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Risk analysis in seawater desalination sector: a case study of Beni Saf Water Company "BWC"

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Abstract: In this present paper, a risk analysis approach is applied to an Algerian reverse osmosis seawater desalination plant using the MADS MOSAR method. MADS MOSAR method is a stepwise risk analysis approach containing many phases. Our work begins with analyzing a review of past accidents triggered by the Ben in Saf Water Company (BWC) seawater desalination plant locating in the Algerian coast in Ain Temouchent region and analyzing their similar seawater desalination plants (or plants that using similar and potential equipment). Then, the MADS MOSAR method will apply essentially for the macroscopic vision (Module A). The macroscopic vision corresponds to a main risk analysis. In the current case study, we were able to identify eight subsystems where sources and scenarios of hazards are identified, accident scenarios are assessed, recognized and ranked by "Severity×Probability" grid. We found twenty-six scenarios whose we were able to assess them in function of their probability and severity using "probability x severity" grid criteria. At the end of the analysis, we were able to define and suggest the most appropriate prevention and protection barriers for the potential elements in the studied seawater desalination plant, including pipelines, transformers, compressors, high pressure pumps, pressure vessels and energy recovery devices.

Keywords: Risk analysis; Beni saf Water Company (BWC); Seawater desalination plant; MADS MOSAR.

1.INTRODUCTION

A hazard is a situation or substance that has the potential to cause harm while risk is the likelihood or probability of a certain undesired event to occur within a certain period of time or under specified circumstances [1]. Although the BWC seawater desalination plant has become a priority for the Algerian freshwater production (provides 200.000 m^3/d of water to meet the needs of Ain Temouchent and Oran regions), there are also potential downsides. Apart hazards inherent of any seawater desalination plant (chemicals occur in the desalination process from numerous origins. these include the source water and chemicals that are used in the treatment process to aid its efficient functioning, to ensure microbiological safety, to stabilize the water before it enters the distribution system, and to control corrosion from contact surfaces during storage and distribution to consumers [2] and the presence of electrical equipments), the plant studied using the reverse osmosis RO membrane type that operates with high pressures than what is normally found in conventional plants assured by high pressure equipments. Membrane desalination processes use semi-permeable membranes with pumping pressure as the driving force-to separate a saline feedwater into two streams: a low-salinity product (permeate) and a high-salinity stream (concentrate or reject) [2]. According to [3] 40 % of total cost of water turns to seawater RO system (percentage could vary depending on project-specific factors). Reliability, service time and safety of these equipments must be considered. As regards death and injuries experienced in such desalination unit, one could refer to two deaths caused primarily by not observing the exiting safety and HSE instructions [4]. Safety precautions should be taken in the plant and shutdown-startup procedures were developed [5] and process monitoring devices are provided to prevent the damage of components due to process upsets [6]. Also, employers should be aware of these hazards and even workplaces must be appropriately designed to ensure proper operations and better health and safety conditions (workers, the public, property and the environment safety). In chemical industries, risk assessment is an approach for better and more efficient management of the process safety, whereby risk is estimated and considering various factors involved, decisions are made on the appropriate tolerability required [6, 7].

1.1 CASE STUDY: BENI SAF WATER COPANY SEAWATER DESALINATION PLANT

The first step of our risk analysis study is to describe study area and desalination process used. Based on a-7-years history (during 2010) of the BWC plant operation, maintenance records and accident reports, the second step is getting past internal/external accident review (the return of experience) for enhanced risk prevention. Then, the MADS MOSAR method is applied and recommended preventives and protective barriers are proposed.

2.STUDY AREA DESCRIPTION

Before hazard identification can begin, it is necessary to understand the system operations so that the risk analysis covers all activities of interest [7]. Some though be given to grasping how the system works and how the hardware, software, people, and environment all interact [8]. Clearly, we need to define the system and theirs functions to bind our analysis. This case study concerns Beni Saf Water Company BWC seawater desalination plant located on the Mediterranean in the Algerian coast in Ain Temouchent region, which has an area of 65,700m2, with a 200 000 m3/d production capacity. BWC has worked since March 2010. The location of the BWC plant is presented in the following map (Fig. 1).

Fig.1. Location of the BWC seawater desalination plant (**Source:** author)

3. PROCESS DESCRIPTION

BWC uses the reverse osmosis's method for the seawater desalination. In general, the main treatment unit includes the following stages: seawater intake and pumping, pretreatment, membrane RO separation unit and post-treatment. Seawater intake system allows seawater to flow to a desalination unit where minerals are then removed from the saline water through a desalination process. At present, practically all RO desalination plants incorporate two key treatment steps designed to sequentially remove suspended and dissolved solids from the source water. The purpose of the first step-source water pretreatment-is to remove the suspended solids and prevent some of the naturally occurring soluble solids from turning into solid form and precipitating on the RO membranes during the salt separation process [9]. Pressures applied in reverse osmosis applications vary between 15 bar (brackish water desalination) and 60 to 80 bar in seawater desalination [10]. which is 65 bar in the BWC case. The RO system consists of a number (usually 2-18) of individual RO trains, each of which is capable of independently producing desalinated water from pretreated source water [11]. Once the desalination process is complete, the freshwater produced by the RO system is further treated for corrosion and health protection and disinfected prior to distribution for final use. This third step of the desalination plant treatment process is referred to as post-treatment [9]. Fig. 2 presents a general schematic process of the BWC plant.

