2007 International Nuclear Atlantic Conference - INAC 2007
Santos, SP, Brazil, August 29 to October 5, 2007
ASSOCIAÇÃO BRASILEIRA DE ENERGIA NUCLEAR - ABEN

VOLUME FRACTION CALCULATION IN MULTIPHASE SYSTEM SUCH AS OIL-WATER-GAS USING NEUTRON

Robson Ramos[1], Luis E. B. Brandão[1], Roberto Schirru[2], César Marques Salgado[1]
Cláudio M. N. A. Pereira[1], Ademir Xavier da Silva[2]

[1] Instituto de Engenharia Nuclear, SECIC/DIRA/IEN/CNEN
Caixa Postal 68550
21945-970 Rio de Janeiro, RJ
robson@ien.gov.br; brandao@ien.gov.br; otero@ien.gov.br; cmnap@ien.gov.br

[2] Universidade Federal do Rio de Janeiro, [PEN/COPPE-DNC/EE]CT
Caixa Postal 68509
21941-972 Rio de Janeiro, RJ
schirru@lmp.ufrj.br; ademir@con.ufrj.br

ABSTRACT

Multi-phase flows are common in diverse industrial sectors and the attainment of the volume fraction of each element that composes the flow system presents difficulties for the engineering process, therefore, to determine them is very important. In this work is presented methodology for determination of volume fractions in annular three-phase flow systems, such as oil-water-gas, based on the use of nuclear techniques and artificial intelligence. Using the principle of the fast-neutron transmission/scattering, come from an isotopic ^{241}Am-Be source, and two point detectors, is gotten measured that they are influenced by the variations of the volume fractions of each phase present in the flow. An artificial neural network is trained to correlate such measures with the respective volume fractions. In order to get the data for training of the artificial neural network without necessity to carry through experiments, MCNP-X code is used, that simulates computational of the neutrons transport. The methodology is sufficiently advantageous, therefore, allows to develop a measurement system capable to determine the fractions of the phases (oil-water-gas), with proper requirements of each petroliferous installation and with national technology contributing, possibly, with reduction of costs and increase of productivity.

1. INTRODUCTION

To measure multi-phase mixtures, type oil-water-gas, has been of oil industry interest since 1980 and to get the volume fraction of each phase that composes the flow system presents difficulty for the engineering process. The used traditionally primary proceedings plants use a technology based on gravitational decanters in the components separation process, where after the separation measuring the flow-rate of each phase for intermediary of conventional instruments.

The search of the volume fractions values exactness in three-phase systems is of so great necessity, that is well known the growth in the research number that comes being published with the most diverse techniques and configurations [1], [2], [3], [4]. This is a positive factor, because to improve its measures it is of the petroliferous industries interest. Therefore, it is of great importance to make use of compact measurement system, not invasive[1] and with national technology capable to determine with exactness and in real time, without the necessity of separation and measurement of each phase separately, with proper requirements of each petroliferous installation contributing, possibly, for improvement in the product quality, cost reduction and of productivity improvement.

The use of neutron in the volume fraction determination comes sufficiently being studied for some researchers. Han and Hussein [5], had used fast neutrons in the accomplishment of volume fractions measures in two-phase flow contend water-gas and had gotten success. Russein and Han [6], used the fast neutrons transmission/scattering method come from a ^{241}Am-Be neutron source and an adequate system of detection together with simulation using a proper code [7] based in the Monte Carlo Method, in the accomplishment of volume fractions measures in a homogeneous three-phase flow contend air-water-oil and had taken satisfactory resulted. Its research demonstrates that the measurement method of volume fractions using fast neutrons is sufficiently promising and still can very be explored.

The thermal neutrons absorption for atom nucleus can result in the production of γ-rays characteristic that can be used to discriminate between oil and water. This method of nuclear activation requires, however, neutrons of low energy, called thermal neutrons, which cannot be produced in the field without the use of a moderator material that involves the fast neutrons source. The loss of neutrons (escape and absorption) during the moderation process and the generally low values of the activation cross-section makes with that it needs of neutron sources with high activities. This brings practical difficulties in terms to providing adequate a biological shielding and to producing a mobile portable device. In addition, thermal neutrons capture may lead to the activation of the piping material and/or other present elements or objects. Further, the direct use of an isotopic neutrons source, with low activity, un-moderate is more attractive for such intention, because fast neutrons easily lose energy by colliding with the majority low-mass number elements.

