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ENVIRONMENT PROTECTION

MODEL MONITORING AND EVALUATION OF RADIOACTIVE CONTAMINATION

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The present paper provides the methodology of monitoring and evaluation of dynamics of radioactive contamination from radioactive waste depositories, which supposes the wide application of the fuzzy set theory results, heuristics and risk-oriented management. The developed technique is based on hybrid modelling and data mining principle and provides effective control operations, realises appropriate environmental monitoring, assures trustworthy of decision making in situations of noise, ambiguity and misrepresented data.

Keywords: *decision making, fuzzy set, heuristics, metrics, model monitoring, radioactive contamination*

1. INTRODUCTION

The problem of storage of radioactive waste is related to the necessity of defence of environment from distribution of radioactive contamination (RC) for the scopes of depositories. Migration of RC can be caused by two factors: diffusive processes, which are characterised by extraordinarily low speeds of flowing, and direct loss from depressurisation of containers caused by the consequences of natural calamities, failures or assassinations. Monitoring of RC migration should include the following activities: determination of level of contaminations in the set (critical) points, such as qualifier wells on the scopes of depository of radioactive waste (RW), tests of air and soil on directions from a depository to the dwelling arrays, areas of rest, etc., comparison of values of contamination with the possible levels and with the levels of contamination of previous supervisions, calculation of trends, rule-making in relation to the further fate of depository (its exploitations, closing or creation of artificial protective barrier with the purpose of deceleration of RC migration).

The problem of the effective monitoring of RC is complicated due to the necessity to control the levels of contamination, which barely exceed the thresholds of sensitiveness of measuring devices, to reduce the amount of drawn samples and ambiguousness of the estimation of results. Such a procedure does not allow exposing the fact of migration of RC at the initial stages of situation. Therefore, there is a necessity to apply such approaches which allow determining motion of «spot» of RC even in similar terms.

Model monitoring of possible migration of RC, taking into account the processes of diffusion, filtration and real conditions of environment, in the affected depositories of RW zones is widely used at present time [1]. In addition, methods, being based on the use of Bayes' theorem, get wide distribution for those cases, when it is necessary to operate with the limited retrieval of data, the laws of their distribution are unknown a priori [2]. Finally, the methods of the fuzzy set theory are used, when the implementation of the probed variables can be described with the use of linguistic estimation, rather than analytically [3]–[5]. However, much of all in-use methods and approaches have one failing: they possess low sensitiveness in the conditions of normal exploitation of depositories of RW and do not allow exposing the dynamics of "spots" of contamination at the initial stages of catastrophic situations.

2. ESTIMATION OF RADIOACTIVE CONTAMINATION DYNAMICS

The aim of the research is to develop and justify an approach of objective estimation of the contamination distribution tendencies in an environment at the early stages, when changes are within the limits of fluctuations of natural background and threshold of sensitiveness of measuring devices and methods, but the presence of external factors allows supposing the latent phase of RC migration process.

As established above, monitoring is carried out under the condition when the speed of RC migration in an environment is very small. However, in case of catastrophic phenomena all changes are determined, as a rule, not after the exposure of considerable concentration of contamination (that can be already too late for making important management decisions), but on the basis of indirect (concomitant) information, for example, information about an earthquake, flood or tornado, fire or assassination, which could influence the terms of RW storage in a depository. One of the main problems of durability of depositories is seismic firmness. Its provision will be implemented both due to the proper construction of depositories and monitoring of buildings and constructions of depository (with the use of direct and mediated methods) with the purpose of exposure and removal of risk of their breakage, collection of the data about strong changes, increase of knowledge about changes in the redistribution of the main direction of motion of ground-waters, drafting of cards of seismically dangerous areas, having connection with the affected depository zone.

Sometimes the relevant monitoring parameters may not be defined and compared between each other and then it is necessary to resort to the methods of the fuzzy set theory, replacing functional dependences, the so-called functions of belonging (FB), and using linguistic variables for the aim of comparison. At the same time, variables can be divided into a few groups, for example, groups where variables are considered belonging to zero (Z), small values (S), mean values (M) and big ones (B). Then the function of belonging *μ(x)* to one or another linguistic variable can be presented as follows:

$$\mu(x)=\begin{cases}0, x\le a, d\le x\\ \dfrac{x-a}{b-a}, a\le x\le b\\ 1, b\le x\le c\\ \dfrac{d-x}{d-c}, c\le x\le d\end{cases}, \quad (1)$$

