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APPLICATION OF THE POSSIBILITY THEORY TO DETERMINE RELIABILITY OF NPP POWER EQUIPMENT

The article considers the prospects of application of the modern possibility theory (expert systems, fuzzy algorithms, fuzzy clustering) for evaluation of indeterminate forms related to the current condition of nuclear power plants equipment.
Keywords: nuclear power, reliability of the basic equipment, possibility theory, fuzzy algorithms and systems, fuzzy clustering.

Formalization of the consolidated design, statistical and expert data on the power equipment reliability is always in attention of nuclear energy experts in Ukraine.

Computational and theoretical (design) assessment of equipment reliability usually gives the equipment developer who should use the results of research of engineering composition of the system as a whole and its major units in particular. In this evaluation, the designer needs to formalize (simulate) the process of changing the technical condition of the system as regards loss of reliability over time. In other words, the developer must provide the consumer with accurate information about the degradation model of the supplied system over time.

Even at this level relations "developer - consumer" can be ambiguous. The desire to increase the sales of the equipment is in conflict with the desire to maintain the image of a reliable manufacturer, and as a result, it may happen that the reliability data does not correspond with the reality.

Statistical evaluation of reliability indices is based on the analysis of failures of systems, its large aggregates, components and items of equipment. And, while predicting reliability parameters, experts use the data of similar systems and units reliability derived from operating experience in similar conditions, and determine the conversion factor of mean time to failure of a system or a machine, believing it to be constant for all similar systems and components.

Statistical evaluation is the most simple and available one. However, to determine the parameters of reliability of systems and aggregates in operation, this information is delayed, and reliability prediction is very roughly: the equipment can vary significantly against the design and actual conditions of its use; moreover, you cannot always trust the means of recording failures that occur during operation.

In recent years, a growing interest is the development and *application of expert methods* for determining the reliability. In this regard, the South Ukrainian nuclear power plant (SU NPP) jointly with the Research Institute for Nuclear Power Plants under the Odessa National Polytechnic University (NII AES ONPU[1]) had already progressed essentially [1, 2] and received encouraging results. For example, using a fairly simple method based on computer technology of expert estimates processing [3], it is possible to obtain the parameters of the distribution of equipment failures.

Fuzzy clustering as a method of possibility theory. The logic of the development of this direction of research suggests that you can maximize the accuracy of the information about the reliability, if you make a generalization (convolution) of all information received.

The easiest, the traditional method of convolution of homogeneous data is their averaging [4, 5]. However, in our case the reliability data are not homogeneous. Some of them are presented in the form of failures distribution law in a simplified form; others - by more complex failures distribution law, which takes into account the increased number of failures at the beginning of operation; the third ones - a set of experimental data points obtained from the logs of system or components failures; the fourth ones - in the form of estimates made by experts. These estimates can be most conveniently presented in the form of inclined lines, located within the failure distribution function.

In such circumstances, the most appropriate is to apply *fuzzy clustering methods* of heterogeneous data [5, 6]. Given that in the normal distribution of failures

[1] transliterated

$$f_i = \frac{1}{\sigma\sqrt{2\pi}} \cdot \exp\left(\frac{-(t_i-\mu)^2}{2\sigma^2}\right) \qquad (1)$$

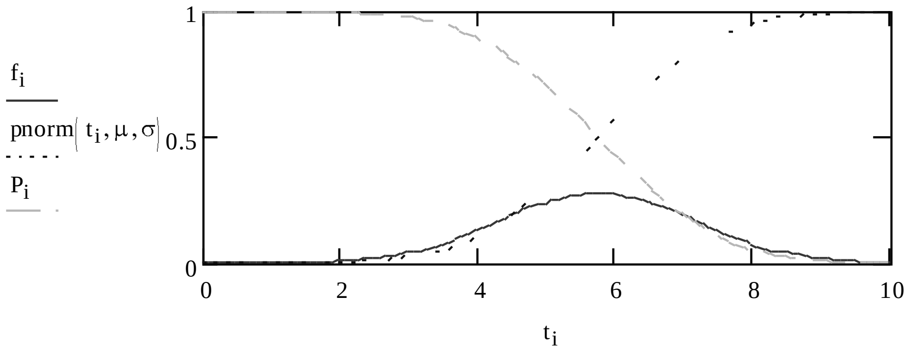
two parameters are used: μ – distribution mode, and σ - standard deviation, fuzzy clustering of heterogeneous data in a field of these two parameters may be carried out. Finding the center of a cluster in this case would mean the determination of generalized parameters of the distribution of failures, or in other words, the reliability model of degradation of a unit during its operation. This can be illustrated by calculations on the model of degradation of individual units, which are subject to strict normal distribution (see Fig. 1).