Aiming at to implement an experimental arrangement that can contribute for the oil industries, this work has as purpose to develop methodology capable to calculate volume fraction in multi-phase system, type oil-water-gas, being used neutrons, MCNP-X [8] and Artificial Neural Network (ANN).

2. THEORETICAL BEDDINGS

2.1. The Monte Carlo Method

The Monte Carlo method can be used to represent a statistical process theoretically, as the radiation material interaction, is very useful in complex problems that cannot be simulated by deterministic methods or in situations where it is needed to make a study preliminary. In this method, the individual probabilistic events that understand a process are sequentially simulated.

The probability distributions that govern these events are showed statistically to describe the phenomenon that is being simulated. This process of sampling statistics is based on the

[1] The not invasive of a multi-phase measurer is on to the lesser consuming of its components and its operational trustworthiness. Of the view point process the invasive implies in operational restrictions, as pigagens and the operational not-continuity.

random numbers selection. Of the radiation transport particle, the Monte Carlo technique consists of following each particle since the source, where its birth occurs, throughout its life until its death (escape, absorption etc.).

2.2. The MCNP-X Code

The computational code based in the Monte Carlo Method, the MCNP-X, contains all the capacities of MCNP-4C [9] and MCNP-5 [10] adding capacity to carry 34 new types of particles (protons, ions light, etc), expansion of the energy band of simulated particles In the MCNP-X, new physical models of simulation, techniques of variance reduction and new techniques of data analysis had been implemented, beyond updates of the cross-section libraries. Its treatment capacity of complex 3 dimensions geometry's and the varieties of options of entrance data make of this code a convenient and very powerful tool in the field of the radiological protection, nuclear modeling installations, detectors, detectors efficiency calculation, radiation shield and etc.

2.3. Artificial Neural Network

The ANN are mathematical models inspired in the human brain, capable to classify, to generalize and to learn unknown functions from a data set.

The network learning is the ANN adaptation to the data that are presented (training data), can be of the not supervised type or supervised. In the first one, only the data of entrances are supplied and in the second, are supplied to the entrances and the respective exits that extract automatically the characteristics necessary to represent the supplied information with the optimum adjustment the training data.

3. METHODOLY

The fast neutrons easily lose energy by colliding with some low-mass number elements, such as those present in the oil that is a natural hydrocarbons mixture (hydrogen and carbon) and in the water. After its interactions with a system contend such elements, appear neutrons where the energy groups division is arbitrary, being the used one in this work, the same one classified for Gibson and Piesch [11], that is: thermal < 0,4 Ev; epithermal 0,4 eV – 100keV; fast > 100 keV.

The mathematical model considered in this work uses a energy spectrum come from a ^{241}AmBe isotopic neutron source and point measures transmitted and scattering 180º and 90º respectively, where they are registered the thermal neutrons flow, thermal, epithermal and fast after the interaction of these with the system. For the volume fraction prediction an ANN was used where the training data, the neutrons flow (transmitted and scattering) in the three bands of cited energies, had been taken by mathematical simulation with the use of the MCNP-X code.

3.1. Mathematical Modeling

In Fig. 1 is presented geometry used in the mathematical modeling that it aimed at to study an approach model of an three-phase system with annular flow. Was considered a collimated bean come from of ^{241}AmBe isotopic neutron source, two point detectors and a iron piping with its inner end outer diameters measuring respectively 18 cm and 20 cm, contend the three- phases studied, oil-saline water-gas, whose volume fractions had been taken varying the x1, x2 and x3 thickness of each material. In the simulation was used a 4% of salt in the saline water, this the average index of the seas [12]. The air represented the gaseous phase and the used oil is a simple hydrocarbon, that has its indefinite molecular composition (as it is the case with the oil majority), whose chemical form and its density are respectively C_5H_{10} and 0.896 g.cm^{-3}. The hydrogen content per unit volumefor this oil is 12.6% less than of water. This difference makes with that the water is more efficient to scatter neutrons than oil, for the same volume [6].

The effect of the metallic walls of the test section on the neutrons scattering can be safetly ignored, since the metals is not an effective neutron slowing-dow material. The amount of neutrons absorbed by the test section walls can also be assumed to be constant, and therefore does not affect the phase fraction measurement.

