

# Improvement of the methodology for calculating damage from possible radiation accidents applicable in energy engineering

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**Abstract.** This article considers an algorithm for calculating the consequences of accidents at facilities using ionizing radiation, including facilities for the production of electrical energy. The problematic issues for carrying out these calculations when solving the problems of energy engineering are indicated and the ways of their solution are proposed. The development of an automated program for calculations is proposed and the advantages of this program are indicated. The proposed methodology is one of the elements of ensuring sustainable development of society.

## 1 Introduction

The use of various sources of radiation has become firmly established in the life of our world, and this is observed in almost all spheres of human activity. At the same time, if there is an accident-free operation of these sources, there is practically no radiation hazard and the requirements laid down in NRB-99/2009 [1] are not exceeded. But, unfortunately, in any activity, various accidents are possible, so it is necessary to assess and calculate the possible consequences of operating such facilities. Usually, such calculations estimate the possible maximum consequences of accidents for people and the world around us. Such calculations usually serve both to understand the danger of objects with radiation sources and assign them different categories, and to identify problematic issues both in the reliability of the object and in the consequences of accidents on it. All this ultimately affects the safety of the object and helps to reserve the necessary funds for the elimination of the consequences of the accident.[2-7]

## 2 Methods

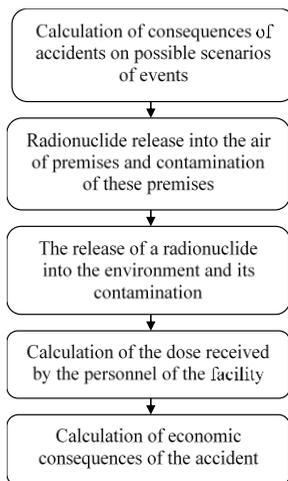
For such calculations, the simulation method (i.e., the construction of an accident model) and the calculation and analytical method are used.[8, 9]

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Carrying out such calculations is a lot of work, at the beginning of which all the necessary information is collected on a radiation-hazardous object, as well as possible accident scenarios are identified, which are subsequently calculated in terms of consequences. After that, the identified scenarios are calculated and the maximum consequences from them are determined, then a decision is made on categorizing the radiation-hazardous object and choosing measures to improve the safety of personnel and the population, as well as recommendations for creating reserves of resources to eliminate the consequences of these accidents.

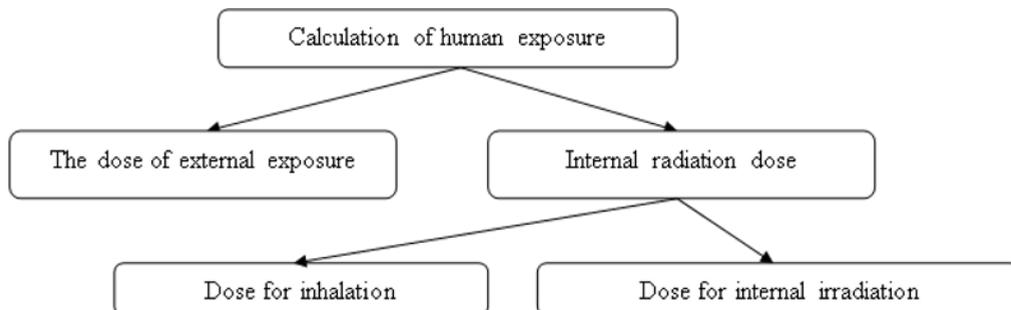
Usually such calculations can be divided into four interrelated parts resulting from each other, namely: determination of the release of radionuclide into the air of premises and contamination of these premises, pollution outflow from the building and pollution of the environment, calculation of the dose received by the facility's personnel, of these accidents (Figure 1).



**Fig. 1.** The scheme for calculating the consequences of radiation accidents.

But first of all, we should be interested in the component connected directly with the person - participant in this incident, since human life and health is the highest value that exists. Therefore, we also need to find out what the maximum dose can get a person - a participant in this incident at a radiation-hazardous facility.

Calculation of human exposure includes two equal components, namely: the dose of external irradiation (through the skin) and the dose of internal irradiation, the latter in turn also divided into two components: the dose for inhalation and dose for ingestion (Figure 2).



**Fig. 2.** Scheme of calculation of human exposure.

Calculation of human exposure can be done using the following formulas [10-12]:

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

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

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),  $\text{Bk} / \text{m}^3$ ;  $B$  - dose coefficient for external exposure, taking into account the type of particles that irradiation occurs (gamma, beta or joint),  $\text{Sv} \cdot \text{m}^3 / \text{Bk}$ ;  $t$  - duration of impact of the radioactive cloud, sec.

