Computational Models and Methods for Automated Risks Assessments in Deterministic Stationary Systems

Ivan Izonin [1[0000-0002-9761-0096]], Igor Nevliudov [2[0000-0002-9837-2309]] and Yurii Romashov[2,3[0000-0001-8376-3510]]

[1] Lviv Polytechnic National University, 12, Bandera str., Lviv, Ukraine, 79013, Ukraine
[2] Kharkiv National University of Radio Electronics, Nauky Ave. 14, Kharkiv, 61166, Ukraine
[3] V. N. Karazin Kharkiv National University, 4 Svobody Sq., Kharkiv, 61022, Ukraine

yurii.romashov@nure.ua

Abstract. It is developed the generalized computational models and methods for automated assessments the risks due to uncertainties of influencing factors in the complicated deterministic stationary systems. The principal idea of these models and method is based on computational solving the finite set of boundary value problems modelling the considered systems to represent the deterministic properties of researched possible risks in the general case. It is shown how further computational handling of these established deterministic properties by using the results of the probability theory will allow to have assessments of the researched risks in the form of probabilities of the dangerous events associated with these risks. These proposed generalized computational models and methods can be used for assessments the risks in the deterministic stationary systems with the different nature and they are can be useful for different purposes including for manufacturers to substantiate the possible warranty life as well as for insurance companies to estimate the possible hazards. The example of using the proposed models and methods deals with the risks assessment of melting the ceramic nuclear fuel pellets during operating in nuclear reactors. Using this example, it is quantitatively shown that the deterministic properties have the significant influencing on the risks assessments. Besides, it is shown that the deterministic properties can almost nullify the uncertainties in the influencing factors, and these properties can provide the low risks of dangerous states during the system operation.

Keywords: Risks, Computational Assessment, Deterministic system.

1 Introduction

Considering risks for different kinds of systems is one of in current interest scientific problem in present necessary to predict possible states and to substantiate required states of the systems under permanently existed uncertainties in their influencing factors for optimal management.

The state of deterministic systems is fully unequivocally predefined by the influencing factors and this is widely used for the different industrial purposes. The stability of operating the most industrial systems is based on supporting the stability of their state and in some cases it is suitable to neglect of changing the state of such systems during the time and to consider such systems as the stationary. Thus the deterministic stationary systems can represent the wide kinds of the industrial used systems. Although, the state of the deterministic systems is predefined by the influencing factors, but the probable deviations of the state are had presenting in such systems during their operation as shown by the experience.

2 Related works

The problems about risks are considered for different purposes including to predict damages in structures [1-3], to estimate the possible cost of new products and services [4-6], to substantiate possibilities of complicated power generation systems [6-8]. Although, listed above [1-8] and the most other researches about risks are dealt with the particular problems only it is obviously that the different particular approaches for risks assessments have some uniform items: the probabilistic nature of the risk as well as the sensitivity conceptions are used explicitly or implicitly. Opportunities of significant improving the management (control) of complicated systems in agriculture, transport, technical, economic, environment and human areas on the basis of risks assessments lead to design the special decision support systems ground on using of modern informational technologies [9-11]. Industrial designing of such decision support systems is based on risk assessments requires to develop of the serious methodological support grounded on the general representations about different aspects of the risk assessments, and such researches are known [12, 13] at present. At the same time, the automation of risk assessments required to efficient decision support systems is not fully developed at present although, some researches [10, 14] are dealt with this.

The purpose of this research is to develop the computational models and methods for automated risks assessments in deterministic stationary systems suitable for using in decision support information systems. To realize this purpose the follows objectives will be accomplish:

- On the base of the theory of probability it will be proposed the formal definition of the quantitative measure of the risk and it will be shown that risks in deterministic systems can be represented as the results of uncertainties in influencing factors.
- The generalized computational models and methods suitable for automated risks assessments in deterministic stationary systems will be developed on the basis of processing the especial sampling sets built numerically using the mathematical models representing the deterministic properties of researched systems by means differential equations with boundary conditions.
- The conception of automation the risks assessments in the deterministic stationary systems on the basis of computer information technologies will be presented and discussed. The different kinds of tasks required for risks assessments will be shown and using of the programming languages suitable for these tasks will be discussed.

- It will be considered the example of using the developed approaches for risk assessments in deterministic stationary systems and this example will be dealt with the risks assessment of melting the ceramic nuclear fuel pellets during operation in nuclear reactors. Using this example, it will be quantitatively shown that the deterministic properties have the significant influencing of the risks assessments. Besides, it will be shown that the deterministic properties can almost nullify the uncertainties in the influencing factors, and these properties can provide the low risks of dangerous states during the system operation despite the uncertainties naturally existing in the influencing factors.

The presented here results about the computational models and methods for automation risks assessments in deterministic stationary systems can be used to research the systems with different natures including the various engineering, economic, human and environment systems unlike the methods proposed for the each particular problems in the most of existed researches [1, 4, 7-9].

3 Models and methods for automated computational risks assessments in deterministic stationary systems

The main principle of using the computational models and methods for risks assessments is to define the quantitative measures of the researched risks, to construct the necessary mathematical models defining these measures, to design the corresponding computational models and methods as well as to make the required software and executing the computer simulations to calculate these measures.

