

TECHNICAL AND MANAGERIAL MEASURES TO REDUCE THE ENVIRONMENTAL RISKS GENERATED BY THE ACTIVITIES CARRIED OUT AT ZĂNOAGA WATER TREATMENT PLANT

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Abstract: *Environmental risk can result from the interaction between human activity and the environment. Human activities can generate certain changes in the environmental components, thus inducing a potential danger for the health of people, flora, vegetation and fauna through the negative effects they have on water resources, air and soil quality, climate, microclimate, and so on. This paper presents the potable water treatment plant from Zănoaga, located in Petroșani Municipality, and highlights the potential risks related to the activity within this plant. Particular emphasis is placed on the risk to the environment and human health that may arise from improper storage and handling of liquid chlorine tanks, chlorine being a toxic gas if found in high concentrations in air, water or soil.*

Keywords: *water treatment plant, Zănoaga, environment, risk, liquid chlorine tanks, toxic gas*

1. Presentation of the objective

Zănoaga water treatment plant is located in Valea Jiului (figure 1), on the administrative territory of Petroșani Municipality, in its southern area (figure 2). Access to the station is along Sălătruc road.

Valea Jiului includes Cimpa, Lonea, Petrila, Petroșani, Aninoasa, Vulcan, Lupeni, and Uricani localities and extends along the two branches of the Jiu River, located over 600 m above sea level.

The Municipality of Petroșani is the main town in the valley.

From a hydrographical point of view, the Municipality of Petroșani is furrowed by the East Jiu River and numerous springs and streams.

From a climatic point of view, the area is characterized by an alpine microclimate, humid and chilly, with quantitatively significant precipitation, in the form of rain and snow. Average annual precipitation is between 700-800 mm.

Days with high cloudiness reach more than 200 per year.

The elongated shape of Valea Jiului and Petroșani Municipality and the isolation between the high mountains have a great influence on the climatic aspects because the circulation of air masses is from north to south, through Bănița-Merișor and Surduc-Lainici gorges.

An interesting thermal phenomenon takes place in the valley, that of thermal inversion. This process can be described as the stagnation and cooling of the air sliding from the mountain heights towards the cities. Under the influence of stagnation and cooling, the lowest temperatures exceed -30 °C (-31.4 °C on January 14, 1893), while at Parâng station located 900-1000 m above, the lowest temperatures do not exceed -24 °C. Thus the frosts are stronger in the valley than on the surrounding heights, but not longer.

Also due to the gathering of cold air, there may be frosts and days with spring frosts in May.

The flora and fauna of Valea Jiului present elements that make it a centre of tourist attraction. In the mountains, coniferous forests predominate (spruce, pine, juniper, yew, bison, etc.). Oak and beech forests are also hospitable; they shelter numerous species of birds and give shelter to animals such as rabbits, wolves, foxes, wild boars, deer, bears, black goats, etc.

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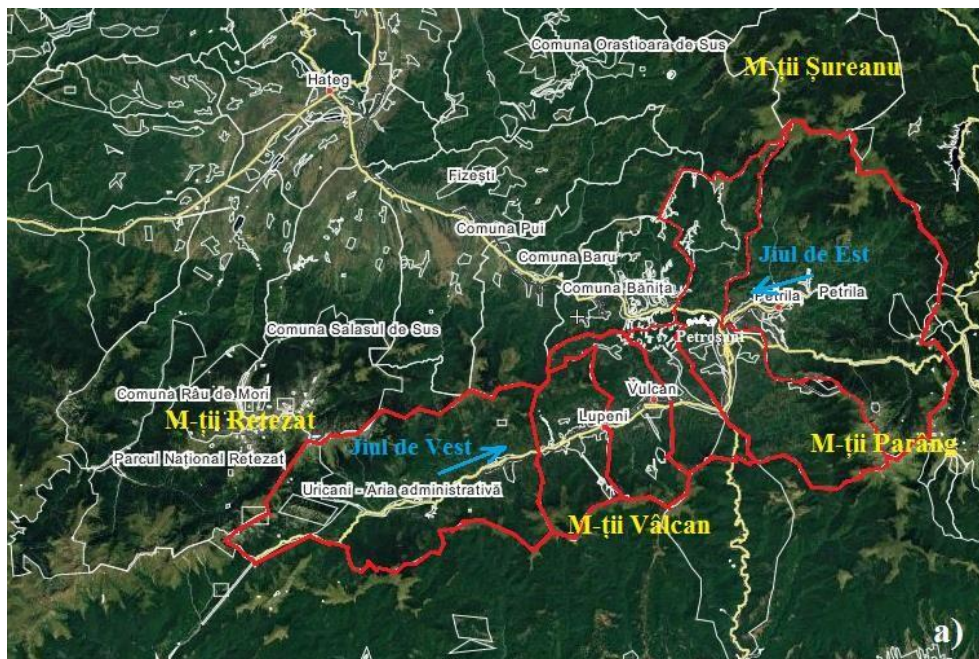


