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Risk Assessment of Accidents During the Transportation of Liquid Radioactive Waste in Multimodal Transport

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Abstract. To enhance the safety of the transport of dangerous goods in tanks, the latter should improve the mechanical (physical) protection to prevent accidental damage to the boilers, such as objects containing dangerous goods directly. Damage to the boiler will almost inevitably leads to such consequences as decompression, the leakage of liquid radioactive waste and radiation pollution of the surrounding area. This article discusses scenarios accidents when overloading with marine railway transport; the explosion of gas cylinders on board the vessel. Calculation formulas are obtained to determine the speed at which the shards is provided by probabilistic the breakout a certain thickness of the tank walls. Received probability distribution function for the specified parameters shards and material barriers, which was determined by conducting a full-scale experiment. The results of theoretical studies, experiments used to improve designs of tanks carrying LRW and recommendations for improving the security of multimodal transport.

1. Introduction

In accordance with the transportation of dangerous goods terminology — radioactive material (RM) is a moving, including the use of various vehicles and its overload, since his departure from nuclear installation (item storage) and ending with the arrival of the nuclear installation (item storage). Radioactive material is a nuclear materials containing or capable to reproduce the fissile materials (substances) and radioactive substances (not related to nuclear material substances which emit ionizing radiation). As the RM are considered liquid radioactive wastes. Thus, the process of transportation includes the following stages of multimodal transport: loading RM onto a ship at the sea port (port facility); transportation of the vessel; transhipment of cargo RM from ship to rail transport; transportation by rail to destination.

To ensure the safe transport of radioactive materials by different modes of transport currently consists in the establishment of the necessary industrial regulatory framework reflecting the specificity of the sector and organizations effective departmental control. Analysis of foreign statistics showed that in the United States from 1997 to 2011 year happened 128 accidents with cargoes of RM (1 death neradiologicheskaja, 1 case of harm, damage, \$2.2 million). With all dangerous goods (og) happened 5 052 170 493 accidents (serious, 138 death 2 825 cases of injury, damage to \$635.58 million.

In the United Kingdom gives full statistics. So for 1958-2008 Gg. 913 occurred incidents during 2006-2008 Gg. 90 incidents occurred. Only three cases have been minor accidents, the rest is incorrect marking, documentation, malfunction, contamination, etc. In France for 1997-2007 biennium. happened 900 events (accidents, incidents, accidents). Adverse events occurred in all modes of

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transport (transportation, loading and unloading, the storage of packages while in transit, transshipment from one mode to another).

In the report, Rosatom in the Forum in Saint Petersburg in 2015, provides data on 33 accidents during transportation. Thus, securing transportation process maritime transport and railways, and especially when handling processes, security of transported goods, environmental security is a very important issue. The aim of the research is to increase the level of security at transportation and transhipment of liquid radioactive waste in multimodal transport. The object of the study are technical means of transport — tanks for transportation of RM in multimodal transport, and subject — processes for assessing the risk of transportation of liquid radioactive waste in tanks when accidental man-made explosions on floating nuclear thermal power stations (FNTPS).

Given that coastal and floating NAVAL and civilian spent fuel storage nuclear fleet is almost completely filled, the path to the burial of several thousand kilometres of marine and rail (fig. 1).



Figure 1. Routes of transportation RM arising from multimodal transportation.

In [2-6] are the results of years of research. "The work took place in several stages. In the first phase, an analysis of real accidents during the carriage of dangerous goods and the development of scenarios of possible developments in emergency regimes. In the second phase, analysed structural features of tanks, influencing their behavior when emergency modes and defined the parameters of mechanical or thermal effects on the boiler (vessel) tank at the time of the loss of tightness (destruction) of the boiler.

The third phase consisted in the development of scenarios of the development of "settlement" emergency situations in which it is possible to save the boiler tightness that complemented the normative documentation in designing tanks for dangerous goods. In the fourth stage modeled various modes that can lead to accidents. The study dealt with the problems of strength, stability, thermal effects, thermodynamic processes, dynamic response, taking into account the dynamics of liquid cargo, etc. accompanied by Research experiments, model and full-scale samples. If this were verified and refined theoretical models were validated designs. Next, on the basis of the developed mathematical models for studies of different modes of emergency interventions. Fifth phase included the development of means of protection against accidental impacts. In this experimental and theoretical studies have been carried out on the basis of the developed methods.

