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ENVIRONMENTAL RISK ANALYSIS FOR CRUDE OIL SOIL POLLUTION

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Abstract: Environmental risk assessment (ERA) is predominantly a scientific activity and involves a critical review of available data for the purpose of identifying and possibly quantifying the risks associated with a potential threat. Risk management (RM) is performed to consider the need to impose measures to control or manage the risk. The working methodology presented in this paper was done based on several research studies for the environmental risk assessment for soil pollution with hidrocarbures from accidental crude oil spills. The qualitative and quantitative assessment of the environmental risk for industrial sites for drilling, gas oil separation it is complex and require several data. For these reasons a environmental risk calculation methodology for soil is presented which is structured in modules and steps. Environment risk assessment of pollution with hydrocarbons from crude oil comprises five interrelated modules: hazard identification, hazard assessment, risk estimation by the award of „grades" for the frequency and severity of consequences environmental risk assessment based on risk criteria (ALARP) and environmental risk management. The modules required data: technical data for the equipment in the upstream industrial activities, extraction and gas-oil separation, physico-chemical analysis for the soil contaminants, soil properties that may influence the severity and consequences of the default risk, charts, mathematical equations and matrix assessment of environmental risk intensity. In the methodology are established the steps needed to calculate the alert threshold and intervention and additional studies needed (geotechnical study, pedological and chemical study).

Keywords: methodology, environmental risk assessment (ERA), risk assessment, soil pollution, crude oil extraction, procedure, hazard assessment.

1. INTRODUCTION

Currently, the basic objective of Sectoral Operational Program (SOP) for Environment is to reduce the gap existing between the EU and Romania, for the issues of environment protection. All constructions/installations in Romania after 2000 must conform to standards Best Available Techniques (BAT) and specific values for the emission limit established in the Reference Document on Best Available Techniques (BREF). There is need to introduce a BAT Environmental Management System (EMS) to prevent and control environment risk.

The term of risk designates a potential danger, predictable as per the laws and regulations. The risk can be classified depending on the cause type in natural or technological risk, depending on the receptor type in health risk, environmental or ecological risk, based on the intensity in not acceptable risk, high or accepted risk. There is a wide range of methodologies for risk assessment both quantitatively and qualitatively: Method Hazard Ranking System (HRS) developed by the EPA; method Baden-Württemberg, the Bavarian (Germany), the BRGM - ME (France).

The environmental risk assessment involves calculating the probability for an ecosystem to receive a dose of pollutant or being in contact with it. Risk is the probability of an adverse effect in a specific time period and is often described as equation (Andretta, 2006).

R = probability x severity (1)

Qualitative risk assessment takes into account the following factors: threat / source, path of action and receptor.

The factor „threat / source" refers to equipment and specific pollutants generated by them which are identified or alleged to be on a site (Mark, 2007).

The factor „path of action" refers to the manner by which pollutants migrate to the receptor. The factor „target / receptor" refers to the subjects/objectives which are affected by the harmful effects of certain toxic substances on site that can include plants, people, environmental factors (Barry, 2009).

Quantitative risk assessment examines the dangers and consequence based on SMART indicators (specific, measurable, available, relevant, timely) estimating the size of such consequences and the probability (Kester, 2005).

To do risk analysis due to environmental pollution generated by specific equipment on extraction, gas-oil separation activity the proposed methodology is divided into five modules, interrelated, each with a series of steps and stages of work. These modules will establish:

- The main sources that can generate negative effects on the environment (sources);
- How are generated these negative effects on the environment (pollution causes);
- The type of substance that affects the environment (pollutant);
- Migration paths (routes) of pollutant reaching the target (receptors submitted to risk);
- Environmental risk by assigning “grades” to the factors that underlie (probability and frequency), correlated with the risk criteria of ALARP;
- Measures to reduce the degree of the environmental risk to an „acceptable level”.

2. MAIN PROCESS FLOW DIAGRAM OF SPECIFIC UPSTREAM FACILITY

To determine the environmental risk it is necessary to know specific process flow activities for crude oil extraction and liquid gas separation. The process flow diagram of field production facility is presented in figure 1.

The upstream process comprises the following main stages: mixture of hydrocarbons in the form of liquid and gaseous accompanied by reservoir water and impurities are extracted from the wells, extracted fluids are transported through pipelines to the Field Production Facilities (FPF), separating the liquid phase (oil-impurities-reservoir water) from gaseous phase in the separators, crude oil mixed with reservoir water obtained after gas separation is stored in provisional tanks, separation is stored in provisional tanks, wet