However, the actual conditions of entering the information about the equipment reliability at nuclear power plants are far from getting the collection of reliable data. Therefore this reduces the reliability of the forecast of potential failures and accidents [1, 2]. In addition to statistical data, the information on the perceived reliability can be obtained in the formats shown in Fig. 2 On the graph on the vertical axis we give the probability of work without failures in the range [0, 1], and on the horizontal axis – an annual-based chronology of equipment operation data.

The curve in Fig. 2, takes into account an increased number of failures in the initial period of the equipment operation (equipment run-in). Such information may be provided for those units that are traditional in the power energy industry and put into standard designs. The curve in Fig. 2 *б* gives no information about the initial failure rate, because supply of equipment is not traditional. Statistical data shown in Fig. 2*в*, are the result of a sampling from the operational database. The curve in Fig. 2, *г* is the inverse in nature, as experts with more confidence (with less doubts) answer the questions: "Do you guarantee that over *N* years, this unit will not get a single failure?". Or: "Can you guarantee that after *M* years the unit will be more in repair than in operation?". Fixation and special treatment of these answers gives us the opportunity to bring expert data to probabilistic-time scale [1, 2].

$\sigma := 1.42 \qquad \mu := 5.76 \qquad i := 0..100 \qquad t_i := 0.1 \cdot i$

$f_i := \frac{1}{\sigma\cdot\sqrt{2\cdot\pi}} \cdot e^{\frac{-(t_i-\mu)^2}{2\cdot\sigma^2}} \qquad P_i := 1 - \mathrm{pnorm}(t_i, \mu, \sigma)$



$\mathrm{pnorm}(4.5, \mu, \sigma) = 0.187 \qquad 1 - \mathrm{pnorm}(4.5, \mu, \sigma) = 0.813$

$\mathrm{pnorm}(3, \mu, \sigma) = 0.026 \qquad 1 - \mathrm{pnorm}(2, \mu, \sigma) = 0.996$

Fig. 1 The calculated curve of the normal distribution of failures:
f_i - density (derivative) of failure function (maximum density accounts for the initial period of operation - 5.76 years);
P_i – reduction of the probability of failure (degradation of reliability);
t_i - time normative, years

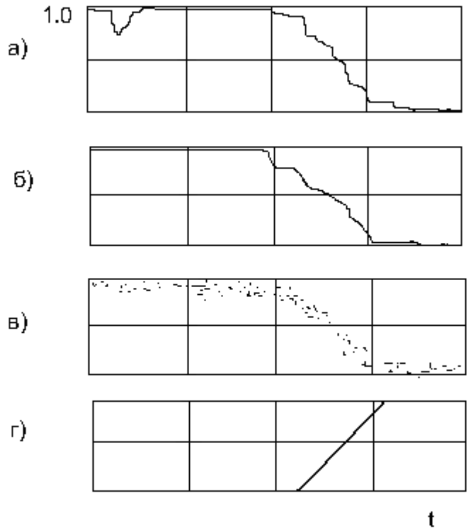


Fig. 2 Typical formats of input data on the forecast of reduction of reliability (degradation) of units in operation:
а - degradation curve for standard equipment;
б - degradation curve for atypical equipment;
в - statistical data accumulated during the operation; *г* - the original data (before treatment), received from the experts

Description of fuzzy clustering algorithm in processing of heterogeneous source data. Currently, the most known software package for the processing of heterogeneous data containing uncertainty is Fuzzy Logic Toolbox. This package is, in turn, a part of a well-known product Matlab [3]. The package Fuzzy Logic Toolbox includes a program Clustering (Clustering), allowing in GUI mode to identify the centers of clusters. Centers of clusters can be seen as points in a multidimensional data space, about which a grouping of selected features occurs.