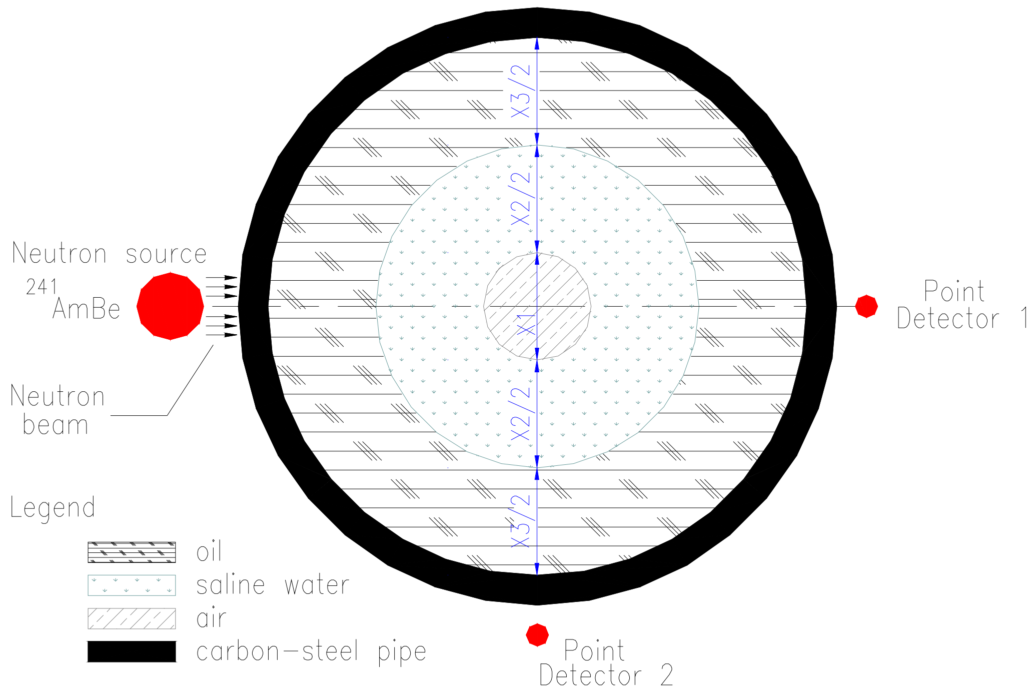

Figure 1. Simulated geometry of the annular three-phase flow.

In the fast neutrons interaction simulation of the emitted by the ^{241}AmBe source with the materials that compose the three-phase flow, had been taken esteem point measured of neutrons flow (thermal, epithermal and fast) transmitted and scattered in point detectors 1 and 2 respectively, in function of the arrangement compositions used. Fig. 2 shows a ternary contends the data sets used for the ANN, for volume fraction predictions with the relative percentages to each one of the phases that compose the multi-phase annular flow studied and the transmitted and scattered neutrons flow, proceeding from the simulation with the MCNP-X.