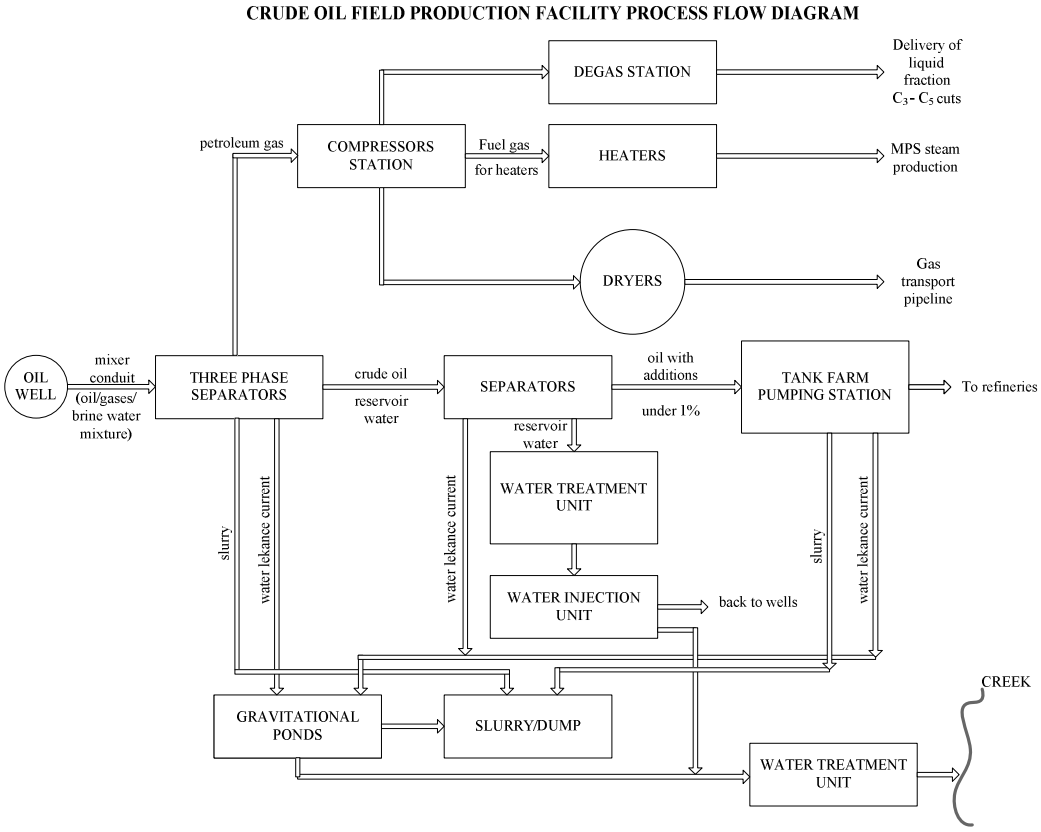

Figure 1. Process flow diagram of Field Production Facility [FPF]

and rich gases are directed towards to the further process: light fuel gas and C_3-C_5 cut, fuel gas is directed to gas distribution systems, the crude oil is thermo-chemical treated in special tanks to destroy the crude oil-water emulsions and brine water is collected (a part is injected back into the reservoir and the other part is sent to water treatment unit).

3. ENVIRONMENTAL RISK ASSESSMENT - METHODOLOGY DESCRIPTION

To identify the factors involved in risk assessment, the methodology has been divided into modules. Each module includes a structured series of stages in a number of steps that determine the data needed for the final evaluation. Modules and their main stages are presented in figure 2.

3.1. Module 1 - Hazard identification

Based on a qualitative analysis, this module deals with the technical aspects of establish the threats (sources, causes, pollutants) that may influence the environmental risk.

In this module is analyzed the area where are located the upstream facilities for the extraction, separation, treatment, storage and transport of crude oil. Within the module are considered activities that cause soil pollution.