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

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

where:  $A_v$  - volume activity of the radionuclide in air,  $\text{Bk} / \text{m}^3$ ;  $B_{\text{ing}}$  - dose rate of internal exposure when inhaled radionuclide intake into the human body,  $\text{Sv} \cdot \text{m}^3 / \text{Bk} \cdot \text{S}$ ;  $t_{\text{eff}}$  - 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 ( $E_{\text{zag}}$ ,  $S_v$ ) according to the formula:

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

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

Usually, when calculating these impacts on the person of the consequences of an incident at the site, a number of restrictions are imposed on the course of the scenario of the development of the incident, most often one of them is the limitation of the time of exposure of the person to polluted air [13, 14]. This restriction is caused by the fact that it is considered that the incident with the source is detected rather quickly, after that an alarm is given and personnel are evacuated from the danger zone. With such a development of the situation, this restriction has the right to its existence, especially when it comes to fairly powerful sources of radiation, but with the development of science and technology, weaker sources became widely used too: for example, in medicine, the so-called radiopharmaceuticals. The peculiarity of the incidents, for example, in the spilled poisons, with such drugs can be that often, according to the instructions, the collection of the spilled product, and, consequently, the elimination of the consequences of the incident, is placed directly on the medical personnel working with these radiopharmaceuticals. Accordingly, in fulfillment of their job descriptions, these workers can not be evacuated, and the overlapping limitation of exposure (usually one hour) is not correct, because in this case, during the impact will also include the time to eliminate the incident, which can significantly exceed the value of one hour.

Another problem when calculating the consequences of accidents with radiation sources is the determination of the concentration of radionuclides in the interior of the rooms where the accident occurred. For a basis of calculations we take the formula:

$$C_m = A_m / V_o = Q [1 - \exp(-nt)] / n V_o, \quad (4)$$

where  $C_m$  is the concentration of the radionuclide in the air;  $A_m$  - the maximum activity of the radionuclide in the room air at time  $t$ ,  $\text{Bk}$ ;  $Q$  - the intensity of the output of the RS from the source (power of the source of the RS),  $\text{Bk} / \text{h}$ ;  $n$  - frequency of air exchange,  $\text{hour}^{-1}$ ;  $t$  - time of action of the source, hour;  $V_o$  is the volume of the room,  $\text{m}^3$ .

### 3 Discussion and results

It is usually assumed that the radionuclide spreads throughout the volume of the room where the accident took place evenly, and then the concentration is calculated according to simple formulas taking into account the room volume and the frequency of air exchange in the

rooms. And if the enterprise has several rooms that are not isolated from each other the assumption is often used that the distribution of activity between the premises is proportional to their volumes. The actual calculation of the concentration is not done, for the reason that at the moment there is no methodology for such calculations, and obtaining data through experiments is not appropriate, since such experiments will have to be carried out for each individual case separately, but not simply to conduct, and also create an experimental model of premises for which it is necessary to know the concentration of radionuclides (taking into account such parameters as: arrangement of equipment in the room, meteorological conditions).

Another "money" issue for the company is the insurance amount and insurance premiums under the insurance contract. A more accurate assessment of the received damage from the incident, in turn, can affect the insurance amount of the hazardous production facility, and immediately in two directions: on the one hand, in the case of a more accurate calculation of the consequences (for example, taking into account the actual concentration of radioactive substances in the room) Accidents, together with the impact on the person participating in the accident, may decrease, which will lead to a reduction in the insurance amount for the enterprise, which will entail a reduction in insurance premiums, paying and, in the end, a reduction in the company's fixed costs, and on the other hand, if the scale of the consequences of the accident increases, including the impact on the person participating in the accident, will lead to an increase in insurance premiums, but in this case the amount of money will also increase, from which compensation will be paid to the victims, and accordingly the enterprise can be freed from material losses related to the payment of damages that the insured sum could not cover (counted "in the old way" more is not exact and, accordingly, it turned out to be less real). [15-17]

One of the ways to solve the questions posed is to translate these calculations into automated calculations using special software.

Using this program allows improving the quality and accuracy of calculations: 10 specialists were offered one object for calculation, the result of calculation is presented in the table 1.

**Table 1.** Setting Word's margins.

Calculation made	Bulk activity of the radionuclide ( $C_m$ ), Bk / m <sup>3</sup>	$D_{ind}$ , for staff, μSv
specialist 1	$1,76 \times 10^3$	27,9
specialist 2	$1,8 \times 10^3$	29,1
<b>specialist 3</b>	<b><math>3,2 \times 10^3</math></b>	<b>51,42</b>
specialist 4	$1,71 \times 10^3$	25,6
specialist 5	$1,74 \times 10^3$	27,63
specialist 6	$1,7 \times 10^3$	27,1
specialist 7	$1,69 \times 10^3$	26,5
specialist 8	$1,73 \times 10^3$	28,42
specialist 9	$1,75 \times 10^3$	27,42
specialist 10	$1,72 \times 10^3$	27,2
<b>Software</b>	<b><math>1,7431 \times 10^3</math></b>	<b>27,42</b>

The strong difference between the results from the total mass in the calculation of Specialist No. 3 is caused, as shown by the check, that the expert did not correctly select one of the coefficients of the characteristic radioactive substance. Accordingly, the application of this program will avoid these errors. Plus, the application of the program makes it possible to improve the accuracy of the calculations carried out by increasing the number of decimal places, which will allow you to adjust the necessary funds that the company pays in the event of an accident.

There is also an economic effect from the application of this program: due to the use of the program, the time of direct calculations is reduced several times, which, according to experts, will reduce the cost of the work done by about 10-15%.

## 4 Conclusion

It is clear that modern methods for calculating the consequences of radiation accidents, along with these problematic issues, have a number of other shortcomings that affect the accuracy of calculations, which in turn affects the assessment of the impact of the accident, primarily in terms of calculating the dose, received by the staff. Elimination of these shortcomings and should be set as one of the main directions in ensuring security when using radioactive substances in the national economy.

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