Figure 1. Valea Jiului, satellite location



Figure 2. Zănoaga station location

The water treated at Zănoaga station arrives here from the 3 catchments: Izvorul, Polatiște, and Stoinicioara (figure 3). They are similarly constructed, being made of a dam with a Tyrolean catchment, a two-compartment sluice, and diversion and flood defence walls.

From Izvorul and Stoinicioara catchments, the water is transported by severity to the treatment station through pipes with a diameter of 300 mm, 400 mm, 600 mm, and 800 mm. The transport of raw water from Polatiște catchment is carried out by severity through a 500 mm pipe, which enters an adduction gallery and then into the 800 mm adduction pipe.

In the yard of the Zănoaga water treatment plant, the stations itself is found, which include the chlorination room, the desander room, the water quality analysis laboratories, a micro hydropower plant (MHC), and two 2000 m³ tanks.

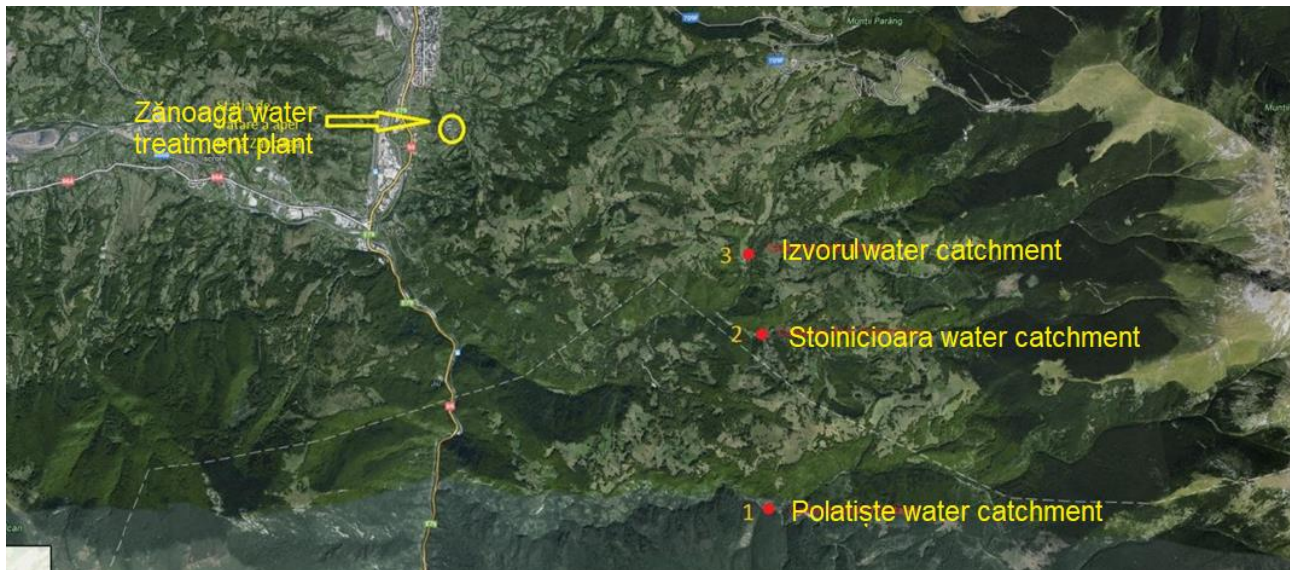


Figure 3. The location of the 3 catchments in relation to Zănoaga station [1]

Polatiște water intake (figure 4) on Polatiște stream is located at an altitude of 800.00 m above sea level. The water captured from the two intakes is collected in a severity wave departure chamber through a 600 mm pipe and is led to the sandblasters.