where $a_i \le b_i \le c_i \le d_i$ correlate with the expert estimations of scopes, in which the proper (*i*-th) linguistic variables of *Z, S, M* and *B* are situated. FB *[*or *μ(x)]* can be presented as in Fig. 1. Thus, if the variable of X_i takes on three concrete values, in the case of $x = X_1$, $FB_Z = 0$, and $FB_S = 0.64$ and the value of X_1 can be determined as the linguistic variable S; in the case $x = X_2$, $FB_S = 0.33$, and $FB_M = 0.76$ and X_2 belongs to the linguistic variable *M*; in the case $x = X_3$, $FB_M = 0.72$, and $FB_B = 0.33$ and X_3 belongs to the linguistic variable *M***.**

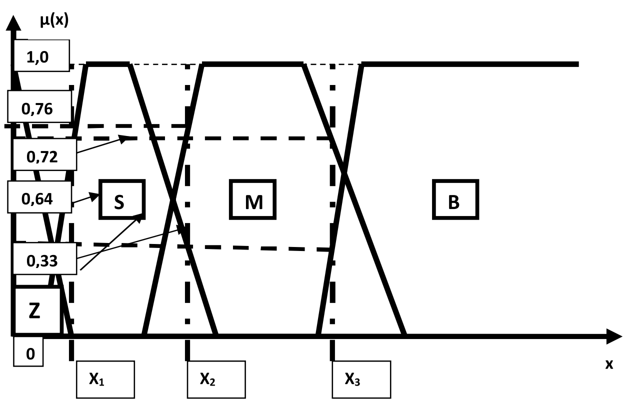

Fig. 1. Procedure of determination of belonging the concrete value to the proper linguistic variables.

During the monitoring it is also important to expose tendencies in the dynamics of RC under conditions of values of RC concentrations approximately equal to the value *σ*. For this purpose it is suggested to use Euclidean metrics, characterising distance between spreading of RC, characteristic for the previous cycle of measuring, and distributing of RC at the current cycle of monitoring. In the case when this metrics does not exceed *2σ*, distributing is considered identical and the dynamics of

RC spot is absent, in opposite case the fact of displacement of RC spot is fixed. This approach was tested on the example of low-level radioactive contamination spot distribution compared to the sensitiveness of detectors. The contaminated area on the territory of alienation of Chernobyl NPS was inspected during a few years; thus, the tests of activity were taken in the same points annually. The information was analysed for ten points of sampling; thus, in every point executed for one hundred measuring, information about which after averaging (Table 1) and standard deviation evaluation were determined, and then the metrics for three cycles of measurement were calculated.

Table 1

Averaged Results of Three Cycles of Activity Measurement, bq/l

# sampling	1	2	3	4	5	6	7	8	9	10
1st cycle	0.507	0.57	0.6	0.6	0.6	0.6	0.6	0.6	0.62	0.6
2nd cycle	0.7	0.7	0.7	0.72	0.68	0.7	0.67	0.51	0.48	0.46
3rd cycle	1.609	1.664	1.626	1.677	1.668	1.242	0.811	0.624	0.532	0.557

Figure 2 presents comparative statistics of pair of actual values of activity distributions taking into account the values of measure of *dE* and *2σ* for the 1st–2nd and 2nd–3rd cycles. Since Euclidian metrics between distributions of values of the 1st and 2nd cycles of measurement does not exceed the value of *2σ*, dynamics of RC is considered to be absent. If Euclidian metrics between distributions of values of the 2nd and 3rd cycles of measurement substantially exceeds the value of *2σ*, it confirms migration of RC spot.

3. DEVELOPMENT OF THE "DEPOSITORY – ENVIRONMENT" SYSTEM MODEL OF RADIOACTIVE STATUS MANAGEMENT

The model of the "Depository–Environment" system radioactive status management (DESRASM) should be based on the cumulative data, the knowledge base, set of rules of production, logical deduction gear and conclusion building gear by means of uncertain and incomplete input data. In other words, DESRASM should be an Expert System (ES).

Cumulative data or Data base (DB) as a rule is formed by the following components:

- background data - the monitoring points with fixed spatial coordinates and related data (number of points, date of measurement, the measurement procedure);
- parameter – defines the general activity of radionuclide's type and spectrum;
- value - defines *α*-, *β*- and *γ*-activity of every component of the spectrum (absolute or comparative);
- attendant factors - define the routine monitoring results or the results caused by force-majeure (earthquake, flood, man-caused ones etc.);

- comments - define the presence and nature of changes in comparison with the previous measurements, other peculiarities.

