Management of information processes under a radiation emergency

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Abstract. The article provides examples of radiation emergencies (ES), emergency response measures aimed at protecting the public and territories, including applicability of a comprehensive monitoring system of the public security conditions. A special attention is paid to scientific approaches and research results aimed at optimization of information processes during the operational use of data from monitoring systems on the conditions status under radiation emergencies. Besides, the expediency and sufficiency of using two data sources producing reports was determined and justified if one of the data sources is a monitoring system. Based on the research results, other provisions concerning the management of information processes under radiation ES conditions related to the requirements for operational public notification were justified. In particular, schemes for constructing such systems under special radiation ES conditions, algorithms for their operation, operating modes, and some parameters that these systems should provide with were justified. The information subsystem as a part of the CSPPCM is a kind of information system for the prompt public notification, and the research results are quite relevant for it.

1. Introduction
The nuclear and energy industry development, as well as the widespread use of radioactive sources in industrial areas and medicine, has not only improved the quality of human life, but also has created new technogenic risks associated with the radiation accidents (RA) onset, radioactive substances (RS) release incidents and environmental pollution. Four grave radiation accidents have happened since NPP started operating: Windscale (UK, 1957), Three Mile Island (USA, 1979), Chernobyl (USSR, 1986) and Fukushima Daiichi (Japan, 2011). For the benefit of the public and environment protection from radioactive contamination, it is necessary to consider various types of RA: accidents at nuclear and power installations, industrial facilities, research and medical facilities, with unattended sources, and other accidents. Radioactive contamination of the environment becomes a substantial environmental factor that affects people health and living conditions in the territories exposed to radioactive contamination, leads to significant economic damage and long-term negative consequences of a socio-economic and political nature [1, 2, 3].
Radiation accidents belong to the category of emergency situations (ES), where decisions on possibility of conducting or continuing previously initiated emergency response measures are built on the results of radiation investigation and received data with regard to the levels of RS in the surrounding environment and the following estimation of doses of the population external and internal exposure. At the same time, the efficiency, reliability and completeness of investigation and monitoring data are important, which enable the proper assessment of the radiation conditions and adequate decision-making with regard to the response to the developed situation. The radiation monitoring systems installed at nuclear fuel cycle facilities and in territorial components of the economy play a key role.

Collection of reliable information for effective decisions making purposes is determined by the availability and equipment status of monitoring systems, as well as the minimum required time for obtaining information. As practice shows, the minimum time to obtain reliable data on a radiation ES is up to 1.5 hours if complete monitoring system is used, and more than a day is required without it.

For example, during the accident at the Mayak production association in 1957, when a chemical explosion occurred in a storage tank for highly active liquid radioactive waste, data on the real scale of the consequences of the accident was obtained late, in facts, more than 3 days after the accident. The lack of operational and reliable information on the level and nature of radioactive contamination did not allow prompt implementation of protective measures [4, 5].

Unfortunately, the accident at the Fukushima-1 nuclear power plant in 2011 did not take into account the experience of previous ES, including Chernobyl. The lack of proper coordination of work among the various elements of the emergency response system left the officials responsible for making decisions at the initial period of emergency without adequate assessments, forecasts and recommendations on protection measures, and left the public without prompt and correct notification on the developed and predicted status of the ES. Effective measures such as notification on the measured values (dose loads on personnel, the population and the environment) and predicted radiation doses, as well as the ratio to certain health hazards have not been taken with regard to notification of decision-makers (and the population in general) to take reasonable protective measures. The experience of ES recovery demonstrates that the elimination of public anxiety may be helpful for mitigation of the radiological and non-radiological accident consequences [6].

If there is a radiological ES, the damage and consequences gravity are determined not only by the impact of ionizing radiation on the human body, but also by non-radiation factors. In radiation-hazardous situations, even if the radiological risks are insignificant, the heightened perception of these risks by the public, as well as the officials responsible for decisions on public protection measures, is a specific factor of vulnerability in the socio-economic sphere. This imposes special requirements for a precise assessment of the developing ES, adequate and timely response, as well as effective and competent public notification.

The basic measures aimed at preventing and eliminating the consequences of RA are carried out in the mode of daily activities, high-alert mode and ES mode, taking into account the features and requirements for ensuring radiation safety [7].

In terms of the rapid development of the information society, there is a real need to change approaches and methods of information handling, especially under threats and ES conditions. The main goals of the public notification system development of EMERCOM of Russia are: operative delivery of the information on public and territories security issues both during daily activities and under high alert conditions regime, threats or evolving ES to the public in due time; ensuring providing the information of maximum accuracy and reliability and maintenance of public trust towards the executive state bodies under the crisis case conditions, including the timely recognition of the spread of unreliable and false information and its prevention; ensuring targeted information delivery – the ability to provide information to both general population and certain target audiences.