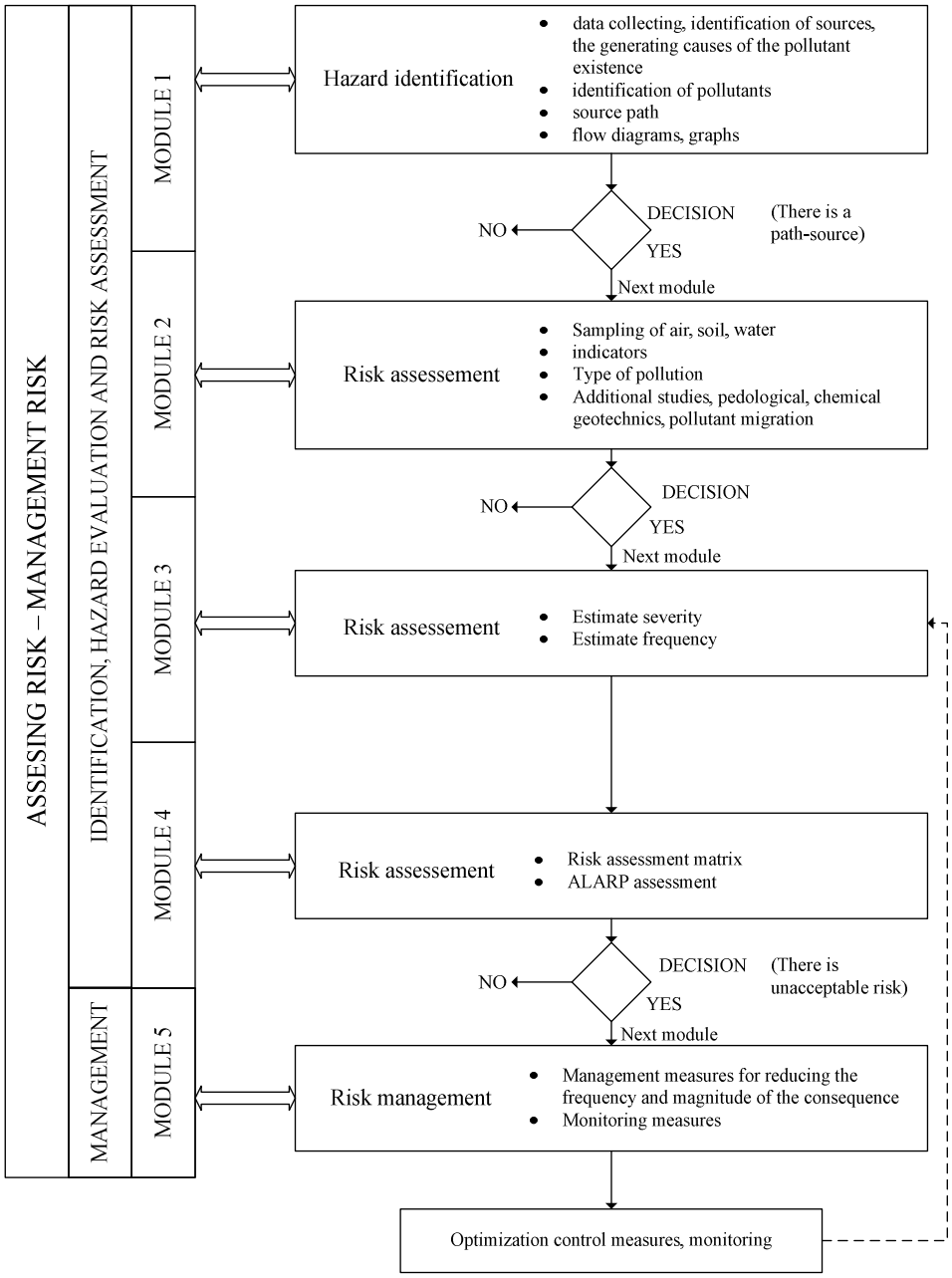

Figure 2. Environment risk assesment modules for Field Production Facility [FPF]

Module 1 has 2 stages.

Stage 1: Collecting the data necessary for qualitative evaluation of hazards includes the following steps:

- Step 1 - setting technological steps for which it assesses the environmental risk;
- Step 2 - establish the process flow;
- Step 3 - establish of the equipment that could be possible sources of pollution;
- Step 4 - identification of potential causes of pollution;
- Step 5 - flow diagram of raw materials, secondary materials and waste;
- Step 6 - election of potential pollutants as a whole;
- Step 7 - drawing the diagram source-cause-effect based on Ishikowa diagram;
- Step 8 – establishment the form of pollution.