3.1 Quantitative measures of the risks

The "risk" notion used in relation to some system can be imagined as the likelihood of some dangerous states of this system and such likelihood can be defined thru the notion about randomness which is the fundamental notion in the theory of probability. Let denote as y the real number representing the value of researched parameter of the considered system. We will assume that the normal states of the considered systems are corresponded to the parameter y with the values (see Fig. 1)

$$y_{\min} \leq y \leq y_{\max} , \tag{1}$$

where $y_{\min}$ and $y_{\max}$ are the given minimum and maximum values permissible for the normal states of the considered system.

Using definition (1), the risks in the considered system can be imagined as any violations of the double inequality (1). Taking into account this circumstance, the quantitative measure of the risk in the considered system can be defined as follows:

$$Q = 1 - P\left\{ y_{\min} \leq y \leq y_{\max} \right\}, \tag{2}$$

where Q is the measure of the risk in the considered system and $P\{\ldots\}$ is the probability of the event corresponding to the satisfied conditions placed inside the brackets.

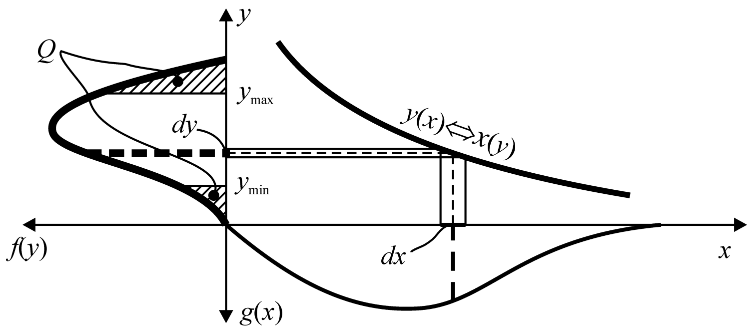

Fig. 1. Origin of the risks in the deterministic system

Let denote as x the real number representing the value characterized the influencing factor which can govern the y value. Due to the assumption that the considered system is deterministic, it is existed the strongly definite functional relation between x and y values (see Fig. 1):

$$y = y(x). \tag{3}$$

The character of the functional relation (3) is the consequence of the properties of the considered system and due to this circumstance the relation (3) represents the deterministic properties of this considered system. Thus, all risks with measure (2) in this considered deterministic system (3) are possible due to the uncertainties of the influencing factors, and these uncertainties can be imagined as the random value of the x parameter. The probabilistic characteristics of the y random value are predefined by the probabilistic characteristics of the x random value as well as by the deterministic properties (3) of the considered system (see Fig. 1):

$$f(y) = g(x(y))\left|\frac{dx}{dy}\right|, \tag{4}$$

where $f(y)$ is the probability density of the y value; $g(x)$ is the probability density of the x value; $x(y)$ is the inverse function to the function (3).

Using the probability density (4) and the risk measure (2), we can define the risks in the considered deterministic system as follows (see Fig. 1):

$$Q = 1 - \int_{y_{min}}^{y_{max}} g(x(y))\left|\frac{dx}{dy}\right| dy. \tag{5}$$

It is necessary to note, that the state of the system can be defined by not one parameter y, but the several parameters y_1, y_2, y_3,... and this case can be reduced to considering the risk measures defined similarly to relation (4) for each of the y_1, y_2, y_3,... parameter. It is necessary to note also, that the influencing factors can be defined by not one parameter x, but the several parameters x_1, x_2, x_3,... and deterministic properties (3) of the system will be the several variable function in this case. The uncertainties of influencing factors will be reduced to the set of probability densities defining the each variable. To find the probability density if the case of several variable function $y(x_1, x_2, x_3, \ldots)$ is the more complicated than in the relation (4), but this will be the typical mathematical task not principal for this research and this case will not be discussed here to avoid the not necessary complications.

3.2 Quantitative defining the uncertainties of the influencing factors

The uncertainties of the influencing factors can be reduced to the random values of the x parameter defining these influencing factors and it is sufficiently to define the probability density $g(x)$ of the x value to estimate the risks quantitatively as was shown by the relations (4) and (5). To define the $g(x)$ function it is possible to use the probability densities well-known in the probability theory including uniform and triangle distributions as well as the Weibull's and others distributions (see Fig. 2). The uniform and triangle distributions can be defined by the possible minimum $x_{\min}$ and maximum $x_{\max}$ values of the x parameter (see Fig. 2), but the Weibull's distribution can be defined by the expected value and the dispersion, which can be defined using the expert assessments.

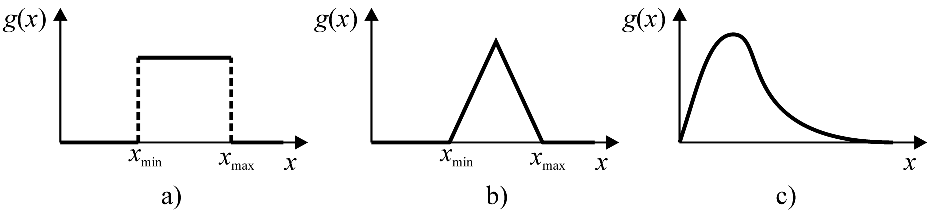

Fig. 2. Uniform (a), triangle (b) and Weibull's (c) probability densities for influencing factors

It is obviously, that the suitable choice of the probability density (see Fig. 2) modelling the uncertainties of the influencing factors will allow defining the risks (5) precisely sufficiently. At the same time, it is impossible to give the formal universal recommendations to make such choice, and only the expert assessments are possible.

