Assessment of occupational risk of enterprises producing energy using sources of ionizing radiation

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Abstract. The article considers an algorithm for assessing professional risk for employees of energy production enterprises using sources of ionizing radiation. The problematic issues in determining the professional risk of employees are identified and the ways of their solution are proposed. There are also two criteria for assessing professional risk: "Dose load" and "Permissible work experience". When assessing professional risk, it is proposed to take into account the impact on the environment and sustainable development of society.

1 Introduction

In our life, both at home and at work, a large number of different sources of ionizing radiation (AI) are used, which, if standard operating conditions are met, do not pose a threat to life and health (there is no excess of the control values laid down in NRB-99/2009 [1]. However, accidents and accidents are not uncommon at AI facilities. Therefore, there is a need to assess the damage caused by such abnormal situations during the operation of these facilities, and its main purpose is to calculate the radiation consequences for employees of enterprises, citizens and nature, as well as the damage expressed in material resources. [2, 3]

In recent years, the concept of occupational risk has been introduced with the transition of the occupational health and safety management system to risk management. [4-8] This raises the question of developing risk assessment methods. However, due to the specific impact of radiation on humans, the calculation of occupational risk for employees of enterprises using radiation sources is very different from the standard approaches to such calculations at other facilities.[9-12]

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2 Methods

In order to understand what is expressed in the specificity of exposure, you first need to understand how radioactive substances enter the human body.

There are several ways of getting substances into the human body, each of them entails a corresponding dose: inhalation, oral, external radiation. The effect of each dose depends on the performance of the source, its characteristics: this implies the consequences for the employee of the enterprise that he will receive in the event of an accident at the facility. [13].

Thus, it is possible to present an "algorithm" for determining the occupational risk for employees of radiation hazardous objects. The algorithm is based on the modeling method (i.e., the construction of the accident model) and the calculation and analytical method.

The algorithm itself is shown in figure 1.

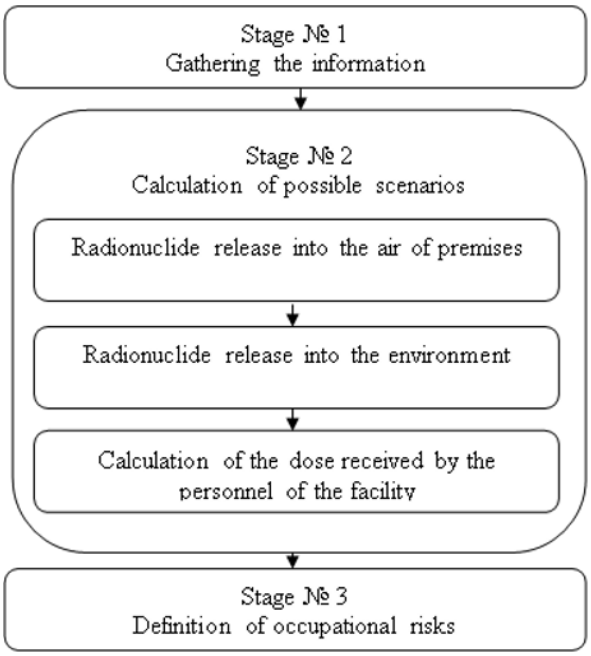

Fig. 1. Algorithm for determining professional risks.

Before assessing occupational risks, it is necessary to calculate the dose that a person will receive as a result of an accident. This calculation includes two equal components, namely: the dose of external irradiation (through the skin) and the dose of internal irradiation, the last in turn also divided into two components: the dose with inhalation and dose upon ingestion (Figure 2).

