Post-Emergency, Multi-Hazard Health Risk Assessment in Chemical Disasters
PEC

Deliverable D.D.3

Health Risk Prioritization Matrix

ECHO/SUB/2015-713844-PREV11 - PEC: Post-Emergency, multi-hazard health risk assessment in Chemical disasters
Project co-funded by ECHO - Humanitarian Aid and Civil Protection

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1 INTRODUCTION

1.1 BACKGROUND

Human health risk assessment is the process to estimate the nature and probability of adverse health effects in humans who may be exposed to chemicals in contaminated environmental media, now or in the future (EPA, 2003). Human health risk prioritization involves assessing and ranking this risk.

Assessing and managing risk is a core element of environmental health assessment. Use of a qualitative (semi-quantitative) risk assessment matrix is a growing practice (Vatanpour, 2015). The comparative simplicity and apparent ease of use of this approach likely contributes to widespread adoption including a generic international standard for risk assessment techniques in support of risk management. The World Health Organization also has adopted this approach for risk assessment of acute public health events.

Rapid development, industrialization, and urbanization have resulted in severe contamination of the environment by different pollutants from catastrophic releases of the chemicals in many areas of the world, either directly or indirectly. Exponential urban and economic development has resulted in human populations settling in urban areas and as a result, being exposed to these pollutants. Depending on the nature of the contaminant, the contaminated environment can have a deleterious effect on the health of exposed populations and may require decontamination, recovery, remediation, and restoration, which is dependent upon the severity of the hazards and amount of chemicals present in the air (A.Peña-Fernández, 2014). Therefore, human health risk assessments and prioritization become essential.

This document aims at developing an integrated Health Risk Prioritisation Matrix considering both technological (e.g. infrastructure vulnerability) and toxic hazards for PEC chemicals in PEC-countries. In this light this matrix represents an innovative tool which is applicable for rapid NaTech health risk prediction and mapping.

The risk matrix developed can be described as Risk = Severity x Likelihood (probability of plant damage), where Severity (measure of human health effects) is expressed as number of affected people. The health risk matrixes were based on the outcomes of the risk assessment exercise carried out in deliverables D.D.1 and considered the likelihood of damage of each plant items taking into account the associated impacts on human health during both the warm (summer) and cold (winter) season.

The main objective of the health risk matrix is to promptly inform authorities responsible for civil safety and public health protection of potential *acute* public health events supporting the identification of priority actions providing a simple though scientifically-based ground for immediate and quick actions. In this light health prioritization matrixes were developed for benzene and acrylonitrile which due their specific phys/chem and toxicological properties are more strongly associated to acute health effects thus posing higher acute health risks for the population and workers living close the chemical facility.

The modeling results have been evaluated according to evidence-based public health criteria, derived from multi-disciplinary scientific knowledge from epidemiology, human toxicology, environmental health and occupational medicine obtained from the biomedical literature. For example, the industrial plant incident likelihood has been expressed as a function of the characteristics of the plant that will drive the amount of material released and the meteorological scenario as well as the (annual) tonnage handled.

Appropriate scores have been allotted based upon pre-definite health severity criteria. In this way, a risk matrix relating the two dimensions, namely likelihood and health impact represent a graphical representation of different risks in a comparative way which may be used as a visualisation tool when multiple risks have been identified thus facilitating the comparison and ranking of different risks. As such the matrix represents an early rapid risk/impact prediction tool and represent an effective way to communicate visually the risk thus helping authorities responsible for civil safety and public health protection to react quickly especially during the emergency phase.

1.2 RISK MATRIX

The risk matrix is done once the risk assessment has been completed. Matrix is the way to communicate the risk effectively through visually attractive methods, like charts, tables, etc. This will help the decision makers or policy makers to understand the risk quickly, especially, in the response period.

To prepare the risk matrix, the likelihood table and health consequence of the particular event are taken into the consideration, which is explained in detail below.

Severity of consequences, for a risk matrix, can be categorized, on a scale of 1-6 (WHO, 2012), as follows:

1. Catastrophic
2. Massive
3. Major
4. Moderate/significant
5. Minor
6. Negligible/slight

Similarly, the likelihood is the probability of damage i.e. is the probability or frequency of a consequence occurring and takes into consideration the probability and frequency of different levels of damages in each plant item.

The likelihood of a consequence may be expressed in qualitative or quantitative terms in a table format (ZHOU Ping Ping, 2014). A likelihood Table 1 shows a range of probabilities on a scale of 1–5 as seen below.

1. Almost certain
2. Likely
3. Possible/occasionally
4. Unlikely
5. Rarely/remote

Table 1 Likelihood Categories

Level	Likelihood Descriptor	Frequency of Incident
1	Rare/remote	Once in more than ten years
2	Unlikely	Once in 5 – 10 years
3	Possible/ occasionally	Once in 3 – 5 years
4	Likely	Once in 1 to 3 years
5	Almost certain	More than once a year

A health or well-being risk is the chance of something happening that may affect a health or well-being outcome of the person or the community. Health or well-being risk is expressed regarding a particular consequence for a particular activity and the likelihood of that particular consequence occurring. A risk level is also an indication of the significance of a health or well-being impact.

Health risk level can be expressed on a scale as follows (WHO, 2012):

1. Extreme
2. High
3. Medium
4. Low
5. Very low

1.3 PRIORITISING ACTIONS

Action prioritization is one of the benefits of creating risk prioritization matrix. It provides the ground for immediate, quick, consolidated actions based on the time about what 'exactly to do and when to do' to emergency responder personnel. The Table 2 below gives the risk level, appropriate actions to be taken and time scale.

