Development of the Theoretical-Practical Model of Protection of the Means of Transport of Radioactive Materials

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Abstract. Ensuring the safety of transportation of radioactive materials is of great importance due to the presence of the potential risk of damage to people, the environment and property during transportation, loading and unloading operations and intermediate storage. This article describes the means of storing liquid radioactive waste, as well as the process of their transportation. During the study, emergency situations during the transportation of LRW were considered. A security model has been developed for the storage of radioactive materials during multimodal transport.

1. Introduction

In order to develop scientifically based requirements for the development of a security model for the transport of radioactive materials that minimizes serious consequences in the event of an emergency, it is necessary to identify the most typical scenarios for the development of emergencies during multimodal transportation. For this purpose, an analysis of statistical data on the state of transport safety and the conditions preceding the occurrence of emergency situations was carried out.

According to the UN data, the share of dangerous goods in the world cargo turnover is constantly growing and now reaches almost half of the cargo turnover. With the transport of dangerous goods associated with significant potential risks of emergency situations. The need for measures to reduce this potential to a level of residual risks acceptable to society and the state is relevant.

In the volume of cargo transported in Russia by all modes of transport, the share of dangerous goods is about 20%, or about 800 million tons. Of these, 65% comes from road transport, about 30% to rail, about 5% to river and sea transport, and about 0.1% to aviation.

The urgency of ensuring safety in the transportation and movement of cargo of radioactive materials is a major inter-sectoral problem associated with the development and implementation of a set of measures for radiation protection and minimizing the risks of emergency situations. Despite the significant decline in recent years work, emergencies and incidents with dangerous goods (EG) practically does not decrease, there are still risks accidents during transportation of exhaust gases.

The aim of the study is to develop a model for the protection of the storage facilities for radioactive materials during multimodal transportation.

The object of the study is the means of storing liquid radioactive waste in multimodal transport.
The subject of the research is the process of transportation of liquid radioactive waste storage facilities.

In accordance with the purpose of the work the following tasks are highlighted:

• Review of regulatory documents in the field of security when moving the Republic of Moldova by rail and sea transport;
• analysis of the process of moving liquid radioactive waste by rail;
• identification of the hazards of accidents, taking into account the impact of the damaging factors of accidents on personnel, population, property and the environment;
• determination of maximum dimensions of hazardous areas of propagation;
• justification of the best options for the application of technical and technological solutions, placement of LRW storage facilities
• determining the degree of danger of accidents for the selection of the safest design solutions;
• development of safety recommendations.

To develop a model of security, the most typical scenarios of emergency situations on railway roads were studied. For this purpose, an analysis was made of data on the state of transport safety and the conditions that preceded the occurrence of emergency situations.

In the complex of problems related to safety, one of the most important is the prevention of accidental damage to tanks for radioactive materials. The destruction of the boiler and other bearing elements almost inevitably leads to such consequences as depressurization, the passage of a product harmful to the environment or an explosion.

Due to the fact that the greatest danger in case of emergency situations is the depressurization of tank wagons for the transport of dangerous goods [19,22]. Depressurization can occur for the following reasons:

• through faulty or damaged plum-bulk fittings or manhole cover;
• through safety valves, due to vessel overflow and excessive thermal effects;
• through cracks of fatigue nature or through holes in the shell of the vessel (boiler), due to corrosion;
• through cracks, openings in the vessel shell (boiler) or its bottoms, caused by excessive dynamic impacts when a car collides, derails or overturns;
• through the cracks of the vessel shell (boiler) with loss of strength properties due to emergency heat exposure and excess pressure increase;
• depressurization of the vessel (boiler) during the production of plumbing operations due to the breakdown of plumbing pipelines or personnel erroneous actions.

The consequence of the depressurization of the vessel (boiler) tank wagons may be leakage or loss of the product, which can cause fire, explosion, poisoning, diseases, burns, frostbite, death of people or animals, dangerous consequences for the natural environment.