Knowledge base (KB) should save alternative models of behavior of all system components and system as a whole undervarious conditions of functioning, with different external factors and various forms and processes of RC migration.

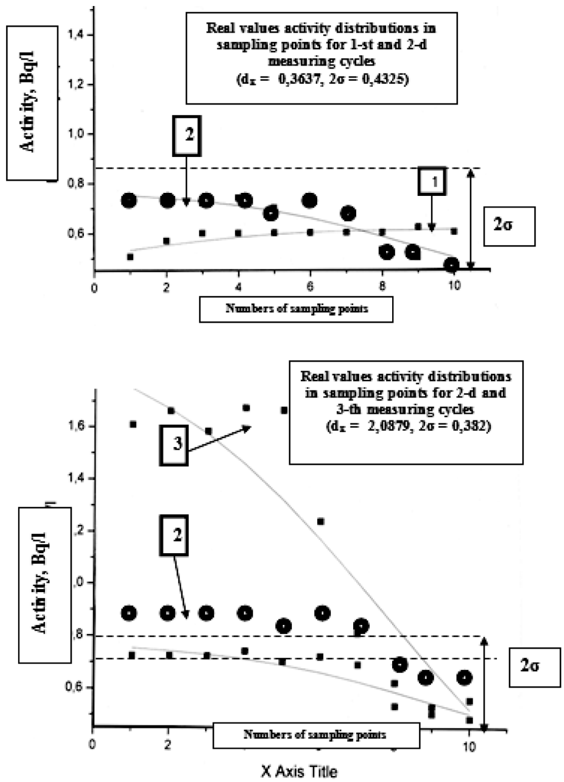

Fig. 2. Comparative statistics of pair of actual activity value distributions for the 1st-2nd and 2nd-3rd measuring cycles.

The rules of production (RP) or heuristics are formed per next sample: IF (precondition), THEN (action) [index of distinctness ID]. As the precondition the above components conjunctions may be used and action includes the components parameter value definition. For the action's ID computation, the rule's ID with the ID of those DB components related to the appropriate rule is used.

The rules may be developed on the basis of relative precondition for action of quintet parameter value awarding (the direct sequence of deduction guided by data) or proceed from action's quintet for ascertainment of those precondition quintets which shall be defined (inverse sequence of deduction which guided by the aim). The main goal is the accumulation of possible preconditions and possible actions. Index of distinctness may be computed by ID precondition, ID rule and output ID of DB. ID precondition is determined by the least of the ID statements which are composed in the precondition.

Obtained values are multiplied by rule ID (for the part of action) and then the resulting index (RI) is arrived. If the quintet is not shaped for this moment, RI may play the role of quintet ID. In this case with the output index (OI) the values of ID are found by next procedure:

$$
\begin{aligned}
&ID = OI + RI(1 - OI), RI, OI \rangle 1 \\
&ID = -(|RI|(1 - |OI|)), RI, OI \langle 1 \\
&ID = \frac{|OI| + |RI|}{1 - \min\{|OI|, |RI|\}}, RI, OI \langle 0
\end{aligned}
\tag{2}
$$

Checking of the model may be implemented by its sensitivity to parameter deviations and adjustment of some parameters for the purpose of accordance of the predicted extrapolation and real measurements of RC values. After this adjustment the RC spot dynamics modeling is implemented along the period of depository functioning. Another step is also permissible (if there are several models of RC spot dynamics): implementation of concurrent modeling by several models and use of the model which has the minimal metric of predicted distribution of RC spot relative to the real distribution.

One of the main problems of depository impermeability is the seismic resistance, which is realized by:

- adequate depository design and by means of installations;
- design monitoring (with the help of direct and mediate methods) for the exposure and elimination of the danger of their destruction;
- the great landslides data collection;
- knowledge level increasing about deviations in the main direction of subterranean waters redistribution;
- drawing up the seismic dangerous maps connected with the depository's influence zone.

Mentioned monitoring in routine process analyzes periodically the depository functioning conditions. However in cases of natural or man-made accidents, which may influence the depository, condition of the code of causal monitoring should be activated.

The monolithic constructions as depositories theoretically may be checked by their reaction on the external vibrations. Their natural frequency and external source vibration absorption factor may be used for evaluation. As several authors claim [6]: the more damages - the less (monotonously) natural frequency, and external vibration absorption arises from the beginning and then – decreases. Hence, the alternations in construction inflexibility and especially vibrations may be used as indices of structural damage. Such research should be carried out after every earthquake which is fixed in-situ of depository. It is also necessary to fulfill some analytical inspection, which supposes the careful study of initial constructive calculations, designed specifications, and extra structural analysis combined with field observations and test data.