Table 2 Risk Levels, Prioritisation Action, and Time Scale

Risk level	Action priority	Timescale
Extremely high!	**Unacceptable risk.** Requires immediate attention and cessation of activity until action to reduce risk is carried out.	Immediate
Very high!	**Unacceptable risk.** Requires immediate attention and cessation of activity until action to reduce risk is carried out.	Immediate
High	**Urgent.** Requires attention as soon as possible. If necessary, stop activity until action to reduce risk is carried out.	Immediate
Medium	**Requires action.** To be dealt with as soon as possible after high priorities.	Within two weeks
Low	**Action if necessary.** Where the action is possible, without significant costs or difficulty. To be dealt with after medium priorities.	Within one month
Insignificant	**No action required.** No need to record as part of risk assessment.	-

2 METHODOLOGY FOR DERIVING THE RISK PRIORITISATION MATRIX

The methodology applied to obtain risk priority matrix is based on the equation Risk = Severity x Likelihood (Yan, 2010). The matrix is thus created in a way that the likelihood of plant damage is reported on the 'X' axis and the health impact on the population living nearby the chemical plant on the 'Y' axis. In this way, the authorities responsible for civil safety and public health protection will have immediate and quick understanding of the different risks associated to a Natech disaster affecting chemical plants allowing to plan immediate actions to face the disaster in a most effective way. To estimate the severity component of the risk matrix we considered the health impact on the whole population living close the chemical plant summing the general population and plant workers (henceforth referred as 'people').

In order to estimate risk from the equation above, the data of severity and likelihood for all plant items need to be estimated. Severity of consequences in PEC context is considered as the number of the people (general population and plant workers) affected by the catastrophic and partial damage of the plant items while likelihood is considered as the probability of the damage of each plant items in a year.

2.1 LIKELIHOOD – PROBABILITY OF DAMAGE

The probability of both catastrophic and partial damage for each single item of the chemical plant have been obtained in Task B of the project. The analysis of the structural components has been carried out with the goal of assessing the vulnerability of existing structures. For this reason, great attention has been devoted to the inventory of recurrent damage mechanisms that have been observed on such structural elements in past disasters. The final goal has been the identification of those damages that could lead to the spilling of the contaminant fluids contained in the structures under consideration.

The procedures described here have been applied to mechanical models defined to be representative of existing storage systems in chemical plants. With this aim, the frequencies of damage have been estimated on the basis of the ratio between diameter (D) and height (H) of the plant items clustered in three different classes as follows: Class 1: 0.7 ≤D/H≤1; Class 2: 1<D/H≤1.5 and Class 3: 1.5<D/H≤2.

Finally, a careful validation of the fragility curves has been carried out by comparison with curves published in the scientific literature. More specifically, in the case of tanks, the fragility curves proposed in Hazus (FEMA, 1999) for the two limit states of moderate and severe damage have been assumed as a reference for the validation of the results obtained. For all three types of plant items the assessment procedure adopted has been based on a careful calibration of geometrical and mechanical data and compared with indications provided by the scientific literature. The simplifications adopted in the analyses of the vessels have been developed with the goal of the identification of a tool applicable to a large portfolio of industrial equipment without the aid of time-consuming analyses.

For all the plant items the probability of both complete (i.e. catastrophic) and partial damages in one year, are reported in Table 3 below.

Table 3: Probability damage of chemical plant items for partial and complete disruption in 1 year

Tanks	Diameter (m)	Height (m)	Ratio	Class	The probability of Damage in 1 year	
					Partial	Complete
Virgin Naphtha Storage Tanks	10	8	1,3	2	0.281069	0.050061
Primary Fractionator	8,3	19	4,6	1	0.331030	0.100850
Primary Fractionator	8,3	19	4,6	1	0.331030	0.100850
Heavy Gasoline Stripper	1,6	6,4	8,0	2	0.288505	0.074485
Heavy Gasoline Stripper	1,6	6,4	8,0	2	0.288505	0.074485
Quench Colum	5,7	15	5,3	1	0.331030	0.100850
Debutanizer	3,2	16,4	10,3	2	0.288505	0.074485
Debutanizer	3,2	16,4	10,3	2	0.288505	0.074485
Cracking Gasoline Unit Buffer Tanks	12	9	1,3	2	0.281069	0.050061
Cracking Gasoline Tank	24	11	2,2	4	0.422875	0.079481
Cracking Gasoline Tank	37	12	3,1	4	0.422875	0.079481
Acrylonitrile Storage Tank	15	11	1,4	2	0.281069	0.050061
Unit Buffer Vessel	2	3,1	3.1	1	0.093867	0.057020
Elastomer Production Reactor	2	3,6	0,6	1	0.448529	0.080212
Stripping Column	3	4,6	0,7	1	0.448529	0.080212

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Legend showing different types of plant items

Storage Tanks
Horizontal Vessel
Vertical Vessels

2.2 SEVERITY – HEALTH IMPACT

In this study, the hypothetical industrial disaster is assumed that will damage either completely or partially the plant items causing catastrophic and partial release of toxic chemicals into the environment. Here, health impact is defined as the number of people who are affected by disease of increasing level of severity after the industrial disaster.

Acute (short-term) health effects of the chemicals released into the atmosphere are examined for each industrial plant item damaged during the incident. The results are evaluated according to clinical toxicology criteria in terms of intensity and magnitude considering (i) type and size of clinical symptoms (i.e. local effects such cutaneous, ocular or pulmonary irritation, and systemic syndromes) and the total number of subjects (worker and the general population) likely affected because of exposure to toxic chemicals. The predicted toxic responses are evaluated in relation to traditional reference parameters such as the Acute Exposure Guideline Levels (AEGLs) and, in addition, are ranked according to increasing levels of acute toxicity manifested as "toxidromes" (respiratory, neurological, cardiovascular) reflecting the constellation of clinical evidence typical of the xenobiotic toxicant of interest.

The expected number of people exposed to different toxic concentration levels is displayed in Table 6 and Table 7 respectively for the winter (i.e. cold) and warm (i.e. summer) season while the health impacts associated to the above exposure levels are reported in Table 8 and

Table **9**.

2.3 WEIGHTING PROCEDURE

To derive the health prioritization matrix we multiplied health impact data (Table 6 and Table 7) by the probability of damage of each single plant item in one year (Table 3) to obtain a proxy of the risk scores. This information indeed does not represent a correct risk scores as it does not include the severity of the health impact but just the “number” of person whose health is affected in some ways by the exposure to toxic compound released into the environment without taking into account the severity of the disease

Thus, to obtain the final scores we made use of a weighting system based on the "severity of the health impact – i.e., “how sever the health effect is " and not simply on "how many people were affected."