Figure 4. Polatiște water catchment [1]

Izvorul water intake on Izvorul stream is located at an altitude of 740.00 m above sea level. The water captured from the two intakes is collected in a severity wave departure chamber through a 300 mm pipe and is led to the sandblaster.

Stoinicioara water intake on Stoinicioara stream is located at an altitude of 720.00 m above sea level. The water captured from the two intakes is collected in a severity wave departure chamber through a 300 mm pipe and is led to the sandblaster.

Each water intake consists of a spillway dam made of reinforced concrete equipped with a central spillway with two different intakes (summer intakes and winter intakes), wash basin and fish scale. The socket structure is provided with summer sockets and winter sockets on the side. The winter outlet is equipped with a flat gate that is completely closed in the summer and open in the winter.

The sandblaster has two parallel streams each with two openings and separate sandblasters. They are divided into two rooms by a vertical wall and have two flat bars at the entrance and exit.

The catchments were built between 1993 and 1996.

2. Sources that can generate environmental risks

The main function of the station is to take raw water through the existing catchment, treat it using technologies specific to a water treatment station and transport it by severity into the storage tanks.

The role of the water intake is exclusive to supplying raw water to Zănoaga treatment plant.

Zănoaga surface source provides water supply to the Aeroport neighbourhood in the town of Petroșani. The average flow for the town of Petroșani is 45 l/s. From Zănoaga surface source Livezeni Mining Exploitation is also fed (average flow – 2 l/s).

Figure 5 shows the technological scheme of Zănoaga station.

Analysing the technological scheme, the main stages for water treatment are (figure 6, [2]):

- decanting;
- filtering;
- chlorination.

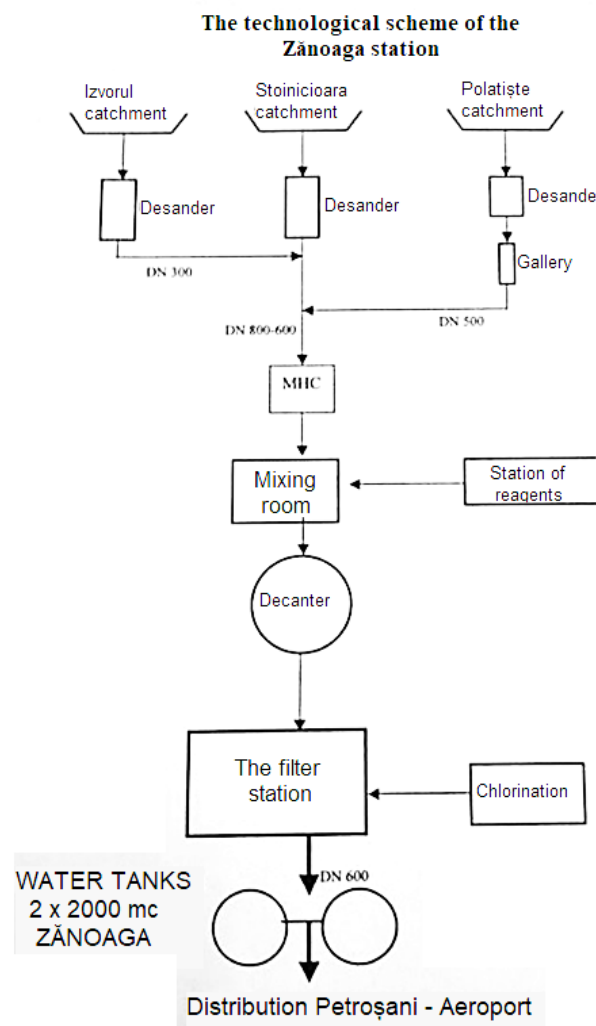


Figure 5. The technological scheme of Zănoaga station



Figure 6. Arrangements and materials within the station:
a. Horizontal radial decanter; b. Filter room; c. Tank with liquid chlorine [1]

Decanting aims to reduce turbidity, the content of organic substances, etc., in order to use the water as such in various industrial processes, or in order to final clarification through filtration, through the sedimentation process of solid particles in suspension at the bottom of the decanter resulting in sludge on one side and clear water on the other side that reaches the filter chamber.

