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THE OVERVIEW OF ENVIRONMENTAL AND POPULATION IMPACT ASSESSMENT OF CHEMICAL ACCIDENTS

Abstract: *At the beginning of the 21st century, the mankind is forced to change its attitude towards the environment and to undertake certain safety measures to save it for long-term survival of humanity and life on our planet. The antropogenic activities have induced significant harm to biosphere and brought about global climate change, destruction of species, waste removal, increased morbidity and mortality of people, etc. This paper describes quantitative indicators (parameters, indexes, etc.) used to calculate the impact of chemical accidents on the environment and the human population. Consequences on human life, health and the environment are estimated on the basis of data obtained by vulnerability analysis.*

Key words: chemical accidents, environment, protection.

INTRODUCTION

Environmental and Population Impact Assessment is based on the analysis of potential impacts that chemical accidents may have on the ecosystem, anthroposphere, biosphere and especially the anthropological components. The significance and the degree of vulnerability of each receptor should be quantified. The analysis of the potential impact of chemical accidents specifies the degree of impact by defining Environment and Population Gravity Index (EPGI) which numerically represents the risk of serious and immediate consequences on the ecosystem, and the human population in the potentially endangered area (PEA).

Calculation of EPGI includes three phases:

- Defining Potential Threat Area (PTA) and gathering the information about the ecosystem and anthropological components within a given dose.
- Rapid assessment of the expansion of chemical accident in the area potentially endangered by serious chemical accidents.
- Rapid assessment of the significance of impacts on the ecosystem and anthropological components that are caused by chemical accidents. This assessment involves specific research of particular characteristics of the ecosystem and anthropological components in the potentially endangered area, as well as rapid assessment of the gravity of incident

DEFINING ZONE OF POTENTIAL RISK

In the case that there is some natural or artificial vector of vulnerable zone (for example, rivers, artificial canals, lakes, etc.) with potential environmental risk in contact with hazardous substances from a particular site, the information about the ecosystem and anthropological components are collected within a zone which is 24 km of river's length, or a 24 km radius in case of lakes, lagoons, water basins or seas. The size of the vectors of vulnerable zones shall be determined in accordance with the methodology of Hazard Ranking System (US EPA, 1991). The length of the vector of vulnerable zone is measured starting from the point of hazardous substance release in a particular chemical accident. In case of river, preferential migration of pollutants in the direction of river flow should be taken into account.

The ecosystem and anthropological components were analyzed in accordance with the criteria defined in the JRC Major Accident Reporting System - MARS (EC/JRC, 1993). Categories of vulnerable zones and index that defines the consequences for the information with serial number S are given in Table 1, as well as the method for selecting information that should be collected when defining the potential risk.

Table 1. *Selecting information when defining the potential risk*

Ref.	Information	Selection of information
S.1	Persons employed in a given facility	-
S.2	Residents	Division of population by age group
S.3	Vulnerable sites (hospitals, schools, etc.)	Capacity
S.4	Rivers in a given area	The use and the level of water quality
S.5	Lakes, ponds	The use and the level of water quality
S.6	Seas	Closed / open sea, pelagic / coastal environment
S.7	Characteristics of the soil and the lower layers of soil	The use of groundwater
S.8	Protected areas	Degree of protection by national / international laws
S.9	The status of fauna and flora	(The IUCN Red List)
S.10	Agriculture	-
S.11	Farms	-
S.12	Fish and shellfish farming	-
S.13	Industry and service sector	-
S.14	Cultural and historical components	Degree of protection by national / international laws
S.15	dominant climate conditions -	-

RAPID ASSESSMENT OF CHEMICAL ACCIDENT PROPAGATION IN PARTICULARLY EXPOSED AREA (PEA)

The exposure to severe chemical accident could be estimated using different models, which generally depends on the vulnerability of ecosystems, biosphere and anthroposphere.