IT development has led to new approaches to notification and informing on a threat or ES. Formerly the public used to obtain information through official media primarily, currently the speed of dissemination of information and the ability to obtain it, including not entirely reliable, has increased
significantly. In this regard, it should be noted that there was quite an acute public resonance in the far Eastern Federal district of Russia to the Fukushima-1 nuclear power plant accident, although the distance to the station of accident was more than a thousand km. Due to prompt public informing actions, which were taken by representatives of EMERCOM of Russia and Rosatom State Corporation jointly with the media, based on the forecasts of the ES development made on time, it was possible to stabilize the situation [8].

Immense capacity of opportunities for the global community to disseminate information must be taken into account when responding to ES. Management of information processing under radiation ES should be based, first of all, on sufficient volume of timely reliable information about the conditions status for its adequate assessment and generation of right decisions regarding the response to ES and public protection. Obtaining, processing and delivery of reliable information to users in due time is one of the key factors of ensuring the public life security and the safety of material assets at prevention, occurrence and elimination of ES stages [9].

2. Materials and methods

The data obtained solely by monitoring system cannot be used for the purposes of resolving the issues on providing information to the public and to the officials which are in charge of decision-making activities under ES. Information from other sources is also to be used, including those that are usually less reliable than monitoring systems.

The considered information processes are presented as an algorithm in Figure 1.

In fact, for the purposes of information collection about ES in general a number of sources can be used. They can be divided into three types: monitoring systems; open sources such as media, social networks, press; information systems of interacting agencies, including organizations in the scientific and technical expertise, internal systems of SUSPRES and INTERCOM of Russia, law enforcement and other agencies involved.

A number of studies on management of information processes under ES conditions were conducted. The mathematical model of the processes of data on ES collection and processing is based on the hypothesis theorem (Bayes formula), which was adapted to the specified terms with a number of other mathematical dependencies [10].

During the research, a posteriori probabilities of radiation ES condition status were determined. Based on a number of conditions and initial data these probabilities were determined, including: a priori probability of a radiation ES condition status, which was determined by using the results of predictive assessments of expert modeling tools; characteristics of data collection tools, first of all, conditions monitoring systems and means of transmitting and receiving messages within data collection process, including using the theory of reliability; use of automated data processing technologies.

The research was carried out according to the developed methodology and was aimed at optimizing information processes and justifying the requirements for the systems used for the population and officials making decisions under ES informing and notification purposes.
Figure 1. Algorithm of information processes under ES conditions: ARMS is automated radiation monitoring systems, CSPPCM is comprehensive systems of the public protection conditions monitoring, ARCSPIN is all-Russia comprehensive system of public informing and notification, SUSPRES is State Unified System of prevention and response to ES.

3. Results and discussion
As the example, some options of radiation ES calculation by using monitoring systems and other sources as data sources are given. A variant to specify the condition status under an ongoing ES is given.

Two data sources and three data sources options are provided. To study the influence of erroneous reports from sources, the combinations when all messages are correct and when messages are contradictory were calculated. Data received and provided by the monitoring system and other sources on the condition status are designated as reports. These reports may be correct and correspond to the
parameters of the conditions, considering the specified errors. They may also be incorrect due to various reasons.

Two options are considered: the first is when the monitoring system and another source are used as the source of information on conditions status; the second is used when the monitoring system and two other independent sources of information are used.

When a monitoring system and another source are used:
1 combination ++, this means that both reports from the sources are correct;
2 combination + -, means that sources’ reports are inconsistent, where the monitoring system gives the correct report; the second source gives the wrong report.

Preliminary a priori probabilities of an ES conditions status are determined by using predictive estimates obtained by systems for predicting the evolving radiation-related ES. Initial probabilities for the forecast are:
- the probability of correctness of the conditions forecast \( P_s(\text{Xe}) = 0.7 \);
- the error probability in the conditions forecast \( P_s(\text{Xn}) = 0.3 \).

The probabilities of receiving and providing correct and erroneous reports about conditions status by monitoring systems and other sources are determined based on the characteristics of these sources, means of transmitting information, as well as by using calculation methods from the theory of reliability [11, 12].

In the variants considered above, to achieve a more correct result, the probability parameters for sources were set within a range of two values.

