Proceedings of the Third International Symposium on Air Quality Management at Urban, Regional and Global Scales. pp. 237-246, 26-30 September 2005, Istanbul – Turkey

FUZZY ASSESSMENT OF HUMAN-HEALTH RISKS

Vladimir P. Reshetin

Joint Institute for Power and Nuclear Research, National Academy of Sciences of Belarus, Sosny-Minsk, 220109, Belarus, vladimir@reshetin.net

ABSTRACT

Uncertainty of input data creates fuzzy conditions for assessing and forecasting ecological risk and risks associated with human health due to environmental pollution. Many uncertainties are difficult to eliminate and they do not have structure so that it could be modeled or described by probabilities and probability processes. With this work a formalism of fuzzy sets was applied to model and assess the risk of carcinogenesis and additional mortality associated with air pollution. With this formalism it is possible to handle uncertainty by means of its modeling. A formulated approach makes it possible to assess the extent of expert confidence that the risk of carcinogenicity (risk of additional mortality) does not exceed some definite value that can be presented both as an accurate and fuzzy number. As an example is examined the risk associated with ten carcinogens; formaldehyde, lead, hexavalent chromium, benzpyrene, benzene, cadmium, nickel, arsenic, acetyldehyde, and carbon tetrachloride. For these three assessments were carried out for 'pessimistic', 'expected' and 'optimistic' scenarios at ten big industrial centers of Russia. For each scenario, the confidence degree that the risk does not exceed the chosen value was also calculated.

Key Words: Human Health Risk, Air Pollution, Fuzzy Logic

1. INTRODUCTION

In the process of decision making for minimizing the risks associated with pollution of the environment we run into one common problem – uncertainty of the input data that creates fuzzy conditions for assessments and forecasting. In striving to make these assessments more reliable, various development scenarios connected with the change of the exposure levels, the volume of emission and the set of harmful substances emitted to the environment are usually generated, and then the assessment of ecological risk and human health risk is conducted to realize hypothetical scenarios. The optimistic scenarios improve the condition of the environment and cut down the risk to human health, but the pessimistic ones make it worse, including the case where the environment is brought to the edge of full degradation.

This work is particularly devoted to the substantiation of the acceptability of fuzzy-set descriptions for assessing human health risk and environmental managing. Though probability as a tool for risk modeling was established a relatively long time ago, fuzzy sets as a tool for the research of ecological risk and human health risk is unusual and new, and this remark is true for many countries worldwide. In spite of the fact that the main focus of attention in this paper is the assessment of carcinogenesis risk associated with harmful chemicals in the atmosphere, the presented approach can be successfully applied for other tasks on environmental risk assessment and management.

2. ASSESSMENT OF THE HUMAN-HEALTH RISK

Human health risk assessment during the analysis of the atmospheric air presupposes the fulfillment of four main stages namely: (1) Hazard identification; (2) Exposure assessment; (3) 'Dose-response' assessment and (4) Risk characterization. In identifying hazard, first of all it is necessary to take into account the factors that are capable of exerting an adverse effect on human health. As applied to the assessment of the air-quality in towns, this stage in the work implies an inventory of industrial effluents, accounting and recording of the chemical substances that are used for industrial and other purposes, etc. In this stage, sampling screening investigations of the atmosphere of towns can be carried out to reveal those hazards that can be overlooked while constructing an emission inventory.

The second stage, for exposure assessment, consists of obtaining the information on actual doses to which population groups are exposed. Usually, this information is provided, first, by the data of air monitoring and, then, from results of calculations. Laboratory measurements carried out in conformity with the active normative monitoring-related documents can provide objective information on the state of the atmosphere. However, these data encompass only a portion of the chemical substances that are actually present in the atmosphere and are related to a particular observation station. Unfortunately the number of these stations is always insufficient and it is difficult to generalize based on vague spatial interpolation. Moreover, these investigations allow one to obtain only an integral estimate of the concentration of chemical substances from all of the sources of emission. The identification of these sources is usually carried out on the basis of expert approaches. Therefore, the authenticity of the results of these works greatly depends on the qualification of the expert. Computational methods allow one to construct a fully adequate model of the contamination of the atmosphere with the possibility of evaluating the concentration of impurity at any point of the space investigated. At the same time, the accuracy of calculations depends on two basic aspects: the quality of the initial information and the model selected.