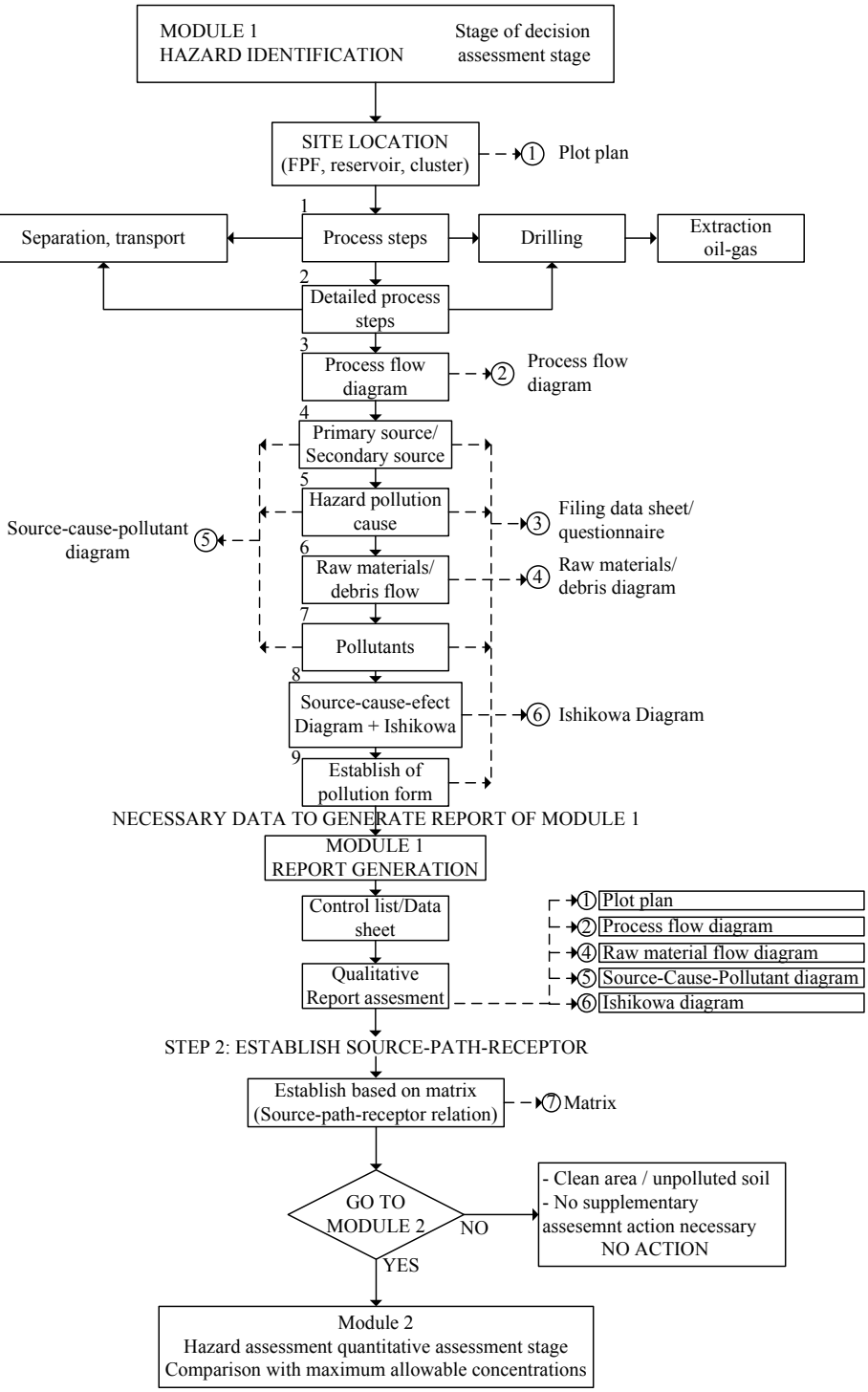

Figure 3. Stages and steps for module 1 - "Hazard Identification"

In step 6 pollutant is chosen as a “whole”, in the following modules to be evaluated based on components individually standardized, which will be analyzed in the laboratory. For oil pollution of soil, total petroleum hydrocarbons (THP) will be analyzed or certain metals that are present in the drilling fluids (Sutter et al., 2000). For establish the nature and intensity of soil pollution by heavy metals, in our country has been made in recent years a number of research studies (Damian et al., 2008; Lacatusu, et al. 2009).

In step 7, cause-effect diagram shows the correlation between the effect (environmental pollution) and causes, and/or if effect may have many causes.

An Ishikawa diagram will be generated in which the effect (consequence) is the horizontal arrow, and the arrows at 45° on the main one represent the main causes. It looks like a consequence (e.g. soil pollution) can have multiple causes and / or sources (Peng & Yirong, 2007). Stage 1 is finalized with establishing the type of accidental / occasionally permanent or chronic, linear or diffused pollution.

Stage 2: Setting matrix source-path-receptor

At this stage will be determined the matrix source-path-receptor that will contain all possible sources of pollution, migration routes and receptor (environmental soil factor) for which environmental risk is calculated. The main parameters that characterize the hazard source are: the nature, the amount, the physical and chemical characteristics of pollutants (density, viscosity, volatility, the flammability limits).

The transport and dispersion paths of pollutants are matrix vectors. Targets / receptors represent the physical, biological or social environment, on which can occur a negative effect of pollution. Based on the matrix source-path-receptor it will be decided if it is necessary to pass to the module 2 "hazard assessment". This is conditioned by the existence of contaminated areas, pollution sources or the pollutants that may affect the ground. In Figure 3 are presented stages within the module "Hazard Identification".

3.2. Module 2 - Hazard Assessment

The "Hazard assessment" is a quantitative assessment based on physicochemical characteristics of various soil samples taken from soil profiles for different depths. For quantitative evaluation specific, measurable, available, relevant, timely (SMART) indicators are needed:

- Specific / Specifics concentration (mg / mc);
- Measurable / measurable - by calculation or laboratory tests;
- Available / available (acceptable cost, laboratory equipment available);
- Relevant / relevant standardized indicators;
- Timely / time - when the risk assessment is done it is necessary to take into account the phenomena of weathering (from pollutant discharge up to the moment evaluation, it is possible some phenomena to occur).

Table 1. Contaminants of soil in upstream industry

Parameters		TPH Total petroleum hydrocarbons	PCB Polyvinyl biphenyl	BTEX [*1] Benzene, toluene Ethylbenzene, xylene	Metals
Wells area	The area around wells	Δ		○	
	Drilling fluid				○
Separators park area	Around treatment, storage tanks	Δ		○	
Electrical transformers area	Electric transformers [*2]		○		
Transportation Pipeline	The damaged area	Δ		○	
Sludge ponds	Area arround the pond	Δ		○ [*3]	○ [*3]

[1] - depending on the benzene percent, crude oil volatility
[*2] - depends on the type, age, state of the transformers
[*3] - depends on the sludge composition
Δ - is likely to be present and should be examined
○ - will be examined whether the records shows that are included in the composition of materials used in site.

Module 2 has three stages.

Stage 1 "Concentration measurement": the concentration is determined for certain indicators accordance with the local regulation for soil quality investigation.

In table 1 are presented a series of oil and gas industry-specific contaminants, which can pollute the soil (Rosalind & Dana, 2005).

Stage 2 "Pollution type" determines the type of pollution based on the concentration measured in laboratory and alert and intervention thresholds in accordance with the environment regulations. Under legislation alert threshold (AT) represents 70% of intervention threshold (IT).

Stage 3 Decision is based on legislation, under which:When concentrations of pollutants in soil are below the level of alert, no special measures are needed, soil pollution is insignificant (IP);

- When measured concentrations in the soil are above the alert threshold, but is below the threshold for intervention is considered that there is a potential impact and measures are needed to monitor, potential soil pollution is present (PP);
- When measured concentration in the soil are above the threshold for intervention and soil presents a significant pollution (SP) it is necessary to take remedial measures.

In the Figure 4 are presented stages in the module 3.