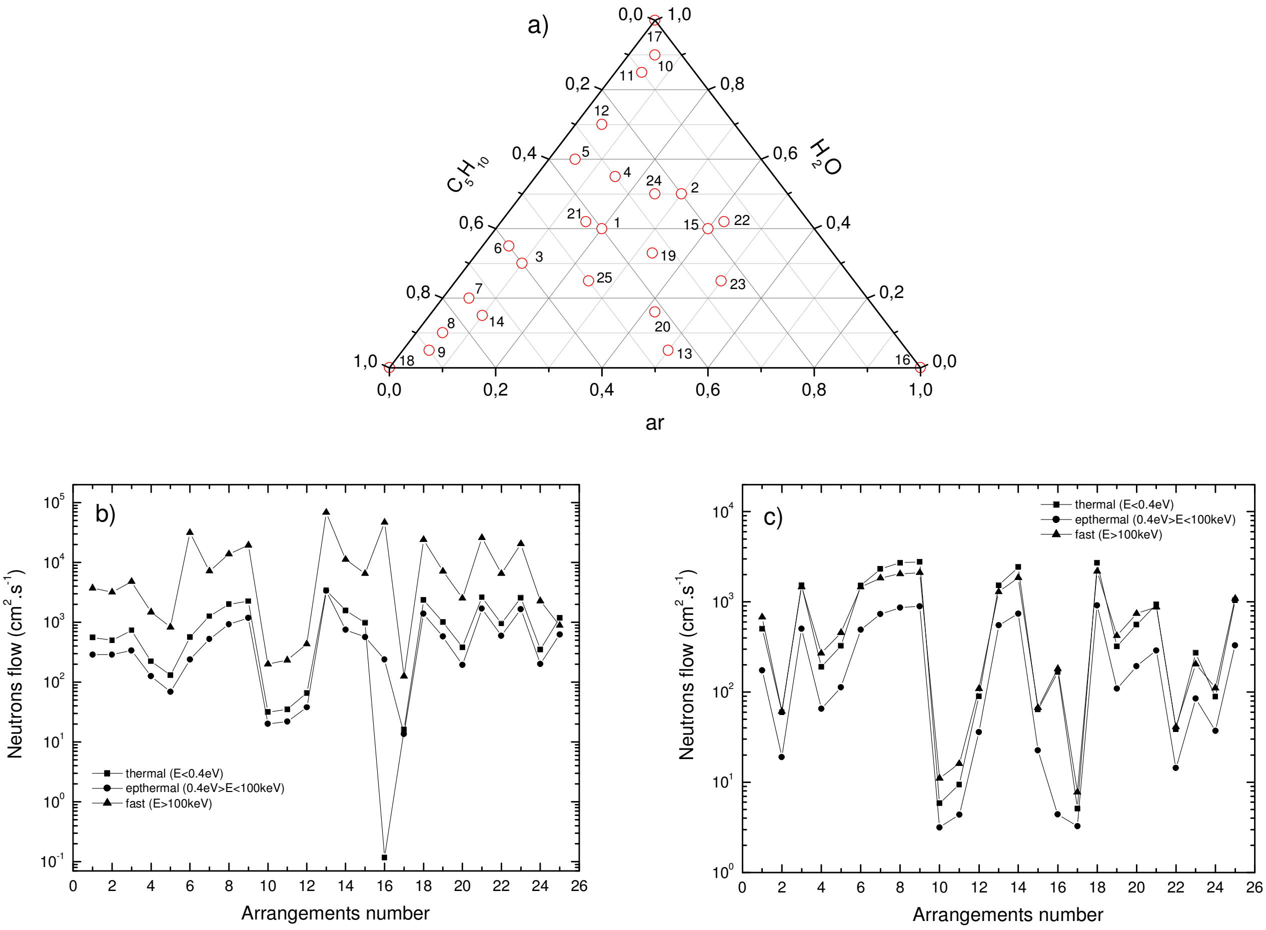

Figure 2. a) Data set used in the ANN; b) Neutrons flow transmitted in point detector 1; c) Neutrons flow scattered in point detector 2.

3.2. Volume fraction prection with ANN

The geometry used in the mathematical modeling, presented in Fig. 1, was used in the attainment of a data set where the referring thickness to each material, x1, x2, and x3, had been varied aiming to take volume fractions that they had formed the 25 arrangements compositions used, as are shown in the Fig. 4a, that they had been used in the MCNP-X simulation. Each material was being varied of 0% the 100% taken the point counting of the relative neutron flows to each configuration, that had been used to train the ANN being aimed at to correlate them with the established values for each materials fraction. The fraction volume referring to the oil (C_5H_{10}) was taken by complement.

The transmitted and scattered neutrons flow taken points in detectors 1 and 2 respectively with the MCNP-X in function of the arrangements, presented in Fig. 2a and 2b, had been the entrance data of the ANN, how to see in Fig. 3. The main parameters of the ANN used that had all supplied the lesser relative average error data set, had been: learning rate η=0,02 Momentum=0,2 and stopped criterion “*cross-validation*” that is, the training of the network stop in the bigger point generalization.

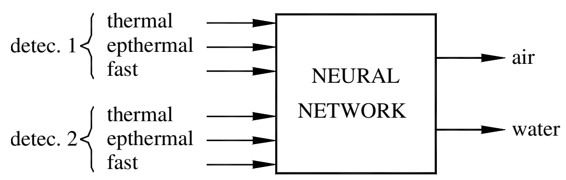

Figure 3. Schematical representation used by the ANN.

In this work used the supervised learning, a network type “ multilayer perceptron” and back-propagation training algorithm [12], one of the most used currently [13], [14], whose construction possess:

- entrance layer: 6 neurons with linear activation function [-1,1]
- intermediate layer: 7 neurons with different activation functions (tanh, Gaussian, Gaussian Comp.)
- exit layer: 2 neurons with Logistic activation function

4. RESULTS

4.1. Volume fraction with neural network

The data gotten for MCNP-X code for the different materials fractions had represented a set of 25 standards that had been used in the entrance layer for ANN training, where 20 standards had been used as training set and 5 as test set. The ANN reply for the set test it is shown in Fig. 4 and the average relative errors for air-water-oil of the corresponding exit data to each standards specific set (training and test) used in the ANN are presented in Tab. 1.

