Computer technology for waste management for Chernobyl remediation

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Abstract The computer technology (CT) for modelling of the ecology-economic situation in the alienation zone (AZ) of Chernobyl is developed. It includes the databases of potentially dangerous objects and program modules (PM) for modelling of the ecology-economic situation in the AZ. The optimal redistribution of means, directed at resource restoration, liquidation of technogenic pollution, the restoration of basis capital, prevention of pollution migration for bounds of the AZ is determined by use of this model. A distinctive feature of the accounts carried out in this work is that they allow the estimation not only of risk value, but also of levels of reserve possibilities of various objects of the AZ. The critical values of measured parameters, at which achievement the emergencies can occur, are also determined. The CT includes the following program modules: geo-information system; PM for risk assessment of emergency occurrences in the AZ; PM for dynamic optimisation tasks.

Introduction

The radiation pollution of territory caused by the Chernobyl catastrophe has resulted in the occurrence of ionising radiation sources in the Chernobyl alienation zone (AZ). This renders long-term effects on the environment, and on man. The efficiency of measures, connected with liquidation of consequences of this pollution in many respects depends on the following factors:

- validity of distribution of means on the various tasks connected with the decreasing risk of extreme situations (ES);
- entirety of environment state monitoring and due decision making at its deterioration;
- accuracy of cost-benefit analysis that allows optimal using means, directed on decrease of ES risk on potentially dangerous objects (PDO).

The Ukrytie (OU) or “sarcophagus” is the most important potentially dangerous object (PDO), where great qualities of radioactive materials are located.

For due and reasonable decision making on the ecological and technogenic safety control of the Chernobyl AZ it is necessary to take into account all of the
above-mentioned factors. However, for their system analysis the creation of appropriate computer technologies (CT) is necessary. They will ensure that administrative staff have the operative information needed for working out effective paths of technogenic safety control on the PDO and the liquidation of ES consequences.

The necessity of development is caused now by absence of techniques oriented on the determination of dynamic invariants, permitting the estimation of a balance of separate regulation mechanisms of ecological systems. Traditional methods and means of collection and data analysis about environment state, antropogeneous load, industrial activity for a prediction of ES occurrence risk and working out effective paths of liquidation of their consequences, cannot ensure operations with the required information control organisations. In this respect there is a necessity to rise the reliability of forecasting possible ES by the creation of effective methods of information analysis about the environment with the help of mathematical models.

The objective of this work is the creation of a similar system allowing the co-ordination in a uniform information field of various technological chains of safety control on PDOs.

**Computer technology for optimum control of safety in Chernobyl alienation zone**

CT for optimum safety control in AZ includes the following program modules (PM):

1. Geo-information system, which allows the receiving of necessary data of ecological monitoring (allocation of radionuclides in AZ, pollution squares belonging to a given range of radionuclide concentration, the information about objects of economic activity and natural resources).

2. A program module (PM) for risk account of ES occurrence in AZ, connected with violation of ecological and technogenic safety. Risk determination is carried out with the help of totality of the following parameters:
   - money equivalent of funds in AZ;
   - money equivalent of funds made in AZ;
   - environment pollution level;
   - volume of production capacities ensuring binding of pollution;
   - flow of budget means directed on realisation of measures, connected with maintenance of appropriate level of safety in AZ and liquidation of consequences of Chernobyl catastrophe.

3. A PM for a dynamic tasks solution. The dynamics of variables describing ecological and technogenic situation in AZ is determined with the help of this PM. It also permits to research the dependence on these variables of following parameters:
• costs that characterise reproduction of pollution binding units, pollution clearing units, funds and preventing of pollution migration outside the AZ;
• periods of fund wear, pollution destruction, pollution generation;
• values of invested funds, capacities of pollution binding, pollution flow outside the AZ, capacities of pollution binding.

(4) A PM for solution of the optimum control of the following tasks:
• risk minimisation;
• decrease of pollution level;
• minimisation of outflow of pollution from AZ;
• maximisation of a level of funds.

(5) A PM for solution of problems connected with using an effective means for a support of a desirable level of ecological and technogenic safety in AZ.

(6) A PM for risk account of diseases for AZ staff depending on ecological situation and level of health services.

