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FORECAST MODELING OF MAN-MADE EMERGENCIES WITH MODERN METHODS

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Abstract

The article discusses the verbal and mathematical foundations of the forecast modeling of the most catastrophic emergencies of a man-made nature, such as: road traffic accidents, aviation catastrophes, explosions in buildings and structures, radiation and chemical accidents, as well as accidents on housing and utilities systems.

Keywords: emergency situations of man-made nature, traffic accidents, aviation catastrophes, explosions in buildings and structures, radiation and chemical accidents, accidents on housing and utilities systems, modeling methods.

I. Introduction

According to the degree of catastrophicity in the Russian Federation, the following emergencies can be distinguished [1,2]: road traffic accidents (accidents), aviation catastrophes, explosions in buildings and structures, radiation and chemical accidents. Given the importance for the life support of the population of municipal communities, accidents on facilities and networks of heating infrastructure and power supply systems can also be attributed to the most catastrophic emergencies [3].

II. Methods

Accidents with grave consequences, aviation catastrophes, explosions in buildings and structures

Such the most catastrophic emergencies as: road traffic accidents, aviation catastrophes, explosions in buildings and structures and some others can be studied by probabilistic statistical methods, in particular, methods of statistical data processing based on the Bayes theorem [4,5], in accordance with which:

$$P(H|e) = \frac{P(e|H)P(H)}{P(e)}, \qquad (1)$$

where:
H — hypothesis;
e — evidence;
$P(H/e)$ — A posteriori probability;
$P(H)$ — A priori probability.

In [6] a typical forecast and analytical model was proposed using the Bayes method for predicting such emergencies. Bayesian networks are used as a mathematical framework of modeling - probabilistic - graph models operating under the conditions of knowledge, intended for the study of probabilistic causal relations between events of the subject area.

In general, the process of developing a typical model based on methods using Bayes methods includes the following steps:

1 stage - meaningful setting of the problem at the conceptual level;

2 stage - training of the learning set;

3 Stage - selection of methods for processing input and output variables.

At the 1st stage, the collection of a priori information about the simulated subject area is carried out.

The features of specific territories should be analyzed: geographical position; climatic conditions; characteristics of the socio-economic system, including (people, organizational and technical systems) and the subject area (residential, public and administrative buildings, industrial and agricultural production, transport, communications, broadcasting, television, technical facilities and utilities systems, watering systems, natural resources, etc.).

When collecting a priori information about the simulated subject area, the established field of application should be analyzed: sources of occurrence; causes of occurrence; the main scenarios of the emergence and development of emergencies; the frequency (statistics) of the occurrence; consequences of impact on various protection objects; means (methods) of control and measurement; impact measures.

According to the results of collecting a priori information, the output variables should be probabilize on the basis of Bayes methods and input variables of the model. The output variables of the models are formed as hypotheses. The assessment and verification of possible events are installed. The variables should be used for indirect judgement of the events possibility corresponding to the established hypotheses.

At the 2nd stage, the training set is prepared. This is a set of structured data, reflecting the states of the input and output variables of the model, ordered by the date and time of observations.

The input variables value should be random. Variables should not changed during observations (the coordinates of measurement points, the constant characteristics of observation objects, etc.), do not affect the output variables.

An objective control system of input and / or output variables, information systems databases, the results of statistical observations of the input and variables in the past, the opinions of the experts – all these may be the sources of learning sets. Data for inclusion in the training set can be obtained using techniques and models which used in practice.

Data quality improving is achieved due to: eliminate duplicate records, contradictory and missed field values; cleaning data from noise and abnormal values; restoration of the structure, completeness and integrity of the data; transformations to installed input formats; elimination of data entry errors; adapt data to a specific task by eliminating their redundancy.

Collecting units of observation for training model should be carried out until sufficient accuracy of the probabilistic assessment of the established hypotheses is achieved. The structure of the learning set should not change during the time interval, within the framework of which the collection and analysis of the values of input variables are carried out, as well as the construction of a probabilistic statistical model on their base.

On the 3rd stage, the model is recommended to use in practice tested Bayesian methods for processing input and output variables.

For each specific model the time interval should be determined.