By way of example, 100 people exposed to 15 ppm of benzene may show clinical symptoms which can be treated at the pre-hospital level, on the other hand, only two people exposed to 1,000 ppm show serious health impact like death. In such example from the civil protection’s perspective, managing two people with severe health impact becomes extremely important as compared to the 100 people showing negligible health impacts.

In any weight assigning method the weights of attributes represent the relative importance among them. Weight also reflect status and effect of each attribute during the process of evaluation and decision-making (Filomena Maggino, 2015) and determining weights of indexes is related to reliability and correctness of order on schemes. In the present study, knowledge-based weights have been assigned to maximize the accuracy of the health risk prioritization matrix and make its interpretation scientifically meaningful (Yanrong, 2015).

The following Table 4 shows the assigned weights to benzene and acrylonitrile population as per the concentration levels (ppm values).

Table 4 Assigned Weights to exposure value ranges

PPM Values	The weight assigned to Benzene	The weight assigned to Acrylonitrile
>4000	100	100
1,000-4,000	100	100
800-1,000	100	100

300-800	50	50
100-300	5	5
52-100	5	5
25-52	0.5	5
10-25	0.50	0.50
05-10	0.001	0.50
2.5-5	0.001	0.001
1-2.5	0.001	0.001
0.1-1	0.001	0.001

After assigning the weight, the final scores of the health risk prioritization matrix were calculated through the following formula: Risk = probability of damage x health impact (number of people affected) x weight. Following this equation, all values for each plant item – concentration wise- is calculated for winter and summer season.

The final scores were finally grouped in eight different intervals according to the increased health impacts and color coded as given in Table 5.

Table 5 Assigned Color Code to final scores

Score	Assigned Color Code	
0		No Impact/safe
1-10		Very Low Impact
10-20		Low impact
20-40		Moderate Impact
40-80		High impact
80-160		Moderate-High Impact
160-320		Very High impact

320-640		Extreme Impact

Table 6 Total number of people (general population + plant workers) exposed to different concentration levels during the winter season

Plant A Item wise Total Number of People + Workers affected in Winter Season															
Concentration (ppm)	Virgin Naphtha Storage Tanks Liquid	Cracking Gasoline Unit Buffer Tanks Liquid	Acrylonitrile Storage Tank Liquid	Unit Buffer Vessel Liquid	Heavy Gasoline Stripper Liquid	Heavy Gasoline Stripper Gas	Debutanizer Liquid	Debutanizer Gas	Cracking Gasoline Tank Liquid	Cracking Gasoline Tank Liquid	Stripping Column Liquid	Elastomer Production Reactor Liquid	Quench Column Liquid	Primary Fractionator Liquid	Primary Fractionator Gas
>4000	0	0	0	0	0	1	1	2	0	0	0	0	0	1	9
1,000-4,000	0	0	0	0	0	2	3	7	0	0	0	1	0	4	27
800-1,000	0	0	0	0	0	1	1	2	0	0	0	1	0	1	9
300-800	1	1	0	0	1	6	8	19	0	1	0	2	2	10	69
100-300	2	2	1	1	2	20	25	52	2	2	1	4	5	32	140
52-100	2	2	2	2	4	27	32	50	2	3	2	7	7	43	157
25-52	5	5	4	4	8	55	50	98	5	6	4	17	15	80	329
10-25*	16	16	13	10	23	104	119	257	15	17	11	45	42	153	901
05-10*	26	24	21	17	37	147	180	404	24	27	18	52	53	228	1441
2.5-5	50	34	41	33	59	274	340	777	46	52	31	86	80	431	2573
1-2.5	108	84	91	73	124	779	972	2237	117	115	64	229	208	1230	4917
0.1-1	1072	1060	894	730	1508	8257	8940	9815	1006	1131	748	2999	2730	9824	7136

Table 7 Total number of people (general population + plant workers) exposed to different concentration levels during the summer season

Plant A Item wise Total Number of People + Workers affected in Summer Season															
Concentration (ppm)	Virgin Naphtha Storage Tanks Liquid	Cracking Gasoline Unit Buffer Tanks Liquid	Acrylonitrile Storage Tank Liquid	Unit Buffer Vessel Liquid	Heavy Gasoline Stripper Liquid	Heavy Gasoline Stripper Gas	Debutanizer Liquid	Debutanizer Gas	Cracking Gasoline Tank Liquid	Cracking Gasoline Tank Liquid	Stripping Column Liquid	Elastomer Production Reactor Liquid	Quench Column Liquid	Primary Fractionator Liquid	Primary Fractionator Gas
>4000	0	0	0	0	0	0	0	1	0	0	0	0	0	1	3
1,000-4,000	0	0	0	0	0	1	2	2	0	0	0	0	0	3	8
800-1,000	0	0	0	0	0	0	1	1	0	0	0	1	0	1	3
300-800	0	0	0	0	1	2	6	6	0	0	0	1	1	8	22
100-300	1	1	1	1	2	6	18	19	1	1	1	3	3	23	67
52-100	2	2	1	1	2	8	25	25	2	2	1	5	5	31	71
25-52	4	4	3	3	6	19	42	42	4	4	3	12	11	66	116
10-25*	11	10	9	7	17	52	90	91	11	12	8	33	31	119	298
05-10*	19	17	15	12	27	63	134	135	19	20	13	44	45	168	467
2.5-5	36	27	30	24	50	97	250	254	36	38	25	66	63	316	897
1-2.5	93	60	76	61	98	257	711	721	102	97	51	171	156	899	2580
0.1-1	793	717	666	544	1107	3408	7667	7755	814	842	552	2195	1996	8912	10091

Table 8 Level of disability and clinical manifestation associated to exposure to different concentration levels