The dose-response function establishes the quantitative relationship between the value of the exposure and the additional morbidity or mortality. For defining this function, one can use the data of the experiments on animals or, what happens less often, epidemiological researches in which groups of exposed humans are involved. It should be noted that there are many different dose-response relationships taking into account the probability that the various toxic effects can arise depending on the levels and the routes of exposure. Risks for a given substance cannot be defined with some degree of belief until quantitative dose-response relationships are obtained, even if it is well known that the substance is hazardous to human health. If the substance in question belongs to carcinogens, the aim of defining the response for a dose consists in establishing the relationship between the dose of the chemical and the probability of the carcinogenesis effect. Assessment of the response for a dose implies the extrapolation from the large doses and the exposures obtained in the epidemiological investigations to the doses and the exposures that will be expected under the contact of a human with a given substance in the environment. For extrapolation from the large doses to the small ones various researches use multi-step models with different number of steps, the loggit-model (US EPA,1999), etc.

In that way, taking into account all the factors leading to the fuzzy assessments, the exposure scenarios used for risk assessments can be combined into the one united scenario in the form of the triangle number, where three points might be marked out: the minimal possible exposure and the minimal possible risk associated with this exposure (correspondingly $LAIE_{min}$; r_{min}), the most expected ($\overline{LAIE}$; $\bar{r}$) and the maximum possible ($LAIE_{max}$; r_{max}) values of the exposure and the risk. In particular for assessment of the carcinogenesis risk and the additional mortality caused by cancer, it is possible to apply the additive models in which the total effect of the impact of all the carcinogens in the atmosphere is defined as a superposition of the effects caused by each carcinogen:

$$\underline{R} = \sum_{(i)} \underline{\alpha_i} \times \underline{LAIE}_i = \sum_{(i)} \underline{\beta}_i \times \underline{CCA}_i , \qquad (1)$$

where, all the values in eq 1 have a form of the triangle numbers, $\underline{\alpha}_i$,, $\underline{\beta}_i$ are the constants, defined by the dose-response function and the exposure conditions. Model additivity is based on the application of the linier dose-response relationship assuming that the exposure level is not high.

3. RISK ASSESMENTS WITH FUZZY SETS AND ESTIMATE OF CONFIDENCE OBTAINED

If all of the parameters in (1) have ‘fuzzyness’, i.e. their exact value is unknown then the triangle numbers with the function form shown in Figure 1 is expediently used. These numbers model the following statement: ‘parameter A is approximately equal to $\bar{a}$ and identically located in the interval of [a_{min}, a_{max}]’. The chosen description permits the taking of the parameter interval [a_{min}, a_{max}] as an input information for risk assessment where the most expected value is $\bar{a}$, so the appropriate triangle

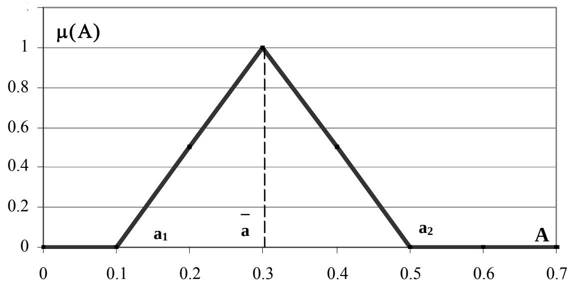

Figure 1. Triangle number A for, exposure, risk of carconogenesis, duration of exposure, etc.

number $\underline{A} = (a_{min}, \bar{a}, a_{max})$ is constructed. Further, we will call the parameters (a_{min}, $\bar{a}$, a_{max}) valuable points of the fuzzy triangle number $\underline{A}$.

Often the subjective probabilities of realizing appropriate scenarios of input data (‘pessimistic’, ‘normal’ and ‘optimistic’) are prescribed to these points. As we can not operate with probabilities whose values we cannot determine or assign, in the process of risk assessment and analysis, the conception of fortuity is substituted for the conception of expectancy and capability.

