3,7\times10^7$ Bq*

| Physical and chemical forms of radionuclides | Time, seconds | | | | |
|---|---|---|---|---|---|
| | 600 | 3600 | 22000 | 43000 | 86000 |
| Molecular iodine | | | | | |
| I-131 | 3,6E+04 | 5,5E+06 | 5,5E+06 | 5,5E+06 | 5,5E+06 |
| I-132 | 3,8E+04 | 7,6E+06 | 7,6E+06 | 7,6E+06 | 7,6E+06 |
| I-133 | 4,1E+04 | 1,1E+07 | 1,1E+07 | 1,1E+07 | 1,1E+07 |
| I-134 | 4,0E+04 | 1,1 E+7 | 1,1 E+7 | 1,1 E+7 | 1,1 E+7 |
| I-135 | 3,5E+04 | 1,0E+07 | 1,0E+07 | 1,0E+07 | 1,0E+07 |
| Organic iodine | | | | | |
| I-131 | 4,1E+02 | 1,0E+05 | 1,0E+05 | 1,0E+05 | 1,0E+05 |
| I-132 | 4,3E+02 | 1,4E+05 | 1,4E+05 | 1,4E+05 | 1,4E+05 |
| I-133 | 4,6E+02 | 2,0E+05 | 2,0E+05 | 2,0E+05 | 2,0E+05 |
| I-134 | 4,5E+02 | 1,9E+5 | 1,9E+5 | 1,9E+5 | 1,9E+5 |
| I-135 | 3,9E+02 | 1,9E+5 | 1,9E+5 | 1,9E+5 | 1,9E+5 |
| Inert radiating gases | | | | | |
| Kr-85m | 6,8E+03 | 2,2E+06 | 2,2E+06 | 2,2E+06 | 2,2E+06 |
| Kr-87 | 1,4E+04 | 4,1E+06 | 4,1E+06 | 4,1E+06 | 4,1E+06 |
| Kr-88 | 2,1E+04 | 6,3E+06 | 6,3E+06 | 6,3E+06 | 6,3E+06 |
| Xe-133 | 8,5E+04 | 2,0E+07 | 2,0E+07 | 2,0E+07 | 2,0E+07 |
| Xe-135 | 3,7E+04 | 5,9E+07 | 5,9E+07 | 5,9E+07 | 5,9E+07 |
| Aerosols | | | | | |
| Cs-134 | 1,1E+04 | 1,1E+06 | 1,1E+06 | 1,1E+06 | 1,1E+06 |
| Cs-137 | 1,0E+04 | 8,5E+05 | 8,5E+05 | 8,5E+05 | 8,5E+05 |

Table 3

*Expected individual irradiation doze of separate persons from various groups of the population*

| Age | Distance from the NPP, *km* | Doze on critical body, *Sv* | | Evacuation | | Time of movement of a radioactive cloud from the NPP, *hour* |
|---|---|---|---|---|---|---|
| | | All body | Thyroid gland | Obligatory | Can be delayed | |
| Children 1–8 years | 3,0 | 3,2E+1 | 4,8E+2 | + | | 0,55 |
| | 14,0 | 1,0 | 1,3E+1 | + | | 2,55 |
| | 16,0 | 6,4E-1 | 9,2 | + | | 2,9 |
| | 17,5 | 6,0E-1 | 8,8 | + | | 3,2 |
| | 18,0 | 5,6E-1 | 8,4 | + | | 3,3 |
| | 27,0 | 2,6E-1 | 4,4 | + | | 4,9 |
| Adults | 3,0 | 2,2E+1 | 2,8E+2 | + | | |
| | 14,0 | 7,1E-1 | 7,7 | + | | |
| | 16,0 | 4,1E-1 | 5,4 | + | | |
| | 17,5 | 3,7E-1 | 5,2 | + | | |
| | 18,0 | 3,5E-1 | 4,9 | | + | |
| | 27,0 | 1,6E-1 | 2,6 | | + | |

Therefore, it is the extremely important to represent the real consequences of uncontrollable emissions, depending on their size, as well as on the characteristics of region of station accommodation and character of the population distribution to provide the adequate and, this is very appreciable, duly measures on the population protection.