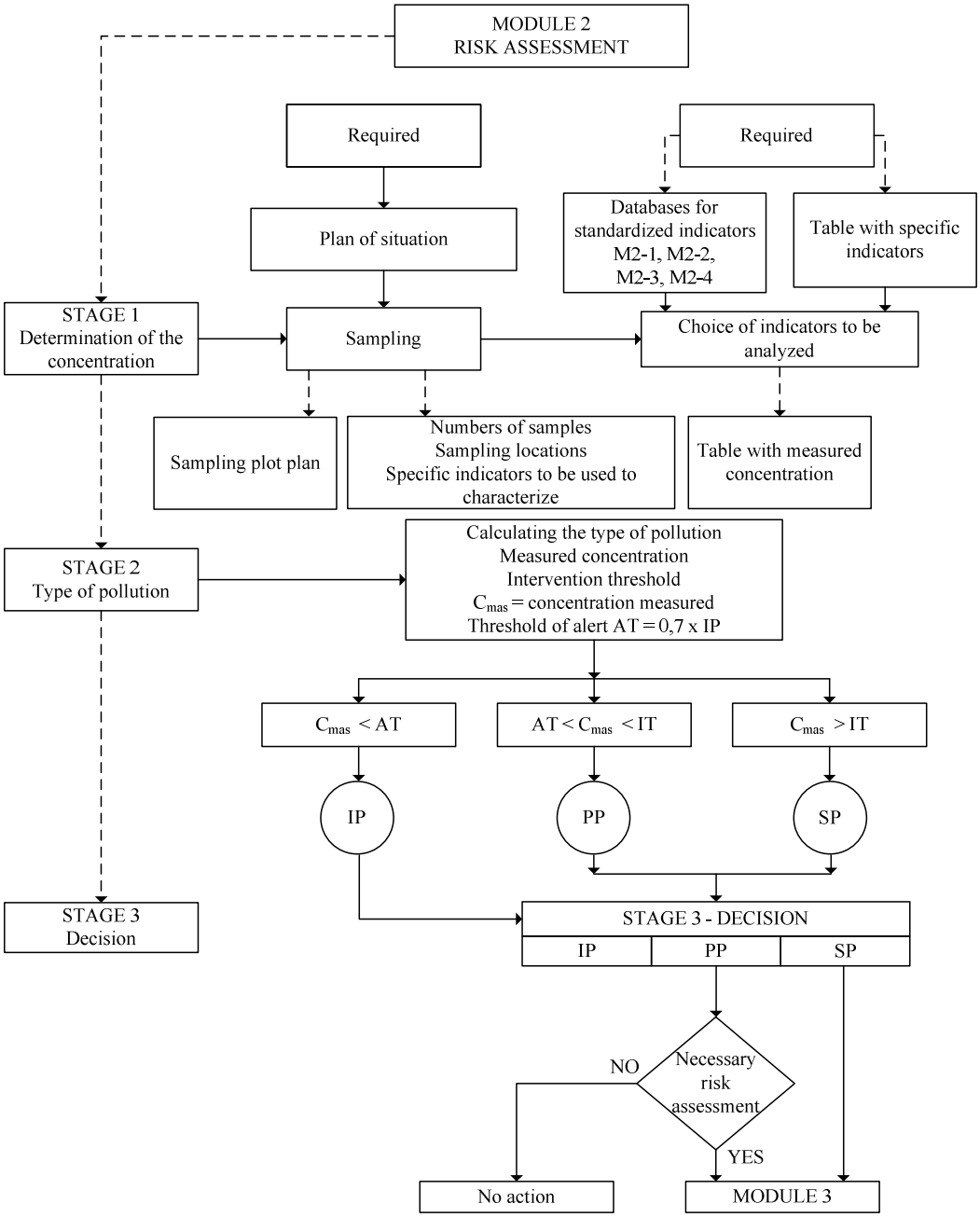

Figure 4. Stages of module 2 - "Hazard Assessment"

3.3. Module 3 - Risk Estimation

In this module it will be estimated the frequency and severity of consequences by assigning "grades". Module 3 has two stages.

Stage 1 „Supplementary studies" quantitative investigation are detailed based on geotechnical soil, chemical studies, that can characterize the pollutant and the soil factor so that it can be arranged in a hierarchy based on the level of environmental risk.

From this stage a final report will result and it contain data on: hydrocarbon concentration in soil, on different depths, grain size diagrams, lithology classes, degree and type of pollution for each soil profile.

Stage 2, „Estimating the probability and severity of consequences" will be assigned "grades" using the final report of Stage 1 of the Module 3.The consequences that may depend on a number of factors (studied in previous modules): pollutant type (characteristics), pollutant quantity, soil characteristics, affected area (industrial, residential), impact time duration (pollution type chronic / acute), pollution degree (SP, PP).Table 2 describes the severity degrees and effect type associated with these degrees.

Likelihood refers to the possibility of occurrence of cases that may affect the environment. In table 3 are described ranges and possible degrees of probability.

In the figure 5 are presented stages in the module 3, studies and parameters which will be included in the final report - Module 3.