Assign the following set of fuzzy numbers for assessment of carcinigenesis risk and risk of death associated with cancer:

$\underline{\beta} = (\beta_{min}, \overline{\beta}, \beta_{max})$ – risk assessor cannot exactly estimate either a dose-response relationship, or an inhalation exposure. In the case of assessment of inhalation exposure, uncertainties are caused by its duration, as well as the diversity and the vagueness of the assigned parameters of the exposure scenarios, whereas for the dose-response relationship, as a rule there is a blurriness of the values of unit risks. For all that, a hypothesis concerning threshold action of carcinogens, accepted or rejected by an expert, influences essentially on risk assessment. In this connection, it should be noted that the hypothesis regarding a non-threshold action of carcinogens accepted by Environment Protection Agencies as well as a linear extrapolation from large doses to small ones in a dose-response relationship, has a conventional nature, and there is not enough epidemiological evidence for its acceptance or its decline.

$\underline{CCA_i} = (CCA_{i\ min}, \overline{CCA_i}, CCA_{i\ max})$ – a risk assessor can not exactly assess the concentration of carcinogen averaged for the exposure duration (for example, the reconstruction of emission and dispersal of carcinogens in the atmosphere in the past can be performed very uncertainly; the same can be said regarding the prediction of concentration in the future).

$\underline{R} = (R_{min}, \overline{R_i}, R_{max})$ – a risk assessor forecasts the range of varying the risk of carcinogenesis caused by inhalation exposure. In the case where the survival of people taken ill with cancer is allowed for, definition of coefficient β, formula (1) gives fuzzy set assessments of risk of death caused by carcinogens in the atmosphere. It should noted that when one of the parameters $\underline{A}$ is known exactly, then the fuzzy number $\underline{A}$ reduces to the real number A for which the following conditions are valid $a_{min} = \overline{a} = a_{max}$. But for all that, the main point of method remains the same.

Establishing the suitable level of discretization of α in the interval of belonging [0,1], we can reconstruct the resulting fuzzy number $\underline{R}$ by means of approximation of its function of belonging μ_R with a broken line passing through the interval points. Often it is possible to reduce $\underline{R}$ to a triangle form where we confine the calculations considering only valuable points of fuzzy numbers of input data.

An important problem arising in the case of the application of a fuzzy set methodology consists of an evaluation of the confidence degree of an expert that carcinogenesis (or additional mortality) risk does not exceed definite criterion value R_{th}, that can be given in the form of a fuzzy or accurate number.

For simplicity in Figure 2 the function of belonging $\underline{R}$ and the criterion value R_{th} in the form of accurate number is presented. The point where the function of belonging crosses the straight line $r = R_{th}$ is a point with ordinate α_1. Choose an arbitrary level of belonging α and define corresponding interval $[R_1;R_2]$. For $\alpha > \alpha_1$ $R_1 > R_{th}$, the point $r = R_{th}$ locates beyond the interval $[R_1;R_2]$, and our confidence that risk does not exceed R_{th}, equals zero. It is appropriate to name the level α_1 as a lower bound of a confidence domain. For $0 \le \alpha \le \alpha_1$ the point $r = R_{th}$ locates inside the interval $[R_1;R_2]$. As all realizations R for the given level of α are equally possible, then the

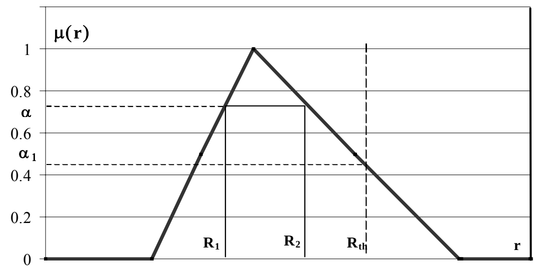

Figure 2. Risk level of R and the criterion of R_{th} .