CT is intended for determination of the following variables:

(1) Optimal means distribution between various directions of economic activity in AZ to minimise risk of technogenic and ecological ES.

(2) Dynamics of pollution and decreasing level of expending means, which are allocated on territory rehabilitation.

(3) Optimal script of rehabilitation measures:
• division of a zone into an optimal amount of sites to increase efficiency of land rehabilitation in terms of economic activity and to decrease danger of pollution flow outside the AZ;
• determination of ranges and time intervals for decrease in pollution in each of the allocated sites, at which the greatest efficiency of expenses of allocated means will take place.

(4) Dependence between changes of an ecological situation and health services level, on the one hand, and risk of AZ staff diseases, on the other hand.

(5) Optimal dynamics of funds allocation, which are necessary for health services support on a level, ensuring the acceptable risk value of diseases in AZ.

The following algorithm of objective achievement is offered:
• Determination of the optimal level of means necessary for territory rehabilitation and decreasing total pollution level in AZ.
Division of AZ into an optimal amount of sites and determination of pollution level with the help of geo-information systems in initial time moment, and the territory of each.

Determination of optimal ranges of a decrease in pollution concentration on each site appropriate to some dynamics of total decrease of pollution level and its expense.

The results of some calculations obtained with the help of CT are presented in Figures 1-2.

The map of Sr-90 allocation in AZ is presented in Figure 1.

These data are entered into a dynamic model, which permits the solving, prognostication and optimisation of tasks. Their results are presented in Figure 2. The curve 0 corresponds to prognostication task solution without controls. The curve 1 corresponds to the optimisation task, connected with ES risk minimisation. The curve 2 corresponds to the optimisation task, connected with funds maximisation and following variables minimisation: ES risk, environment pollution level in AZ, the outflow of pollution from AZ.

The dynamics of control actions appropriate to optimisation task solution are presented in Figure 3.

Problems of ES risk estimation on the object “Ukrytie”

According to generally accepted notions, nuclear energetics makes the following demands to safety of its objects:

- the safe construction and quality of PDO;
- appropriate maintenance of PDO, minimising risk of emergencies;

Figure 1. The map of Sr-90 allocation
Figure 2. Results of model experiments
The majority of experts working on the problem of liquidation of the Chernobyl accident consequences consider that OU does not answer the above-mentioned conditions and represents the greatest threat for nuclear safety among all objects that are in the Chernobyl AZ (Kupnyi, 1999).

The following factors make the main contribution to such an unsuccessful situation:

- progressing wear of building constructions of OU;
- destruction processes, proceeding in fuel-containing masses (FCM);
- plenty of easily inflammable materials in OU that cause the threat of fires.

Mass gush of a radioactive dust outside the OU will take place with disastrous radiation consequences in case of ES occurrence, caused by any of the above-listed reasons, namely:

- disturbance of the OU shell (including the destruction of carrying constructions and roof);
- transition of radionuclides from the binding state to sliding dust particles;
- gush of aerosols.
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The values of parameters, characterised as a state of FCM, contained in the OU, and its shell state, are constantly varying. In these conditions the task of decreasing the degree of uncertainty with regard to the estimation of the state of the OU becomes of prime importance. It is due to the creation of automated technologies of estimation and ranking of risks on the basis of methods of mathematical modelling. In numerous works connected with various aspects of the Chernobyl catastrophe risk estimation is based on the application of probability theory methods. Thus the authors should meet with difficulties of authentic probability estimation not only because of the incompleteness of the sample, but also more often because of the complete absence of the information, owing to the impossibility of taking measurements in some premises of the OU which are inaccessible because of a high radiation level. Besides, there are some methodological difficulties stipulated first of all by uniqueness of the event – accident on NPP, by virtue of which it is impossible to calculate probability of the event on the basis of statistical data processing (Kupnyi, 1999; Kopchinsky, 1997; Sergienko et al., 1997).

In the works of Sergienko et al. (1997), Yanenko (1999) and Atoyev et al. (1998) another approach to risk estimation was developed. It is based on the methods of theory of catastrophes. The risk is estimated on a degree of approximation of system parameters to their bifurcation values, which characterise system transition from one state (norm) to another (catastrophe). The realisation of this approach allows not only the estimation of the risk of ES occurrence, but also the receiving of the quantitative characteristic of reserve possibilities of the system and its components.