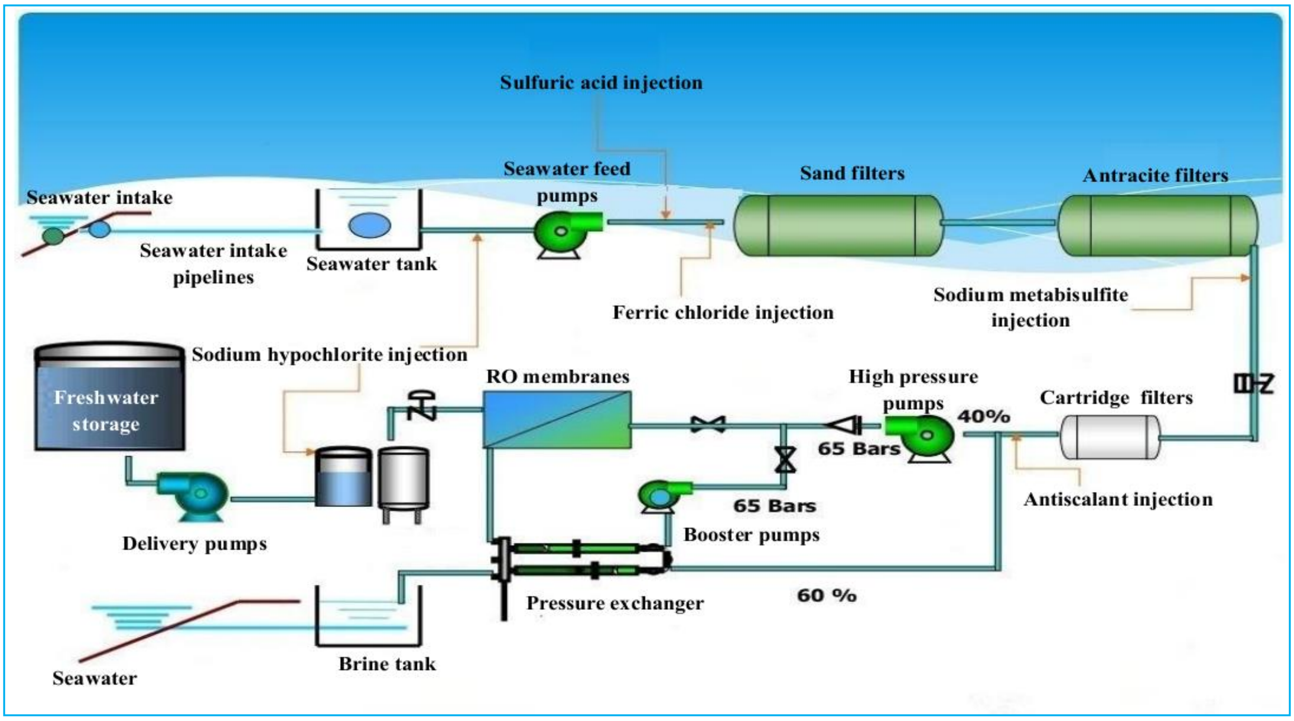
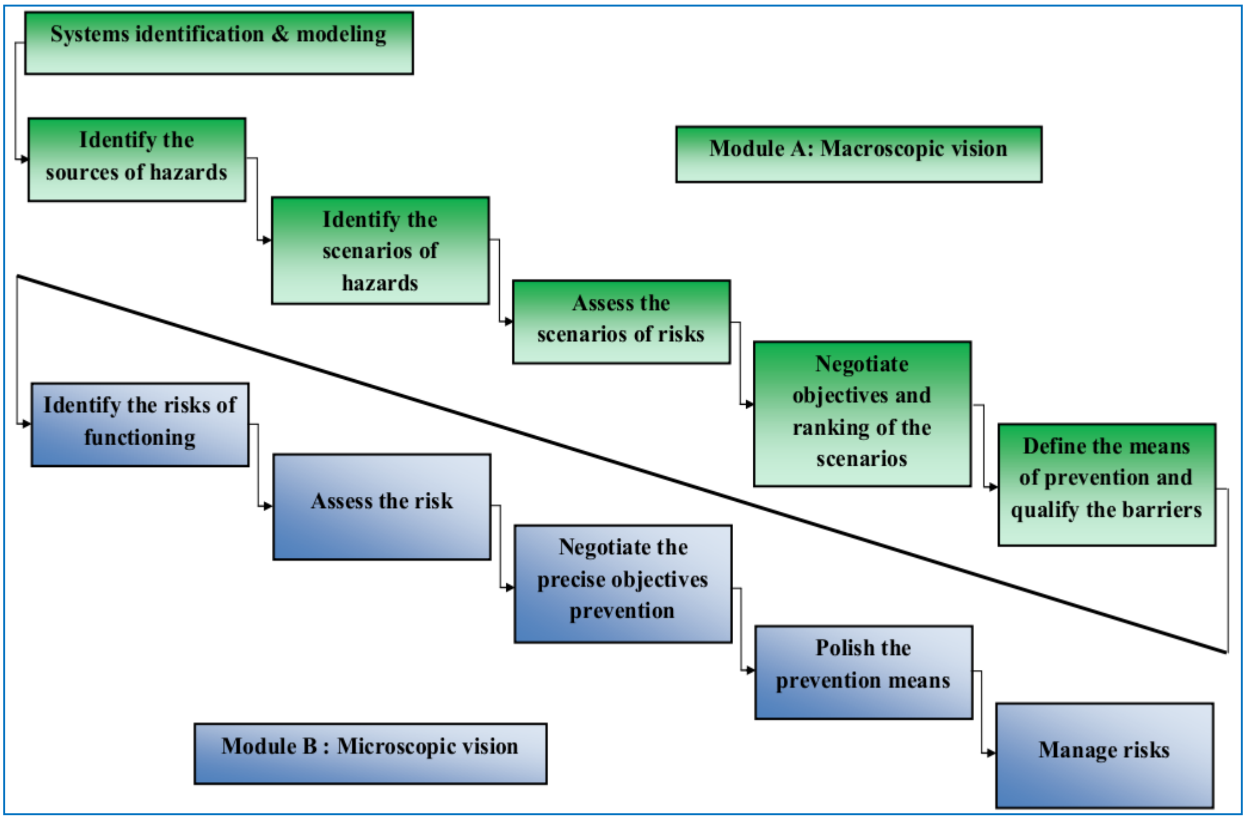