The real depository status may be found out by taking into account the accumulated effect of seismic stresses (landslides, fractures, shocks). Therefore, it is necessary:

- to determine the frequency and strength of shocks in-situ of depository over the entire observation period and on the base of these data to formulate the forecast in the future;
- to simulate the influence of accumulated landslides, fractures and shocks on the depository constructions from the point of view of the probability of structure changes in depository walls and bottom, which may stipulate the formation of microcrack net, summary area of which promotes the RC component departure (migration).
- to determine the threshold exceeding of which guarantees more than 50% probability of microcrack net rise.

After listed steps it is necessary to equip the stations for depository status monitoring by accelerometers which are connected with automated monitoring system (AMS).

Inadequacy of RC component expansion optimal model may be determined by several reasons:

- Truncation (on purpose of simplification) of separate member (regarded as inessential) equation, which describes the processes in depository and environment;
- Assumption of invariability of separate arguments or variables in specific prescribed conditions;
- Selection of unequal (to real conditions) values of coefficients and parameters;
- Combined action of steps indicated above.

To avoid the errors caused by the above-mentioned reasons, it is necessary to use several alternative models. The simulation may be implemented simultaneously by using several (*k*) models with the same input data. The object of simulation is getting the spectral characteristic in *N* points of checking at the predetermined time of forecast. When that time comes, it is necessary to compare the simulation forecasting results x_n^i with the real RC component distribution in points of monitoring by means of metrics calculation. The metrics is characterised by the difference of simulation results from real RC component distribution in points of checking. Metrics may be two-dimensional and presented for the *k* models as follows:

$$d_{\underset{i=[1,k]}{iE}}\left[f^f, f^i\right] = \sqrt{\frac{1}{n-1}\sum_{n=1}^{N}\left(x_n^f - x_n^i\right)^2}. \qquad (3)$$

The optimal model *Mopt* must correspond to the next condition:

$$dMopt = \min\left[d1E, d2E, ...dkE\right]. \tag{4}$$

The decision-making procedure (DMP) during the depository status monitoring, i.e. elaboration of either one or another strategy, may be implemented on the basis of the following operator:

$$DMP :\to K\{A, TA, E, PA, R\}, \tag{5}$$

where A – a set of alternatives, i.e., decision variants which correspond to certain conditions (task limitations) and achieve the aim. These alternatives are formulated in advance (for example, by decision making person (DMP) or decision making system (DMS)). Each of them has a typical set of “trifles” – TA – which under defined conditions may initiate some unwanted evolution of an event, where E – environment of DMP task, i.e., the conditions under which the decision making is implemented (including the functioning conditions of specific technical-organisational system). This environment should be necessary taking into account formalization and solution of the task. PA – priority, established by DMS and related to the main criteria, advantages and disadvantages of some alternatives from the point of view of specific reality, relevant to specific RW depository or environment conditions and factors in force, as well as from the point of view of taking into account suitable “trifles”. This allows implementing single-minded selection of members from A-set corresponding to the R-procedure over the A-set, in which connection R is characterised by the type of DMP (looking for the most inviting alternative, separation of the set of alternatives which are not dominating, regulating of alternatives’ set which are admissible etc.). Here “trifle” is the factor, which under specific circumstances (as a rule extreme), determines the management strategy in close conditions especially at information imperfection and fuzziness as well as the time lack during DM (under normal conditions this factor as a rule “hides behind the background”, i.e. “conceals” behind more meaningful under these condition factors).

DMS priority system is the decisive component of DM. However, this system snaps into action generally on the assumption of transparency and unambiguity criteria, which define the desired optimal alternative. Under real conditions, PA is frequently characterised by conceptual imperfection (“opacity”), lack of distinct boundaries (fuzziness), which prevent from confident selection of a concrete alternative among the forward-looking (from the point of view of DMS) alternatives. In these cases the next approach may be used.