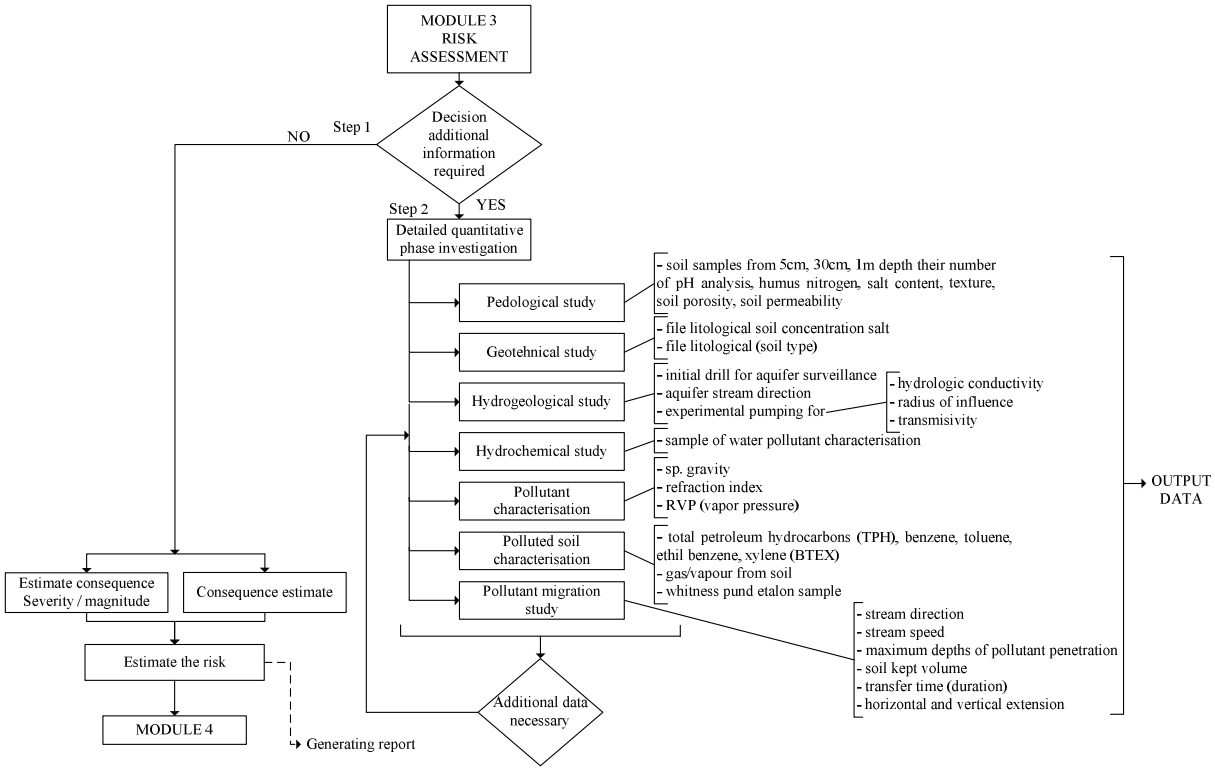

Figure 5. Module 3 Stages of "Risk Estimation"

Table 2: Severity degrees

Severity	Description
5	Mass effect - severe environmental damage that persists / Large exceeding AT
4	Major effect - severe environmental damage. Need to take extensive measures .
3	Localized effect - Repeated exceeding AT. Recovery after one year
2	Minor effect - Contamination. Damages sufficient to harm the environment. A single exceeding of AT. There are no permanent effects.
1	Light Effect - any local negligible consequences
0	No effect

Table 3 Degrees of probability

Range	Degree of probability	Define
Sure	5 (E)	The cause is under normal operating conditions
Very likely	4 (D)	Very likely to occur under normal operating conditions
Perhaps	3 (C)	Likely to occur under normal operating conditions
Unlikely	2 (B)	Unlikely during normal operation
Highly unlikely	1 (A)	Very unlikely to appear but in the exceptional circumstances

