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Final Master Project

Environmental Risk Assessment in a LNG Plant

Análisis del Riesgo Ambiental en una Planta de almacenamiento y regasificación de GNL

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Report

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1. SUMMARY

This study is devoted to implement an environmental risk assessment (ERA) methodology for a Liquefied Natural GAS (LNG) plant located in Spain. ERA also includes the estimation of the Environmental Damage Index (EDI) and the calculation of the economical guarantee established by the Environmental Responsibility Offer Model (EROM). This study has been carried out according to Spain regulations, in particular, Royal Decree 183/2015 of environmental responsibility.

The environmental risk assessment was performed using the Spain Natural Gas methodology unified with ERA procedure established by AENOR in UNE-150.008-2008 standard.

Applying the methodology, different hazardous agents were identified in the LNG plant such as diesel, THT, hydraulic oil, sodium bisulfite, natural gas and others. They were also considered different initiating events (including tanks failure, pipeline ruptures and cisterns leakage) reaching different accidental scenarios where marine water and seabirds were the resources affected.

Seawater pollution with diesel was the accidental scenario selected to calculate the financial guarantee, because it has the highest percentage of risk. Environmental evaluation identified the affectation of 708 m^3 of marine water, 4 threatened and 178 non-threatened seabird species. The marine water affectation covers 84.91% of the total guarantee estimation, representing the relevant damage to the environment by diesel spill.

2. INTRODUCTION

Currently, the industrial growing in the world has increased the concern about the environmental impact of the human activity. Europe has been established rules for industrial operations and properly legislation to reduce environmental affectation in the continent.

According to the Environmental Responsibility Spain Regulation, Royal Decree 183/2015 of March 13th, the operator has to develop the Environmental Risk Assessment (ERA) and establish the economic guarantee estimation to support the industrial activity. This study is devoted to the implementation of ERA methodology for a Liquefied Natural GAS (LNG) plant, including the evaluation of the Environmental Damage Index (EDI) and the calculation of the economical guarantee established by the Environmental Responsibility Offer Model (EROM).

The ERA preparation has been taken as a reference framework established by the Spanish Association for Normalization and Certification (AENOR), in the standard UNE 150.008-2008, and the "Methodological Guide for the Preparation of Environmental Risk Analysis for LNG plants" prepared by the Spanish Gas Association (SEDIGAS) and approved in March 2015

2.1. Liquefied Natural Gas (LNG)

Natural Gas is a fossil hydrocarbon formed in permeable rock of the earth´s court and is found in association or not with crude oil. It might occur alone in separate reservoirs, but more commonly it forms a gas cap entrapped between petroleum and an impermeable layer, covering rock layer in a petroleum reservoir. Under high pressure conditions, it is mixed with or dissolved in crude oil. Natural gas named dry has less than 0.013 dm3/m3 (0.1 gal/1000 ft3) of gasoline. Above this amount, it is named wet. [1]

Table 1 Natural Gas Typical composition *[1]*

Composition, vol%	**Range**	
	Low	**High**
Methane	86.3	95.2
Ethane	2.5	8.1
Propane	0.6	2.8
Butanes	0.1	0.7
Pentanes	0.0	0.4

Table 1 Natural Gas Typical composition *[1]*

Composition, vol%	Range	
	Low	High
Hexanes plus	0.0	0.1
CO_2	0.3	1.1
N_2	0.3	2.5
Hexanes plus	0.0	0.1
Heating Value MJ/m^3 (Btu/ft^3)	38.15 (1024)	40.2 (1093)
Specific gravity Ref: Air at 288K	0.6	0.6

When the natural gas has been cooled to the condensation point, which occurs at -256^{o}F (-161^{o}C) and atmospheric pressure, we obtain the Liquefied Natural Gas (LNG). Liquefaction reduces the volume by approximately 600 times so making it more economical to transport between continents in specially designed ocean vessels, whereas traditional pipeline transportation systems would be less economically attractive and could be technically or politically infeasible. Thus, LNG technology makes natural gas available throughout the world. [2]

For these reasons, LNG can be an alternative, cheaper and friendlier with environment fuel source in the world. Many countries are involved in this change, installing storage and regasification plants, and being part of this emergent market.