The system for cleaning and evacuating the sludge from the decanter depends on the type of decanter and can be: manual, hydraulic or mechanical systems.

Due to the very low speed of water circulation, approximately 98% of the suspensions are deposited in the decanter.

Filtration is the process of passing water through a porous medium (sand) where some water constituents, mainly mineral suspensions, are retained through physical processes.

Filtration is used for the recovery of some raw materials entrained in the water for the retention of mineral suspensions that could not be removed by settling and for dewatering the sludge retained in the decanters before it is transported to the beneficiaries or to the drying platforms.

Chlorination is a method of sterilizing or disinfecting water. The water distributed for the household and drinking needs of the population must not be harmful to people's health, so it must not contain pathogenic bacteria. For water sterilization, at Zănoaga station, pure gaseous chlorine or lime chloride is used.

Chlorine is a yellow-green gas, 2.5 times heavier than air. Introduced into the water, chlorine acts on the organic substances found in it, as well as on the bacteria, destroying them, but not completely. In combination with water, chlorine forms hypochlorous acid (HOCl – an unstable compound that decomposes into oxygen and hydrochloric acid) and hydrochloric acid (HCl). Active or effective chlorine is hypochlorous acid (HOCl) or hypochlorite ion (OCl^-). Along with the oxidative action of HOCl , it can also combine with the compounds of the cells of microorganisms, the organ chlorine compounds formed being incompatible with the life of germs.

At the time of its formation, free oxygen acts as a strong oxidant on organic substances and bacteria found in water. The amount of oxygen, and therefore the amount of chlorine, needed to sterilize the water, should not be determined by the number of pathogenic bacteria, but by the total amount of organic substances and microorganisms, as well as non-oxidizable inorganic substances that are found in water treated with chlorine

Correct fixation of the chlorine dose is very important, failure to do so poses serious problems when using this method. An insufficient dose of chlorine can cause it not to show its bactericidal action, and an excessive dose of chlorine (over 0.3 mg/l) worsens the taste of the water. Therefore, the dose of chlorine must be determined by the individual properties of the water, which are corrected based on the laboratory experiments made on this water.

The calculation dose of chlorine for the design of the correction facilities must be based on the need to correct the water during the period of its maximum impurity (for example, during the period of high water).

In the case of introducing chlorine into filtered water, good mixing of it with the water and a necessary time for the contact of the chlorine with the water must be ensured, before it is distributed to the consumer. The contact time must be at least 30 minutes.

Analyzing the activities carried out within the station, resulted that the one of the sources that can generate environmental risks is chlorine. Any error in its handling, such as the use of increased doses, and cracking of chlorine containers, can lead to accidental ingestion, damage to human and fauna health, first of all, but also damage to environmental components.

Its high toxicity makes it an excellent water disinfectant, but also a danger to humans who handle it. It is a respiratory irritant and can irritate the skin, and mucous membranes, possibly even causing death with high exposure to the substance.

At concentrations found in drinking water, chlorine is not considered to be toxic to humans. However, it can still have harmful effects. In addition, chlorine treatment does not guarantee that drinking water is free of harmful microorganisms, as they can develop resistance to this environment (table 1).

Health hazards: Liquefied gas, toxic by inhalation. It irritates the skin, eyes, nose, and throat, and causes lacrimation, coughing, and chest pain. A high level of exposure causes burns to the lungs, pulmonary edema, and even death.

Environmental hazards: Chlorine is classified as an air and water pollutant. Degradation in air is immediate by exposure to the UV component of sunlight. Although it is slightly soluble in water, chlorine reacts easily with water forming ionized species. Free chlorine reacts rapidly with organic matter naturally present in the soil leading to chlorinated organic compounds. Due to the high chemical reactivity, bioaccumulation of molecular chlorine in the environment was not observed.

Free chlorine is very toxic to microorganisms active in biodegradation processes in biological treatment plants.

Misuse Hazards: Chlorine cylinders can discharge rapidly and explode under fire. Chlorine vapors present a risk of explosion when mixed with oxygen, hydrogen or combustible gases in closed or open spaces when in contact with an open flame.