Table 1. Relative average errors for the test set: a) ar, b) C_5H_{10}

Set	Relative average error (%)		
	air	water	oil
Training	6,60	4,08	13,60
Test	10,21	11,96	5,25

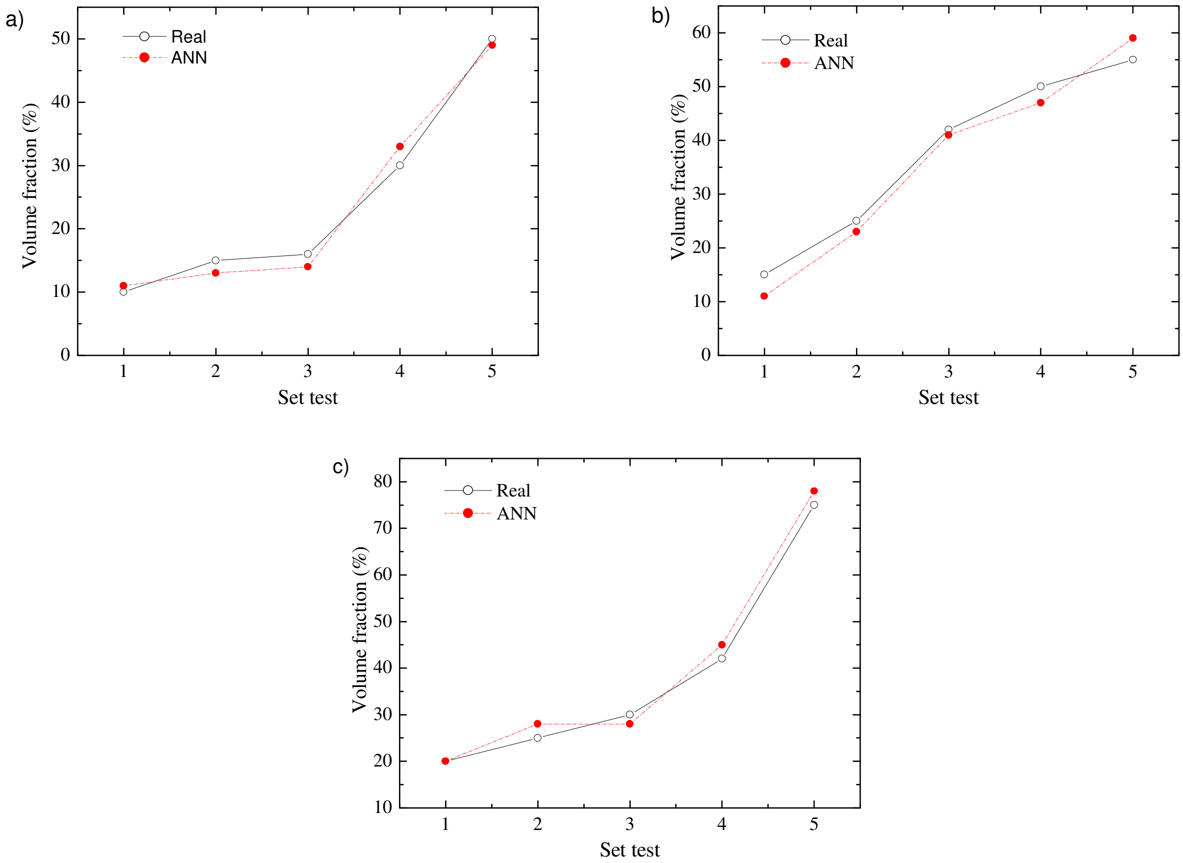

Figure 4. Test Set selected for the ANN with its respective results taken for: a) air, b) water and c) C_5H_{10} (was taken by complement).

5. COMMENTARIES AND CONCLUSIONS

The MCNP-X code demonstrated to be a very efficient tool, therefore, with its use was possible to esteem the neutrons flow, transmitted in detector 1and the scattered in detector 2, referring to each volume fraction phases of the three-phase flow annular, air-saline water-oil, regimen studied. Such results would be difficult attainment in the initial phase of the project, therefore, problems of the neutron source types availability, detectors, system geometry and etc had been eliminated with the use of the code what it will facilitate in the engineering scope the development of a test section for methodology proposal.