Fig.2. Schematic of BWC plant (**Source:** author)

4. IMPLEMENTATION OF THE MADS MOSAR MEDTHOD: MACROSCOPIC VISION

Risk management: a continuous management process with the objective to identify, analyze, and assess potential hazards in a system or related to an activity, and to identify and introduce risk control measures to eliminate or reduce potential harms to people, the environment, or other assets [12]. Two main purposes of the risk management are to ensure that adequate measures are taken to protect people, the environment and assets from undesirable consequences of the activities being undertaken, and to balance different concerns, for example safety and costs [13]. The risk analysis discussed here is one that anticipates and prevents undesired events during the implementation of the combustion pilot, using MADS–MOSAR. MADS refers to "The Analysis Method of Dysfunctional Systems", and MOSAR refers to "The Organized and Systemically Method of Risk Analysis". MADS proposes a general model of hazard, MOSAR builds a global methodology for the risk analysis [14,15]. The retained approach is the "MADS-MOSAR" methodology was developed by a team of specialists from the CEA (French atomic energy authority) [16]. It makes it possible to model our industrial field by a "Man-Installation-Environment" system [17, 18]. It is an integrated approach that allows progressive analysis of risks an industrial site [19]. MOSAR method consists of two modules (Module A and B) which can be used more or less independently. Module A corresponds to a macroscopic analysis of the risks of an industrial site and requires a preliminary risk analysis. Module B is used for a more detailed analysis of the scenarios identified in Module A, realized with specific instruments of safe operation. The two modules are almost the same structure [20]. MADS MOSAR structure process is shown in Fig.3.

Fig.3. MADS MOSAR process steps (Adapted from **[21]**).



As shown in the figure above, the first step of the MOSAR method consists of modeling the BWC plant by means of functional division into subsystems. So that for each subsystem (SS_i) the type of hazard source is identified and the hazardous processes are defined (short and long scenarios). Hazard identification is an iterative process. To identify each hazard, we need to decompose the system into many subsystems.

4.1. Systems identification and modeling

The main system constituting the study context is the industrial installation on which the risk analysis is carried out (the BWC desalination plant in our case). There are several possible divisions, the aim being to make the complex entity to be studied in sub-units (subsystems) simpler. From the previous description of the process, we can distinguish **eight** subsystems: **SS1:** seawater intake and pumping section; **SS2:** seawater pretreatment section;

SS3: reverse osmosis section; **SS4:** post-treatment section; **SS5:** electrical substation; **SS6:** administrative building; **SS7:** human; **SS8:** environment. Our system can be broken down into following subsystems (**Fig.4)**.

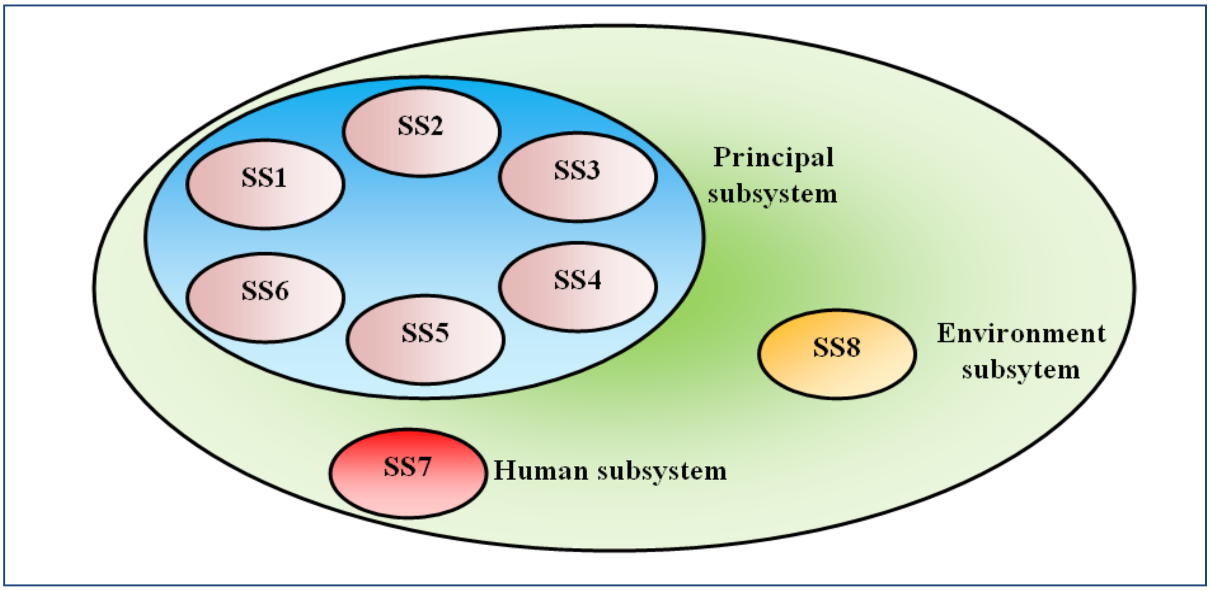


Fig.4. System decomposition into subsystems.