In case of release of hazardous substances in soil, starting from the hypothesis that possibly contaminated ground has been localized within the site and that there is no impact of land degradation in the area outside the site, there is no need to conduct vulnerability assessment of the area outside the site. If we start from the hypothesis that there is dispersion of hazardous substances in soil and potential groundwater contamination, we can use various models for assessing vulnerability of the area outside the site. The models are interrelated and intended to provide a framework of possible impacts on the different components in the environment.

In case of release of hazardous substances in the gaseous or vapour phase (fires, explosions and toxic dispersion), the determination of potentially vulnerable zone comprises two phases:

- Determining the maximum concentration of a substance that can be released into the atmosphere, which is calculated for each selected incident.
- The use of models for rapid assessment of potentially endangered area in case of gas / vapuor discharge in the atmosphere.

The assessment of the size and the form of the area affected by a chemical accident is based on a model which can determine the distance and the zones where severe impacts on the ecosystem, biosphere and anthrophosphere are expected.

The model used for Rapid assessment of potentially endangered area in case of hazardous gas or vapours release is based on the methodology of IAEA *Manual for the classification and prioritization of risks due to major accidents in process and related industries* (IAEA, UNEP; UNIDO; WHO, 1996).

First of all, the model allows us to determine the two zones of vulnerability: the high mortality zone and the irreversible effect zone.

Risk assessment vulnerable zone is based on the released quantity and characteristics of hazardous substances. It should be noted that the released quantity determines the dispersion, while the characteristics of hazardous substances determine the possible scenarios, according to the three alternatives: fires, explosions and dispersion of toxic substances into the atmosphere.

Information necessary for Rapid Environmental Assessment (REA) in case of gas and vapour release have been given in Table 2.

Table 2. *Information needed for the application of atmospheric dispersion models*

Ref.	Informacija
R.1	Substance / compounds (already added when calculating IDSI)
R.2	Terms of risk (already documented when calculating IDSI)
R.3	The physical state (already documented when calculating IDSI)
R.4	The maximum amount of a substance that can be discharged into the air
R.5	Steam pressure
R.6	Apparatus at which the accident occurred
R.7	The physical state of the substance in process
R.8	The molecular mass of a given substance
R.9	LC50 (30 minutes of substance exposure)
R.10	IDLH of the substance

The reference distance (RD) from the center of the incident is a border of the zone of expected fatal outcome in the exposed population. The procedure for defining the reference distance involves a combination of substance hazards (flammability, toxicity, explosiveness, etc.) and their discharge quantity as a consequence of the incident.The procedure for defining the reference distance includes the following phases:

- Separation of hazardous substances at the moment of accident (according to their number and type).
- Data on the toxicity of substances are classified into levels based on the integration of information collected in the stages of risk assessment. Input parameters for the classification of a substance are toxicity class and volatility class.

CALCULATING THE SCOPES OF EXPOSURE OR DAMAGE

The assessment of severity of consequences, due to exposure to hazardous substances, to the components of the ecosystem, biosphere, human population and anthrophosphere can be done by determining the two zones of vulnerability. The first vulnerability zone is defined as "high mortality" zone which is characterized by mortality of the exposed population and severe damage to the components of the ecosystem and / or the biosphere and / or anthrophosphere. The second zone is the irreversible effect zone, with rather heavy consequences but not as much as to cause the death of the exposed human population.

The scope of irreversible effect zone can be estimated through the impact coefficient (I) which multiplies the possibility of high mortality, thus increasing the zone that can be compromised by consequences of the incident. It should be noted that the coefficient of impact of flammable or explosive substances is constant and its value is 2.