3.3 Modelling the properties of the deterministic stationary system

As noted above, the risks assessments will be reduced to the simplest computing by using the calculus of definite integrals in the case of the explicitly given relation (3) and for the given probability density $g(x)$. At the same time, the difficulties of risks assessments are due to the implicitly given relation (3) such that the y parameter is defined thru some other state parameters of the considered system as follows:

$$y = y(\mathbf{u}), \tag{6}$$

where $\mathbf{u}$ is the vector of the state parameters of the considered system.

Defining the vector $\mathbf{u}$ in general case is significantly depends from the nature of the considered system and can be based on the different mathematical approaches. One of the most general approaches for defining the vector of state parameters is based on the differential equations using. The considered system is imagined as the set of the points $\vec{r}$ in some suitable space; we will denote as Υ and υ the full domain including the boundary and the boundary of the considered system. In the case of the stationary system the state is depends on the point $\vec{r}$ only:

$$\mathbf{u} = \mathbf{u}(\vec{r}) \quad \forall \vec{r} \in \Upsilon . \tag{7}$$

Depending of the vector $\mathbf{u}$ represented as (7) from the influencing factors defined by the x parameter in the most general case can be represented by using the boundary value problem

$$\mathbf{A}\big(\mathbf{u}(\vec{r}); x\big) = \mathbf{f}(\vec{r}; x) \quad \forall \vec{r} \in \mathrm{p}_{\Upsilon}\upsilon , \tag{8}$$

$$\mathbf{B}\big(\mathbf{u}(\vec{r}); x\big) = \mathbf{p}(\vec{r}; x) \quad \forall \vec{r} \in \upsilon , \tag{9}$$

where $\mathbf{A}$ is the operator of deferential equations; $\mathbf{f}$ is the given vector in some space agreed with the properties of the $\mathbf{A}$ operator; $\mathrm{p}_{\Upsilon}\upsilon$ is the complementary of the υ boundary to the domain Υ; $\mathbf{B}$ is the operator defining the boundary conditions agreed with the properties of the $\mathbf{A}$ operator; $\mathbf{p}$ is the given vector in some space agreed with the properties of the $\mathbf{B}$ operator.

The relations (8), (9) representing the set of the boundary value problems parameterised by the x value will allow defining the set $\mathbf{u} = \mathbf{u}(\vec{r}; x)$ of solutions. The solutions $\mathbf{u} = \mathbf{u}(\vec{r}; x)$ and the relation (6) will allow representing the deterministic properties of the considered system as (3). The basic idea of modelling the deterministic properties of the considered system is to solve the boundary value problem (8), (9) for some especially chosen values $\{x_1, x_2, \ldots\}$ of the x parameter and to compute the values $\{y_1, y_2, \ldots\}$ of the y parameter using the solutions $\{\mathbf{u}(\vec{r}, x_1), \mathbf{u}(\vec{r}, x_2), \ldots\}$ set and the relations (6). Defining the function (3) required for the risks assessments using the data sets $\{x_1, x_2, \ldots\}$ and $\{y_1, y_2, \ldots\}$ is reduced to the well-known problem about identification of the system and can be realised by the least square method for example. Thus, we can build the approximation of the implicit defined function (3). It is necessary to understand, that solving the boundary-value problem (8), (9) for the given x values cannot be realised exactly in the most cases, and it is necessary to use the numerical methods like the finite elements method or the finite differences (the grid) method. Numerical methods for solving the boundary value problems are well-known and notions about these are not necessary in this research.

3.4 Automation the risks assessments procedure

The decision support systems wide implementation in the modern managing procedures requires providing the opportunities of quickly risks assessments for different variants of decisions which can be achieved due to the complex automation of the risks assessments procedures. The algorithm of the automated procedure of the risks assessments in the deterministic stationary systems based on the proposed approach is presented on the Fig. 3. It is possible to provide the wide automation and in some cases the full automatic solving the separate tasks using the different programming technologies, but it is impossible to provide the fully automatic of the risks assessments procedure globally due to the required expert estimations of the interim results (see Fig. 3). Thus, the risks assessments procedure can include the cyclic solving of some interim tasks until the expert positive qualifying of results will be given, and then solving the next required task will be started (see Fig. 3). Considering these circumstances, the automated risks assessments systems can be operated only by the experts fully qualified in the corresponding necessary subject areas, but automation of typical processing required for the risks assessments procedure (see Fig. 3) will allow increasing the productivity of this procedure.