4.2. Identify the sources of hazards

The source of hazard should not be ignored. The first step is to identify the sources of hazard for each subsystem or to identify how each subsystem can be a source of hazard. By making this identification for all subsystems, a list of the hazards of the installation is obtained.

Table 1 illustrates the areas, subsystems decomposition and hazard sources associate to each subsystem.

Table 1. Sources of hazards presented the BWC plant

Area	SubSystems (SSi)	Hazard sources
Seawater intake and pumping area	**SS1: Seawater intake and pumping**	-Seawater intake pipelines -Intake screens -Feed pumps (11 pumps) -Seawater storage reservoir -Electric substation -Sodium hypochlorite tank (120 $m^{3)}$ -2 Compressors
	SS2 : Seawater pretreatment	-Ferric chloride tanks (34 $m^{3)}$ -Sodium metabisulfite tanks (14 $m^{3)}$ -Antiscalant storage tank (7 $m^{3)}$ -Sulfuric acid storage tanks (2x 100 m^3) -Sand filters (48 reservoirs) -Antracite filters (28 reservoirs) -Cartridge filter (20 filters)
	SS3 :RO unit	-10 High pressure pumps (65 bar) -RO membrane trains racks (10

Production area		racks) : • 1792 membranes -Energy recovery devices (22 units) • Pressure exchanger • Booster pumps and valves -256 pressure vessels -Caustic soda tank (1 m^3)
	SS4 : Post-treatment	-Chemical dosing system: neutralisation or chlorination -Sodium hypochlorite tank -Produced water tank -Brine disposal -10 pumps -Chemical cleaning tanks -Sand and anthracite filters cleaning -03 Membranes cleaning pumps. -Produced water tanks : 11 Pumps & Pipelines
	SS5 : Electrical substation	-Transformer power station
	SS6 : Administrative building	-Offices -Laboratory -Control room
	SS 7 : Human	-Operators - Trainees
	SS 8 : Environment	- Climatic and natural conditions - Material environment

To identify hazards, our work begins with analyzing a review of past accidents triggered by the BWC plant and their similar facilities. Based on the analysis of the accident balance sheets, an example of the repartition per month by accident triggered by the BWC plant during 2010 is shown in the following diagram (Fig.5).

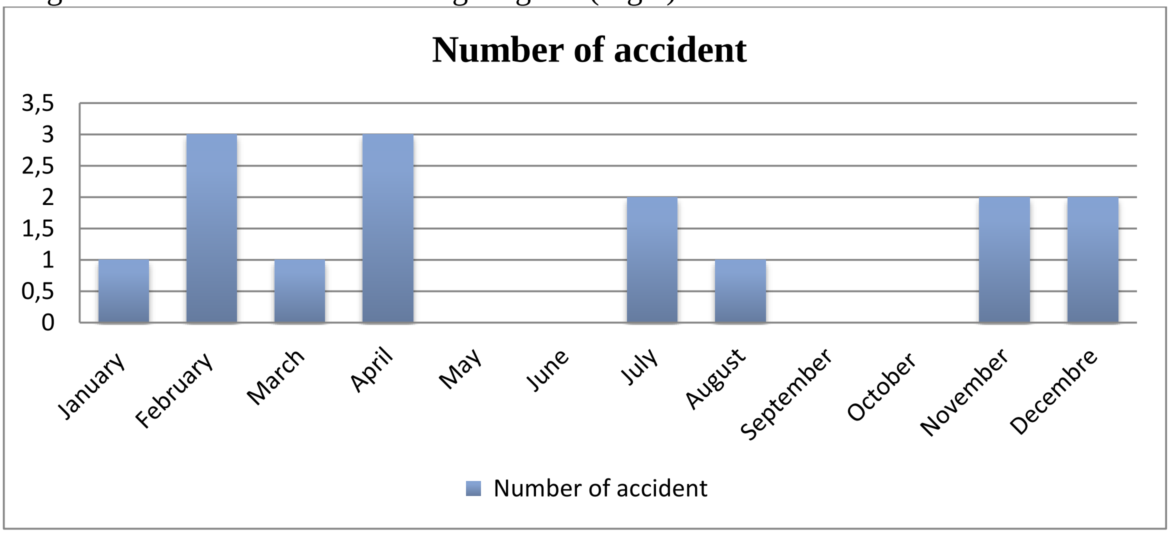


Fig.5. Accident distribution per month during 2010 (**Source:** BWC)

Then, and according to accident reports and accident balance sheets, we analyzed accidents triggered by major desalination plants in Algeria. As is apparent from the table 2, **37.5%** of accidents are related to the transformer accidents while **25%** of the accidents caused pipeline leak. Also, **25%** of the accidents present an environmental pollution while **12,5%** of them are due to an electrical cause (short-circuit generated fire in the storage area).