degree of confidence $\Psi(\alpha)$, that risk does not exceed the value R_{th} represents a geometrical probability of the event that the value of risk R is inside the interval $[R_1; R_{th}]$. Then the total value of the confidence degree that the risk does not exceed the value R_{th} will be equal to:

$$CONF = \int_0^{\alpha_1} \Psi(\alpha) d\alpha \qquad (2)$$

In the important case where the limitation $\underline{R_{th}}$ is defined exactly by the level R_{th}, the function $\Psi(\alpha)$ can be presented in the form:

$$\Psi(\alpha) = \begin{cases} 0 & , \text{ for } R_{th} < R_1 \\ \dfrac{R_{th} - R_1}{R_2 - R_1} & , \text{ for } R_1 \le R_{th} \le R_2 \\ 1 & , \text{ for } R_{th} > R_2 \end{cases}, \quad \alpha = [0, 1]. \qquad (3)$$

To collect all the necessary input data for assessment of the function we need two values of the inverse function $\mu_{NPV}^{-1}(\alpha_1)$. The first one is R_{th} (by definition of the upper bound of risk domain α_1), and denote the second value - R_{th}'. In a similar way denote R_{min} and R_{max} – for two values of the inverse function $\mu_{NPV}^{-1}(0)$. Denote also indication $\overline{R}$ - for the most expected value of $\underline{R}$. Taking into account eqs 2-3 the expression for the confidence degree CONF has the following form:

$$CONF = \begin{cases} 0, \quad R_{th} < R_{min} \\ \dfrac{R_{th} - R_{min}}{R_{max} - R_{min}} - \dfrac{R_{th} - \overline{R}}{R_{max} - R_{min}} \times \ln\left[\dfrac{\overline{R} - R_{th}}{\overline{R} - R_{min}}\right], \quad R_{min} \le R_{th} < \overline{R} \\ \dfrac{R_{th} - R_{min}}{R_{max} - R_{min}} - \dfrac{R_{th} - \overline{R}}{R_{max} - R_{min}} \times \ln\left[\dfrac{R_{th} - \overline{R}}{R_{max} - \overline{R}}\right], \quad \overline{R} \le R_{th} < R_{max} \\ 1, \quad R_{th} \ge R_{max} \end{cases} \qquad (4)$$

We analyze the expression described by eq 4 for three particular cases:

For $R_{th} = R_{min}$ $R = 0$, $\alpha_1 = 0$, $R_{th}' = R_{max}$, then the limit transition in (4) gives CONF = 0. In other words the degree of confidence that risk does not exceed R_{th}, equals zero and the degree of confidence that risk is higher then R_{th} equals unity.

For $R_{th} = R_{th}' = \overline{R}$ (average confidence) $\alpha_1 = 1$, the limit transition in (4) gives CONF = $(R_{max} - \overline{R})/(R_{max} - R_{min})$.

For $R_{th} = R_{max}$ (extremely high confidence) $\alpha_1 = 0$, $R_{th}' = 0$, and limit transaction in (4) gives CONF = 1.

Hence, a degree of confidence CONF varies from 0 to 1. In accordance with preferences the risk assessor or decision-maker can classify the values of CONF, selecting for themselves the interval of unacceptable values of a degree of confidence. It is possible to introduce more detail gradation of function CONF. For example, if we introduce the variable 'Degree of confidence' with its own term-set of values {Negligible, Low, Medium, Relatively high, Unacceptable} then every assessor or decision-maker can perform their independent description of corresponding fuzzy sub-sets by assigning five functions of belonging $\mu_*(\text{CONF})$.

If all of the parameters that are used for risk assessment have interval symmetry then the assessment of risk itself (R) can be reduced to interval symmetrical form. Define $\overline{R}$ as average expected value of R, Δ is scattering of $\underline{R}$ from average value, i.e. $\Delta = \overline{R} - R_{min} = R_{max} - \overline{R}$, $\underline{R} = (\overline{R} - \Delta; \overline{R}; \overline{R} + \Delta)$. Introduce the coefficient of assessment stability:

$$\lambda = ((\overline{R} - R_{th}) / \Delta. \qquad (5)$$

It is clear the closer the value of stability coefficient λ to ± 1, the more reliable the assessment of risk and decision made on its basis that will be achieved. For $\lambda = \pm 1$ the assessments can be used without any risk of mistaken decision. Turning to another variable λ in eq 4 it is easy to derive the following expression for the function CONF:

$$\text{CONF} = \begin{cases} 0, & \lambda \leq -1 \\ (1 + \lambda - \lambda \times \ln(|\lambda|))/2, & |\lambda| < 1 \\ 1, & \lambda \geq 1 \end{cases} \qquad (6)$$