It is known that "transportation RM carried out by the railway wagon-liternymi container trains consisting of locomotives, wagons, escorts for posting armed guards and attendants, cover wagons and carriages. Routes mainly run from NPP to and Krasnoyarsk (fig. 2). For transportation RM uses the following modifications to the cars.

2. Baseline data

Estimated assessment of radiation effects is made using the following source data [19]. Volumes of LRW are: drainage capacity to-4 PCs of 8 M3 = 32 M3; draining tanks d-4 PCs of 8 M3 = 32 M3; water tank decontamination unit overload-40 M3; Bucky excerpts-3 PCs for 5.49 M3 + 1.4 m3 (s) = 17.9 m3. The weight of the coolant I contour-20827 kg. The content of radionuclides in thermal liquid (I) at the time of circuit 3 phase is given in table 1 [18-19].

Act	ivity,10 ⁴ Bq/kg					
Cor	rosion products	Fissi	ion products			The sum
⁵⁴ Mn	⁶⁰ Co	90 Sr+ 90	¹³⁴ Cs	$^{137}Cs+^{137m}Ba$	$^{144}Ce^{+144}Pr$	
		Y				40
2	2	5	8	15	8	

Table 1. Maximum volumetric activity of LRW and its dose-forming radionuclide.

Construction of storage tanks. For liquid radioactive waste according to the normative requirements of security [10, 11, 12.13] capacity for LRW consists of an outer protective shell and placed in her tank. Shell is a vertical or horizontal cylindrical container sealed with bottoms. Material-stainless steel 12x18h10t. The gap between the walls of the tank shell and is filled with special sorbent to absorb leaking liquid radioactive waste in the event of damage to the tank or to seal formed holes. The tank is equipped with a mounting for mounting the nodes in the shell. Placed in the tank level sensors LRW injection systems/plum and mixing LRW, ventilation, alarm, outages LRW intensity required when waste level sensor, as well as heating (for preheating LRW and packaging systems in operation it offline in the cold season). At the bottom of the tank is the sump to collect remnants of LRW from pipelines after discharge.

Characteristics of LRW. LRW is a predominantly mineral solutions with a total salt content of not more than 500 g/l, including suspended matter (insoluble salt and sediments) with the total salt content of not more than 100 g/l density-no more than 1.25 t/m3 pH-6-10, kinematic viscosity of no more than 2.5 centistokes. Volumetric activity waste shall not exceed $3,7*10^6$ kBq/M3 (10-4 CI/l) for α -and β -emitting radionuclides with the energy of the radiation is not more than that of 137Cs, and $3,7*10^3$ kBq/M3 (10^7 CI/l) for the rest of the α -and β -emitting nuclides. The design capacity of the dose from transported LRW, according to Sanpin 2.6.1.1281-03, does not exceed 2 mSv/h at any point on the surface of the package, and 0.1 mSv/h at any point 1 m from the packaging. Overall mass characteristics RM containers allow you to ship by rail rolling stock in sizes 02-VM GOST 9238-83, taking into account existing transportation and handling chain TUK. For example it is possible to transport in the wagon-container TC-13 with minor rework of the design of the car.

Emergency scenarios with LRW during transportation of the RM in scripted accidents lie exploration of possible hazardous effects on an object (packaging, container, etc.), as well as the surrounding Wednesday (exit and the spread of dangerous substances). As hazardous substances were considered.

When designing scenarios of accidents within the conservative approach considered the accident a third category.

Radiation effects Radiation accidents consequences in the form of receipts of LRW in surrounding Wednesday are possible with the following scenarios: partial destruction of transport packing container with LRW: fire and explosion defralgacionnom railway tank when overloading LRW from sea to rail fire in and subsequent explosion of oxygen cylinders on board the vessel during towing and parking; flooding or prolonged landing on the Rocky Shoal in storm conditions when towing along the Northern sea route.