Table 2. Accident triggered by the Algeria's desalination plants (**Source:** author)

Desalination plant	Years	Accidents	
Arzew (Oran)	17-10-2005	Transformer fire	
Arzew (Oran)	12-02-2006	Hydrocarbon pollution	
Skikda	10-02-2008	Fire in the storage area	
Ain Temouchent	14-04-2010	Explosion of water HP pipeline	
Mers El Hadjadj (Oran)	28-07-2011	Transformer fire	
Kahrama (Oran)	19-05-2012	Hydrocarbon pollution	
Honaine (Tlemcen)	25-08-2012	Transformer explosion	
Honaine (Tlemcen)	26-09-2016	Water leak	
Results			
Transformer accidents	Pipeline leaks	Environmental pollution	Electrical causes
37,5 %	**25 %**	**25 %**	**12.5 %**

4.3. Identify the scenarios of hazards

MOSAR method insist on hazard chaining flow between component systems of industrial plants and is specially adapted for studying the effects of simultaneous accidents or "domino“ effects [19]. Each subsystem in Table A (from module A) is characterized by inputs (initiating events) and outputs (principal events). We can also make the relation to find the danger flux to compete the models. The table A is the best tool to establish that. As a part of our risk analysis study, Table 3 presents initiating events, initial events and main events (flux of danger) for the SS5 for the element transformer.

Table 3. Identify the source of hazard for the transformer

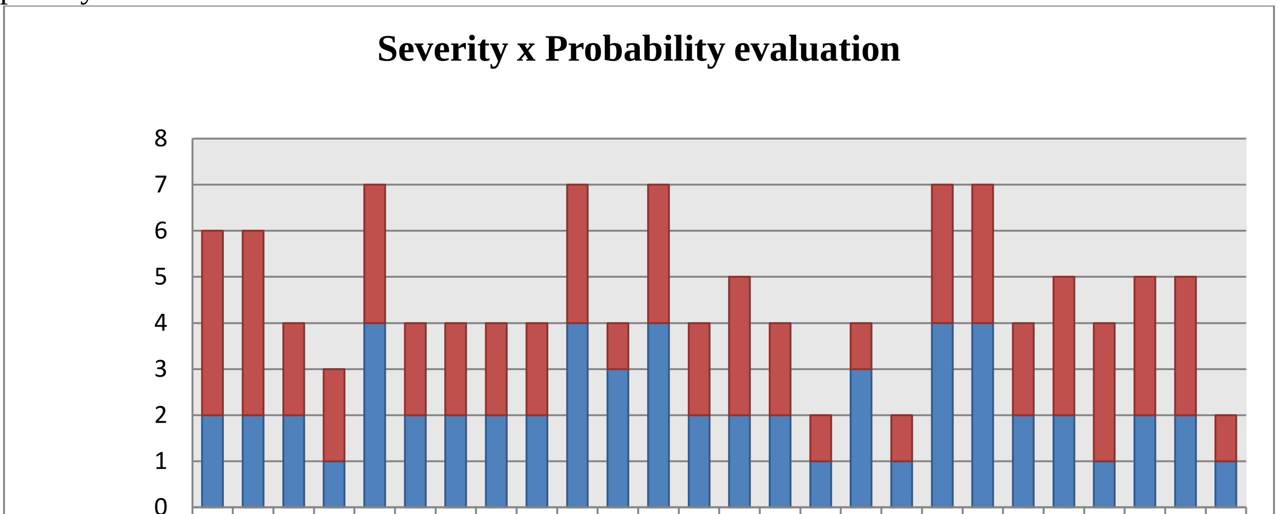
Source of danger SS5	Phase of process	Initiating events		Initial events		Main events (flow of danger)
		External	Internal	Container	Contonent	
Transformer	**Exp**	-Transformer overheating -Thermal radiation -No compliance with the safety instruction -Maintenance operations -As a consequence of the lightning -Hazardous discharge of static electricity -Humidity -Effect of defective joint -Low impedance faults -Electrical malfunction	-Corroded cables -Internal heat -Locking of the disc -Electric arc -Short-circuit -Over-voltage -Degradation of insulation like decay of the transformer oil due to moisture or ageing or decomposition -Loss of containment	-Corrosion of the tank -Crack in the wall of the oil conservator - Corrosion and rupture of the tank due to aging or magnetic shock - Insufficient maintenance or too infrequent inspection.	-Oil overheating -Oil leak -Accidental oil spill - Inflammation of the transformer oil contained inside the metal envelope - The presence of flammable gas	-Explosion -Fire -Pollution - Human damages -Production shutdown -Atmospheric pollution due to smokes -Loss of cooling oil in transformer -Materials loss or damage (premises destruction, plant damage)

Using the black-box concept by subsystems such as presented the Fig.6, We can make the reduction of the variety. Short scenarios of undesired events can be structured from the links between them. From Table A and short scenarios, we can easily define long undesired scenarios (as an example, Fig.7 presents long scenarios for transformer explosion).

4.4. Assess the scenarios of risks

Probability assessment can be made, at the option of the analyst, qualitative, semi-quantitative or quantitative, using classical instruments (trees of failures, trees of events). MOSAR method explicitly provides for identify and assess security measures and distinguish between technical measures and usage measures (called in other methods, human protective measures") [22].

In this study, 26 accident scenarios were identified as those most relevant to our system and analyzed. The Figure bellow (Fig.8) shows the combination of risk severity and probability for each scenario. It allows scenarios to be classified and decided the relative priority.



	Sc 1	Sc 2	Sc 3	Sc 4	Sc 5	Sc 6	Sc 7	Sc 8	Sc 9	Sc 10	Sc 11	Sc 12	Sc 13	Sc 14	Sc 15	Sc 16	Sc 17	Sc 18	Sc 19	Sc 20	Sc 21	Sc 22	Sc 23	Sc 24	Sc 25	Sc 26
Probability	4	4	2	2	3	2	2	2	2	3	1	3	2	3	2	1	1	1	3	3	2	3	3	3	3	1
Severity	2	2	2	1	4	2	2	2	2	4	3	4	2	2	2	1	3	1	4	4	2	2	1	2	2	1

Fig.8. Severity x Probability combination.