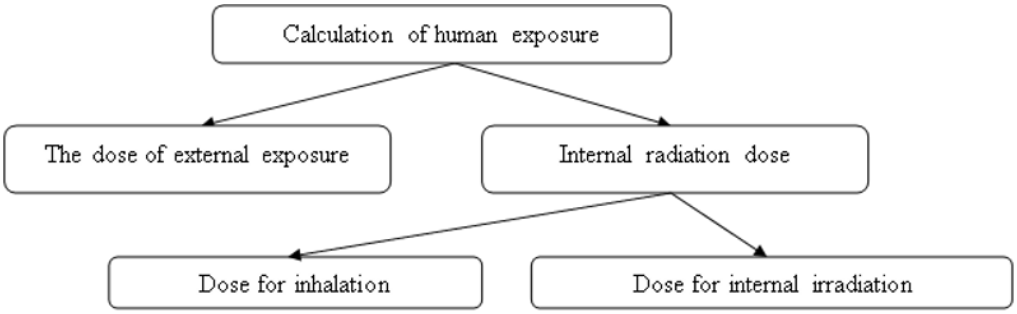

Fig. 2. Scheme of calculation of human exposure.

Calculation of human exposure can be done using the following formulas [14, 15]:

The dose of external irradiation (E_{ext}, Sievert (S_v)) of the formula:

$$E_{ext} = A_v \cdot B \cdot t, \quad (1)$$

where: A_v - surface volumetric activity of the radionuclide on the axis of the torch at a distance of x meters from the source (in the direction of the wind), Bk / m^3; B - dose coefficient for external exposure, taking into account the type of particles that irradiation occurs (gamma, beta or joint), $Sv \cdot m^3/Bk$; t - duration of impact of the radioactive cloud, sec.

For internal irradiation with an inhalation intake of a radionuclide, the effective dose (E_{ing}, S_v) according to the formula:

$$E_{ing} = A_v \cdot B_{ing} \cdot t_{eff}, \quad (2)$$

where: A_v - volume activity of the radionuclide in air, Bk/m^3; B_{ing} - dose rate of internal exposure when inhaled radionuclide intake into the human body, $S_v \cdot m^3/Bk$ S; t_{eff} - is the effective time of exposure of the radionuclide radionuclide to the recipient, sec.

For internal irradiation with ingestion of the radionuclide, the effective dose (E_{zag}, S_v) according to the formula:

$$E_{zag} = A_m \cdot B_{zag} \cdot t_{eff}, \quad (3)$$

where: A_m is the activity of a unit mass of the swallowed substance, Bk/kg; B_{zag} - dose coefficient of internal irradiation with ingestion of a radionuclide into the human body, $S_v \cdot m^3/Bk \cdot s$; t_{eff} - is the effective time of exposure of the radionuclide ingestion.

For a number of commonly used radionuclides, E_{ing} and E_{zag} and E_{ext} are listed in Table 2.

Table 1. E_{ing} and E_{zag} and E_{ext} for a number of commonly used radionuclides.

Radionuclide	**$E_{эфф}$, Sv with inhalation (E_{ing})**	**$E_{эфф}$, Sv when swallowed (E_{zag})**	**$E_{эфф}$, Sv with external irradiation (E_{ext})**
Pu-238	$1{,}5 \cdot 10^{-5}$	$2{,}3 \cdot 10^{-7}$	$3{,}8 \cdot 10^{-16}$
Pu -239	$1{,}5 \cdot 10^{-5}$	$2{,}5 \cdot 10^{-7}$	$3{,}5 \cdot 10^{-16}$
Am-241	$3{,}9 \cdot 10^{-5}$	$2{,}0 \cdot 10^{-7}$	$8{,}9 \cdot 10^{-14}$
Cs-137	$4{,}8 \cdot 10^{-9}$	$1{,}3 \cdot 10^{-8}$	$2{,}7 \cdot 10^{-12}$
^{60}Co	$5{,}6 \cdot 10^{-8}$	$3{,}4 \cdot 10^{-9}$	$1{,}2 \cdot 10^{-11}$

If the calculation of the consequences from possible accidents at a radiation hazardous facility is practically not difficult (with the exception of collecting information about the facility, but this is already a matter to be solved directly at the facility), the stage of assessing occupational risks causes difficulties, primarily because of the absenceof criteria.

One of such criteria can serve as "Dose load" and "Limits of work experience".