One of the basic phases of the analysis of possible nuclear power plant influence on the population (both in a mode of normal operation and in emergency situations) is the analysis of distribution of the population in area of the NPP accommodation. In the present paper the criterion conception is introduced for a quantitative estimation of radiation risk degree for the population by different azimuths ($P_i$), into which the territory around the NPP is divided and the technique of its calculation has been also described. The characteristic feature of such criterion is the circumstance that it defines the azimuth radiation risk without dependence on the various accidents consequences.

For definition of the concept of azimuth risk degree we divide the territory around the NPP with radius $R$ into 16 azimuths. As the values characterizing the above-stated criterion we have chosen three parameters:

- $n_{ij}$ is the attitude of the population number, living in $j$-th settlement of $i$-th azimuth, to the whole population, living in territory with radius R;
- $r_{ij}$ is the attitude of distance between settlement $j$, located in $i$-th sector, and radius $R$, $r_{ij} = \frac{l_{ij}}{R}$ (Fig. 1);
- $l_{ij}$ is the distance between settlement located in $i$-th settlement and NPP;
- $W_i$ is the mid-annual probability of a wind in a direction of an azimuth $i$ (Fig. 2).

The formula for criterion $P_i$ value calculation is following:

$$P_i = \sum_{j=1}^{j=N_i} \frac{n_{ij}}{r_j} + W_i, \quad j=1, 2, \ldots N_i, \quad i = 1\text{–}16, \tag{1}$$

where $N_i$ is the number of settlements in $i$-th azimuth.

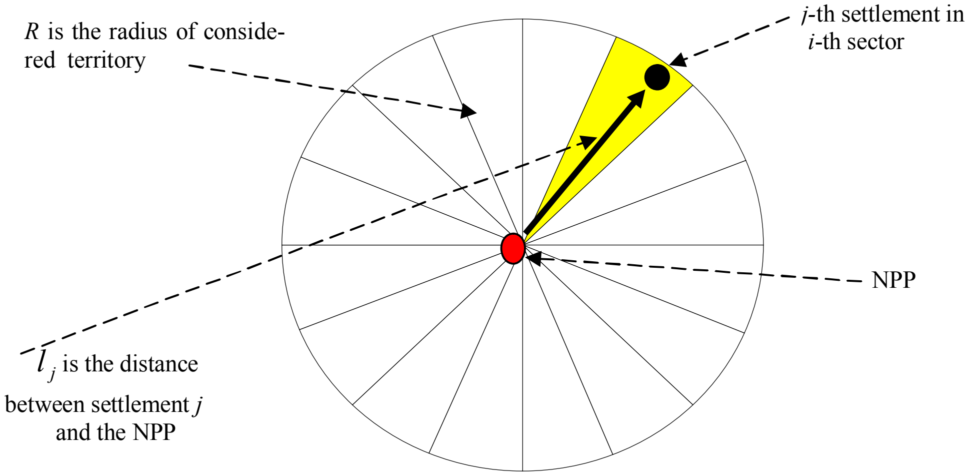



Fig. 1. The symbols used in expression (1).

The first item of expression (1) describes distribution of the population in $i$-th azimuth of area around the nuclear power plant, the second one – meteorological characteristics *of* $i$-th azimuth.

It is very important to choose correctly the value of $R$ as the arbitrary choice can lead to distortion of the expression first item of (1). At too large value of $R$

during the $P_i$ calculation the part of the population not subject to risk of an irradiation will be considered and, therefore, the value of $P_i$ will be unreasonably overestimated. Therefore, it is necessary to analyze radiation consequences of possible accidents in details, and the influence of emissions from the NPP in a mode of normal operation too. In addition to data presented in Tables 2 and 3, corresponding calculations have been done by means of program InterRAS (version 1.2, 1997), recommended by IAEA (though it is known that calculations by means of this program give greater mistakes). The $R$ value equal to 25 *km* has been accepted as a result of calculations.

What practical importance can have the calculations of azimuths risk degrees? The values of the azimuths risk degrees, received on the basis of the population spatial distribution estimation and the account meteorological conditions, will help to choose the sectors more subject to influence of the accidents radiation consequences. The knowledge of sizes of an "azimuths degree of risk" in the area of an nuclear power plant accommodation will help:

- at the planning of the volume of emergency radiation monitoring – to define the azimuths with the maximal risk degree in which it is necessary to establish the special monitoring, in particular, the greater number of the emergency automatic online monitoring devices must be installed;
- at the planning of the actions for the population protection in case of accidents at the NPP at a federal level – to define the azimuths with bigger degree of risk for which it is necessary to provide a lot of protective means and evacuation technique;
- at the planning of the current monitoring volume – to define azimuths to which it is expedient to pay greater attention (a lot of monitoring points, etc.).