As mentioned in the figure above, scenarios 5, 10, 11, 19 and 20 have a high "severity x probability" scores whereas scenarios as 16, 18 and 26 present the low "severity x probability" scores. The rest scenarios have medium "severity x probability" scores.

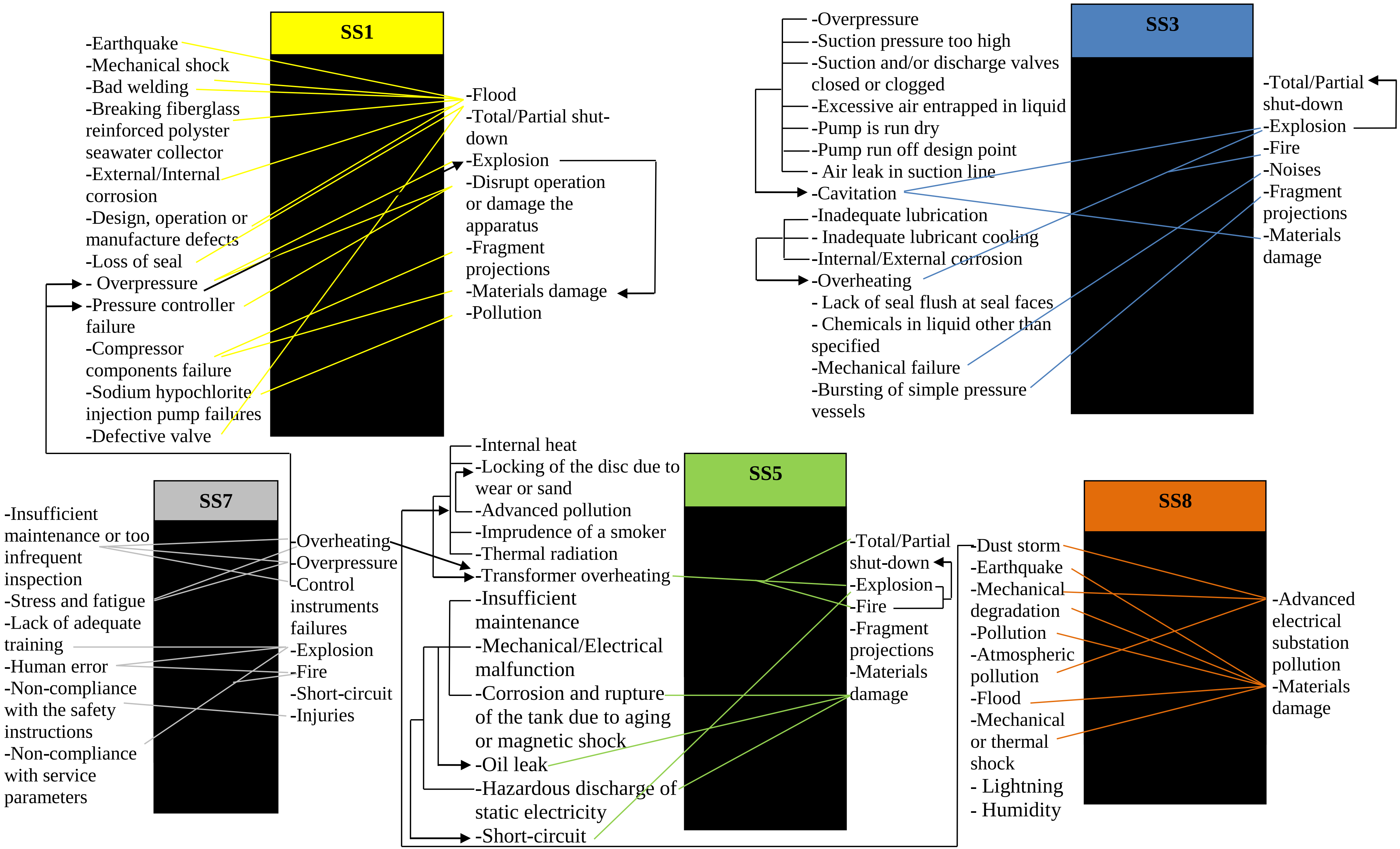


Fig.6. Examples of short and long accident scenarios

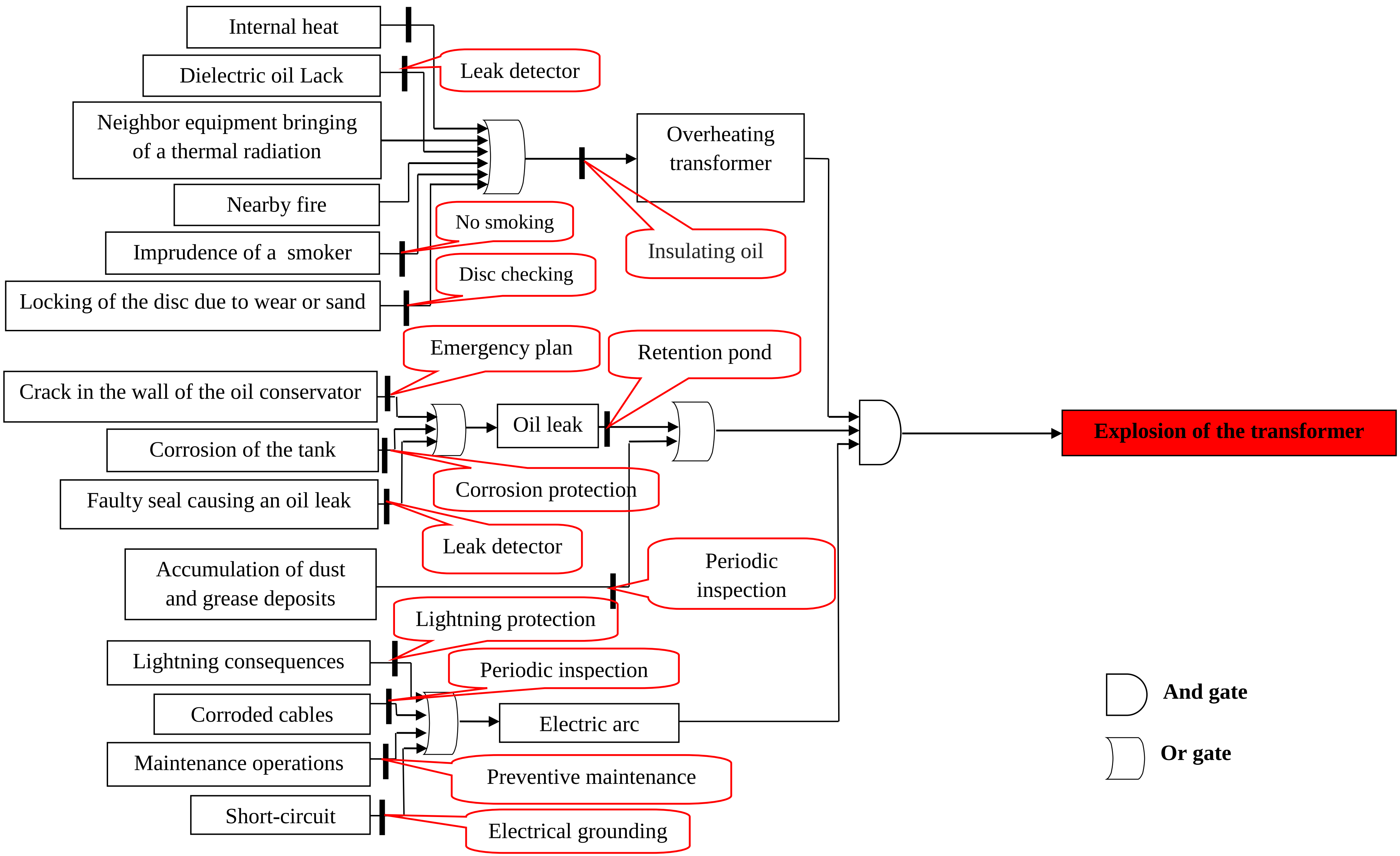


Fig.7. Long scenarios for SS5: Transformer explosion

Risk management plan is a step in the overall risk management procedure following the risk assessment step. After all risks are identified in the risk assessment step, risks that are not acceptable must be selected. The main task in the risk management plan step is to treat each selected unacceptable risk. To perform risk quantification, a risk matrix must be developed for each accident initiator from the corresponding accident matrix [7]. Once scenarios have been identified, they must be assessed and grouped in a grid by their severity and probability as shown in the figure 9.