So, to assess the degree of impact on the worker, we will determine the dose load for the entire period of the actual or anticipated exposure to radiation, that is, the amount of dose the worker receives during the whole period of professional contact with radiation:

$$DL = K \times t \times N \times T + D_a, \quad (4)$$

where: K - the actual average radiation level in the workplace, μSv / h; t - the number of hours in the shift, h, N - the number of working shifts in a calendar year; T - number of years of work; The dose actually received by the employee as a result of an accident with a radioactive substance, μSv (in the absence of accidents, is 0)

In this case, the value of D_a is taken as the sum of all the doses received by the employee as a result of all accidents for all periods of work:

$$D_a = D_1 + D_2 + ... + D_n, \quad (4)$$

where: D_1, D_2 - the dose actually received by the employee as a result of an accident with a radioactive substance, during the time of a single accident, μSv.

This values DL are compared with the value of the control dose load (KDL) formed under the condition of observing the mean-for-age acceptable level of radiation during the entire period of professional contact with radiation. The value of the KDL is calculated depending on the actual or anticipated length of service, the remote control radiation in the workplace:

$$\mathrm{KDL} = RCR \times t \times N \times T, \quad (5)$$

where RCR is the middle level in the workplace, μSv / h.

If the actual dose load corresponds to the control level, the working conditions are referred to the permissible hazard class of working conditions and confirm the safety of continuing work under the same conditions.

When the KDL is exceeded, it is necessary to calculate the work experience (T_1) at which the DL will not exceed the KDL. At the same time, it is recommended that the KDL be determined for an average work experience of 25 years. In those cases where the duration of work is more than 25 years, the calculation is made based on real work experience.

$$T_1 = \frac{KDL_{25}}{K \cdot N \cdot t + D_a}, \quad (6)$$

where T_1 is the limitted work experience under the given conditions; KDL_{25} - control dose load for 25 years of operation under conditions of compliance with the remote control, μSv.

In this case, the value of K is taken as the average amount for all periods of work:

$$K = \frac{K_1 \cdot t_1 + K_2 t_2 + ... + K_n \cdot t_n}{\sum t}, \quad (7)$$

where: K_1, K_2 - the actual average radiation level in the workplace, for individual work periods, μSv / h; t_1 - t_n - periods of work during which the actual radiation levels were constant, year.

For clarity, let's take a production employee belonging to the group b staff, with a real work experience of 15 years, working 8 hours, an average of 247 shifts per year, with an actual average shift radiation level at the workplace equal to 1.8 mSv/hour, and who during his activity was involved in accidents, as a result of which he received a Yes equal to 15 mSv (approximately 1 mSv/year). We will also assume that outside of work, as the "population" receives 1 mSv per year (natural background radiation, radiation from medical procedures, etc.). Using the initial data, we calculate the necessary values: Calculate the Dose load and compare the Control dose load: DL = K×t×N×T+Da=0,018×8× 247 × 15 +15= 68,35 but taking into account 1 mSv per year, received as "population", DL = 83.35, which, respectively, is more than KDL (for simplification, we take the KDL for 15 years equal to 75 mSv, and for 25 years -125 mSv).

Calculate the allowable length of service in these conditions (T_1), also taking into account 1 mSv per year, received as «population»:

$$T_1 = \frac{KD\,L_{25}}{K \cdot N \cdot t + D_{as}} = 22{,}5 years \quad (8)$$

This calculation allows us to find out the estimated allowable length of service (in our case, it is 22.5 years) after which we need to transfer a person to a safe job to reduce the risk to their health. But at the same time, it is necessary to understand that this calculation is approximate, with a number of assumptions that can significantly affect the result of calculating the allowable length of service and, accordingly, requires more detailed study.

3 Conclusion

Calculation of occupational risks for employees of enterprises using ionizing radiation makes it possible to calculate the forecast of occupational risks (this issue is widely considered in the work "Method of forecasting occupational risks" [5]), as well as to identify areas for improving employee safety.

Therefore, determining the criteria for assessing occupational risks is a priority task for improving the safety of employees of enterprises using radioactive substances.