For toxic substances, the impact coefficient I depends on LC50 according to the equation:

$$I = 0{,}35 + 0{,}65\sqrt{\frac{LC_{50}}{IDLH}}$$

if:

IDLH - Immediately Dangerous to Life or Health Consequences (*NIOSH Chemical Listing and Documentation of Revised IDLH Values (as of 3/1/95)*);

LC_{50} - median lethal concentration or population critical concentration 50:

$$d = RU_{\min} + \frac{(Q - Qi_{\min})}{(Qi_{\max} - Qi_{\min})} \cdot (RU_{\max} - RU_{\min})$$

where:

d - radius of the circle zone of vulnerability (m);

RU_{min} - minimum reference distance (m);

RU_{max} - maximum reference distance (m);

Qi - Maksimalna količina koja se ispušta (t);

Qi_{min} - The minimum value at the moment of hazardous substance discharge in a particular threat zone;

Qi_{max} - The maximum value at the moment of hazardous substance discharge in a particular threat zone.

Human health risk assessment due to environmental pollution has been widely used in the field of toxicology and hygiene for a long period of time. It is related to the need of applying a number of factors that determine the impact of harmful substances on human organism. Nowadays, there are various methodologies that enable us to obtain the approximate risk assessments on the basis of general indicators (degree of hazard for substances, exceeding the permissible concentration, etc.).

Adverse health effects due to daily or professional contact with toxic substances are generally probabilistic in character. This is a consequence of significant variations in human physical state, and also the inability to directly control the risks such as dosage, time of contact, the method of penetration of substances into the body, etc.

The definition of the frequency of negative changes in population’s health in medical statistics is referred to as "illness".

Illness is a statistical indicator which is determined as the ratio of the diseased patients and the average number of population in a certain territory for the observed period of time. It is calculated as::

$$O = \frac{p(N_3)}{N}$$

if:

O - illness, 1/year;

$p(N_3)$ - frequency of illness, man/years;

N - number of inhabitants, man..

The risk has to be regarded as an additional illness, which is associated with the penetration of exotoxicants into the body:

$$O = a + bR_3$$

if:

a - additional illness, 1 / year;

b - coefficient of proportionality;

R_3 - the risk of disease, 1 / year

The risk of disease is a function of doses of toxicants which enter the human body of the average representative of the observed population groups during the lifetime. According to the pollution of the atmosphere, a toxicant dose can be estimated on the basis of the data on the concentration of toxic substances in the air and the time spent in the polluted atmosphere. In order to better describe the negative health impact of polluted environment which can be presented in the form of current or chronic toxic effects (carcinogenic and immunotoxic), there are two groups of models: bound and boundless.

As it is already familiar, huge toxicity (current toxic manifestations) has a very pronounced boundary character. Risk assessment of current toxic effects can be determined using a single boundary effect model. When it comes to atmospheric pollution, the general form of this model may be presented by the following formula:

$$RI_3 = \frac{1}{\sqrt{2\pi}} \int a + b \lg c \cdot \exp(-\tau^2/2) d\tau$$

if:

a i *b* - a and b - the parameters which depend on the properties of the toxic substance;

c - concentration of toxic substances in the atmosphere;

τ - integration parameter

The above mentioned risk of toxic effects is a conditional individual risk, which is equal to the probability of a lethal outcome (or disease) during the impacts mechanisms; the formula which shows the territorial indicator of potential risk is $RI_3 = P(L)j$.

Integral in the formula cannot be shown as an elementary function. It is necessary to use a program or a mathematical table for calculation.

The value of the coefficients a and b in the formula are determined on the basis of special toxicological studies of the properties, and as a rule, they are given only in the scientific literature (Table 3). To implement practical calculations, it is recommended to connect the coefficients a and b with the values of standard parameters, which are used as characteristic of toxic substances and the assessment of their content in the environment, such as the level (class) of substance toxicity, the maximum allowable concentration (MAC), etc.:

$$RI_3 = \frac{1}{\sqrt{2\pi}} \int a + b \lg c(e / MDK_{m,r}) \cdot \exp(-\tau^2/2) d\tau$$

if:

MAC - maximum allowable concentration of hazardous substances in the air in settlements in mg / m3. This concentration, when inhaled within 30 minutes, should not cause any reflex (nor subsensory) reactions in the human body.