Risks assessments procedure is actually the data (information) transformation process, and due to this automation of the risks assessments procedure can be realized using the computer aided technologies. The risks assessment procedure includes a lot of the typical mathematical computing like the matrix computing required to numerically solve the boundary value problem (see Fig. 3) representing the mathematical model of the considered deterministic stationary system as well as for computing the risk quantitative measures. Besides, the risks assessment procedure must use the expert systems based on the artificial intelligence technologies like the logical programming and knowledge bases required for the automated analysing of the influencing factors uncertainties considering with the known knowledge in the corresponding subject areas. Also, the data analysis for the system properties identification must be necessarily used in any automated risk assessments procedure. It is suitable to use the FORTRAN language for the mathematical computing required to solve the boundary value problems representing the mathematical model of the considered deterministic stationary system as well as to compute the risks quantitative measures. The PYTHON language is suitable to solve the data analysis tasks required for the system identification, but the

PROLOG, the LISP and similar programing languages are more suitable to realize the expert systems required for the automated risks assessments.

4 Computer simulations, results and discussions

We will consider further the problem about assessments the risks of melting the ceramic nuclear fuel pellets in the core of nuclear reactors to show the example of using the proposed models and methods for automated computational risks assessments in deterministic stationary systems. The nuclear fuel common for the most of existed nuclear reactors including the VVER-1000 nuclear reactor widely used in Ukraine and some countries of Eastern Europe and Asia is the compact product is made as the cylinder with the central hole (see Fig. 4a) to exclude melting in the central volume surrounding the longitudinal axis; the typical sizes of the fuel pellets are the height $h \approx 20\text{mm}$ and the radii $a \approx 5\text{mm}$ the hole and $b \approx 10\text{mm}$ of the pellet. These fuel pellets are placed inside the cladding of the long fuel rods (see Fig. 4b) with lenght about 5000mm, and the heat producing due to the nucleus fission reactions inside these pellets 1 is transferred thru the gaseous gap 2 and thru the cladding 3 to the heat carrier 4 surrounding the cladding on moving along the cladding's longitudinal axis.