The obtained calculations allow the description of the current state of the system by ranking the set of risks of ES occurrence into their separate links, and by that finding the “weakest” link, the strengthening of which is necessary to direct main efforts.

By using this method, the probability account of OU roof collapse will be based on the parameters of separate elements of building construction most sensitive to earthquakes, tornadoes and other natural cataclysms, which are close to critical values (exhaust tower of the block “C”, supports of beams B1 and B2, southern shields – between axes B-C, western zone of OU).

Risk estimations of ES occurrence in a zone of alienation of Chernobyl NPP

In work (Atoyev, 1999) on the universal deformation of the theory of catastrophes (UDTC), the butterfly was used to research the safety of the system subject to the effect of internal and external factors. This system, described in a similar way, has three steady states. First, it is characterised by external and internal safety. Second – by external safety (the internal safety is broken). Third – by full loss both internal and external safety.

We use this approach for risk estimation of ES occurrence in Chernobyl AZ. Let us consider that the first steady state of the system corresponds to a regular
situation in AZ. Second – occurrence of some local ES, which do not result in a growth of radiating pollution levels outside of the AZ. Third – ES occurrence which results in growth of radiating pollution level outside of AZ.

Let us base this on representations (Kupnyi, 1999) that the threat of AZ safety disturbance is connected on the one hand with a state of elements of building constructions in the OU (parameter A), and on the other hand, with destruction processes, proceeding in FCM (parameter B).

The safety level also depends on flows of radionuclides from different sources in the AZ territory, which are transferred by water, air, biogenic and technogenic paths (parameter C) (Kholosha et al., 1999). Let us suppose that the level of these flows depends on a state of various protective systems. They are the dams, technical devices for preventing migration of pollution outside the AZ, fire-prevention appliances and systems of radioecological monitoring.

The human factor also influence the safety level. By estimating this we should take into account the level of professional abilities of staff (which means that AZ workers have passed careful professional selection) and the social component (parameter D).

According to Atoyev (1999) safety levels ($X$) is described by the following equation:

$$\frac{dX}{dt} = X^5 + AX^3 + BX^2 + CX + D,$$

We shall estimate the coefficient $A$ with the help of parameters characterising the state of following parameters:

- a support of beams B1 and B2;
- a western zone of AZ;
- a southern shields between axes B-C;
- exhaust tower of the block “C” (Kupnyi, 1999; Krivosheev et al., 1999).

The observations of appropriate block offsets can help us to determine these parameters. For instance, the risk destruction was calculated in Kupnyi (1999) for building constructions of the OU’s “sensitive” zones. This result also can be used for an estimation of the parameter $A$.

The observation of parameters, characterising a current state of FCM congestion, radiating effect of accident consequences on staff and slowly proceeding processes of interaction between the object and environment shall help to estimate the coefficient $B$.

The first group of these parameters includes: density of neutron stream (DNS), power of an exposition doze (PED) of $\gamma$-radiation, temperature in different premises of OU, volumetric activity of air, gushing out in vent-pipe through by-pass of exhaust ventilating system of OU. These results are received with the help of monitoring systems and diagnostics of OU state (Kupnyi, 1999).

The second group includes:
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- power of γ-radiation dose in places of production in OU;
- activity of air tests on α- and β-aerosols;
- activity of water tests in premises.

The third group includes:
- PED of γ-radiation on OU roof;
- specific activity and radionuclide structure of water tests in observant drill-holes.

We shall estimate the coefficient C with the help of the following parameters:

1. Radionuclide flows from different sources in AZ, which are transferred by water (river drain, carrying out Prpypat river, a drain with filtration waters from a reservoir-cooler), air, biogenic (migrating birds, small and large mammals, blood-sucking mosquitoes, dragonfly and other insects) and technogenic paths (vehicle, staff, cargoes) (Kholosha et al., 1999).

2. Power of various protective systems which include:
   - the system of gadolinium solution feeding in central hall of the 4th block;
   - the dust suppression system (DSS) of the OU;
   - the system of water pumping out from the lower marks of the OU;
   - the technological system of exhaust ventilation and gas-refining;
   - the system of cooling of the underfoundation plate, dams, technical devices for the prevention of pollution migration outside of the AZ and radioecological monitoring in the AZ;
   - fire-prevention devices;
   - dams and other systems of flood prevention.