Benzene concentration (ppm)	Clinical manifestations	Level of disability* (Tier and emergency intervention)
0.1-1	No medical problems	
1-2.5	No medical problems	
2.5-5	No medical problems	
5-10	No medical problems	
10-25	Mild skin and ocular irritation	**(1):** Can be managed at the pre-hospital level
25-52	Transient systemic alterations, primarily nausea, mild drowsiness, and headache	**(1):** Can be managed at the pre-hospital level
52-100	Drowsiness, dizziness, headache, initial mental status alterations (e.g., euphoria), pronounced mucous membrane, skin, eye, nose, pulmonary irritation	**(2):** Require admission to hospital
100-300	Pronounced drowsiness preceded by excitatory symptoms, staggering, weakness, impaired ability to take protective action	**(2)**: Require admission to hospital
300-800	Excitatory symptoms followed drowsiness, staggering, impaired ability to take protective action, palpitations, tightness in the chest, blurring vision	**(3):** Require prompt hospitalization and intensive care support in subjects presenting neurological and cardiac alterations
800-1,000	CNS depression, loss of consciousness, arrhythmias, shallow and rapid respiration, signs of pneumonitis, lethality in the most susceptible individuals	**(4):** Require on-site stabilization and resuscitation measures
1,000-4,000	Severe CNS depression, coma, paralysis, convulsions, non-cardiogenic pulmonary edema, lethality	**(4):** Require on-site stabilization and resuscitation measures
> 4,000	As above, rapid deterioration and loss of physiological function, lethality	**(4):** Require on-site stabilization and resuscitation measures

Table 9 Level of disability and clinical manifestations associated to exposure to different concentration levels

Acrylonitrile concentration (ppm)	Clinical manifestations	Level of disability* (Tier and emergency intervention)
0.1-1	No medical problems	**-**
1-2.5	No medical problems	**-**
2.5-5	No medical problems	**-**
5-10	Initial dermal and mucous membrane irritation in susceptible individuals	**(1):** Can be managed at the pre-hospital level
10-25	Mild skin, ocular irritation, CNS irritability	**(1):** Can be managed at the pre-hospital level
25-52	Moderate skin irritation, strong eye, and pulmonary irritation, nausea, light headedness, behavioral reactions associated with odor perception	**(2):** Require admission to hospital
52-100	Intense mucous membrane irritation, dermal burn. Autonomic symptoms including salivation, lacrimation, weakness, and mild headache	(**2):** Require admission to hospital
100-200	Skin redness, renal function changes (proteinuria), irregular breathing, weakness, dizziness, headache, flushing, vomiting, chest discomfort	(**2):** Require admission to hospital
200-400	Hepatic dysfunction with malaise and jaundice, respiratory depression and other cyanide-like effects. Possible lethality in susceptible individuals	**(3):** Require prompt hospitalization and intensive care support
400-800	As above with symptoms developing early after initial exposure	**(3):** Require prompt hospitalization and intensive care support
800-4,000	Hallucinations, unconsciousness, severe respiratory depression cyanosis, drop in blood pressure, lethality after exposure for up to 4 hrs	**(4):** Require on-site stabilization and resuscitation measures
> 4,000	Coma, convulsions, asphyxia, cardiovascular collapse. Lethal effects after 5-15 min exposure.	**(4):** Require on-site stabilization and resuscitation measures

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3 HEALTH RISK PRIORITIZATION MATRIX ASSOCIATED TO CATASTROPHIC DAMAGE OF PLANT ITEMS DURING THE SUMMER SEASON

According with the methodological framework illustrated four health risk prioritization matrixes have been obtained respectively for the catastrophic and partial damage of each plant item and for both the meteorological scenarios considered (i.e. summer and winter).

The Health Risk Prioritization Matrix associated to a catastrophic damage of each plant item during the summer season is shown in Figure 1 below where the growing likelihood of complete damage each plant item is reported on the X-axis and the increasing impacts on total population health is reported on the Y-axis.

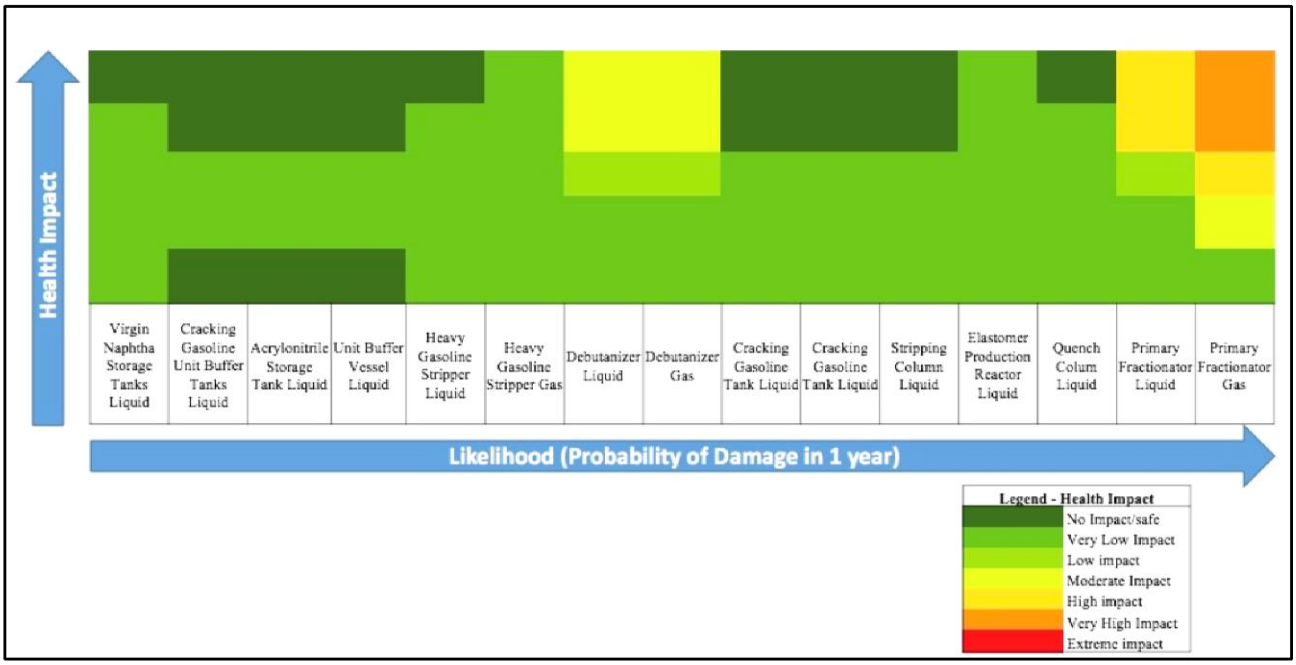

Figure 1 Health Risk Prioritization Matrix associated to a catastrophic damage during the summer season