The program run is started by using the directive "*findcluster*". In particular, let the initial data on the reliability are presented in the form of a log of the processes that occurred during the real operation of a certain unit at different times, and consist of five realizations, or trends (see Fig. 3).

On the second step, the program generates a conditional fuzzy inference GENFIS 2. In the structure of the program (see Fig. 4) each of the five trends is designed as an input of a linguistic variable (*in1* - *in5*), and the result of clustering - in the form of the output variable *out1*.

In the third step the program produces a first grouping of experimental data in the two scales on the vertical axis: from 0 to 60 units, and from 0 to 10 units (Fig. 5). The final stages of the program are shown in Fig. 6 and 7.

To solve this problem, one can use another clustering program, allowing in the GUI mode to search for cluster centers. This program is also included in the package Matlab / Fuzzy Logic Toolbox (demo version).

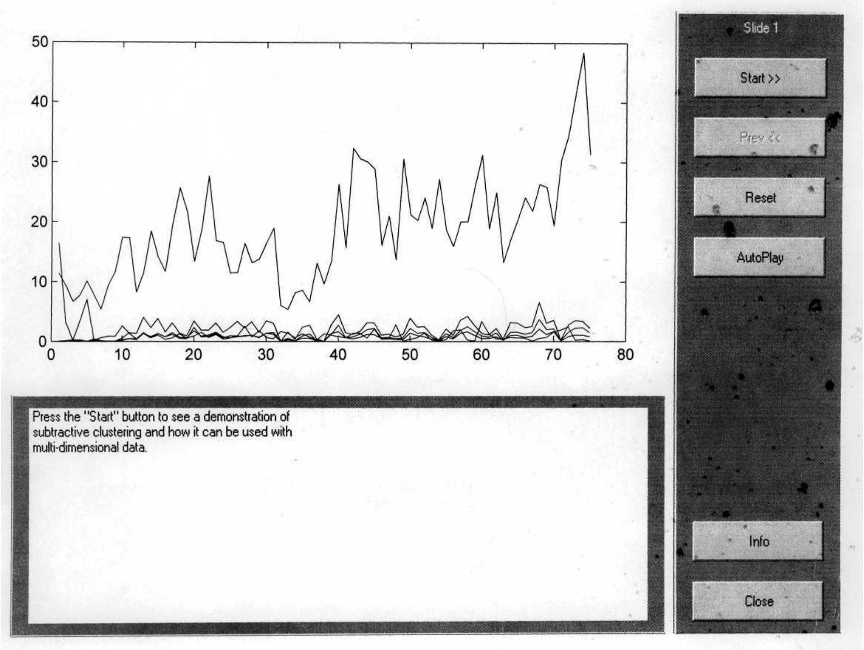


Fig. 3 Illustration of the program of fuzzy clustering of heterogeneous statistical source data. Pressing the "Start" button allows us
to watch the fuzzy clustering procedure step-by-step