We shall estimate the parameter D with the help of data describing labour payment and work conditions, adoption of new technologies and managing methods, foreign investments, inflation level, rates of taxes, level of credits, level of unemployment, minimum size of salary, timeliness of labour payment, living-wage level.

The ranges of parameters which correspond to various amounts of steady states of a polynomial (1) can be determined. Bifurcation values of parameters can also be determined, at which there is a change of number of steady stationary states and transition of the system from one state to another.

Let the system be at norm (state 1). There are trajectories of change of its parameters, which pass the system at first in state 2 (local ES, not causing pollution growth outside of AZ), and then in state 3 (ES, which result in pollution growth outside of AZ). Also there are trajectories immediately passing the system from state 1 to state 3.
If the initial state of the system corresponds to state 2 or 3, the trajectories that return the system to state 1 (normalisation of ecological-radiation situation) can be determined. The task of optimum control can also be formulated to minimise the time of output from crisis and resources used at it.

For risk account the algorithm (Atoyev, 1999) can be used:

1. the values of parameters (1), adequate to current state of system, are determined;
2. the array of their bifurcation values is determined;
3. the 4th dimensional vector of distance from an initial state of the system up to surfaces, which divide parameter areas corresponding to different number of stationary states (1) is determined;
4. the risk value is determined as the ratio of this vector to a vector describing appropriate distances in norm. In this case risk is determined as follows:

$$\text{RISK} = \frac{R^{(4)}}{R^n}$$

The coefficients of a polynomial (1) can be determined as mean-square deviations from norm of above-mentioned parameters.

The results of the comparative risk analysis obtained in Kholosha et al. (1999) and with the help of the method shown are given in Tables I and II.

Here $R_i$ and $S_i - (i = A, B, C, D)$ accordingly risks and reserves of appropriate protection systems in AZ. The account of parameters A, B, C, D was carried out with the help of data (Kupnyi, 1999; Kholosha et al., 1999, Krivosheev et al., 1999).

After analysing Tables I-II it is necessary to note that the data given in them are obtained as a result of accounts of different techniques of risk estimation. Some have only probability interpretation (for example risk estimation of fires), others are based on techniques of risk estimation for the destruction of constructions, and others take into account not only probability, but also the significance of each potential source of ES (Kholosha et al., 1999). Therefore only the ratio between the contributions of separate objects in AZ can be compared.

As follows from Table II, flows of radionuclides from various sources in AZ give the greatest contribution to radiation danger, whereas the risk from accident of building constructions in OU is much lower (Kholosha et al., 1999).

<table>
<thead>
<tr>
<th>Research State</th>
<th>ES type</th>
<th>Risk</th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Norm</td>
<td>Transition to state 2</td>
<td>0.53</td>
<td>0.3</td>
<td>0.7</td>
<td>0.03</td>
<td>0.9</td>
</tr>
<tr>
<td></td>
<td>Transition to state 3</td>
<td>0.33</td>
<td>0.2</td>
<td>0.8</td>
<td>0.01</td>
<td>1.1</td>
</tr>
<tr>
<td>2 Norm</td>
<td>Transition to state 2</td>
<td>0.45</td>
<td>0.3</td>
<td>0.7</td>
<td>0.04</td>
<td>0.7</td>
</tr>
<tr>
<td></td>
<td>Transition to state 3</td>
<td>0.67</td>
<td>0.2</td>
<td>0.8</td>
<td>0.01</td>
<td>0.8</td>
</tr>
</tbody>
</table>

Table I.
The accounts performed on the basis of a technique offered in this work also testify about prevalence of risks connected with radionuclide flows from different sources in AZ, and also with change of capacities of various protective systems. However, as the analysis carried out shows, risks connected with building construction accidents in the OU are also great.

A distinctive feature of the accounts carried out in this work is that they allow the estimation not only of risk value, but also of the levels of reserve possibilities of various objects in AZ, and in addition they determine critical values of measured parameters, at which emergencies can occur.

The offered approach permits not only the ranking of various objects in the AZ by their contribution to formation of emergencies, but also the estimation risk dependence on parameters characterising social sphere (social intensity in AZ).

References


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