The confidence achieves 80% and more values if $|\lambda| \geq 0.2$. For $\lambda \rightarrow -1$ the function CONF tends to zero, and. the confidence increases that the counter event is true, i.e. risk exceeds the given value.

4. AN EXAMPLE OF FUZZY SET ASSESSMENT FOR THE RISK CARCINOGENESIS AT TEN MAIN TOWNS OF RUSSIA

For analyzing the exposure to dangerous chemicals contained in the atmosphere, the initial data were taken from the Russian Weather Service (by Rosgidromet) who examined the air contamination of the atmospheric in the towns of Russia for 1993 and 1998. These data contain information on concentrations of 75 various chemicals (groups of substances) in the atmosphere of 291 populated areas, in which their monitoring was carried out. Among the controlled substances, we selected the data of ten carcinogens, namely, formaldehyde, lead, hexavalent chromium, benzpyrene, benzene, cadmium, nickel, arsenic, acetyldehyde, and carbon tetrachloride It should be noted that the data of the Russian Weather Service for 1993 involve the most complete set of controlled chemical substances, and therefore they are most suitable for a comparative analysis and integral evaluations. In the present work, no risk assessment was made for suspended substances and soot, since substantiated assessments require data not only on the concentrations of suspended substances and their size distribution, but also on the chemical composition of particles. The use of universal procedures to evaluate the risk of death from exposure to dust and soot irrespective of their chemical compositions (see, e.g., US EPA, 1989; US EPA,1999) is, in our opinion, incorrect.

In the present work no risk assessments were made for exposure to asbestos whose concentrations are presented by the Russian Weather Service in mg/m^3 rather than in the number of fibers per unit volume (as required by US-EPA's procedures), which made it difficult to use these data for risk assessment. Some of the controlled substances, such as soot, also, as a rule, involve carcinogenic substances. However, their complete identification and, more so, the determination of concentrations does not seem possible. A sampling analysis of the accessible data on the contamination of the atmosphere of Russian towns (Reshetin, Kazazyan, 2004; State Report, 1998) allows a conclusion that though a considerable group of carcinogens are being controlled at the present time, there are carcinogens in the air of towns that are not controlled by the Russian Weather Service. Among them are: benzoanthracene, chrysene, benzo(b)fluoranthene, benzo(k)fluoranthene, indeno(1,2,3-cd)pyrene, 1,3-butadiene, 1,2-dichloroethane, tetrachloromethane, tetrachloroethylene, chloroform, and some others. The particularity of the data on monitoring of chemicals in the atmosphere of Russian towns is the fact that a set of controlled substances varies across different towns. Hence, it is difficult to assess the total risk of carcinogenesis caused by all the carcinogens in the atmosphere.

With this work the fuzzy set methodology is used for assessment of risk of carcinogenesis in the ten biggest industrial centers of Russia with a total population above 21.7 million, which approximately corresponds to 20% of the total urban population of the country. Concentration of the carcinogen is presented in the form of a triangle number. In those towns where there were the data of daily monitoring we selected the annual average concentration as the most probable value for exposure assessment. The assessments were performed separately for the exposure levels of 1993 and 1998. For 'optimistic' and 'pessimistic' scenarios of the input data, the maximum and minimal annual values among the data collected on various observation stations were chosen. In towns where there were no data of Rosgidromet on a certain chemical, expected values of concentrations corresponding to a 'normal' exposure scenario were calculated in accordance with the formula

$$\overline{CCA_i} = CCA_{av,i} \times \Psi_i , \quad (7)$$

Where, $CCA_{av,}$ is average concentration calculated on the basis of inventory data and a stochastic trajectory model of impurity propagation in the atmosphere[5], Ψ_i is a correction factor, representing the ratio of measured and calculated annual average concentrations averaged across Russian towns where Rosgidroment carried out daily monitoring. Analogous assessments were performed for 'optimistic' and 'pessimistic' values of concentration:

$$CCA_{min,i} = \overline{CCA}_i \times \Psi_i^{min}; \quad CCA_{max,i} = \overline{CCA}_i \times \Psi_i^{max}, \tag{8}$$