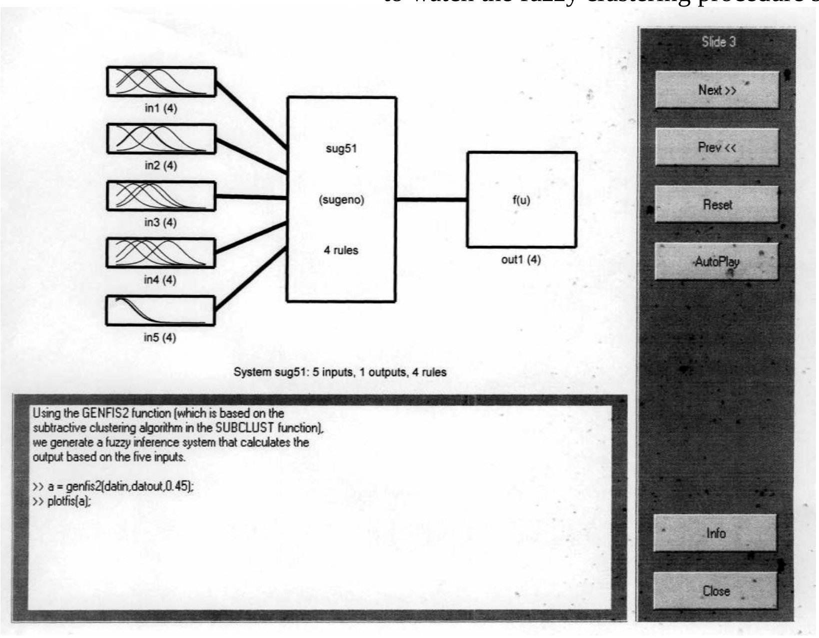


Fig. 4 Application of the functions GENFIS 2, which is based on algorithms of
computational clustering in the form of SUBCLUST – a function that generates a system of fuzzy conditional output, and computes in this case the value of one output as a result of five inputs

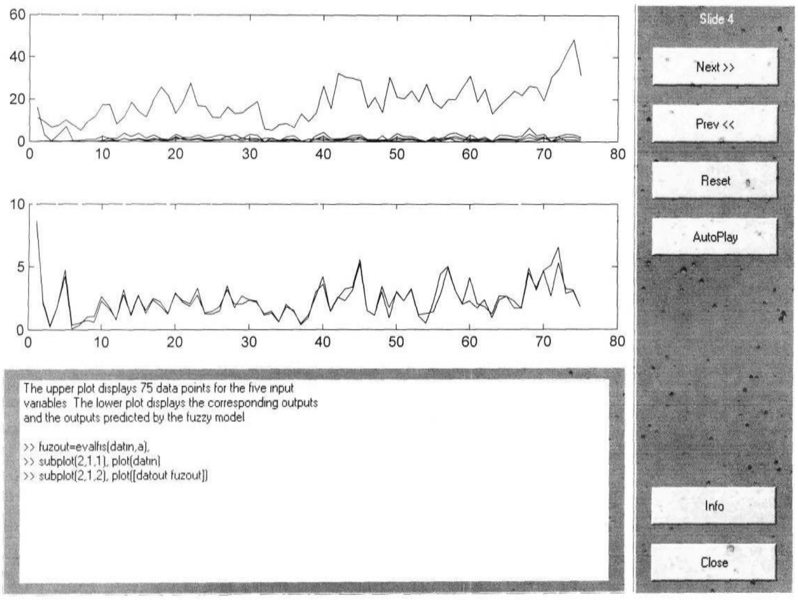


Fig. 5 in an upper part of the display shows approximately 75 strongly differing points obtained experimentally for the five cases. The lower part of the display corresponds to these inputs, resulting in a unified scale of 0-10, and predicts the output of fuzzy model.

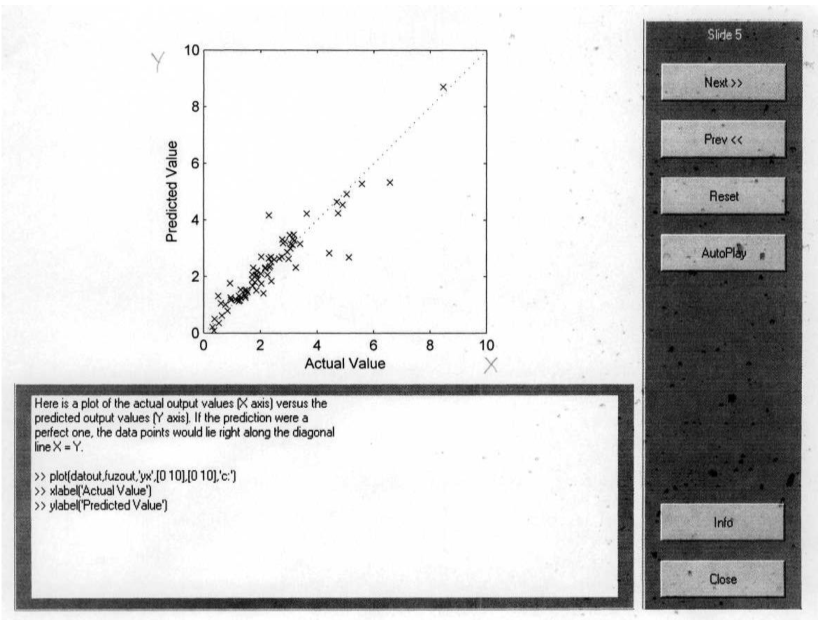


Fig. 6 The field of predictable correspondence between inputs X and outputs Y generalized by cluster analysis. If the model is correct, points are grouped along the diagonal X = Y