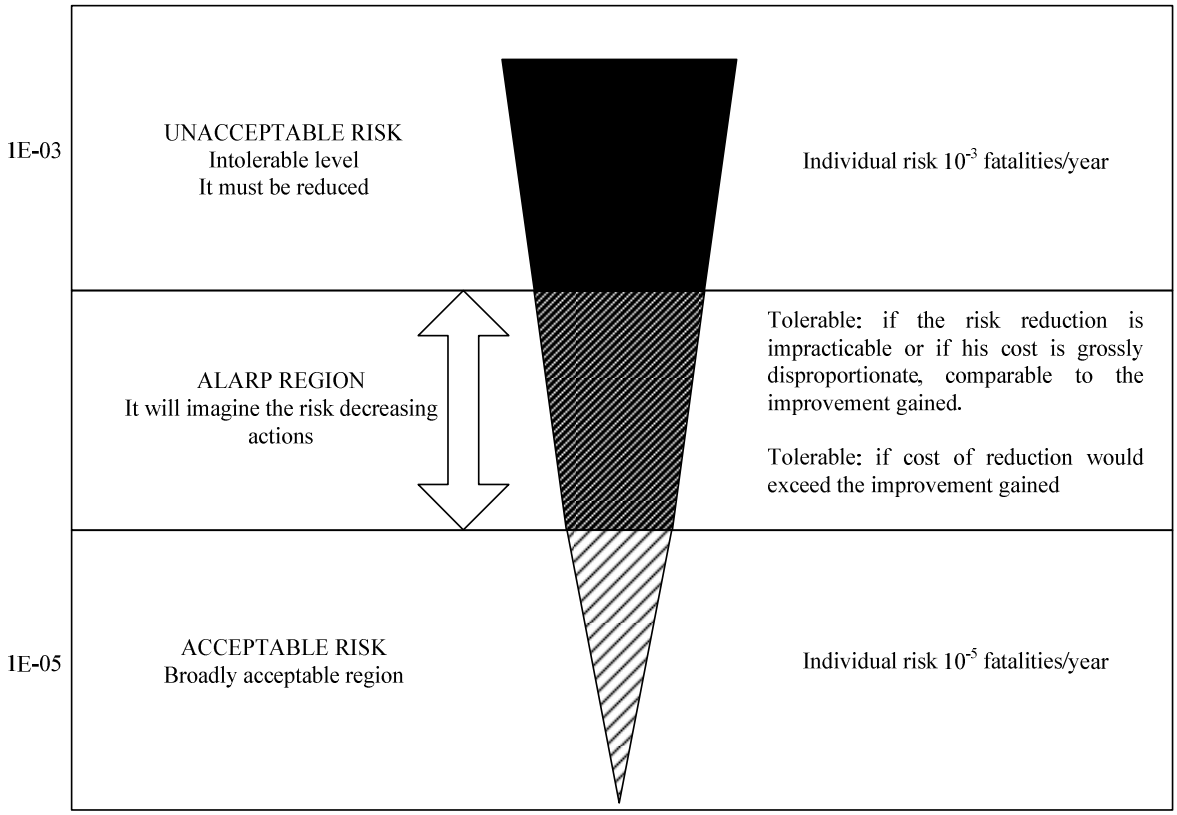

Figure 6. Risk criterion/Admissibility of the risk

Table 4: Risk Assessing Criteria

Types of risk	Maximum risk criteria	Individual
	Existing equipments	New equipments
Acceptable	IR < 1x 10^{-5}	IR < 1x 10^{-5}
Unacceptable	IR < 1x 10^{-3}	IR < 1x 10^{-3}
Regime ALARP (Tolerable)	1 x 10^{-3} <IR< 1 x 10^{-5}	1 x 10^{-3} <IR< 1 x 10^{-5}

IR - individual risk (the frequency with which an environmental factor is comprised of a harmful effect, expressed as risk / year).

3.4 Module 4 - Risk Assessment

ALARP risk criteria is introduced to assess the risk and the risk must be reduced to an ALARP level, which is an acceptable risk (O'Connor, 2005). ALARP principle can be used to assess risk and to evaluate risk tolerability and those measures to be taken to reduce the hazard probability and limit the consequences before becoming unacceptable risk (Tab. 4). Schematic principle of reducing risk at ALARP is shown in figure 6 (Salvi, 2004).

From Module 4 will result the risk matrix that established if necessary to get to the Module 5 "Risk Management" (Tab. 5).

Table 5. Risk Assessment Matrix

RISK EVALUATION MATRIX								
CONSEQUENCES				PROBABILITY				
Severity	Employees	Environment	Impact severity	A	B	C	D	E
5. Massive effect	Multiple casualties	Massive effect	International impact	M	H	H	H	H
4. Major effect	Single casualty	Major effect	National impact	M	M	H	H	H
3. Local effect	Injuries, sickness	Local effect	Big impact	M	M	M	M	H
2. Minor effect	Health minor effect	Minor effect	Limited impact	L	M	M	M	M
1. Weak effect	Light effect	Light effect	Light impact	L	L	L	M	M

L – Acceptable without action
M – Acceptable but need to be kept on ALARP level – Maintaining measures
H – Unacceptable – Decreasing measures necessary – Rehabilitation measures
A – Not encountered
B – Encountered
C – Incident in the crude oil production facility
D – It is happening few times per year in the crude oil production facility
E – It is happening few times per year on location