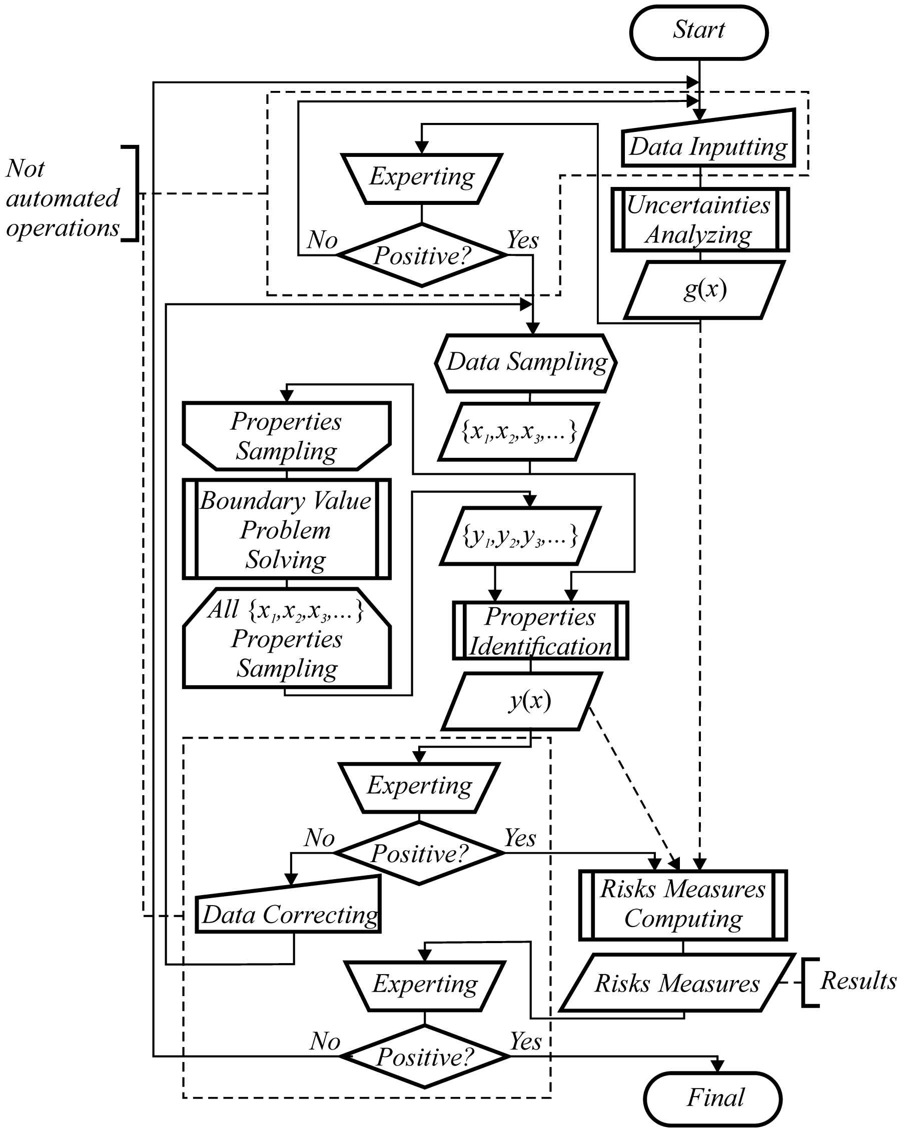

Fig. 3. Risks assessments procedure

1 - nuclear fuel pellet; *2* - gaseous gap; *3* - cladding; *4* - heat carrier

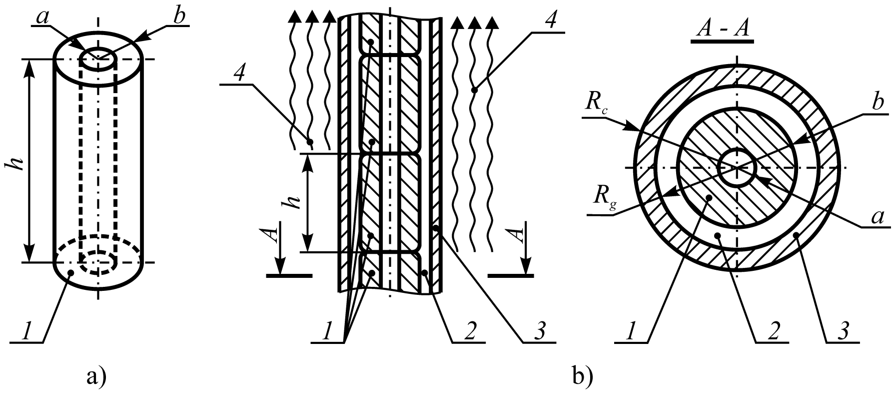

Fig. 4. The sizes (a) nuclear fuel pellet and position of this pellet inside the fuel rod (b)

The temperature of the nuclear fuel pellet 1 is defined by the intensity of the internal heat volume sources due to the nuclear fission reaction as well as by the heat transfer of generated heat thru the gaseous gap 2, thru the cladding 3 and outside the cladding into the heat carrier 4 (see Fig. 4b). The heat transfer processes are very sensitive to the mode of moving the heat carrier and it is possible to have the local perturbations of moving the heat carrier which can lead to the minimum heat transfer from the cladding to the heat carrier and as the result of this can lead to the extremely high temperatures and to melting the fuel pellets. It is impossible to fully exclude melting of fuel pellets during operation the nuclear reactor, but melting the pellets inside of 1 or 2 or even 10 fuel rods from about 50000 fuel rods forming the core is not dangerous. Thus, it is necessary to substantiate that the risks of melting the nuclear fuel pellets inside the fuel rods are negligible during operation the nuclear reactor.

4.1 Modelling the fuel pellet temperature state with the uncertainty in the heat transfer to outside the cladding

The mathematical model of the fuel pellet temperature state can be represented using the equations and the boundary conditions all-known in the theory of heat conduction. We will consider the radial heat flows only and we will neglect the axial and the circumferential heat flows in the fuel pellet. Such simplification will allow considering the principal heat flows providing the heat exchange during operation the fuel pellets, and it is useful for initial researches. Considering these circumstances, the mathematical model of the fuel pellet temperature state can be represented as follows [15]:

$$\frac{dq}{dr} + \frac{q}{r} = H, \quad a < r < b, \tag{10}$$

$$q = -\lambda(T)\frac{dT}{dr}, \quad a \le r \le b, \tag{11}$$

$$q = 0,\ \ r = a\,, \tag{12}$$

$$q = k\left(T - T_{H.C.}\right),\quad r = b\,, \tag{13}$$

where $q = q(r)$ and $T = T(r)$ is the radial heat flow and the temperature inside the fuel pellet; r, $a \le r \le b$ is the radial coordinate; H is the intensity of the volume heat sources due to the fission nuclear reactions in the pellet; $\lambda(T)$ is the thermal conductivity of the fuel pellet depending on the temperature; k is the heat transfer coefficient defining the heat flow from the fuel pellet to the heat carrier; $T_{H.C.}$ is the temperature of the heat carrier.

The intensity of the volume heat sources can be approximately defined considering the axial offset as [15]

$$H = \frac{1,5W}{n\pi\left(b^2 - a^2\right)L}\,, \tag{14}$$

where W is the heat power of the nuclear reactor; n is the count of the fuel rods forming the core; L is the length of the fuel cylinder inside the fuel rod.

The heat transfer coefficient from the fuel pellet to the heat carrier is defined by the widths and the thermal conductivities of the gaseous gap and the wall of the cladding, as well as by the heat transfer from the cladding to the heat carrier and can be represented as all-known in the heat transfer theory for the cylindrical wall [15]:

$$k = \left(\frac{b}{\lambda_{\mathrm{g}}}\ln\frac{R_{\mathrm{g}}}{b} + \frac{b}{\lambda_{\mathrm{c}}}\ln\frac{R_{\mathrm{c}}}{R_{\mathrm{g}}} + \frac{b}{\alpha R_{\mathrm{c}}}\right)^{-1}, \tag{15}$$

where λ_{g} and R_{g} is the thermal conductivity and the radius (see Fig. 4b) of the gaseous gap; λ_{c} and R_{c} is the thermal conductivity and the radius (see Fig. 4b) of the cladding; α is the heat transfer coefficient defines the heat flow from the cladding to the heat carrier.