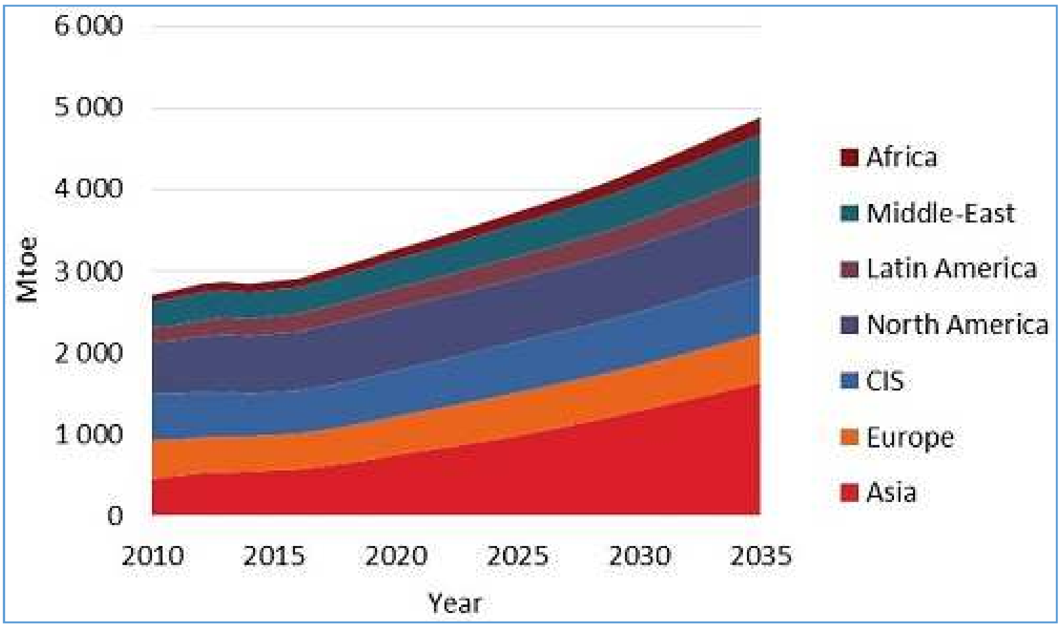

Figure 1 World LNG Growth demand *[3]*

2.2. Liquefied Natural Gas Process

The LNG Plants main function is to receive LNG from vessels, storage the product and distribute it to the different systems (Final clients). Due to the natural gas (NG) volatility, all the process occurs at cryogenic conditions to maintain the liquid state of LNG guaranteeing the transportation and storage of the highest possible amount of product. The final stage of the process is distribution where the LNG is vaporized for the final consumption. Figure 2 shows the typical configuration of a LNG plant.