Risk assessment from a given algorithm is the implementation of the scenarios where population is exposed to the toxicants whose concentration in the air (mg / m3) and the exposure time (residence time in the polluted atmosphere) are not less than 30 min.

The first part of the equation represents the redundancy in exceeding MAC of toxic substances (s/MAC) defined in the interval from 0 to ∞ (if s/MAC = 0).

Table 3. *The value of empiric coefficients a i b*

The class of hazardous substance	Characteristics of a substances	a	b
1	Extreme hazard	'-9,15	11,6
2	Serious hazard	-5,51	7,49
3	Moderate hazard	-2,35	3,73
4	Slight hazard	-1,41	2,33

To describe the risk of chronic intoxication (as well as the risk of carcinogenic substances), which is associated with pollution of the atmosphere, we often use the exponential equation:

$R_3 = 1 - \exp(-UR \cdot t \cdot c^{\beta})$

if:

UR - Unit Risk - the factor of proportionality which connects the risk with the concentration of toxicants;
c - concentration or substance dose that shows the interaction in the course of time t;
β - coefficient, taking into account the characteristics of the toxic properties of substances.

The parameters of the equation can be shown in the equation which is more suitable for practical calculation:

$$R_3 = 1 - \exp\left[-0{,}174\left(\frac{c}{MDK \cdot K_3}\right)^{\beta}\right] t$$

if:

MAC - about acceptable concentration chemical substances in the air, during the day, in a populated place mg / m3. This concentration should not directly or indirectly have harmful impacts during the long exposure time (years).

The parameters β i K_3 which are recommended for the calculations of 25 year exposure time, are given in Table 4. In addition, regardless of the class of substances at the concentrations below the MAC β = 1,00.

Table 4. *Risk parameter estimation*

The class of hazardous substance	Characteristics of a substances	β	K_3
1	Extreme hazard	2,40	7,5
2	Serious hazard	1,31	6,0
3	Moderate hazard	1,00	4,5
4	Slight hazard	0,86	3,0

RISK INDEX RANKS IN THE FACILTY

Ranking Environment Risk Index in the facility (ERI) is done according to the Table 5.

Table 5. *Ranking risk index (ERI)*

ERI values	Risk levels in the facility
0 ≤ ERI < 1.6	**Low**
1.6 ≤ ERI < 3.6	**Moderate**
3.6 ≤ ERI < 6.4	**Serious**
6.4 ≤ ERI < 10	**Extreme**

TOXICOLOGICAL HAZARD INDEX

Environmental and population hazards are associated with the emission of certain substances in terms of the estimated substance emissions and its toxicity. The numerical value of the toxicological hazard index is determined by the equation:

$STRI_i = EPO_i \cdot TPRV_i$

if:

$STRI_i$ - toxicological hazard index of a dangerous substance *i*;
EPO_i - the ratio of the quantity of dangerous substance *i* per facility, the real environment and the number of employees;
$TPRV_i$ - the relationship between the coefficient of toxicity of the substance *i* and the number of employees.

The amount of pollutants for each substance emitted from a given facility (EPO) is calculated by multiplying the IRRS coefficient for each substance within the ecosystems (air, water, soil) and the total number of employees in the facility.

$EPO_i = IPPSc_i \cdot TE$

if:

$IPPSc_i$ - Coefficient of pollution intensity of a substance in a certain environment which refers to a four numbered ISIS code that classifies the facility according to the number of employees;
TE - total number of employees.

POPULATION AND ENVIRONMENT VULNERABILITY INDEX

Assessment of vulnerability of population and the environment is done by determining the appropriate index, which is called GEHVI (General Environment and Health Vulnerability Index). The index is calculated on the basis of the list of environmental and anthropological components within Potential Threat Area (PTA) and information about their vulnerability and importance. The components that are considered in the analysis were divided into: anthropological, environmental, socio-economic and cultural-historical. A specific index of vulnerability is determined for each of these components. General index GEHVI which determines the overall vulnerability of the site is calculated as the sum of four indices:

$$GEHVI = \frac{5 \cdot PVI + 3 \cdot EVI + ECVI + ECI}{10}$$

if:

PVI - Population Vulnerability Index;
EVI - Environmental Vulnerability Index;
ECVI - Economic Resource Vulnerability Index;
ECI - Cultural-Historical vulnerability Index;
Numerical values of 5 and 3 are weighting coefficient related to the weight factors consequences;
10 - Normalizing factor.