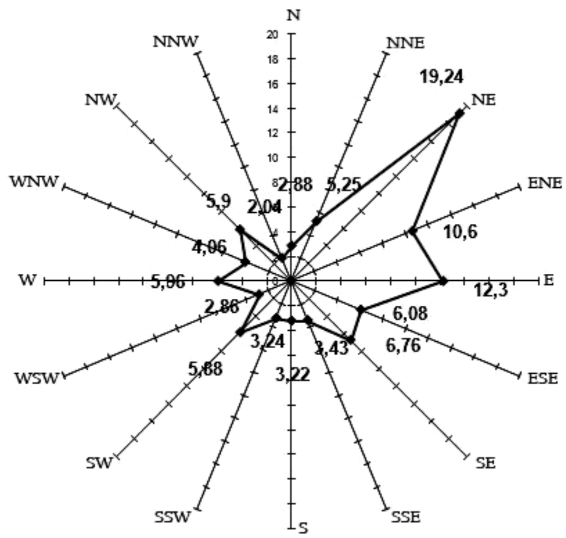



Fig. 2. Mid-annual probability of a wind direction in area of the Armenian NPP (average for the period from 1970 to 1998).

The calculated values of the relative contribution of the population, living in $i$-th azimuth, to the general number of the population are presented in Fig. 3.

The general number of the population, living around the Armenian nuclear power plant in radius of 25 *km*, equals 295610 people. The values of $P_i$ have been calculated (Fig. 4).

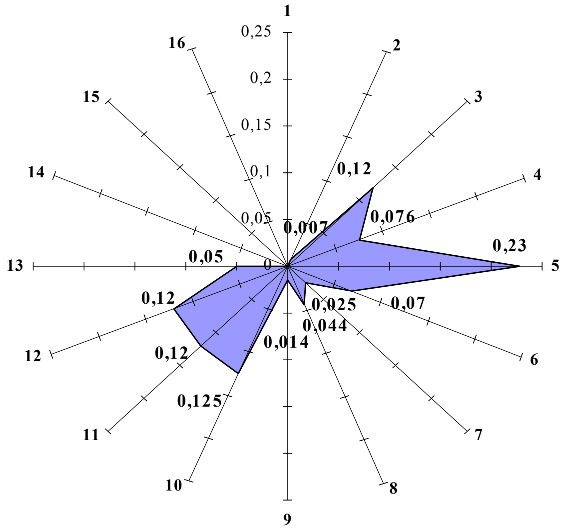
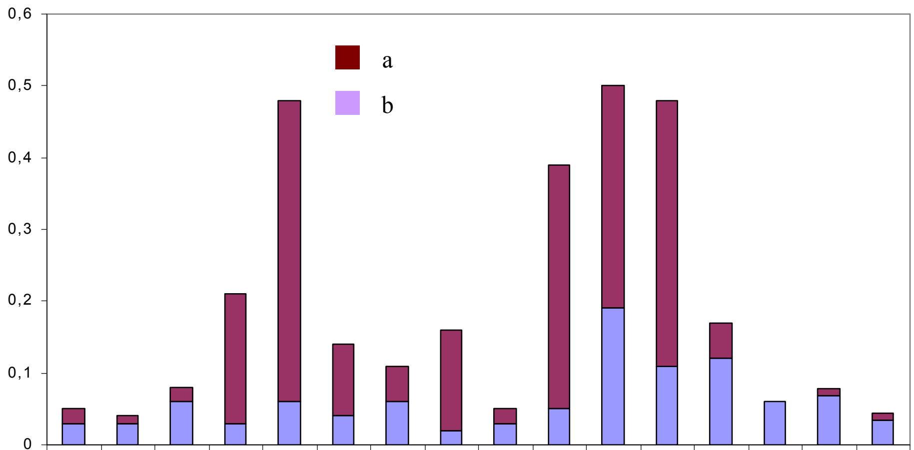



Fig. 3. The relative contribution of the population, living in *i*-th azimuth to the general number of the population with radius of 25 *km* around Armenian NPP.




| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Ряд2 | 0,02 | 0,01 | 0,02 | 0,18 | 0,42 | 0,1 | 0,05 | 0,14 | 0,02 | 0,34 | 0,31 | 0,37 | 0,05 | 0 | 0,01 | 0,01 |
| Ряд1 | 0,03 | 0,03 | 0,06 | 0,03 | 0,06 | 0,041 | 0,06 | 0,02 | 0,03 | 0,05 | 0,19 | 0,11 | 0,12 | 0,061 | 0,068 | 0,034 |

Fig. 4. $P_i$ are the values distribution by azimuths: (a) the value of $P_i = \sum_j \frac{n_{i,j}}{r_j}$ for *i*-th azimuth, (b) the probability of the wind direction in *i*-th azimuth.

The distribution of the $P_i$ values plotted on the map of Armenian NPP location is shown in Fig. 5.

As follows from Figures 4 and 5 the azimuths with greater degrees of risk are 5-th, 10-th, 11-th and 12-th (i.e. directions E, SSW, SW and WSW). Therefore, at planning radiation, monitoring in a zone of Armenian NPP location, it is necessary to establish the raised supervision over these azimuths, namely, to provide greater number of monitoring points and automatic online devices.

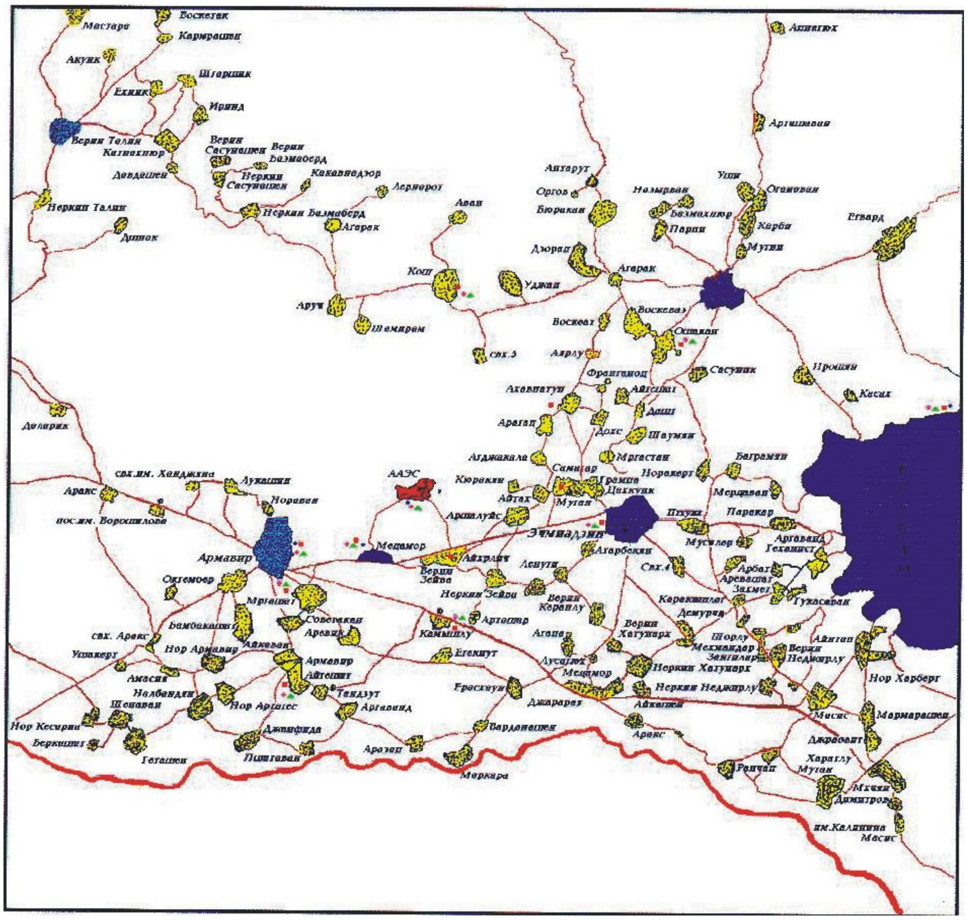



Fig. 5. The scheme of Armenian NPP monitoring zone.

Besides, at planning the actions on protection of the population in case of accidents on the nuclear power plants at a federal level it is necessary to provide a lot of protective means and evacuation technique for these azimuths.

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