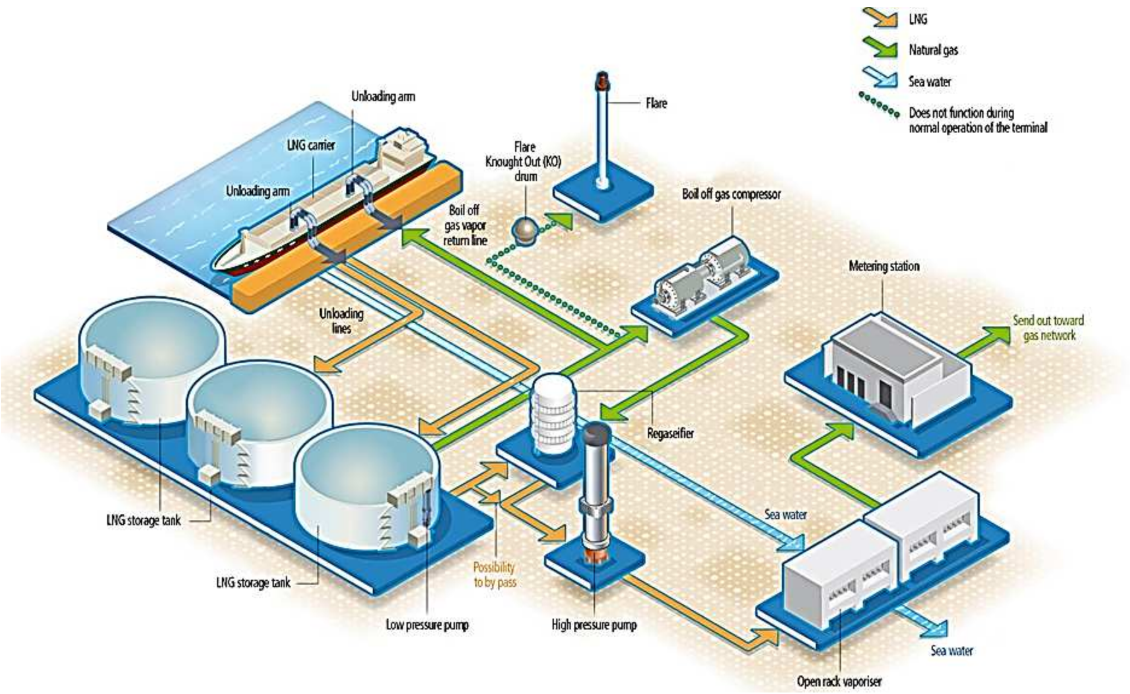

Figure 2 Typical LNG Plant configuration *[4]*

- Marine Facilities: loading/unloading arm, hydraulic system and the port area.
- LNG Storage Tanks: cryogenic tanks with especial configuration.
- Regasification system high pressure pumps, vaporization exchanger.
- Sea water system: it is the complement of the regasification system, It includes the sea water pumps and the water chemical treatment to avoid scale in the exchanger.
- Boil-off gas compressor: to recover the technical minimum gas and reliquefy in the storage tanks or distribute to natural gas pipeline.
- Utilities area: nitrogen, instruments air, fuel gas, electricity.
- Natural Gas exportation: measurement Station.

2.3. Environmental Risk Assessment (ERA)

Environmental Risk Assessment (ERA) is a methodology for the evaluation of the adverse effects that could affect environment as a result of industrial activity. The ERA procedure is triggered prior to a significant decision affecting the environment, It can be divided into three wide steps: [2]

- Preparation: involving collecting and examining relevant background information, and establishing the focus for the assessment.
- Conducting and prepare the assessment.
- Interpreting, reporting and applying results of the assessment.

ERA is a support tool for policy evaluation, land use planning, and resource management making. It is systematic and can be applied in a variety of situations, ranging from those with minimal available data and resources to those with detailed inventories and complex systems modeling. ERA can be used on the back of an envelope while preparing for a meeting or developed to provide risk information to a formal legislated process such as SEVESO influenced process.

ERA provides information for making reasoned decisions by defining the range of risks associated with various options, but it does not dictate a specific outcome.