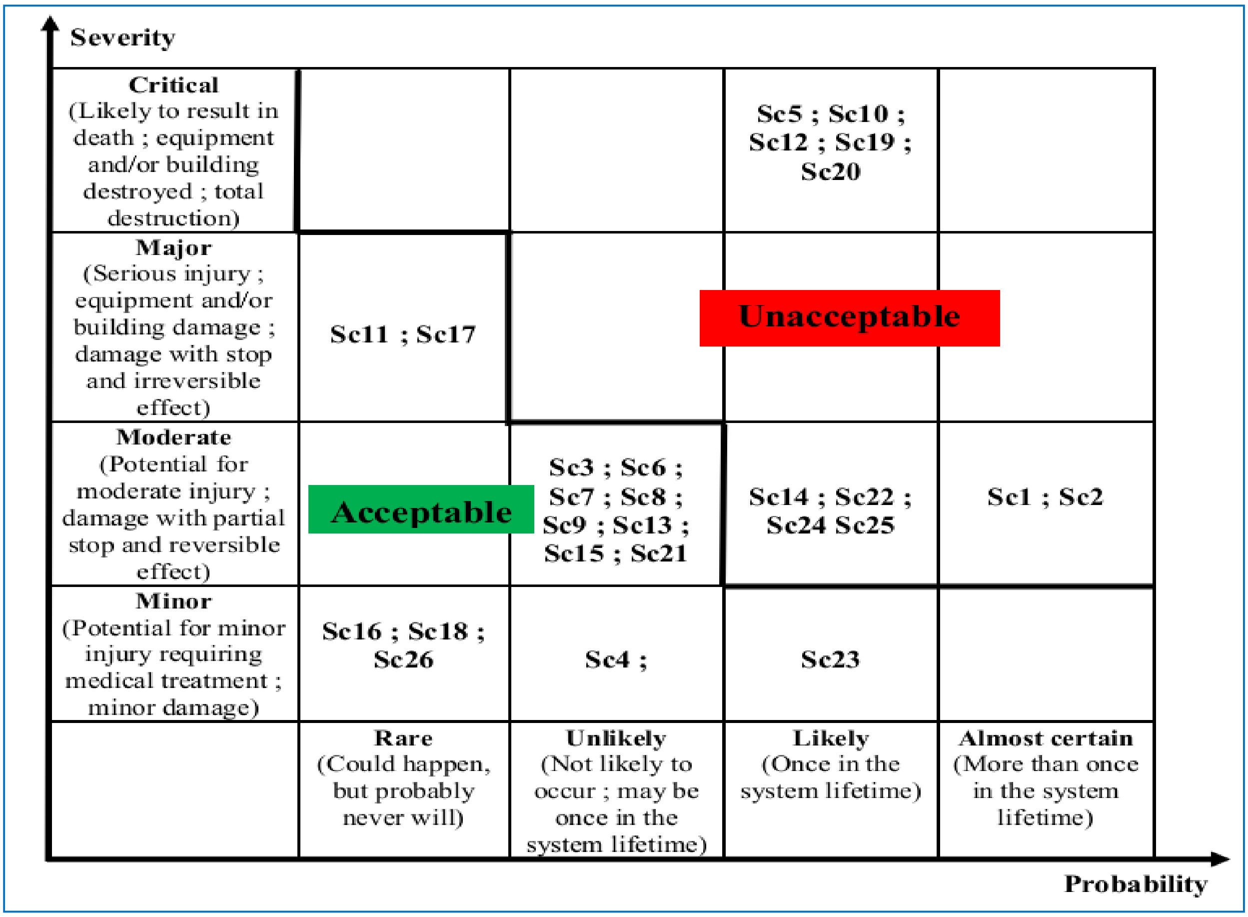


Fig.9. "Severity x Probability" grid

The "Severity x Probability" grid (Fig.9) shows that only **42.3%** of the scenarios are located in the **acceptable zone** (green zone). However, **57.7%** of the scenarios are located in the **unacceptable zone** (red zone).

4.5. Define the means of prevention and qualify the barriers

The last step of the MADS MOSAR approach is to suggest/define and to quantify barriers. In order to improve safety approach, preventive and protective appropriate barriers are cited in Table 6.

The table below presents some proposed preventive and other protective barriers that should be available for potential elements (elements that may present a significant hazard) in the BWC seawater desalination plant. These elements are respectively: pipelines, transformers, high pressure pump, compressors, pressure vessels and energy recovery devices.

Table 6. Recommendations

Component	Recommendations
Pipelines	**1-** The implementations of an accidental spill prevention plan for preventing and controlling accidental spills or discharges (especially brine discharges). **2-** Damaged or leaking containers will be isolated, when possible, in a containment area or repackaged to prevent loss, exposure or hazards. **3-** Leak detection of water pipeline. **4-** Periodic inspection of the water pipeline systems (routine maintenance of piping system). **5-** The replacement of old pipes with new pipelines. **6-** Prevention of corrosion. **7-** Preventive and corrective maintenance of the fiberglass reinforced polyster seawater collector (estimate the lifetime of collectors and change them periodically).
Transformer	**1-** Transformer status check/control. **2-** Preventive maintenance of the various safety and protection devices of the transformer (relays, fuses, circuit breakers, powder and carbon dioxide extinguishers). **3-** Dielectric oil transformer quality control (transformer oil aging) and replacement. **4-** Compliance with safety instructions. **5-** Design to the appropriate electrical standards. **6-** Periodically temperature oil checks. **7-** Gas emission control and periodic oil analysis.
High pressure pumps	**1-** Preventive and corrective maintenances are recommended. **2-** Install flow indicators. **3-** Increase pressure indication and alarms. **4-** Preventive and corrective maintenance can reduce the physical hazard of noise. **5-** Recommend anti-vibration pump core.
Compressors	**1-** Installing a pressure sensor. **2-** Carbon dioxide extinguishers. **3-** Emergency response for projections accidents. **4-** Fire fighting equipment, procedures and alarms for emergency response. **5-** Personal protective equipment (PPE) uses.
Pressure vessels	**1-** Periodic pressure vessels inspection. **2-** Operating service pressure respect. **3-** Respect of the safety distance (explosion prevention). **4-** Pressure control instrument.
ERD (Energy recovery devices)	**1-** Periodic verification is recommended. **2-** Leak and seal detectors. **3-** Ensure the ERD support. **4-** Never exceed permitted flow limits. **5-** Parameters service respect (flow and pressure: ERD recommends au minimum 1.0 bar). **6-** ERD cavitation prevention (most recognized problem for ERD).

5. CONCLUSION

In this study, we carried out the BWC plant risk analysis throughout its life cycle, including seawater intake and pumping, pretreatment, reverse osmosis desalination, post-treatment, electrical substation, environment and human. To control or mitigate risks those appear to be the most critical, we were applied the MADS MOSAR method**.**

The most important problem in the BWC plant or in the similar plants lies in RO membranes in several pressure vessels, which are placed in a certain order. This process requires that a higher pressure (more than 65 bars) be exerted on the high concentration side of the membrane which would render the unit being out of service and pipes being burst.

Many hazards can be related to the BWC plant equipments such as the transformers, compressors, high pressure pumps and the energy recovery devices. They can involve fires, explosions, high-voltage electrical arcs, fragments projections, oil ignition and dispersions, and potential injuries or may up to death. They make noises and they also give off heat during operation. There is also a wide range of chemicals in the workplace (for the seawater desalination process or laboratory analysis). Hazardous chemicals can be a health, physicochemical or environmental hazards if not handled or stored correctly. The safe clean up of a chemical spill requires knowledge of the properties and hazards posed by the chemical to also protect the environment.

This study offered valuable results in terms of safety as indeed the recommendations and improvements yielded are expected to lead directly/indirectly to help the BWC plant in its safety approach. The risk management plan is a continuous risk controlling and monitoring process.

Risk assessment is only one step in the overall approach to risk management. It belongs to a dynamic approach. In addition, it is recommended that a new risk assessment be carried out on a regular basis to determine whether the risks have been eliminated definitively or whether other risks have arisen since the last assessment. The actions resulting from the evaluations must be performed, formalized and documented.

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