For numerical simulations of the fuel temperature states we will use the parameters values included in the (10)–(14) corresponding to the fuel of the VVER-1000 nuclear reactor and all-known in scientific literature [15]:

$$a = 1{,}15\mathrm{mm},\, b = 3{,}765\mathrm{mm},\, W = 3000\mathrm{MW},\, n = 50856,\, L = 3530\mathrm{mm},\, T_{\mathrm{HC}} = 583\mathrm{K}\,, \tag{16}$$

$$R_{\mathrm{g}} = 3{,}86\mathrm{mm},\, R_{\mathrm{c}} = 4{,}55\mathrm{mm},\, \lambda_{\mathrm{g}} = 0{,}3\,\mathrm{W}/(\mathrm{m}\cdot\mathrm{K}),\, \lambda_{\mathrm{c}} = 20{,}5\,\mathrm{W}/(\mathrm{m}\cdot\mathrm{K})\,. \tag{17}$$

The thermal conductivity of the fuel pellet is significantly depended on the temperature and this is the one of principal circumstance which must be considered. We will use the follows function defining this temperature dependence:

$$\lambda(T) = A\cdot T^{B}\,, \tag{18}$$

where $A \cong 793{,}909118652344$ and $B \cong -0{,}766199052333832$ are corresponded to the approximation of all-known literature data about the thermal conductivity of the UO_2 ceramic nuclear fuel; $\lambda(T)$ and T is measured in $\mathrm{W}/(\mathrm{m}\cdot\mathrm{K})$ and in K.

In the proposed mathematical model (10)–(18) all uncertainties of the influencing factors are concentrated in the value α of the heat transfer coefficient. It is known [10] that the α values corresponded to the normal operation of the nuclear reactor VVER-1000 must satisfy the follows double inequality [15]:

$$33 \le \alpha \le 35 \ \ \mathrm{kW}/(\mathrm{m}^2\cdot\mathrm{K}). \tag{19}$$

For fuel pellets melting risks assessments we will consider the more wide values of the α coefficient:

$$\alpha_m \le \alpha \le 50 \ \ \mathrm{kW}/(\mathrm{m}^2\cdot\mathrm{K}), \tag{20}$$

where α_m is the value of the α coefficient corresponding to the melting temperature $T_m \approx 2820\mathrm{K}$ on the radius $r = a$ (see Fig. 4) of the fuel pellet.

Solving the nonlinear boundary value problem (10)–(15) for the input data (16)–(18), (20) was realized numerically using the finite differences method and all-known the Picard's iteration method. It was used the LU-method to solve the linear algebraic equations system representing the linear problem in each of iterations. The programs for automated processing of these was developed using the FORTRAN programming language considering the notes about automation discussed above. These programs realize the typical all-known numerical methods and they will not be discussed here.

4.2 Results and discussing

Computer simulations of the fuel pellet temperature state using the mathematical model (10)-(15) for the initial data (16)-(18), (20) allow to find the α_m value, corresponded to melting temperature of the fuel pellet on its internal radius:

$$\alpha_m \cong 0{,}75\,. \tag{21}$$

Besides, such computer simulations allow to build the sampling data required to establish the deterministic properties of the considered system as the functional depending of the α coefficient from the temperature $T_a = T(r = a)$ on the internal radius of the fuel pellet (see Table 1). The sampling data (see Table 1) can be approximated as:

$$\alpha(T_a) = e^{C_1 \ln^2 T_a + C_2 \ln T_a + C_3}\,, \tag{22}$$

where numerical parameters $C_1 \cong 28{,}39302401293563$, $C_2 = -436{,}299681002904$ and $C_3 \cong 1673{,}757077973671$ are defined using the all-known list square method for the α coefficient measured in $\mathrm{kW}/(\mathrm{m}^2 \cdot \mathrm{K})$ and the temperature T_a measured in K.

Representing the deterministic properties of the fuel pellet temperature state using the approximation (22) and the sampling data (see Table 1) are shown on the Fig. 5a. Comparing the line and the markers on the Fig. 5a, allows seeing that the proposed approximation (22) has the good agreement with the sampling data.

Table 1. Sampling data for defining the deterministic properties.

The temperature T_a, K on the internal radius of the fuel pellet	The heat transfer coefficient $\alpha, \mathrm{kW}/(\mathrm{m}^2 \cdot \mathrm{K})$ defining the heat flow from the cladding
2840,85696253441	0,75
1458,60125430316	10,0
1420,06137960674	15,00
1400,76319976693	20,00
1389,1751065182	25,00
1381,44584776636	30,00
1375,92304476484	35,00
1371,77989675907	40,00
1368,5568265724	45,00
1365,97797773063	50,00