For the calculation of the correcting factor Ψ_i^{min}, the ratio of minimal among the observation stations annual concentration to annual concentration averaged over the observation stations were calculated for all the cities. As a correcting factor Ψ_i^{min}, the minimal value of this ratio was chosen. A correcting factor Ψ_i^{max} was defined analogously. In addition to the data enumerated above, the data of the case studies (Surrounding medium, 1999) on the following five carcinogens: 1,2- dichloroethane, tetrachloromethane, etrachloroethylene, chloroform, 1,3-butadiene which concentrations were measured by other organizations were used for assessments.

To evaluate a mean individual exposure, four universal exposure scenarios have been developed that allow one to take into account different physical activity of urban residents. In evaluation of mean individual exposure averaging was made over the four scenarios; this made it possible to take into account their contribution to the town-average activity of the population. The weights in the scenario convolution were assessed on the basis of existing data on age, sex and activity of population (Reshetin et al., 2000). In the current paper for assessment of impact of small doses the US-EPA approach was applied. In particular for assessment of carcinogenesis risk the no-threshold hypothesis was taken and the values of unit risks from well-known informational system IRIS created by US-EPA's specialists were used (US EPA, 1999). In such a way init risks were assigned in the form of exact numbers. For fuzzy coefficients $\underline{\beta}$ (see eq 1) we use interval symmetric assessment ±20% from expected value $\overline{\beta}$. In our opinion such a value represents sufficiently weighted assessment of uncertainties connected with assignment of weights in the exposure scenario convolution.

In the case of estimation of attributable deaths caused by cancer, the number of people who fell ill with cancer was multiplied by the factor 0.6, which corresponds to the average for Russia's survival rate of cancer patients. It should be noted that according to the Russian Federation report (State Report, 1998), of 50 people who developed cancer of upper respiratory tracts in Russia 47 die. However, taking into account the fact that formaldehyde, just as other carcinogens present in the atmosphere of towns, can induce cancer of different localizations, the survival rate of cancer patients is on average higher than the value 3/50, which is typical of the cancer of upper respiratory tracts.

Attributable cases are commonly interpreted as the preventable fraction, which is meant to be taken as prevented had exposure been removed. Caution, however, is warranted with such an interpretation. First, for long-term effects − the benefit of lower air pollution levels − would take years to be fully realized. Second, the attributable risk estimate does not take competing risks into account. Removing one risk factor − e.g., air pollution − will increase the relative importance and contribution of other risk factors and causes of morbidity and mortality. Accordingly, it is well-known in multicausal diseases that the sum of attributable cases across several risk factors will not add up to 100% but may be larger (Smith et al.,1999). So, for reduction of the risk of premature death, measures should be undertaken to cut off all the competing risks.

The contribution of each carcinogen in total mortality caused by all the carcinogens is shown in Figure 3.

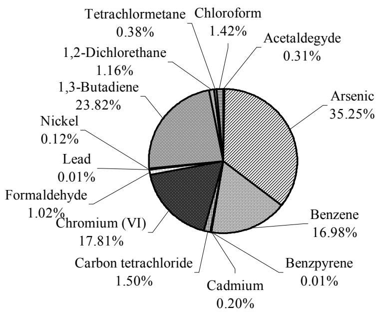

Figure 3. The fraction of various carcinogens in the total cancer incidences from exposure to 'expected' (or 'normal') scenario.