Other Hazards: Chlorine is non-combustible, but most combustibles burn in chlorine as they burn in oxygen. The major risk is related to the toxic and corrosive properties of chlorine, chlorine being a toxic gas with an irritating and suffocating effect.

Table 1. Safety data sheet for liquefied chlorine (in accordance with Regulation 830/2015) [3, 4]

Labelling in accordance with the official classification - Annex VI to Regulation 1272/2008, CLP	
Word of warning	DANGER
DANGER ICONS	
Icon GHS03 (flame above a sky)	
Icon GHS04 (gas cylinder)	
Icon GHS06 (skull over crossbones)	
Icon GHS09 (environment)	
DANGER PHRASES	
Hazard phrases, Code(s)	H270: May cause or aggravate a fire, oxidizer H280: Contains a gas under pressure; danger of explosion in case of heating H331: Toxic if inhaled H319: Causes serious eye irritation H335: May cause respiratory irritation H316: Causes skin irritation H400: Very toxic to the aquatic environment Acute M-FACTOR = 100

Ingesting water containing chlorine can have a number of adverse health effects, such as [5, 6]:

- symptoms of asthma;
- aggravation of respiratory problems;
- congenital anomalies: A Taiwanese study carried out on almost 400,000 people found that the risk of giving birth to children with anomalies increased in the case of pregnant women exposed to chlorinated water.
- bladder cancer;
- allergies;
- unpleasant taste and smell;
- effects on hair and skin, drying them considerably.

Through accidental leaks, environmental components can be affected as follows:

- the deterioration of the quality of soils that can no longer support vegetation in optimal conditions;
- affects the quality of underground and surface water;
- very toxic for the aquatic environment;
- chlorine can kill the beneficial microorganisms in the soil, thus affecting the growth of plants, even causing their death.

In addition, according to the safety data sheet, liquefied chlorine, found in pressurized tanks, presents a risk of explosion if heated. Within the station, at the time of the study, there were approximately 5 tanks of liquefied chlorine under pressure.

3. Qualitative and quantitative analysis of the highlighted risks

In order to carry out this analysis, the content of the safety report was taken into account [7]:

- description of the location;
- description of the environment;
- description of activities, processes and facilities;
- the inventory and characteristics of dangerous substances;
- risk to humans and the environment;
- scenarios and possible causes for major accidents;
- assessment of consequences, proportions and severity;
- prevention/limitation measures;
- emergency plans.

Qualitative risk assessment will consider the hazard/source, pathway and target/receptor. The risk depends on the severity of the event and the probability of its occurrence.

Based on the detailed characterization of the location from a physical and chemical point of view, the classification in five levels of severity and probability (table 2 and table 3) was made and resulted that there is a major level of severity, respectively a possible level of production of an unwanted event.

Table 2. Risk severity levels [6, 7]

No.	Levels	Effects
1.	Insignificant	For people (population): insignificant injuries; Ecosystems: Some insignificant adverse effects in few species or parts of the ecosystem, short-term and reversible; Socio-political: Insignificant social effects of no concern to the community.
2.	Minor	For people (population): minor injuries; Ecosystems: Some minor adverse effects on few species or parts of the ecosystem, short-term and reversible; Socio-political: Minor social effects of no concern to the community.
3.	Moderate	For humans (population): medical treatments are required; Economic: reduction of production capacity; Emissions: emissions within the objective contained with external help; Ecosystems: temporary and reversible damage, damage to habitats and migration of animal populations, plants unable to survive, air quality affected by compounds with potential long-term health risks, possible damage to aquatic life, pollution requiring physical treatments, limited contamination of soil and which can be remedied quickly; Socio-political: Social effects of moderate concern to the community.
4.	Major	For people (population): special injuries; Economic: interruption of production activity; Emissions: off-site emissions without harmful effects; Ecosystems: death of some animals, large-scale injuries, damage to local species and destruction of extensive habitats, air quality requires "safe haven" or the decision to evacuate, soil remediation is only possible through long-term programs; Socio-political: Social effects of serious concern to the community.
5.	Catastrophic	For people (population): death; Economic: stopping the production activity; Emissions: off-site toxic emissions with harmful effects; Ecosystems: the death of animals in large numbers, the destruction of flora species, the quality of the air requires evacuation, permanent contamination and over extended areas of the soil; Socio-political: social effects of particular concern to the community.