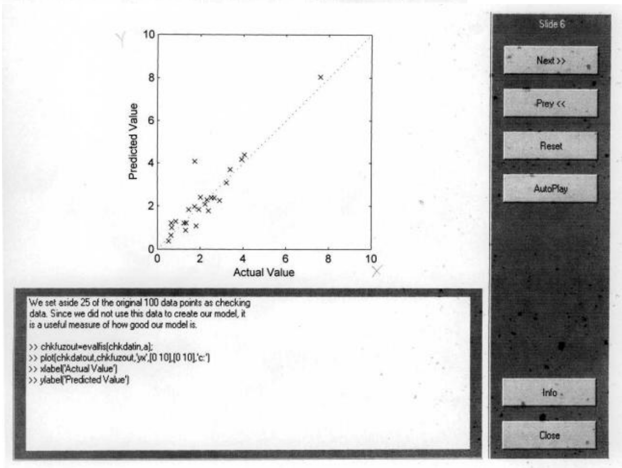


Fig. 7 identifies 25 points (cluster centers) from the original 100 points of heterogeneous statistical data. While the use of primary array was difficult, after the fuzzy clustering we have 4 times "fold" of the data array

The program is started from the command line by the directive *findcluster*. In the resulting window (see Fig. 8), in addition to the standard set of items (File, Edit, Window, Help), there is a set of control buttons and options:

download button for input data file - Load Data;

selection button for clustering algorithm - Method;

four algorithm option buttons below (their names are changed depending on the algorithm);

start button for an iterative process of finding the centers of clusters - Start;

button to save the results of clustering - Save Center;

reset (erase) charts button - Clear Plot;

button for background information - Info;

Program Shut down button - Close.

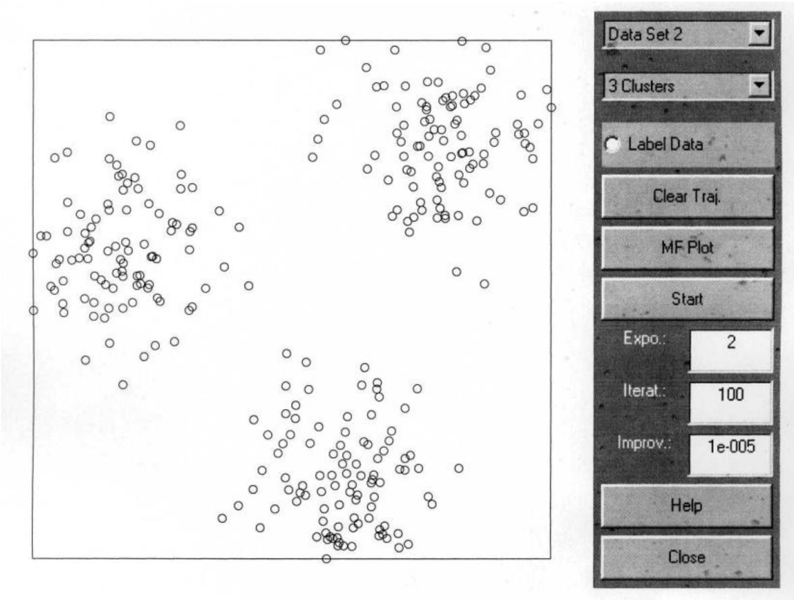


Fig. 8 Operating window after loading the clustering data. The data consist of three groups, which have clearly present fuzziness (dense grouping of point in some places and sparseness in others)