Emergency situations with tanks in the event of a fire accompanied by an explosion, are the most severe for the damage caused. An important factor in this is the time of the accident. In this case, personnel of fire or recovery trains may die or be seriously injured. Therefore, when developing a safety strategy for the transport of dangerous goods, it is necessary to consider the size of explosive methane areas. These parameters can later be used in the development of a security model, as well as in the development of methods to eliminate accidents involving fires.

2. Methods

This paper discusses the accident scenario:

There was an explosion of a tank with liquefied gas, which touched the car in which the liquid radioactive waste Co-60 was transported in a tank container (Fig. 1). The tank is a container that falls into the fire zone, where the temperature reaches 1970 °C. Due to the damaging factors of the
explosion of a tank with methane, the tank container partially burns and collapses; the container is further involved in a fire for which Type A packaging is not designed. The boiling point of Co-60 is 29 °C, and, since the packaging is destroyed, all of the Co-60 activity is involved in the methane burning cloud. Then this burning stops, and the cloud of products of combustion together with the Co-60 migrates.

Tank cars are usually used to transport dangerous goods by rail. The tank designs are presented and described in the [1-5].

A tank container is a container (Fig. 1) consisting of a frame (frame elements) and a tank equipped with drain fittings and devices for unloading, both under the action of gravity and under pressure. IMO 1 (T11-T22) Fig.1. In such a container is allowed to transport hazardous chemical media, as well as substances under high pressure. These are alkalis, acids, household chemicals, petroleum products. An overflow may be present, as determined by the properties of the liquid load. If necessary, equip with a heat-insulating layer, a system of steam or electric heating.

The tank container is suitable for safe road, rail and sea (river) transport in domestic and international traffic and for storing liquid safe and dangerous goods from the consignee. The tank container complies with the provisions of the International Convention for Safe Containers and the Customs Convention for Containers.

Was, the calculation of the maximum size of explosive methane distribution zones was calculated, using formulas (1) and (2). In the course of the decision, it was assumed that the dimensions of the explosive zones of methane distribution coincide with the sizes of the zones of its combustion products together with RM after the cessation of combustion. In the future, a cloud of products of combustion of methane from the RM is moved by the wind in a constant state. For combustible gases, the zone will be geometrically a cylinder with a base of radius R and height H, inside of which there is a source of possible emission of combustible gases.

\[
R = 7,8 \times \left( \frac{m_g}{p_g \times N} \right)^{0.33}, \quad (1)
\]

\[
H = 0,26 \times \left( \frac{m_g}{p_g \times N} \right)^{0.33}, \quad (2)
\]

where R is the radius of the explosive methane distribution zone, m;
H is the height of the explosive methane distribution zone, m;
mg is the mass of methane that entered the open space during a fire-hazardous situation, kg;
p_g is the density of the methane gas fraction at design temperature and atmospheric pressure, kg / m^3;
N is the concentration limit of the spread of methane flame.

Methane density p_g was calculated by the formula (3)

\[
p_g = \frac{M}{V_0 \times (1 + 0,00366 \times t_p)}, \quad (3)
\]
where \( pg \) is the density of the methane gas fraction, kg/m³;
\( M \) is the molar mass of methane, kg/kmol;
\( V_0 \) is the molar volume equal to 22.314 m³/kmol;
\( t_p \) – design temperature, °C.

Methane density \( pg \), calculated by the formula (3) taking into account the molar mass of methane, equal to \( M = 16 \) kg/kmol, and the calculated ambient temperature, adopted \( t_p = 35 \) °C, is \( pg = 0.63 \) kg/m³.

To calculate the radius and height of a burning methane cloud, it is necessary to determine the mass of methane released \( mg \) when the tank is depressurized. When calculating the mass of methane released \( mg \), an assumption was taken - the value of the coefficient \( k \) (the fixing coefficient, which determines the mass of \( mg \)) was taken to be 0.01. The mass of methane in the tank was taken \( m = 24,500 \) kg. Hence, the mass of methane released is \( mg = 245 \) kg, the value of which was calculated by the formula (4).

\[
m_g = k \times m, \tag{4}
\]

The minimum concentration of flammable gases and vapors in the air, at which they are able to ignite and spread the flame, is called the lower concentration limit of flame propagation (LEL).