Figure 1 shows that the complete damage of the Primary Fractionator (gas phase) has the highest scores in term of impact on population health ("*Very High Impact*"), followed by the complete damage of the Primary Fractionator (liquid phase) which has been scored as "*High Impact*". The catastrophic rupture of the Debutanizer (both – gas and liquid form) shows '*Moderate Impact*,' and remaining plant items show scores ranging from '*Very Low Impact*' to '*No Impact/Safe*'.

Following the complete damage of the Primary Fractionator (gas phase) three (3) persons result exposed to more than 4,000 ppm concentration and eleven (11) people (plant workers + general population) would be exposed to concentrations ranging from 800 ppm to 4,000 ppm; the latter are associated to hepatic dysfunction with malaise and jaundice, respiratory depression and other cyanide-like effects up to possible lethality in susceptible individuals requiring immediate on-site stabilization and resuscitation measures. One hundred sixty (160) subjects would be exposed to concentrations ranging from 52 ppm to 800 ppm; the latter are associated to health symptoms requiring prompt hospitalization and intensive care support.

Following the complete damage of the Primary Fractionator (liquid phase) one person would be exposed to more than 4,000 ppm and four people would be exposed to concentrations ranging from 800 ppm to 4,000 ppm. In this scenario sixty-one (61) subjects were exposed to concentrations ranging from 52 ppm to 800 ppm.

The catastrophic damage of the Debutanizer (both in gas and in liquid phase) is categorized as '*moderate impact*' event. One person is exposed to concentrations higher than 4,000 ppm associated to Tier 4 health impact level requiring immediate on-site stabilization and resuscitation measures.

The catastrophic rupture of every other plant item during the winter season has been scored from '*very low impact*' to '*no impact/safe* events.

4 HEALTH RISK PRIORITIZATION MATRIX ASSOCIATED TO CATASTROPHIC DAMAGE OF PLANT ITEMS DURING THE WINTER SEASON

The Health Risk Prioritization Matrix associated to a catastrophic damage of each plant item during the winter season is shown in Figure 2 below where as usual the growing likelihood of complete damage each plant item is reported on the X-axis and the increasing impacts on total population health is reported on the Y-axis.

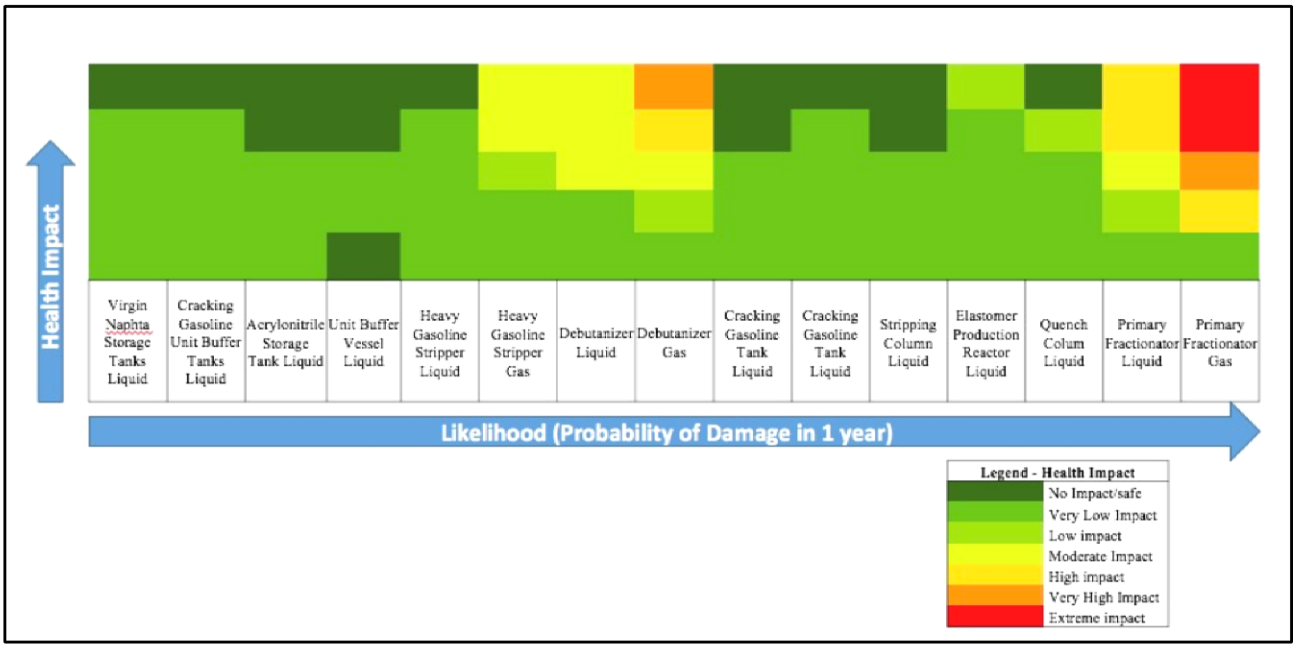

Figure 2 Health Risk Prioritization Matrix associated to a catastrophic damage during the winter season

Figure 2 shows that during the winter season the complete damage of the Primary Fractionator (gas phase) is scored as an event associated with "*Extreme Health Impact*" while the same item in the liquid phase is scored as of "*High Impact*". The catastrophic rupture of the Debutanizer (gas phase) is marked with a '*Very High Impact*' score while the same item in liquid phase is scored as having "*Moderate Impact*" like the Heavy Gasoline Stripper (in gas phase). All the remaining items show scores ranging from '*Very Low Impact*' to '*No Impact/Safe*'.