Depending on the value of the index that are functional dependence with GEHVI it is possible that the index value GEHVI be greater than 10 and Tadas adopts a value of 10 for consistency and comparability with other indices.

POPULATION VULNERABILITY INDEX

Population vulnerability index (PVI) uses the information regarding number of working people, resident population, and it is calculated by the equation:

$$PVI = \frac{OPVF + IPVF}{21} \cdot 10$$

if:

OPVF - Overall Population Vulnerability Factor;
I*PVF* - Population Vulnerability Factor that refers to workers;
The numeric value of 21 is the normalizing factor;

PVI value ranges between 0 and 1.

Overall Population Vulnerability Factor OPVF) is defined on the basis of the following equation:

$$OPVF = \frac{IF}{IF_{\max}} \cdot 10 \cdot IFP_1$$

if:

IF - Factor that refers to the number of inhabitants ranges from 0 to 10;

IFP_1 - Factor of increase related to the number of inhabitants by age groups, ranging from 1 to 1.1; Factor OPVF has variability interval between 0 and 11.

Factor that is associated with the number of inhabitants is defined by logarithmic function::

$IF = 2 \cdot log(NI + 1)$

if:

NI - the number of registered inhabitants within the RTA, plus the estimated capacity of vulnerable centers that are located within the RTA. The logarithm allows IF factor to stay within the values of 10, even in case of large population (100 000). In case when the number of inhabitants is more than 100 000 and the calculation is greater than 10, the value of a factor is 10 with the aim to maintain the normalization and comparability with other indices.

CONCLUSION

Possible environmental and population impacts are assessed on the basis of data obtained by analyzing vulnerabilities, and they are usually referred to as insignificant, significant, severe, major and catastrophic.

Consequences on human life, health and the environment are estimated on the basis of data obtained by vulnerability analysis, i.e., the number of people killed, poisoned, wild dead animals, dead fish, contaminated surfaces and damage after accidents.

On the basis of quantitative indicators (parameters, indexes, etc.) given in the paper, we can calculate the impact of chemical accidents on the environment and the human population, which is in other words the level of consequence. For this reason, the above mentioned quantitative indicators could be used as a basis for assessing risks of chemical accidents.

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BIOGRAPHY

Sveta Cvetanović was born in Donje Dragovlje, in Serbia in 1961. He graduated from the Faculty of Occupational Safety in Niš. He was employed in occupational safety and fire safety sector in AIK bank in Šabac. He has been working at Faculty of Occupational Safety since 1990.

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PREGLED PROCENA POSLEDICA HEMIJSKIH UDESA PO ŽIVOTNU SREDINU I POPULACIJU

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Rezime: *Na početku 21. veka, čovečanstvo je primorano da promeni svoj stav prema životnoj sredini i da preduzme određene mere zaštite kako bi se obezbedio dugoročni opstanak čovečanstva i života na planeti. Antropogene aktivnosti su prouzrokovale značajne poremećaje u biosferi i dovle do globalnih klimatskih promena, uništavanje vrsta, nagomilavanja otpada, povećanja morbiditeta i mortaliteta ljudi, i sl. Ovaj rad opisuje upotrebu kvantitativnih pokazatelja (parametara, indeksa, i dr.) koji se koriste za određivanje uticaja hemijskih udesa na životnu sredinu i ljudsku populaciju. Posledice po zdravlje i životnu sredinu procenjuju se na osnovu podataka dobijenih analizom ugroženosti.*

Ključne reči: hemijski udesi, životna sredina, zaštita.