In the intention to make a estimate of the neutrons flow after the interaction of these with the system, was used in the simulation with the MCNP-X code two point detectors. Knowing the neutrons flow, will be made in future works studies aiming at to the adequate choice of detectors for neutrons measurement that they will be used in the place of the point detectors.

As well the MCNP-X the Artificial Neural Network was a very efficient tool, being capable to correlate the data taken in the MCNP-X simulation with the volume fractions of the phases that compose the annular three-phase flow system model, making possible to predict with good precision the volume fractions of air, saline water and oil.

The not invasive method for volume fraction prediction of the three-phase annular system studied, using as nuclear technique the neutrons interaction with the material and ANN, demonstrated good efficiency in the percentage prediction of each material that composes the phases of the three-phase system studied, satisfying the proposal of this work and demonstrating to be promising to the method of volume fraction measurement using neutrons.

REFERENCES

1. Abouelwafa, Kendall, “The Measurement of Component Ratios in Multiphase Systems Using Gamma-ray Attenuation” Journal of Physics E: Scientific Instruments, 341-345 (1980)
2. Abro, E., Johansen, G. A., Opedal, H., “A radiation Transport Model as a Design Tool for Gamma Densitometers” Nuclear Instruments and Methods in Physics Research, A431, pp.347-355 (1988).
3. Salgado, C. M., Brandão, L. E., Nascimento, C. M., Ramos, R., Silva, A. X., Schirru, R., “Determinação de Frações de Volume em Sistema de Escoamento Multifásico Utilizando Atenuação de Raios Gama e Redes Neurais” IX Encontro de Modelagem Computacional, Novembro, Belo Horizonte, MG, BR (2006).
4. Salgado, C. M., Brandão, L. E., Nascimento, C. M., Ramos, R., Silva, A. X., Schirru, R., “Cálculo de Frações de Volume em Sistema de Escoamento Anular (óleo/água/gás) Utilizando MCNP-X e Rede Neural” IV Congresso Rio Automação, Maio, Rio de Janeiro, RJ, BR (2007).
5. Han, P., Husseim, E. M. A., “Nonintrusive Measurement of Transient Flow Boiling in Rod-Bundle Channels Using Fast-Neutrons Scatering” Nucl. Instrum. Methods, A. 353 pp. 695-698 (1994).
6. Husseim, E. M. A., Han, P., “Phase Volume-fraction Measurement in Oil-Water-Gas Flow Using Fast Neutrons” Nuclear Geophysics Vol. 9, No.3, pp229-234 (1995).
7. Hussein, E. M.A., “Center-of-mass Monte Carlo Simulation of Neutron Scattering Experiments” Applied Radiation and Isotopes 41, pp1033-1039 ((1990).
8. Pelowitz, D. B., “MCNPXTM User’s Manual, Version2.5.0. LA-CP-05-0369” Los Alamos National Laboratory (2005).
9. BRIESMEISTER, J. F., “MCNP – A General Monte Carlo code for neutron and photon transport” Version 4C. Los Alamos National Laboratory report LA-13709-M, March (2000).
10. X-5 Monte Carlo Team, “MCNP – A General Monte Carlo N-Particle Transport Code” Version 5 Vol.1: Overview and Theory, LA-UR-03-1987. Los Alamos National Laboratory (2003).
11. Gibson, J. A. B., Piesch, E., “Neutron Monitoring for Radiological Protection” Tecnical Reports Series n.252. International Atomic Energy Agency, Viena, Austria (1985).
12. G. A. Johansen, P. Jackson, “Salinity independent measurement of gas volume fraction in oil/gas/water pipe flows”. /Applied Radiation and Isotopes/, *V. 53*, pp. 595-601 (2000).
13. Chauvin, Y., Rumelhart, D. E., “Backpropagation Theory” Architectures and Applications (1995).
14. Rumelhart, D., Hinton, G., Williams, R., “learning Internal Representation by Error Propagation, In: Explorations in the Microstructure of Cognition” Vol.1, cambridge: MIT Press (1986).
15. Freeman, J. A., Skapura, D. M., “Neural Networks: Algorithms, Applications and Programming Techniques” Addison-Wesley Publishing, Reading, pp.401 (1992).