The obtained values of the probabilistic estimate of the hypotheses (risk - coefficients) are intended for use by relevant officials when making decisions on response to emergencies. The risk of coefficients should establish criteria in accordance with this one can identify the level of technogenic hazards. The coefficient should determine its linear trend and the time to achieve a higher level of danger regarding the current risk. Time is one of the main parameters for making a threat response solution.

Radiation accidents

The threat of an accident on a radiation-hazardous object is a combination of conditions and factors that create the likelihood of ejection or strait of radioactive substances capable of leading to mass radiation damage to people, animals and plants, as well as environmental pollution.

All radiation-hazardous facilities related to the nuclear industry of the economy can be divided into nuclear-dangerous (YAOO) and radiation-dangerous (ROO) objects.

YAOO has the potential danger of the occurrence of spontaneous chain reaction in emergency situations, when processing, storing and transporting nuclear materials. YAOO includes objects of nuclear fuel cycle enterprises: nuclear power plants of various types, enterprises for regeneration of spent fuel and temporal storage of radioactive waste, research organizations with experienced reactors and particle accelerators, sea vessels with nuclear power plants, nuclear ammunition storage facilities and polygons.

ROO includes enterprises using radioactive substances in small quantities, and products based on them (devices and installations that do not represent nuclear hazards). The danger of YAOO and ROO is determined by their possible radiation impact on personnel and the population.

At all phases of the development of emergencies, events on the localization and elimination of the accident are performed in accordance with the pre-developed plan and the resulting radiation situation after the accident. The behavior of personnel and population at the polluted territory is determined by the requirements of the IAEA, NRB-99/2009 [7], OSPORB-99/2010 [8], GOST R 42.4.02-2015 [9] and other regulatory documents.

There is no method that allow promptively in real time to carry out a reliable forecast of the radiation situation and its consequences for various types of ROO and which would be verified and standardized. Existing research techniques require the knowledge of the peculiarities of the flow of physical processes, technology and technical implementation in systems and installations of the ROO, and at the same time are limited to a number of assumptions and a small probability and accuracy of the final results.

As a standardized methodology for operational prediction of the situation during the project development, GOST R 22.2.11-2018 "The methodology for assessing the radiation situation during the projected accident at the nuclear power plant." This technique is intended to evaluate the radiation situation during the projector of the NPP with the VVER-440, VVER-1000 type reactors and RBMK-1000 by forecasting.

With regard to the prediction of radiation consequences at the enterprises of the nuclear cycle, the following guidelines are recommended:

RB-134-17 Safety Guide "Recommended methods for assessing and predicting the radiation consequences of accidents at the nuclear fuel cycle facilities" (approved by the order of the Federal Service for Environmental, Technological and Nuclear Supervision of November 16, 2017 No. 479);

RB-106-15 Security Guide "Recommended methods for calculating the parameters required for the development and establishment of standards for extremely permissible emissions of radioactive substances into atmospheric air" (approved by the order of the Federal Service for Environmental, Technological and Nuclear Supervision of November 11, 2015 № 458).

Chemical accidents

For advanced and operational prediction of infection in the case of emissions of poisonous substances into the environment during accidents (destruction) on chemically hazardous objects and transport used: "Method of predicting the scale of infection with poisonous substances during accidents (destruction) on chemically hazardous facilities and transport (RD 52.04.253-90)" [10].

This technique allows predict the scale of infection zones during accidents on technological containers and storage facilities, during transportation of railway, pipeline and other types of transport, as well as in case of destruction of chemically hazardous objects. The technique applies to the case of emission by driving into the atmosphere in a gaseous, vapor or aerosol state. At the same time, this scale depending on the physical properties and the aggregate state conditions, and calculated for the primary and secondary clouds: for liquefied gases - separately for primary and secondary clouds; for compressed gases - only for the primary cloud; for poisonous liquids, boiling above ambient temperature - only for the secondary cloud.

To predict the scale of possible chemical infection during the accidents on technological containers and storage facilities, during transportation of railway, pipeline and other types of transport, as well as in the case of the destruction of chemically hazardous objects, used "Method of predicting the scale of possible chemical infection of emergency chemically hazardous substances in cases of chemically hazardous objects and transport (application b to SP 165.1325800.2014)"[11]. The technique applies to the event of an emission of emergency chemically hazardous substances into the atmosphere in a gaseous, vapor or aerosol state.