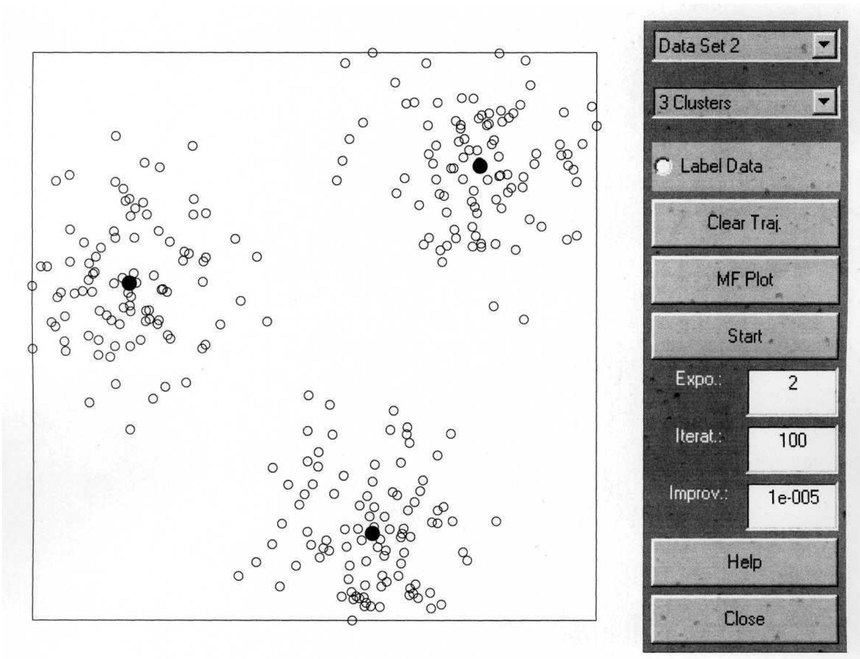


Fig. 9 As a result of the program run three centers of clusters were found.
Coordinates of the centers were saved before the last step of the clustering - finding a common center

The program uses two algorithms to identify the cluster centers: *Fuzzy c-means* (can be translated as "fuzzy algorithm centers") and *Subtractive clustering*.

As a result of the program run three centers of the clustering are found (see Fig. 9). Coordinates of the centers are saved before the last step of the clustering - finding a common center.

Thus, on the basis of verifying the effectiveness of the discussed algorithms we can confirm the possibility of "folding" of the three types of data on the reliability of equipment of any NPP, namely the design and production data, statistics data (including those as a result of operation at other NPP) and expert data obtained for the operating equipment. Nevertheless, this processing should be regarded as a preliminary evaluation, because the results of reliability studies require additional verification.

The ultimate goal of assessing the current value of reliability of nuclear power plant equipment is to detect the least reliable element unit, namely:

the least reliable technological system;

the least reliable item of unreliable technological system;

the least trusted part of unreliable item;

the least reliable component (or a detail) of the unreliable part.

The presented hierarchy of structural and technological structures allows one [6, 7, 8], starting from consideration of the basic unit of nuclear power - the power unit, purposefully move to an item that could be the root cause of the accident. In this case, the cost of finding and fixing the root cause of a possible accident would be minimal.

Operation of nuclear power plants is highly cost-effective, but it accompanied by a strong environmental and psychological impact. Therefore, in contrast to the known ways in which the filling of the matrix of fuzzy relations is performed by one expert, we recommend to create a team of experts consisting of no less than five experts in order to achieve a higher level of reliability of the estimates. Given the diversity of design and operational factors unit, team of experts is advisable to select the following specializations:

technological systems, mechanics and metallurgy;

electricity, electrical and electric drivers;

I&C systems, automation and technological protection;

operational activities of the operating personnel.

In treating the problem of reliability as a multi-criterion problem [6, 8, 9], it is necessary to orient the work of experts in the application by them the design data on the inspected equipment, as well as all available historical data. The solution should be developed only on the basis of the consolidation of all reliability criteria

Conclusions

1. Application of the possibility theory jointly with the methods of hierarchy analysis provides results that can serve as the scientific basis for expert collecting and processing the information about the current value of reliability indices of power equipment.

2. The technology for collecting and processing the expert information in a particular nuclear power plant could be based on the above-stated approaches.

3. Models of degradation of the power equipment may be defined through expert approximation with sufficient accuracy for practical purposes. The normal distribution law can be used as the basic law of distribution of failures.

4 For consolidation of heterogeneous data on the reliability obtained from organizations that design and produce the power equipment and components, statistics data on failures resulting from operation, and the data received from the experts, it is advisable to use fuzzy clustering algorithms.

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