All the data that characterise specific alternatives are formed in a way of “spectrum”, in which the every component is situated on the fixed place (“strict format”). Connection of the amplitude of “spectral line” (or the inverse value if the amplitude is a negative trait of alternative) characterises a relative value of a corresponding component, which may be presented as part of maximum possible value or may be characterised as some notion from possibility theory’s field (for example “relevant”, “conformal”, “identical” and so on, which may also be presented as numbers from 0 to 1). In this case, the absence of a spectrum component in real characteristic is reflected as a component with the zero amplitude. For example, the component that does not have any relation to the problem is characterised as 0; the component that has some relevancy to the problem is characterised as 0.25; the component that has considerable relevancy to the problem is characterised as 0.5; conformal – as 0.7 and identical – as 1.00. The curve that bends the "ideal" spectral characteristic (i.e. characteristic which has only the "one's" spectral values) may be represented as a straight line parallel to abscess axis. The curves which bend the real spectral characteristics differ from "ideal" one. As a measure of discrepancy of the real and "ideal" characteristics the Euclidean metrics (which is the reciprocal to function affiliation) may be used:

$$\frac{D_r}{r=1,R} = \sqrt{1/[j-1]\sum_{j=1,n}[1-x_{rj}]^2}, \tag{6}$$

where j – total amount of spectral lines including the "trifle spectrum", R – total amount of alternatives that are examined (correspondingly j and r – numbers of spectra and alternatives which are examined at the given moment), x_{rj} – numeric values of j-th spectral line of the r-th alternative.

Under these circumstances, the optimal alternative should correspond to the following condition:

$$Dr(opt) = \min[D1, D2,...DR]. \tag{7}$$

In case of alternative ranking procedure accomplishment (for example, separation of alternatives which have the metrics out of permissible limits or linear regulating of alternatives which are acceptable in principle) these procedures may be accomplished by the algorithm:

$$\begin{aligned} &Dr(opt) :\rightarrow 1,...k :\rightarrow k \pm 1,...k \neq R \\ &Dr(range) = Dr(opt) :\rightarrow Dk \leq D\max, k = R \rightarrow STOP \\ &k = 1 :\rightarrow Dk \geq D\max \rightarrow STOP \end{aligned} \tag{8}$$

In other words, the k-th optimal alternative determines successively from alternative set in which instead of each earlier determined optimal (with minimal metrics) spectral line substitutes its maximum (single or "1") value $Dr(opt) : \rightarrow 1$. If the next metrics is equal or exceeds acceptable bounds $Dk \geq Dmax$ the subsequent search is ceased as soon as the quantity of successive fixed alternatives runs up to quantity of alternatives in A-set, i.e., when $k = R$. The alternatives fixed by such an approach are ranked automatically according to monotonous increasing metrics values and get the respective numbers (k).

The proposed approach is sufficiently general and effective way of optimal alternative (or alternatives' subset which is acceptable in principle for the decision making under specific conditions) searching. It may be used if there are general set of possible alternatives under circumstances, which are characterised by slipshod depending on several factors and hence are not sufficiently “transparent” as to the DMS so as to independent experts, invited especially for optimal alternative selection.

4. CONCLUSIONS

1. Definition of monitoring parameters under conditions of fuzzy and incomplete data implies determination procedure of belonging of the concrete value to the proper linguistic variables and estimation of scopes.
2. Euclidean metrics characterising the distance between spreading of radioactive contamination, characteristic for the previous cycle of measurement and its distribution at the current cycle of monitoring is used for radioactive spot dynamics reliable evaluation.
3. The model of the “Depository–Environment” system radioactive status management should be based on the cumulative data, the knowledge base, set of rules of production, logical deduction gear and conclusion building gear by means of uncertain and incomplete input data.
4. Checking of the developed model is implemented by definition of its sensitivity to parameter deviations and their adjustment for the purpose of accordance of the predicted and real measurements of contamination.
5. Implementation of the developed procedures ensures the effective and reliable estimation of the state of environment in zone of depository of radioactive waste and prognostication of radioactive contamination dynamics.

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RADIOAKTĪVĀ PIESĀRŅOJUMA UZRAUDZĪBA UN NOVĒRTĒŠANA

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K o p s a v i l k u m s

Rakstā piedāvāta radioaktīvo atkritumu glabātuvju radioaktīvā piesārņojuma dinamikas uzraudzības un novērtēšanas metodoloģija, kas paredz izplūdušo kopu teorijas rezultātu, heiristikas un uz risku orientētas vadības plašu izmantošanu. Izstrādātās metodes pamatā ir hibrīda modelēšana un datu izraces principi. Metode nodrošina efektīvas kontroles operācijas, atbilstošu vides uzraudzību, kā arī uzticamu lēmumu pieņemšanu trokšņu, neskaidrības un nepareizi attēlotu datu gadījumā.

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