For all the scenarios, exposure to hexavalent chromium, benzene, 1,3-butadiene makes a large contribution to carcinogenesis risk. Taking into account that the cancer rate in Russia is equal to 238 and 168 incidences per 100000 people correspondingly for men and women (data for 1998) (State Report, 1998), the contribution of 15 carcinogens presented in the atmosphere, to the cancer rate are approximately equal to.1%, 6% and 16% of the number of incidences recorded every year in selected towns or 450, 2860 and 7540 cancer incidences per year corresponding to 'optimistic', 'normal' and 'pessimistic' scenarios. At the cities examined by this work the total number of recorded cases of cancer was 45.4 thousands during 1998.
The confidence function CONF plotted against the value of carcinogenesis risk is shown at Figure 4. As is seen from this figure in the framework of selected fuzzy set model, in mentioned towns carcinogenesis risk for life does not exceed 0.013 with probability of 80% and the same probability has the event that risk is lower than 0.008. Note that the contribution of four known human carcinogens, namely, benzene, hexavalent chromium, arsenic and nickel into the total cancer rate caused by all the carcinogens from which the other 11 belong to the group of probable human carcinogens is equal to 85%, 70% and 71% correspondingly for 'optimistic', 'normal' and 'pessimistic'.

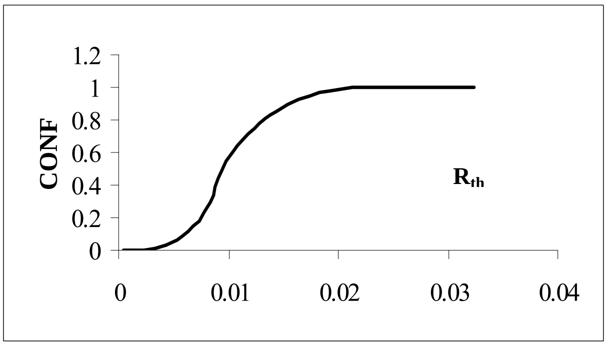

Figure 4. CONF as a function of carcinogenesis risk for ten Russian towns.

On the whole, assessments for the data of monitoring in 1998 coincide with presented results. However, the fuzziness of assessments increases still more by taking into account that the data in 1998 are considerably less representative in comparison to those of 1993.

5. CONCLUSIONS

The methodology of fuzzy sets allows the modeling of uncertainties of data needed for exposure assessment when data of low representativeness and of relatively low quality are available. With this method all the exposure scenarios for individual factors were reduced into one combined scenario in the form of a triangle number where three points can be marked out; the minimum possible, the usually expected and the maximum possible values. In this case, the weights of scenarios were presented in the form of triangular function of exposure level and risk to the fuzzy set of 'approximately equal average value'.

Assessments presented in this work testify that in the ten of the largest industrial centers of Russia with total population of 21.7 million, the contamination of the atmosphere with carcinogens might cause 450, 2860 and 7540 annual cancer incidences under an 'optimistic', a 'normal' and a 'pessimistic' scenarios. These correspond respectively to approximately 1%, 6% and 16% of the cancer incidents recorded every year in the towns examined by this work.

The methodology of fuzzy sets allows also the estimation of the degree of confidence that the risk does not exceed the given level. Particularly in the framework of the selected model, one can assert with confidence of 80% that carcinogenesis risk for life in ten towns is not higher than 0.013.

REFERENCES

Reshetin V.P., Lantsov I.E., Zenich T.S.,2000, Sustainable urban development problem: environmental risk assessment as a tool for decision-making, Final report on ISTC. Project #320d.

Reshetin, V.P., Kazazyan, V.I.., 2004, Public health impact of outdoor air pollution in Russia. Environmental Modelling and Assessment, 9, 43-50.

Smith, K., Corvalan, C.; Kjellstrom, T.,1999, How much global ill health is attributable to environmental factors?, Epidemiology, 10, 573-84.

State report, 1998, 'Concerning the State of the Environment of the Russian Federation for the Year 1998', Moscow.

Surrounding Medium. Health risk Assessment. Risk Assessment. Risk Monitoring, 1999, Report on the Project 'Substantiation of the priority of measures on environmental protection in the Samara region on the basis of the efficiency of expenditures on risk reduction for the health of people', Moscow.

US EPA., 1999, Integrated Risk Informational System, IRIS Database, Cincinnati.

US EPA.,1989, Exposure Factors Handbook, 1600/8-89/043.