References

1. Normy radiacionnoj bezopasnosti (NRB-99/2009): Gigienicheskie normativy.- M.: Minzdrav Rossii (2009)
2. A.S. Usy`pko, O.N. Terent`ev, *Raschet ushherba ot radiaczionny`kh avarij pri ispol`zovanii radioaktivny`kh veshhestv na ob`ektakh narodnogo khozyajstva*, V sbornike: Nedelya nauki SPbGPU. materialy` XLII nauchno-prakticheskoj konferenczii c mezhdunarodny`m uchastiem, S. 107-109 (2014)
3. A.S. Usy`pko, O.N. *Terent`ev, Oczenka professional`ny`kh riskov dlya sotrudnikov radiaczionno-opasny`kh ob`ekto*v, V sbornike: Nauchny`j forum s mezhdunarodny`m uchastiem "Nedelya nauki SPbPU". Materialy` nauchno-prakticheskoj konferenczii, S. 227-230 (2015)
4. J. I. Idrisova, T. T. Kaverzneva, N. V. Rumyantseva, I. L. Skripnik, *Neural network modeling of safety system for construction equipment operation in permafrost zone* Paper presented at the IOP Conference Series: Earth and Environmental Science, 302(1) doi:10.1088/1755-1315/302/1/012128 (2019)
5. J.I. Idrisova, V.N. Myasnikov, A.I. Uljanov, N.V. Belina, *Increasing the efficiency of labor protection in the enterprise*, Paper presented at the International Conference on Information Networking, 2018-January 586-588 (2018).
6. T. Kaverzneva, N. Rumyantseva, A. Uljanov, N. Belina, *Use of the logical-statistical model as a procedure for assessing occupational risks in the OSH management*, Paper presented at the IOP Conference Series: Materials Science and Engineering, 666(1) doi:10.1088/1757-899X/666/1/012091 (2019)
7. S. Efremov, Y. Logvinova, I. Russkova, M. Polyukhovich, *A method for assessing climatic parameters working at low temperatures as an element of technological safety*, Paper presented at the IOP Conference Series: Earth and Environmental Science, 539(1) doi:10.1088/1755-1315/539/1/012031(2020)
8. I. V. Aladyshkin, S. V. Kulik, S. V. Efremov, *The conceptual bases of the scientific direction "technosphere safety"*, Paper presented at the IOP Conference Series: Earth and Environmental Science, , 459(2) doi:10.1088/1755-1315/459/2/022029 (2020)

9. A. Byzov, A. Pak, D. Kuznetsova, G. Ostapenko, *Analysis of the statistical correlation between the estimated value of individual risk and the hazard class of a hazardous production facility in the russian federation*, Paper presented at the E3S Web of Conferences, 140 doi:10.1051/e3sconf/201914008004 (2019)
10. M. Borisova, A. Byzov, S. Efremov, *Assessment of the maximum possible number of victims of accidents at hazardous production facilities for insurance purposes*, Paper presented at the IOP Conference Series: Materials Science and Engineering, 666(1) doi:10.1088/1757-899X/666/1/012096 (2019)
11. A. P. Byzov, A. I. Shershneva, M. A. Ens, *Assessment methodology for personal risk assessment in the field of waste storage*, Paper presented at the Proceedings of the 2018 IEEE International Conference "Management of Municipal Waste as an Important Factor of Sustainable Urban Development", WASTE 2018, 49-51. doi:10.1109/WASTE.2018.8554146 (2018)
12. M. Avdeeva, A. Byzov, K. Smyshlyaeva, N. Leonova, *Assessment of the fire situation of a certain building using fenix+,* doi:10.1007/978-3-030-57453-6_35 (2021)
13. Mezhotraslevaya metodika rascheta ekonomicheskogo ushcherba ot radiacionnyh avarij pri ispol'zovanii radioaktivnyh veshchestv v narodnom hozyajstve, OOO «REScentr», reg.№ R-03/98, Sankt-Peterburg (2006)
14. Vremennaya tipovaya metodika opredeleniya ekonomicheskoj effektivnosti osushchestvleniya prirodoohrannyh meropriyatij i ocenki ekonomicheskogo ushcherba, prichinyaemogo narodnomu hozyajstvu zagryazneniem okruzhayushchej sredy (utv. 28.10.83 g. postanovleniem Gosplana SSSR, Gosstroya SSSR i Prezidiuma Akademii nauk SSSR za № 254/284/134) (1983)
15. A.D. Zimon, V.K. Pikalov, Dezaktivaciya, M., IzdAT (1994)