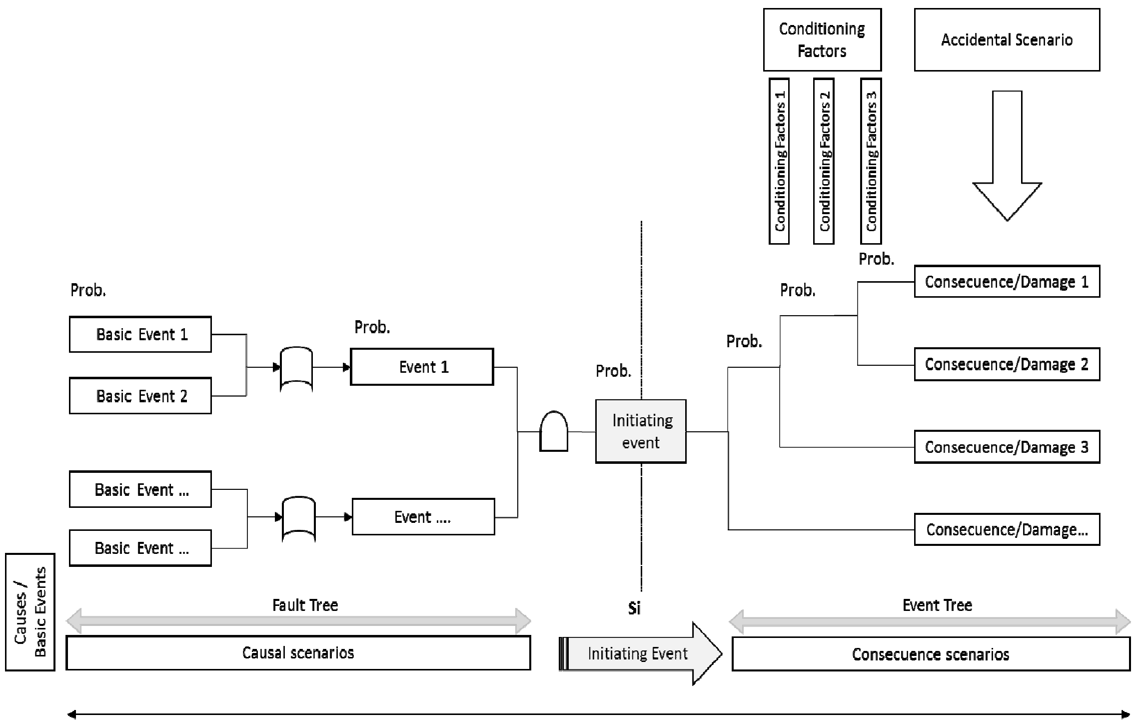

Figure 3 General Framework Risk Analysis Methodology *[5]*

2.4. FAULT TREE METHODOLOGY

The Fault Tree methodology constitutes a well-known and a widely used technique in risk assessment and reliability studies, because it provides both qualitative and quantitative results. This method is based on the laws of Boole's algebra, and it is based on a deductive process that lets the determination of a studied event's expression, depending on the basic failures of the elements that take part in it [6].

The first step must be the identification of the "not wished" or TOP event (accident to be avoided), which is going to be ranged on the peak upper part of the representative graphical structure of the tree. The TOP events can be the accidents previously identified by the event tree methodology, and they must be properly and clearly defined because the successful development of the whole tree hangs on it

The second step is the systematic identification of all the immediate causes that contribute to its occurrence (conditioning factors). In this step, the so called intermediate events are settled down in a systematic way and can be decomposed to their direct causes. In the graphical representation, these are reflected inside rectangular boxes and the union between them is made by the use of logical gates.

The connections between gates are made with the AND and OR signals: [6]

- The AND gate is used to symbolize a logical "and". In the case presented below, the logical exit S will happen only if both logical entrances (e1 **and** e2) occur at the same time.
- OR is used to show a logical "or", Its symbol is the one showed below and means that the logical exit S will happen as long as, at least one of both logical entrances (e1 **or** e2) occurs.

The splitting process of the intermediate events is successively repeated until getting to the basic (initial) events of the tree. These elements do not require being further split attending to two main reasons: on the one hand, its division would not provide additional information, and on the other hand, their failure rate does not depend on any other element and can be directly found in any reliable available data bank.

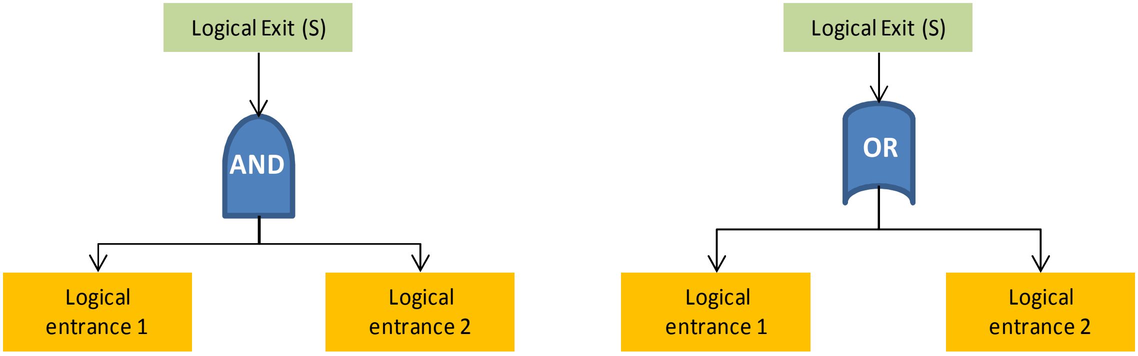

Figure 4 AND and OR representation in a fault tree

These basic events could either represent an equipment failure, an operational human error or even the occurrence of an external event (such as fire, earthquake, etc.). Their graphical representation in the Fault Tree figures is commonly reflected by circles which are normally numbered to facilitate the identification. [6]

In this analysis, there are two well differentiated stages. The first one consists on the Tree elaboration, where all knowledge related to the functioning and operation of the facility must be integrated.

The second stage pretends to quantify the Fault Tree. Thus, the logic of the Tree is therefore reduced until reach the minimal combinations of the primary events, whose simultaneous occurrence drives to the occurrence of the TOP element. Each of these combinations, also called minimal cut-sets, belong to a logical intersection of several basic elements. Since in a Fault Tree it is assumed that each of the basic events is independent (the materialization of one of the events does not have any influence in the occurrence of any other), the probability of a minimal cut-set is the result of each of the individual probabilities of the basic elements. [6]

Figure 5 shows a typical fault tree development for chemical spill during a truck discharge.