The maximum concentration of combustible gases and vapors, at which flame propagation is still possible, is called the upper concentration limit of flame propagation (VCPR). The work presents determinated assessment methods [22]. Probability assessment methods are presented in [7,8,18,21].

3. Results

The values of the concentration limits for the propagation of the flame of methane are: \( NKPR = 2.3\% \); \( VCPR = 9.5\% \). By asking the Mathlab program to change the concentration value of N1 for methane from the minimum (LEL) to maximum (LPR) values of the concentration limits with a step of 0.001, taking \( N1 = 0.023 \sim 0.024 \sim 0.095 \), and substituting the value for N1 in formulas (1) and (2) The results of the dependence of the change in the radius \( R \) and the height \( H \) of the methane burning cloud on the change in the concentration of methane in it are shown in Fig. 2 and fig. 3.

\[ R(N1) \]

\[ H(N1) \]

**Figure 2.** Dependence of the radius \( R \) of the explosive zone of methane distribution on the concentration of methane.

\[ H(N1) \]

**Figure 3.** The dependence of the height \( H \) of the explosive zone of methane distribution on the concentration of methane N1
From presented on fig. 2 and fig. 3 graphs show that the greater the concentration of gas, the smaller the size of the explosive methane distribution zones, and the greater the likelihood of an explosion. Therefore, when calculating the sizes of the zones, the value CWCRP = 9.5% of the upper concentration limit of the propagation of the methane flame for formulas (1) and (2) was used. The size of the zones R = 121 m; H = 4 m. Calculations of methane distribution zones were performed in the Mathlab program. Measures to protect the public after an accident.

In the course of the work, measures were proposed to protect the population for the first period after the accident, which would also reduce the social risk [19,22]:

- timely notification of the population;
- reduction of time of stay of people in the contaminated area, and restriction of access to it;
- if possible, the shelter of citizens (preferably in equipped protective structures, where the level of radiation will be many times lower);
- sealing of premises to exclude the possibility of ingress of the sprayed radionuclide in residential buildings;
- use of personal protective equipment and medical protective equipment - anti-radiation drugs (Preparation B-190 from external radiation exposure, Ferrotsin - a means of preventing the accumulation and acceleration of cesium radioisotopes, the Preparation "Protection" to remove radionuclides from the skin);
- exclusion or restriction of the consumption of certain foods and water, the organization of the importation of food and drink from outside contaminated areas;
- observance of personal hygiene rules (use different hangers for clothes outdoors and indoors at the entrance to the shelter, put a basin with soapy water for washing shoes, etc.);
- decontamination of the terrain and premises, followed by monitoring; if necessary, evacuate people.

4. Discussions
The results were discussed at scientific seminars and were presented during national and international conferences.

5. Conclusion
Thus, in the course of the study, the maximum dimensions of explosive methane areas were calculated. For the territory of Russia, a wind speed of 3-6 m / s is typical. In the Mathlab program, setting the change in the distance S to which the cloud of methane combustion products moves together with the PM, with time T at wind speed Vb = 3 m / s, a dependence was obtained. It was determined that at a wind speed of 3 m / s, a cloud in 6 minutes will cover a distance of 1 km. This suggests that the situation considered when a cloud settles in a locality is quite likely. It should be borne in mind that roads can pass through settlements, and some cities are the point of formation of trains. The calculation of the distance to move the cloud, was performed in the program Mathlab.

This work will contribute to the improvement of the existing security system for the transport of cargoes of radioactive materials. The theoretical significance of the work lies in the fact that the results obtained in assessing the risk of radioactive contamination can be used in accidents similar to those considered in this work.

The practical significance of the research results is that the conclusions and suggestions can be used as an improvement in the transportation of cargoes of radioactive materials.

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