Situation monitoring system is:
- probability of a correct report \( P(Ce/\text{Xe}) = 0.95; 0.9 \);
- probability of an erroneous report \( P(Cn/\text{Xe}) = 0.05; 0.1 \).

Other data sources are:
- the probability of a correct report \( P(Cn/\text{Xe}) = 0.7; 0.6 \);
- probability of an erroneous report \( P(Cn/\text{Xe}) = 0.3; 0.4 \).

The results of determining a posteriori probability of the conditions status \( P_k(\text{Xe}/\text{S}) \) for the considered variant are shown in Table 1.

| Name                        | Values | Average |
|-----------------------------|--------|---------|
| 1 source: Monitoring system | \( P(Ce/\text{Xe}) = 0.95 \) | 0.9     |
|                            | \( P(Cn/\text{Xe}) = 0.05 \) | 0.1     |
| 2 source: Other data source | \( P(Ce/\text{Xe}) = 0.7 \)  | 0.6     |
|                            | \( P(Cn/\text{Xe}) = 0.3 \)  | 0.4     |
| 1 combination ++            | \( P_k(\text{Xe}/\text{S}) = 0.990 \) | 0.985   |
| 2 combination + -          | \( P_k(\text{Xe}/\text{S}) = 0.950 \) | 0.967   |

When using the monitoring system and two other sources: 1 combination ++, all reports are correct; 2 combination ++ --: reports are inconsistent, the monitoring system and the second data source provide the correct report, the third source gives an erroneous report; 3 combination + --, the monitoring system gives the correct report, the second and third sources give erroneous report.

A priori probabilities of the conditions status, as well as the values of the probabilities of correct and erroneous reports for the monitoring system and for the second data source were taken in the same way as above. And for the third data source it was: the probability of a correct report \( P(Ce/\text{Xe}) = 0.7; 0.6 \); the probability of an erroneous report \( P(Cn/\text{Xe}) = 0.3; 0.4 \).

The results of determining a posteriori probability of the conditions status \( P_k(\text{Xe}/\text{S}) \) according to the variant for the monitoring system and two other data sources are shown in Table 2.
| Name                  | Values            |
|-----------------------|-------------------|
| 1 source:             | 1P(Ce/Xe) = 0.95  |
| Monit. system         | 1P(Cn/Xe) = 0.05  |
| 2 source              | 2P(Ce/Xe) = 0.7   |
| 2P(Cn/Xe) = 0.3       |
| 3 source              | 3P(Ce/Xe) = 0.7   |
| 3P(Cn/Xe) = 0.3       |
| 1 comb. + + +         | Pk(Xe/S) = 0.996  |
| 2 comb. + + -         | Pk(Xe/S) = 0.978  |
| 3 comb. + – –         | Pk(Xe/S) = 0.891  |
| Average values        |                   |
|                      | 0.95 0.95 0.95    |
|                      | 0.05 0.05 0.05    |
|                      | 0.7 0.7 0.6       |
|                      | 0.3 0.3 0.4       |
|                      | 0.7 0.7 0.7       |
|                      | 0.3 0.4 0.3       |
|                      | 0.990 0.991 0.991 |
|                      | 0.994 0.997 0.997 |
|                      | 0.990 0.997 0.997 |
|                      | 0.987 0.987 0.987 |
|                      | 0.970 0.970 0.970 |
|                      | 0.955 0.955 0.955 |
|                      | 0.931 0.931 0.931 |
|                      | 0.903 0.893 0.893 |

4. Conclusion

Some conclusions were made based on the results obtained. The calculations results analysis showed that in the considered ES, when the monitoring system is used as a data source, it is advisable to rely on forecast data and data from the most reliable source, such as the monitoring system, when determining the conditions status. In the case of two data sources, even if an erroneous report is sent from the second one, the probability of correctly determining the state of the situation will not be lower than 0.938.

When using three sources, the probability of a correct assessment of the situation, even if the forecast is of low reliability and there are conflicting data from the second and third data sources for the average parameters, will be high and at least 0.889.

This article presents only two options, and a number of options for the studied combinations in a reasonable range were examined within surveys which allow to justify the priority of using automated monitoring systems as a data sources on the conditions status under radiological ES. Besides, the expediency and sufficiency of using two data sources producing reports was determined and justified if one of the data sources is a monitoring system. Based on the research results, other provisions concerning the management of information processes under radiation ES conditions related to the requirements for operational public notification were justified. In particular, schemes for constructing such systems under special radiation ES conditions, algorithms for their operation, operating modes, and some parameters that these systems should provide with were justified. The information subsystem as a part of the CSPCCM is a kind of information system for the prompt public notification, and the research results are quite relevant for it.

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