Following the complete damage of the Primary Fractionator (gas phase) during the cold period nine (9) person would result exposed to more than 4,000 ppm and thirty-six (36) people (plant workers + general population) would be exposed to concentrations ranging from 800 ppm to 4,000 ppm. The latter are associated with hepatic dysfunction with malaise and jaundice, respiratory depression and other cyanide-like effects up to possible lethality in susceptible individuals requiring immediate on-site stabilization and resuscitation measures. Three hundred sixty-six (366) subjects would be exposed to concentrations ranging from 52 ppm to 800 ppm. This concentration range is associated with health symptoms requiring prompt hospitalization and intensive care support in subjects presenting neurological and cardiac alterations.

Following the complete damage of the Primary Fractionator (liquid phase) one person would be exposed to more than 4,000 ppm and five (5) people would be exposed to concentrations ranging from 800 ppm to 4,000 ppm. In this scenario one eight-five (85) subjects would be exposed to concentrations ranging from 52 ppm to 800 ppm.

The catastrophic damage of the Debutanizer (in gas phase) is categorized as a '*High Impact* ' event. In this scenario two (2) persons would be exposed to concentrations higher than 4,000 ppm and eight (8) persons exposed to concentrations ranging from 800 to 4,000 ppm. All would require immediate on-site stabilization and resuscitation measures. One hundred twenty-one (121) subjects would be exposed to concentrations ranging from 52 ppm to 800 ppm; the latter are associated with health symptoms requiring prompt hospitalization and intensive care support. Following the catastrophic damage of the Debutanizer (liquid phase) one (1) person would be exposed to concentrations higher than 4,000 ppm and four (4) persons exposed to concentrations ranging from 800 to 4,000 ppm. In this scenario sixty-five persons would be exposed to concentration levels ranging from 52 ppm to 800 ppm.

The complete damage of the Heavy Gasoline Stripper Gas during the cold period has been scored as a "*Moderate Impact*" event. In this case one (1) person would be exposed to concentrations higher than 4,000 ppm, three (3) persons exposed to concentrations ranging from 800 to 4,000 ppm while fifty-three (53) persons exposed to concentration levels ranging from 52 ppm to 800 ppm.

The catastrophic rupture of every other plant item during the winter season has been scored from '*very low impact*' to '*no impact/safe* events.

5 HEALTH RISK PRIORITIZATION MATRIX ASSOCIATED TO PARTIAL DAMAGE OF PLANT A ITEMS DURING THE SUMMER SEASON

The Health Risk Prioritization Matrix associated to partial damage (i.e. not involving a complete rupture of the plant items) of every plant item during the summer season is reported in Figure 3 below where as usual the growing likelihood of partial damage of each plant item is reported on the X-axis and the increasing impacts on total population health is report on the Y-axis.

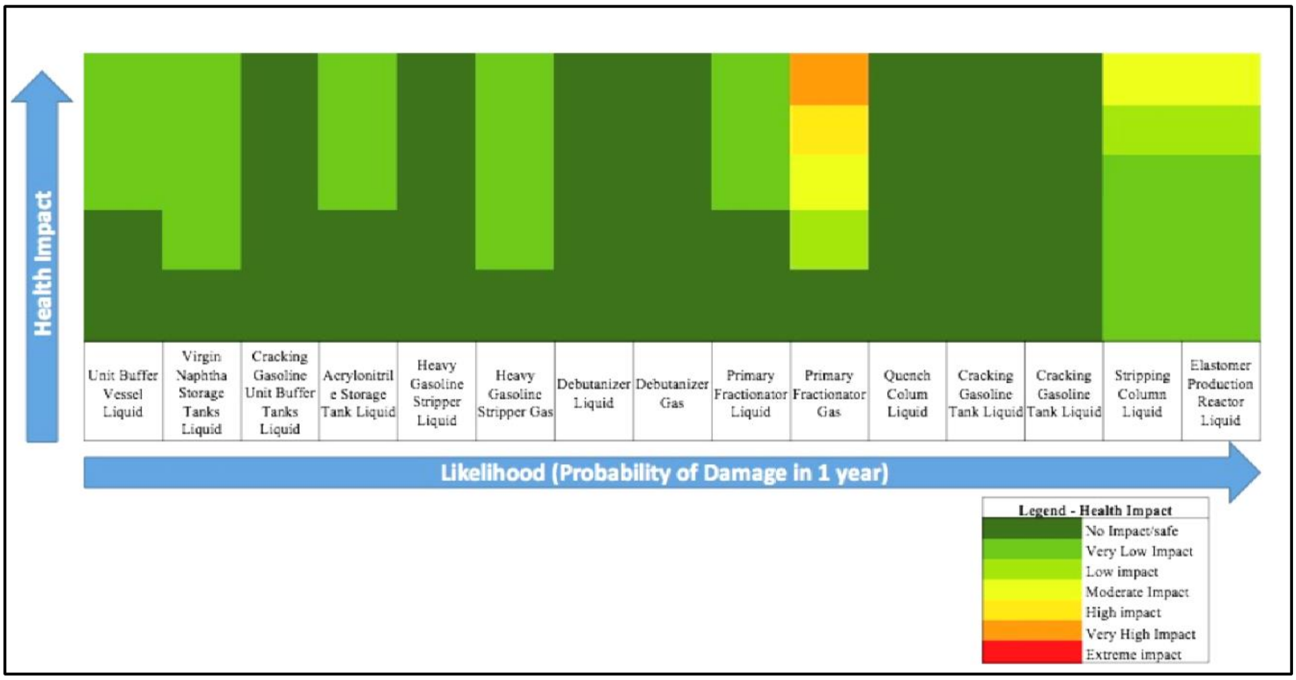

Figure 3 Risk Prioritization of Health Impact of total population (workers + general people) resulting from damage of chemical plant items during the summer season

Results show that a partial damage of the Primary Fractionator (in gas phase) is the most impactful event which has been scored as of '*Very High Impact*' followed by partial damage of the Stripping Column and of the Elastomer Production Reactor which are both scored as events with '*Moderate Impact*'. All the remaining plant items show scores ranging from '*Very Low Impact*' to '*No Impact/Safe*'.