Table 3. The levels of risk occurrence probability [6, 7]

No.	Probability	When it can occur	Frequency of occurrence
1.	Rare (unlikely)	only in exceptional conditions	less than 10^{-12} (a probability of annual occurrence in 10^{12} years)
2.	Unlikely	it might happen someday	between 10^{-8} și 10^{-12} (between 10^8 and 10^{12} years)
3.	Possible	it can happen sometime	between 10^{-6} și 10^{-8} (between 10^6 and 10^8 years)
4.	Probable	it can happen in most situations	between 10^{-4} și 10^{-6} (between 10^4 and 10^6 years)
5.	Almost sure	is expected to happen in most situations	over 10^{-4} (possible in a period less than 10.000 years).

From a qualitative point of view, the level of risk is calculated as the product between the level of severity (consequence) and the level of probability of the analysed event.

Using the information obtained from the analysis, the risk of an adverse event related to the handling of liquefied chlorine tanks is estimated to be moderate (tables 4 and 5).

Quantitative risk assessment includes five stages [7, 8]:

- description of the intention;
- hazard identification;
- identifying the consequences;
- estimation of the size of the consequences;
- estimating the probability of the consequences.

Table 4. Qualitative risk assessment matrix [6, 7]

Consequences			Insignificant	Minor	Moderate	Major	Catastrophic
			1	2	3	4	5
Rare (unlikely)	$< 10^{-12}$	1	1	2	3	4	5
Unlikely	$10^{-8} - 10^{-12}$	2	2	4	6	8	10
Possible Probable	$10^{-6} - 10^{-8}$	3	3	6	9	12	15
Almost sure Rare (unlikely)	$10^{-4} - 10^{-6}$	4	4	8	12	16	20
Unlikely	$> 10^{-4}$	5	5	10	15	20	25

Table 5. Risk levels [6, 7]

Risk levels	Definition	Actions to be taken
1 – 4	Very low risk	Conducting actions through usual, routine procedures
5 – 9	Low risk	
10 – 14	Moderate risk	It is acted through specific standard procedures, with the involvement of management from the workplaces
15 – 19	High risk	Prompt actions, taken as quickly as the normal management system allows, with the involvement of senior management
20 – 25	Extreme risk	Being an emergency situation, immediate actions are required and available resources will be used as a priority

Based on the detailed characterization of the site, these requirements were also met.

The matrix method was applied for analysing the source-pathway-receptor relationship, even though it is generally used when there are a large number of important pollutants in the assessment, to summarize the known information in the form of a checklist so as to simplify the assessment conditions (table 6).

Table 6. Matrix for the analysis of the source-path-receiver relationship [6]

Pollutant	Hazard(s)	Source(s)	Path(s)	Targets	Significance of risk	Need for remedial works
Liquefied chlorine	Toxic, skin and respiratory irritant, explosive	Water treatment plant In pressure tanks	Ingestion Direct contact Migration through soil and subsoil, underground and surface water	Human health	Medium/High	Yes
				Soil, basement	Small/Medium	No
				Groundwater and surface	Small/Medium	No
				Flora and vegetation	Medium	No
				Fauna	Small/medium	No

The importance of each receiver's risk can then be evaluated, identifying those risks that require a form of remediation, this actually representing the risk estimate.

Risk quantification can be based on a simple classification system where the probability and severity of an event are classified in descending order, assigning them a random score. A simplified model is given in table 7.

Table 7. Simplified risk calculation model [6, 7]

The elements of risk	Probability, P_i			Consequence, G_j			The size of the risk, R
	high	average	small	major	medium	minor	
Scores	3	2	1	3	2	1	$R = P_i \times G_j$ R = 6

Considering the 3 classes of severity, respectively 3 classes of probability, the following scale was established for the assessment of the risk:

- For $R = 1 \rightarrow$ reduced risk;
- For $R = 2 \div 4 \rightarrow$ average risk;
- For $R = 5 \div 9 \rightarrow$ major risk.

The higher the result, the higher the priority that will have to be given in controlling the risk. Based on this model, a major risk was estimated so measures have to be taken in order to prevent and/or reduce this risk.