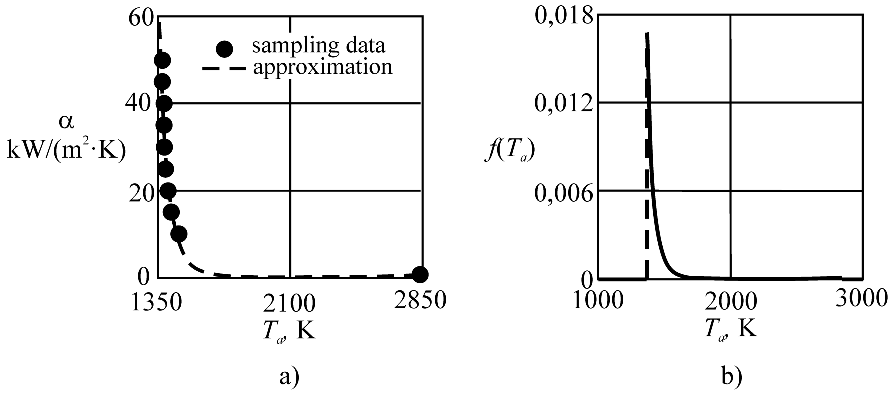

Fig. 5. Representing the deterministic properties (a) of the temperature state and the probability density (b) of the researched temperature

The values of the heat transfer coefficient α are inside the interval defining by the double inequality (20) and the value (21), but the real value is uncertain. Let assume that the heat transfer coefficient α can have any value from the interval (20), (21) with the equal probability, i.e. the probability density of the α value is uniform as on the Fig. 2a inside the interval defining by the double inequality (20) and the value (21). The probability density of the temperature T_a can be defined using the relation (4) and the approximation (22) and considering the noted above assumption as:

$$f\left(T_a\right) = Pe^{C_1 \ln^2 T_a + C_2 \ln T_a + C_3} \left| 2\frac{C_1}{T_a} \ln T_a + \frac{C_2}{T_a} \right|, \tag{23}$$

where $P \cong 0,020304568527919$ is defined by the uniform probability density of the heat transfer coefficient α value in the interval defined by the inequality (20) and the value (21).

Although, the probability density of the random value α representing the influencing factors was assumed as the uniform (see Fig. 2a) the probability density (23) of the researched temperature T_a inside the fuel pellet is significantly differ from the uniform distributions (see Fig. 5b) due to the deterministic properties of the temperature state of the fuel pellet. Thus, this obtained result (see Fig. 5b) is quantitatively shown that the deterministic properties (see Fig. 5a) of the considered stationary system can have significant influencing on the probability function defining the risks assessments.

In this particular example the risk Q of melting the nuclear fuel pellet during operation in the nuclear reactor can be computed using the relation (5) which can be reduced to the follows suitable view:

$$Q = \int_{S \cdot T_m}^{T_m} f\left(T_a\right) dT_a \,, \tag{24}$$

where S is the parameter defining the maximal available value of the temperature T_a in the internal radius of the fuel pellet during the nuclear reactor operation.

The risk quantitative measure defined by the relation (24) actually shows the probability of the event corresponded to the double inequality

$$S \cdot T_m \le T_a \le T_m \,. \tag{25}$$

Results of the risks assessment using the relation (25) and the defined above probability density (23) are shown that the risks of melting is significantly decreased with increasing the maximal allowed temperature of the fuel pellet (see Fig. 6). Although, these results are obtained using the significant assumptions and simplifications these results are in good quantitative agreement with the all-known experience of the nuclear reactors operating.

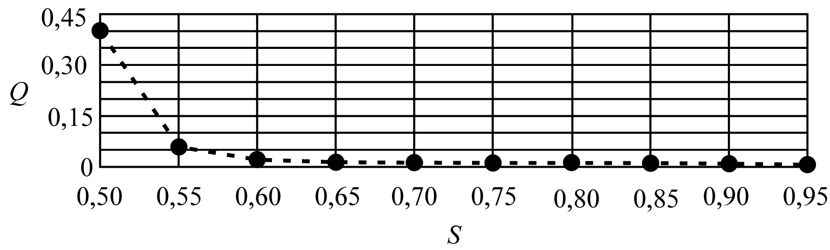

Fig. 6. Estimation of the quantitative measure of the risk of melting the nuclear fuel pellets

5 Conclusions

The generalized computational models and methods for automated risks assessments in deterministic stationary systems are developed in this research to be used for researching the risks in the systems with different natures including the various engineering, economic, human and environment systems unlike the particular approaches discussed in the most of the existed researches. Due to this research the follows results were developed:

- It is proposed the formal definition of the quantitative measure of some risk in the form of the probability value of the hardly events corresponded to the researched risks. Using this formal definition and the all-known results of the theory of probability, it is shown that risks in deterministic systems can be represented as the results of uncertainties naturally presenting in the influencing factors.
- It is developed the generalized computational models and methods suitable for automated risks assessments in deterministic stationary systems on the basis of computational processing the especial sampling sets built numerically using the mathematical models representing the deterministic properties of researched stationary systems by means differential equations with boundary conditions.
- It is proposed the general conception of automation the risks assessments in deterministic stationary systems on the basis of computer information technologies. It is shown that the risks assessment procedure includes a lot of the typical mathematical computing required to numerically solve the boundary value problem representing the mathematical model of the considered deterministic stationary system as well as for computing the risk quantitative measures, and the FORTRAN language is suitable more for them. Besides, it is shown that the automated risks assessment must use the expert systems based on the artificial intelligence technologies like the logical programming, and the PROLOG, the LISP and similar programing languages are suitable for them. It is also shown that the risks assessments must include the data analysis required for the system identification, and the PYTHON programming language is suitable more for them.
- It is considered the example about the risks assessments of melting the ceramic nuclear fuel pellets during operation in nuclear reactors to show of using the developed generalised approaches. It is quantitatively shown that the deterministic properties have the significant influencing on the risks assessments. Besides, it is shown that

the deterministic properties can almost nullify the uncertainties in the influencing factors, and these can provide the low risks of hazard states during the system operation despite the uncertainties naturally existing in the influencing factors.