It has to be pointed out that that the probability of damage of the various plant items reveals a different increasing order with respect to the catastrophic events with the Unit Buffer Vessel showing the lowest probability of partial damage and the Elastomer Production Reactor the highest one. The latter however, is associated to less severe impacts on human health than the Primary Fractionator, which is still associated to the highest health risk matrix scores.

Following the partial damage of the Primary Fractionator (gas phase) during the warm period no person would be exposed to more than 4,000 ppm while four (4) people (plant workers + general population) would be exposed to concentrations ranging from 800 ppm to 4,000 ppm. The latter are associated with hepatic dysfunction with malaise and jaundice, respiratory depression and other cyanide-like effects up to possible lethality in susceptible individuals requiring immediate on-site stabilization and resuscitation measures. Twenty-three (23) subjects would be exposed to concentrations ranging from 52 ppm to 800 ppm; the latter are associated with health symptoms requiring prompt hospitalization and intensive care support in subjects presenting neurological and cardiac alterations. Eighty-nine (89) persons would be exposed to concentrations ranging from 10 ppm to 52 ppm, which are associated to transient systemic alterations, primarily nausea, mild drowsiness, and headache which can be generally managed at the pre-hospital level.

Partial damage to the Stripping Column has been scored as event with '*Moderate Health Impact*' on the health risk matrix scale. One (1) person is exposed to concentration levels ranging from 300 ppm to 800 ppm showing symptoms like hepatic dysfunction with malaise and jaundice, respiratory depression and other cyanide-like effects. These symptoms would require prompt hospitalization and intensive care support. Four (4) persons would be exposed to concentration levels ranging from 25 ppm to 300 ppm; the latter are associated with intense mucous membrane irritation, dermal burn and autonomic symptoms including salivation, lacrimation, weakness, and mild headache and require hospitalization.

Similarly, Partial damage to the Elastomer Production Reactor has been scored as event with '*Moderate Health Impact*' on the health risk matrix scale. In this scenario no one would be exposed to concentration levels ranging from 300 ppm to 800 ppm, while four (4) persons would be exposed to concentration levels ranging from 25 ppm to 300 ppm with symptoms which require hospitalization.

The partial damage of every other plant item during the summer season has been scored from '*very low impact*' to '*no impact/safe* events.

6 HEALTH RISK PRIORITIZATION MATRIX ASSOCIATED TO PARTIAL DAMAGE OF PLANT A ITEMS DURING THE WINTER SEASON

The Health Risk Prioritization Matrix associated to partial damage (i.e. not involving a complete rupture of the plant items) of every plant item during the summer season is reported in in Figure 4 below.

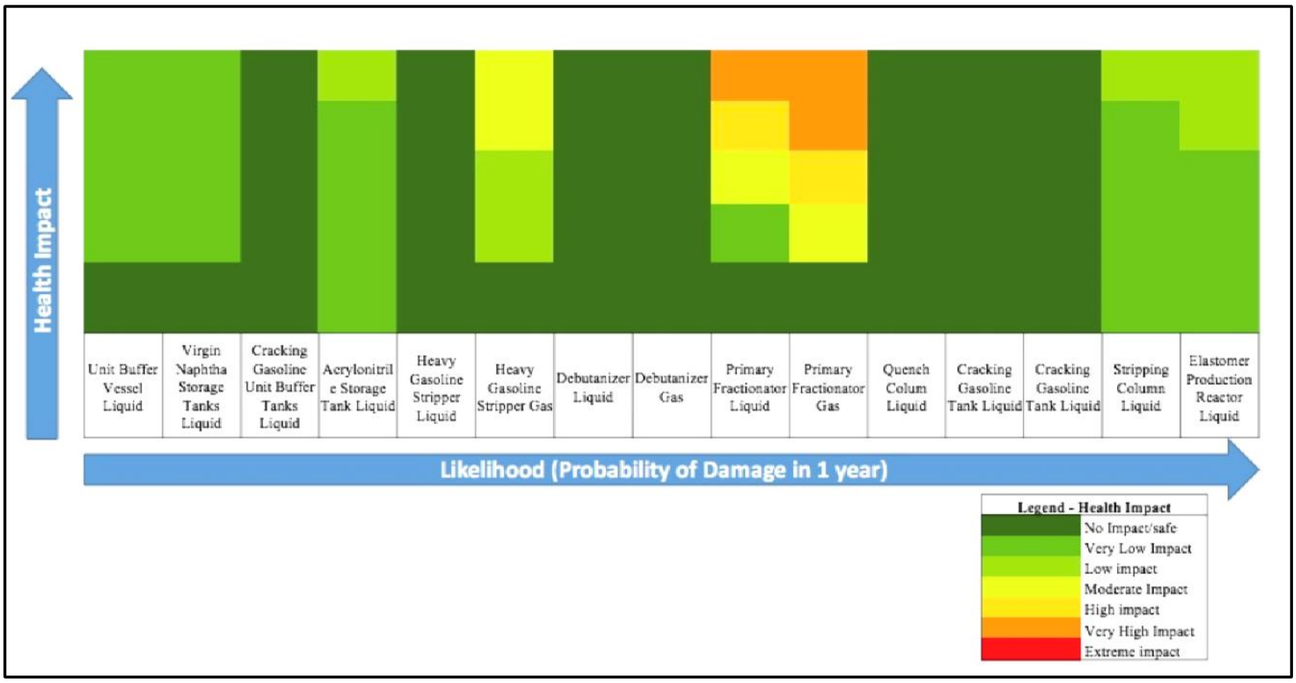

Figure 4 Risk Prioritization of Health Impact of total population (workers + general people) resulting from damage of chemical plant items during winter season

Results shows that during the winter season the partial damage of the Primary Fractionator (both gas and liquid phase) has the highest scores term of impact on population health ("*Very High Impact*"), followed by partial damage of the Heavy Gasoline Stripper, which has been scored as event with '*Moderate Impact*'. All the remaining plant items show scores ranging from '*Low Impact*' to '*No Impact/Safe*'.