4. Measures to prevent and/or reduce the highlighted risks

4.1. Preventive measures

In order to prevent the highlighted risks, it is necessary to replace the current chlorination system, which is in a state of advanced degradation (old pipes and faucets, etc.) with a new, modern and safe one, such as the automatic installations AS02004/9 (figure 7) or standard CHLORMIX HS -.3 (figure 8).



Figure 7. Automatic chlorination unit AS02004/9

Automatic unit AS2004/9 is intended for the dosing of gaseous chlorine, according to the modern principles of computerized control of the chlorination process, and has a number of important advantages, being preferable as a chlorination option:

- Continuous operation
- High reliability
- Dosing accuracy - "step by step" linear servomotor
- Automatic dosing control depending on water flow and residual chlorine concentration, synchronized or individual
- Includes the functions of the residual chlorine analyser, the chlorine detector in the air and the automatic chlorine dispenser
- Measurement, control and direct display of residual chlorine concentration in water.

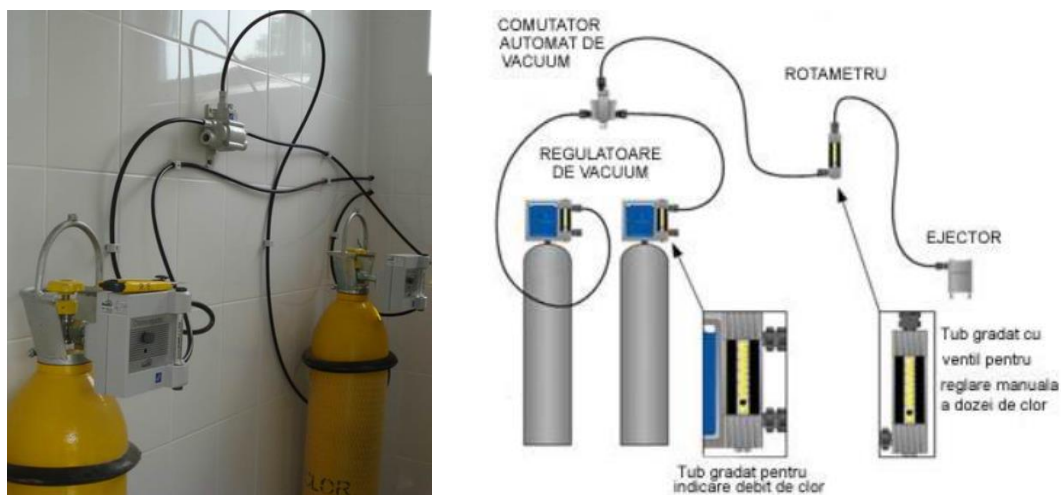


Figure 8. Standard CHLORMIX HS-.3 chlorination installation

The CHLORMIX HS - 3 standard installation is composed of:

- vacuum regulators with chlorine flow measuring tube,
- automatic vacuum switch,
- separate rotameter with measuring tube equipped with a valve for adjusting the chlorine dose,
- ejector.

4.2. Protective measures

The main protective measures can be considered [5, 7, 9]:

- wearing protective equipment (butyl rubber or neoprene gloves, chemical safety glasses and face mask where there is a possibility of splashing liquid, waterproof equipment made of butyl rubber, viton with penetration time > 8 h, fluorocarbon rubber, teflon with penetration > 4 h, polycarbonate and chlorinated polyethylene to prevent any skin contact with liquid chlorine, respirator with chlorine retention cartridge or, in case of breakdowns, self-contained breathing apparatus with air or oxygen reserve);
- cleaning the equipment before reuse;
- equipping workplaces with eyewash points, showers and spaces for cleaning contaminated equipment.
- monitoring the concentration of chlorine in the atmosphere and keeping it below the imposed limits (exposure limit value at 8 hours/-, exposure limit value at 15 min/1.5 mg/m³);
- compliance with the recommendations regarding the management of chlorination facilities;
- proper handling and storage of liquefied chlorine tanks.

It is recommended to install automatic warning systems for monitoring to detect the presence of chlorine gas.

4.3. Developing a risk management program

Environmental risk management requires planning, organization, implementation and control in order to achieve a successful program.

Briefly, figure 9 shows how to manage a risk situation involving chlorine pressure tanks as sources of risk [6, 7].