3. Explosions of gas cylinders on board

Gas cylinders are sources of potential danger of explosion, which leads to the destruction of hull structures, failure of equipment delivered, and the emergence of a radiation accident. The explosion of cylinders may be caused by the following reasons. Violation of the integrity of the gas cylinder as a result of breakdown of any node (armature), damage or corrosion of the casing, improper operation can lead to an explosion of a cylinder at the working pressure. The probability of explosion of a cylinder (of the vessel) high pressure in this case is 10⁻⁷ 1/year [18, 19]. Exceeding the limit value of pressure in the event of a fire. For cylinders with nereagirujushhimi gas (air, nitrogen, argon) with the failure of the safety valve pressure of gas when heated increases until a blast. In cylinders with reacting gases (oxygen and acetylene) detonation may occur, resulting in a dramatic increase in pressure and explode.

Methods of evaluating the amount of destruction caused by the explosions of gas cylinders, is based on the provisions set forth in [10]. Affecting factors in the explosive destruction of the pressure vessels are shards, gas-dynamic Jet and overpressure in the emergency room as a result of the expiration of the gas from the vessel. Force the gas Jet, pouring from the vessel, with increasing distance quickly decreases and excess pressure in the emergency room because of the relatively large size of ship premises and the presence of "unloading" openings (doors, hatches, as well as the looseness of the damaged hull constructions) is not dangerous, as does not exceed the thresholds of excess pressure in the shock wave front (50 kPa). Thus, the major destruction of hull constructions and equipment are determined by influence of splinters. In the course of calculation is determined by the speed of fragments damaging the container, the equivalent thickness of a steel impenetrable barriers and the size of the area of devastation.

The study developed a model of accidents of the third category in which the impact of damaging factors on blast tanks with LRW resulted in holes in the wall of the tank. The challenge facing a researcher is to determine the minimum thickness of the wall of obstacles from a particular material, which may impair the integrity of the tank at the specified speed and configuration of the shard. For this purpose it is necessary to explore the mechanism of breaking through barriers and build a model of disruptive actions of the fragments in the explosion of gas cylinders.

Mechanism of breaking through barriers depends on many factors, among which prevail shard speed on approach to target and the ratio of the thickness of the barrier s to characteristic size fragment, for example, $d_0 = 2 r_0 - r_0$ (the radius of the spherical fragments equivalent mass). At high speeds the shard and $d_0 > s$ a powerful shock wave that occurs in hazard, reaches its opposite side and is reflected from it in the form of waves of rarefaction.



Figure 2. Mechanism of breaking through barriers fragment-the scoop on stages: introduction and bball movement with stopper.

4. Cumulative distribution function

Cumulative distribution function F(D) of this random variable is schematically represented in Figure 3. In this case, on the basis of the definition, distribution function F(D) there is a probability that a random variable D, calling the object specified effect will be smaller than a certain size. For our task in the light of the conditions of breaking through barriers (4) observations about the randomness of x values, and therefore D as well as symbol (5) the probability of breaking through barriers by a pb can be defined as the conditional probability that a random variable (D) will a value that is not greater than

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D1, i.e. pb = p ($D \le D$) = F (D1) = Dp, where F (D1) is the distribution function of the random variable (D). According to the definition of the function F (D1) is an integrated distribution law of relative values holes (D) made by shrapnel. So, with probability P = F (D1) the object will show no effects below the set (not below the specified force) [9-11].



Figure 3. Distribution law of relative values holes.

5. Recommendations

The development of a standardized tank module for multimodal transport of the RM, which can perform various tasks such as transporting a wide range of liquid radioactive waste by different modes of transport with opportunity safe overload, taking into account not only the rules for calculation and design of tank wagons [5, 6, 7, 8], but also taking into account the dependence of thickness of the tank from the probability of penetration by shrapnel.

6. Conclusion

The study examined the construction of tanks and the requirements of the normative documents applicable to transportation LRW rail and sea transport. Emergency scenarios are considered: partial destruction of transport packing container with LRW in transfer of marine to rail transport; the explosion of gas cylinders on board the vessel. Received payment formulas for determining the speed and weight of v_{lim} shard m at which break through obstacles thickness *s*, and limiting the thickness of s_{lim} barriers easily by a given mass m and velocity *v*.

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