Following the partial damage of the Primary Fractionator (gas phase) during the cold period one (1) person would be exposed to more than 4,000 ppm, while six (6) individuals (plant workers + general population) would be exposed to concentrations ranging from 800 ppm to 4,000 ppm requiring immediate on-site stabilization and resuscitation measures. Forty-six (46) subjects would be exposed to concentrations ranging from 52 ppm to 800 ppm; the latter are associated with health symptoms requiring prompt hospitalization and intensive care support in subjects presenting neurological and cardiac alterations.

Following the partial damage of the Primary Fractionator (liquid phase) during the cold period one (1) person would be exposed to more than 4,000 ppm, while three (3) individuals would be exposed to concentrations ranging from 800 ppm to 4,000 ppm requiring immediate on-site stabilization and resuscitation measures. Finally, twenty-two (22) subjects would be exposed to concentrations ranging from 52 ppm to 800 ppm, which are associated to health symptoms requiring prompt hospitalization and intensive care support in subjects presenting neurological and cardiac alterations.

Partial damage of the Heavy Gasoline Stripper has been scored as event with '*Moderate Health Impact*' in the health risk matrix scale. In this scenario one (1) person would be exposed to concentration levels ranging from 800 to 1,000 ppm requiring immediate on-site stabilization and resuscitation measures while other fourteen (14) individuals would be exposed to concentrations ranging from 52 ppm to 800 ppm requiring prompt hospitalization and intensive care support in subjects presenting potential severe neurological and cardiac alterations.

Partial damage of every other plant item during the winter season has been scored from '*low impact*' to '*no impact/safe* events.

7 CONCLUSIONS

A health risk prioritization matrix is a widely used tool useful to define the level of risk by considering the category of probability or likelihood against the category of consequence severity (Anthony, 2008). The comparative simplicity and apparent ease of use of this approach contributes to its widespread adoption in risk management.

Action prioritization is one of the benefits of creating a risk prioritization matrix, thus providing a simple, yet science-grounded basis for immediate and timely actions based on the time regarding 'what exactly and when to do' to emergency responder personnel. In this way, the authorities responsible for civil safety and public health protection will have immediate and quick understanding of the different risks associated to a NaTech disaster affecting chemical plants allowing to plan immediate actions to face the disaster in a most effective way.

In this report health risk prioritization matrices were developed to visualize the existing risks effectively and efficiently. These risk matrices were created for the complete and partial damage of all plant items and for both the cold (winter) and warm (summer) season using Risk = Severity x Likelihood equation. The final scores were finally weighted to account for the severity of the health effects caused.

Results show that winter is associated to higher matrix scores compared to the summer season due to the meteorological conditions which may hamper (in winter) or favor (in the summer) the atmospheric dispersion of the toxic plumes. In addition, complete rupture due to catastrophic events affecting plant items generally result in higher risk scores than partial damages regardless the season.

Among the plant items, the catastrophic damage of the Primary Fractionator is associated with the highest risk scores classified as *Extreme Health Impact* because of the high amount of toxic chemicals released. In this worst-case scenario around ten persons would be exposed to more than 4,000 ppm and thirty-six people (plant workers + general population) to concentrations ranging from 800 ppm to 4,000 ppm; the latter are associated with hepatic dysfunction with malaise and jaundice, respiratory depression and other cyanide-like effects up to possible lethality in susceptible individuals requiring immediate on-site stabilization and resuscitation measures.

Overall the population living in the proximity of the industrial facility would be exposed to excessive concentrations, although lower than those measured inside the industrial plant, with toxicant levels progressively decreasing at increasing distances from the affected plant. Nevertheless, the overall consequences of the disaster in the general population would very likely be serious given the large amount of population involved and the presence of susceptible individuals such as children and the elderly amongst them. Particular subjects at risk would be asthmatic children and elderly people suffering from COPD or other chronic respiratory diseases that typically are exacerbated by exposure to chemical irritants.

8 REFERENCES

A.Peña-Fernández, M.-M. M.-B. (2014). *Establishing the importance of human health risk assessment for metals and metalloids in urban environments.* Universidad de Alcalá, Unidad Docente de Toxicología. Barcelona: UdA.

Anthony, L. (2008, 04 16). What's Wrong with Risk Matrices? *Risk Analysis*, *28*(2), 497-512.

EPA. (2003). *Human Health Risk Assessment.* Retrieved from EPA, Inc.: https://www.epa.gov/risk/human-health-risk-assessment

FEMA. (1999). *HAZUS 99 "Earthquake Loss Estimation Methodology.* Federal , Federal Emergency Management Agency.

Filomena Maggino, E. R. (2015). *Obtaining weights: from objective to subjective approaches in view of more participative methods in the construction of composite indicators.* Università degli Studi di Firenze (Italy). Florence: Università degli Studi di Firenze (Italy).

Vatanpour, S. (2015, Aug 14). Can Public Health Risk Assessment Using Risk Matrices Be Misleading? *Int J Environ Res Public Health*, 30-46.

WHO. (2012). *Rapid Risk Assessment of Acute Public Health Events.* WHO, Environmental Safety. Geneva: WHO Press .

WHO. (2012). *Rapid Risk Assessment of Acute Public Health Events.* Environmental Safety . WHO Press.

Yan, D. J. (2010, 10 20-24). *Disaster Risk Assessment: Understanding the Concept of Risk.* Retrieved from GRIP - Global Risk Identification Programme: http://www.wamis.org/agm/meetings/slovenia10/S5-2a_GRIP_Understanding_Risk.pdf

Yanrong, L. H. (2015). An Evaluating Method with Combined Assigning-Weight Based on Maximizing Variance. *Scientific Programming*(2015), 8.

ZHOU Ping Ping, L. Z. (2014). *Methodology and Application for Health Risk Classification of Chemicals in Foods Based on Risk Matrix*.* Health and Family Planning Commission , Health and Family Planning Commission & National Major Scientific and Technological Special Project. Beijing: ELSVIER.