Figure 9. Managing a risk situation

Risk description

Increasing chlorine concentration in drinking water
Contamination of soil, groundwater and surface water
Intoxication
Dermatological and respiratory irritation
Explosion

The source of risk

Tanks under pressure of liquefied chlorine

Control measures

Compliance with the safety data of the chemical substance according to the suppliers' recommendations
Ensuring the sanitary protection perimeter in case of severe emergencies
An additional control area before drinking water from reservoirs reaches the population
Careful examination of the integrity of chlorine tanks, chlorine-water mixing facilities
Regular checking and correct calibration of devices so that there is no risk of introducing into the water amounts above the permissible limit of chlorine
Proper storage of chlorine tanks and avoiding their deposition in heated spaces

Admissible limits

0.5 mg/l network input, 0.25 mg/l network output

Monitoring

Monitoring the level of chlorine in the water
Monitoring the state of chlorine tanks, their integrity, storage conditions

Corrections and corrective actions

Bringing drinking water quality parameters within normal limits
Eliminating errors
Development of a special management manual for chlorine tanks
Implementation of new risk management strategies

Responsible

General Director
Quality manager
Station master

4.4. Risk monitoring

Knowing the potential risks requires [6]:

- Monitoring the level of chlorine in the water;
- Monitoring the state of the chlorine tanks, their integrity;
- Monitoring of storage-storage conditions of chlorine tanks.

The monitoring must be carried out over a sufficiently long period of time, so as to allow the detection, not only of the immediate potential effects, if applicable, but also of the delayed effects, identified in the environmental risk assessment.

Monitoring methodology

Parameters to be monitored: residual free chlorine;

Areas to be monitored: at the entrance to the tanks and at the exit from the tanks (fig. 10);

Sampling / analysis: every 2 hours;

Data collection and compilation, analysis, reporting, review, evaluation: all data resulting from the analyses will be electronically recorded, stored and used for possible statistical analyses.



Figure 10. Proposed monitoring points

5. Conclusions

Chlorine is a toxic gas by inhalation, it irritates the skin, eyes, respiratory tract, causes lacrimation, coughing and chest pain. A high level of exposure causes burns to the lungs, pulmonary oedema and even death. Being stored in pressurized containers, it presents an explosive risk.

The incorrect storage and handling of liquefied chlorine tanks at Zănoaga water treatment plant and the existence of old and degraded chlorination facilities represent a source that can generate important environmental risks.

The qualitative and quantitative risk assessment was performed. From a qualitative point of view, the classification in the five levels of severity and probability was made and the results showed that there is an major level of severity, respectively a possible level of occurrence of an unwanted event. Using the information obtained from the analysis, the risk of an unwanted event related to the handling of liquefied chlorine tanks is estimated to be moderate ($R = 12$).

From a quantitative point of view, the matrix method was applied in order to analyse the source-pathway-receptor relationship (even though this is generally used when there are a large number of important pollutants in the assessment, to summarize the known information in the form of a checklist) and the quantification of the risk based on a simple classification system was made where the probability and severity of an event are ranked in descending order, assigning it a random score, and estimated the risk as medium.

By applying the simplified risk assessment model, which considers 3 classes of severity, 3 classes of probability, respectively 3 classes of risk, a major risk was estimated.

Taking into account all the results, it is clear that some important measure has to be established and implemented in order to prevent and/or reduce the risks that can occur regarding the chlorine tanks.

To prevent risks, the authors recommend the correct storage and handling of chlorine tanks under pressure and the urgent replacement of the chlorination plant with a new, modern and, if possible, automatic plant, which doses exactly the required amount of chlorine into the water and which constantly, measures the level of chlorine in drinking water but also in the atmosphere.

As protective measures, the authors recommend the use of protective equipment and the monitoring of chlorine concentration in drinking water and in the atmosphere.

Also, the authors recommend the development of a risk management program that takes into account the description of potential risks, the description of sources of risk, the description of control measures, admissible limits, the monitoring program, corrections and preventive actions and, last but not least, the description of those responsible.

The proposed monitoring program considered the monitoring of free residual chlorine every 2 hours at the entrance and exit of the 2000 m³ water reservoirs, the recording and analysis of the recorded data.

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