References

1. Leander, J., Honfi, D., Björnsson, Í.: Risk-based planning of assessment actions for fatigue life prediction. Procedia Structural Integrity 5, 1221–1228 (2017). doi: 10.1016/j.prostr.2017.07.047.
2. Nevliudov, I.Sh., Borshchov, V.M., Palagin, V.A., Razumov-Fryziuk, I.A., Tymchuk, I.T., Nevliudova, V.V., Petrova, A.Y.: Mathematical model of bending two-layer film aluminium-polyimide structure due to temperature changes. Functional Materials 26 (2), 342–346 (2019). doi: 10.15407/fm26.02.342.
3. Romashov, Yu.V., Povolotskii, E.V.: Influence of the temperature state on the damageability due to the creep of claddings of cylindrical fuel elements. Visnyk of V.N. Karazin Kharkiv National University Ser. “Mathematics, Applied Mathematics and Mechanics” 87, 13–28 (2018). doi: 10.26565/2221-5646-2018-87-02
4. Fontem, B., Smith, J.: Analysis of a chance-constrained new product risk model with multiple customer classes. European Journal of Operational Research 272(3), 999–1016 (2019). doi: 10.1016/j.ejor.2018.07.042.
5. Mondoro, A., Frangopol, D.M.: Risk-based cost-benefit analysis for the retrofit of bridges exposed to extreme hydrologic events considering multiple failure modes. Engineering Structures 159, 310-319 (2018). doi: 10.1016/j.engstruct.2017.12.029
6. Portugal-Pereira, J., Ferreira, P., Cunha, J., Szklo, A., Schaeffer, R., Araújo, M., Better late than never, but never late is better: Risk assessment of nuclear power construction projects. Energy Policy 120, 158-166 (2018). doi: 10.1016/j.enpol.2018.05.041.
7. Zaroni, H., Maciel, L. B., Carvalho, D. B., de O. Pamplona, E.: Monte Carlo Simulation approach for economic risk analysis of an emergency energy generation system. Energy 172, 498–508 (2019). doi: 10.1016/j.energy.2019.01.145.
8. Samper, M.E., Eldali, F.A., Suryanarayanan, S.: Risk assessment in planning high penetrations of solar photovoltaic installations in distribution systems. International Journal of Electrical Power & Energy Systems 104, 724–733 (2019). doi: 10.1016/j.ijepes.2018.07.052.
9. Isigonis, P., Critto, A., Stefan, M., Zabeo, A., Ciffroy, P., Marcomini, A.: "AMORE" Decision Support System for probabilistic Ecological Risk Assessment - Part I: Exposure and risk assessment of the case study on cyanide. Science of The Total Environment 648, 693–702 (2019). doi: 10.1016/j.scitotenv.2018.08.124.
10. Oger, R., Bénaben, F., Lauras, M., Montreuil, B.: Towards Decision Support Automation for Supply Chain Risk Management among Logistics Network Stakeholders. IFAC-PapersOnLine 51(11), 1505–1510 (2018). doi: 10.1016/j.ifacol.2018.08.287.
11. Caeiro, S., Vaz-Fernandes, P., Martinho, A.P., Costa, P.M., Silva, M.J., Lavinha, J., Matias-Dias, C., Machado, A., Castanheira, I., Costa, M.H.: Environmental risk assessment in a contaminated estuary: An integrated weight of evidence approach as a decision support tool. Ocean & Coastal Management 143, 51-62 (2017). doi: 10.1016/j.ocecoaman.2016.09.026.
12. Piet, G. J., Knights, A. M., Jongbloed, R. H., Tamis, J. E., de Vries, P., Robinson, L. A.: Ecological risk assessments to guide decision-making: Methodology matters. Environmental Science & Policy 68, 1–9 (2017). doi: 10.1016/j.envsci.2016.11.009.

13. Thekdi, S. A., Aven, T.: A methodology to evaluate risk for supporting decisions involving alignment with organizational values. Reliability Engineering & System Safety 172, 84–93 (2018). doi: 10.1016/j.ress.2017.12.001.
14. Pacaux-Lemoine, M.-P., Millot, P.: Adaptive Level of Automation for risk management, IFAC-PapersOnLine, 49(19), 48-53 (2016). doi: 10.1016/j.ifacol.2016.10.460.
15. Romashov, Yu.V., Chibisov, D.O.: Approximate estimates of the temperature state of ceramic nuclear fuel in cylindrical fuel elements and the influence of processes and parameters of a nuclear reactor core. Bulletin of the National Technical University "KhPI". Series: Power and Heat Engineering Processes and Equipment 2, 28–32 (2019). doi: 10.20998/2078-774X.2019.02.05.