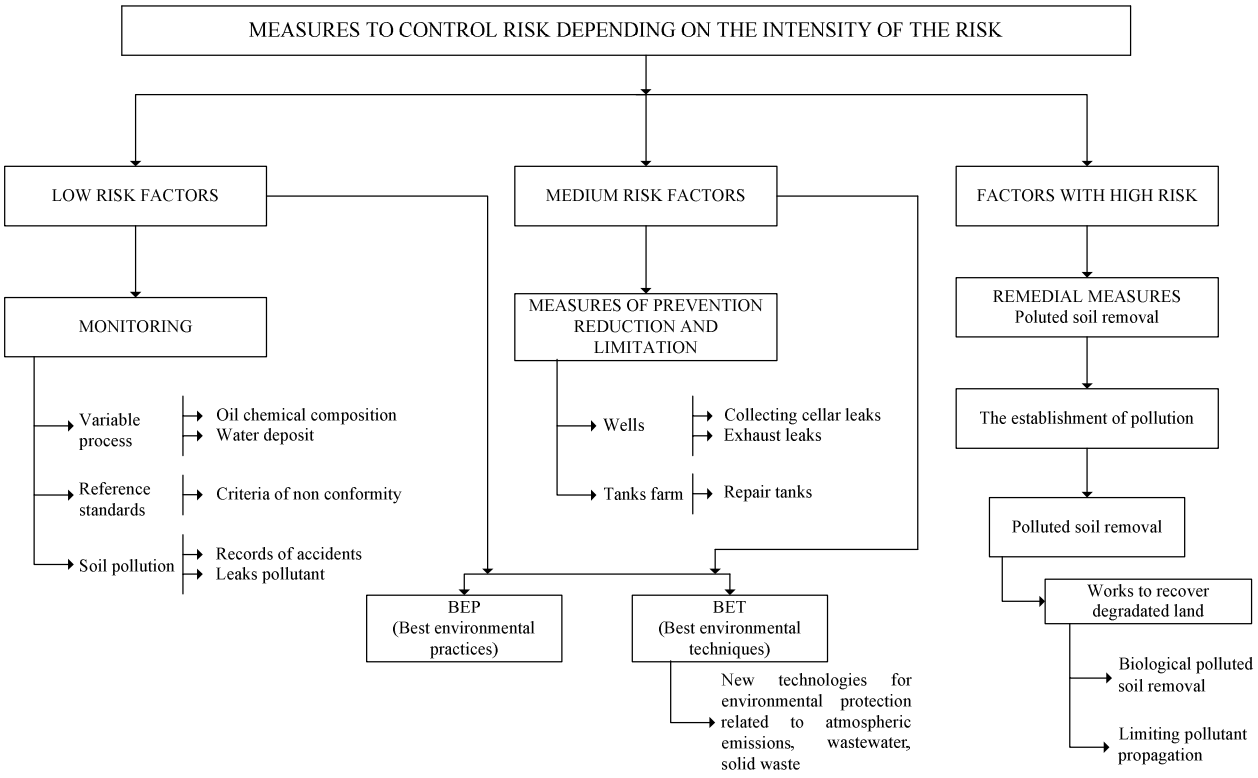

Figure 7. Actions for decreasing environmental risk

3.5 Module 5 - Environmental risk management

This module determines the measures for maintaining an environmental risk at an acceptable level.

It is based on the steps and stages from the previous modules. In case the risks are unacceptable a series of strategic elements are proposed to control the environmental risk. The strategic elements based

on risk type may be: monitoring, prevention, reducing and remedial measures (Kester, 2005). The strategic elements for soil and the action for decreasing environmental risk are shown in figure 7.

Management practices for soil pollution prevention are:

- develop and implement a methodology to improve prevention and reduce impacts of spills and other accidental release from operations
- periodically review and identify pollution prevention options
- develop approaches for reducing release

4. CONCLUSIONS

Topic approached in this paper responds to current priorities for protection of soil quality, an issue of great interest on international standard and in particular to Romania, too. In connection with all the elements presented in the article, the objectives attained by the research work are:

1. Accomplishment and implement for a structured methodology of five modules, interrelated, which can ascertain and to form an hierarchical system environmental risk for soil polluted with hydrocarbons from crude oil
2. Hazard estimate and establishment for upstream specific zones by identifying the sources, causes and pollutants that can generate significant pollution for soil
3. Application of assessment techniques (work stages) for identifying critical points that are needed for further supplementary studies (physical-chemical study, geotehnical and pedologycal study).
4. Risk assessment based on risk matrix and on ALARP criteria, where the parameters of probability and severity of consequences involve like fundamental ones, are taken into consideration.
5. Establishment of some strategical elements as a part of an environmental management system for reducing risk to an acceptable level.

The methodology presented in this paper can be used to assess hierarchical system risk and to treat and monitor the environmental risks. It is a rapid method for evaluating the environmental risk of pollution in case of significant accidents at a level of accuracy required by European Union laws and regulations to which Romania has joined.

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REFERENCES

Andretta, M., Serra, R., Villani, M., 2006. A new model for polluted soil risk assessment. Computers and Geosciences, 32, Issue 7, 890-896.

Barry, L., 2009. Environmental Studies&Management. Human and Ecological Risk Assessment, vol. 15, 214-215.

Damian, F., Damian, Gh., Lăcătuşu R., & Iepure Gh., (2008), Heavy Metals Concentration of the Soils Around Zlatna and Copsa Mica Smelters Romania. Carpathian Journal of Earth and Environmental Sciences, vol. 3, No. 2, 65-82.

Lacatusu, R., Citu, G., Aston J., Lungu Mihaela, & Lăcătuşu Anca Rovena (2009), Heavy Metals Soil Pollution State in Relation to Potential Future Mining Activities in the Rosia Montana Area, Carpathian Journal of Earth and Environmental Sciences, vol. 4, 2, 39-50.

O'Connor, G. A., Elliott, H. A. 2005. Sustainable Land Application: An Overview. Journal of Environmental Quality, 34: 7-17.

Kester, G.B., Brobst, **R. B.,** 2005. Risk Characterization, Assessment, and Management of Organic Pollutants in Beneficially Used Residual Products. Journal of Environmental Quality, 34: 80-90.

Kester, G.B., Brobst, R.B., 2005. Risk Characterization, assessment and management of organic pollutants in beneficially used residual products. Journal of Environmental Quality, 34 (1), 75-79.

Mark Manion, 2007. Ethical issues in risk assessment and management.International Journal of Risk Assessment and management, vol. 7, 3, 281-298.

Peng Lu, Yirong Su, 2007. Geostatistical Analysis and Risk Assessment on Soil Total Nitrogen and Total Soil Phosphorus in the Dongting Lake Plain Area, China. Journal of Environmental Quality, 36, 935-942.

Rosalind A. Schoof & Dana Houkal, 2005. The Evolving Science of Chemical Risk Assessment for Land-Applied Biosolids. Journal of Environmental Quality, 34, 114-121.

Salvi, O. and Gaston, D., 2004. Risk assessment and risk decision-making process, related to hazardous installation in France. Journal of risk Research, 7(6), 599-608.

Sutter, G.W., II, Efroymson, R.A., Sample, B.E. and Jones, D.S., 2000. Ecological Risk Assessment for Contaminated Sites. Lewis Publishers, 4, 3, 285-289.