Accidents on heat supply systems

General requirements for the organization and procedure for predicting the consequences of the disconnection of heat supply on the controlled territory are presented in [12].

The main reasons leading to emergency disconnections of heat supply on distribution power grids are [13]: natural phenomena; physical (constructive), including mechanical damage as a result of construction and repair work; actions (inaction) of the service personnel (human factor); technological disorders, including functional failures in the operation of thermal network equipment and thermal energy consumers.

In general, the process of developing this model includes: collecting source information and the formation of a basic learning set; the choice of the Bayesian classifier, the preparation of methods for analyzing and interpreting the results of statistical processing.

The main data for the formation of a basic learning set of models for a separate observed territory, are the following: the overall characteristics of heat supply systems of heat supply organizations; historical data characterizing the emergency and operation of the heat supply system as a whole; historical data of objective control of the heat supply system as a whole; data characterizing heat supply sources; historical data of objective control of the source of heat supply; data characterizing pipelines; historical data of objective control of pipelines; data characterizing thermal chambers; historical data of objective control of thermal chambers; data characterizing thermal points; historical data of objective control of thermal points; data characterizing consumers of thermal energy; historical data of objective control of buildings and structures, characterizing the parameters of heat supply consumers; data on weather stations located within the boundaries of the observed area; Historical data on the meteorological situation at the observed area.

When choosing a Bayesian classifier, it is necessary to take into account that the classification algorithm must be optimized for processing a large amount of input and output data. A probabilistic assessment using the chosen Bayesian classifier is subject to hypotheses given in [12]. The main types of crisis situations and / or incidents associated with the disconnection of heat supply and the directories of individual observed parameters are presented.

Accidents on power supply systems

General requirements for the organization and procedure for predicting the consequences of turning off the power supply on a controlled territory are given in [14].

The main reasons leading to emergency disabling power supply on distribution power grids are [15]: natural phenomena; network overload; Functional failures; human factor; mechanical damage.

In general, the process of developing this model includes the steps described in the previous subsection.

The main data for the formation of a basic training set of the model, are the following: historical data characterizing the emergency room on the power supply; data characterizing the power grid organization; data characterizing the power centers of distribution electrical networks; data characterizing the sections of the supply air (cable) lines; data characterizing 6-10 kW camshafts; data characterizing the section of the supply air (cable) lines from the distribution device to the consumer distribution point; data characterizing the consumer distribution point and the main reduction substation of the enterprise; data characterizing the distribution (cable) line from the distribution point to transformer substations; data characterizing distribution reductions transformer substations of the power supply; data characterizing cable lines with a voltage of 0.4 kV from the transformer substation to the introductory and distribution devices; data characterizing input and distribution devices; data characterizing consumers of electrical energy; historical data characterizing the consequences of emergencies; data on weather stations located within the boundaries of the observed area; historical data on meteorological setting.

At the same time, the probability of trouble-free operation of objects (sections) of distribution power grids (P(t)) should be determined by the equation:

$$P(t) = \frac{N_0 - n(t)}{N_0} = 1 - \frac{n(t)}{N_0}, \tag{2}$$

where:

N_0— the number of objects at the beginning of the test;

n(t) — the number of refusal objects for the observable time.

The probability of trouble-free operation of objects (sections) of distribution power grids ($P(t)$) is allowed to be determined by the formula:

$$\mathrm{P}(t) = \mathrm{e}^{-\omega t}, \tag{3}$$

where: t — settlement period, years;

ω — parameter of the failure of objects (sections) of distribution power grids, 1 / year.

A probabilistic assessment using the chosen Bayesian classifier is subject to hypotheses given in [14]. There are also presented the main types of crisis situations and / or incidents associated with the disconnection of power supply, and the directories of individual observed parameters.

III Results

Thus, this article presents the verbal and mathematical foundations of modeling the most catastrophic emergencies of a technogenic nature, such as: road traffic accidents, aviation catastrophes, explosions in buildings and structures, radiation and chemical accidents, as well as accidents on housing and utilities systems.

IV Discussion

The verbal and mathematical foundations of the forecast modeling of the most catastrophic emergencies of a technogenic nature are actively discussed in recent years on the pages of scientific literature [1, 2, 4, 5]. Classic mathematical models for predicting emergency situations of a technogenic nature are described in [16 - 20].

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