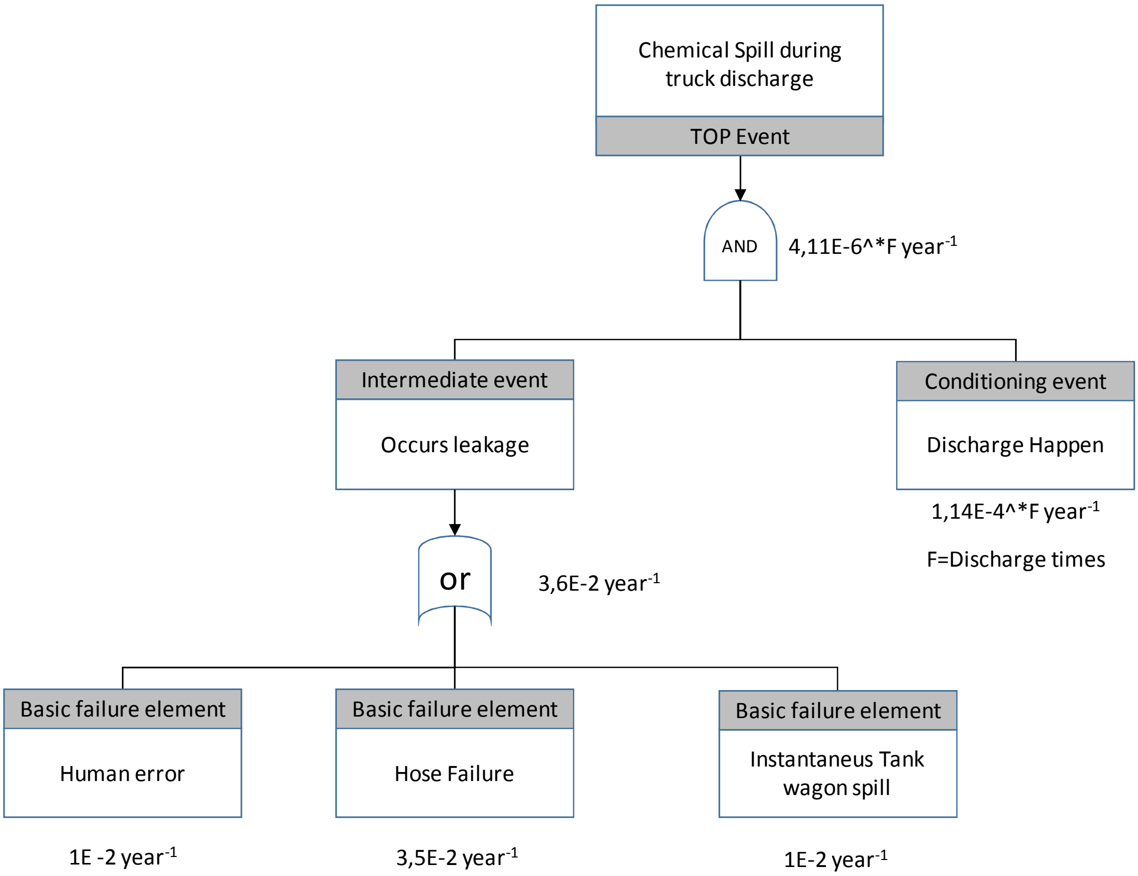

Figure 5 Chemical Spill during truck discharge, Fault tree example

2.5. EVENT TREE METHODOLOGY

The Event Tree analysis (also called Event Sequence Analysis) is an inductive method providing a qualitative and quantitative assessment of what occurs between an initiating accidental scenario and an eventual accident according to the characteristics of the initiator, the characteristics of the installation and the safety systems. [7]

Starting with the initial fault, or initiator, and considering the conditioning factors involved. the tree describes the accidental sequences leading to possible accidents. The Event Tree construction and evaluation start with the identification of the factors that define the evolution of an incident from the beginning to the final accident. next followed by the determination of the probability of success/failure of each one of those factors. The graphical representation will be developed by positioning each of the N factors identified as headers and starting with the initiator. followed by systematically plotting two branches: the upper branch showing the success or occurrence of the event (with probability P) and the lower branch showing the failure or non-occurrence of the event (probability 1-P). [7]

As a result of this distribution, 2N combinations or sequences are obtained. However, because of the dependent relationships between events, the occurrence or success of one may eliminate the possibility of others, consequently decreasing the total number of sequences. The headers are usually plotted horizontally in chronological order of the evolution of the accident, although this criterion is in some cases difficult to apply.

The following event tree provides an example of how it is constructed and evaluated:

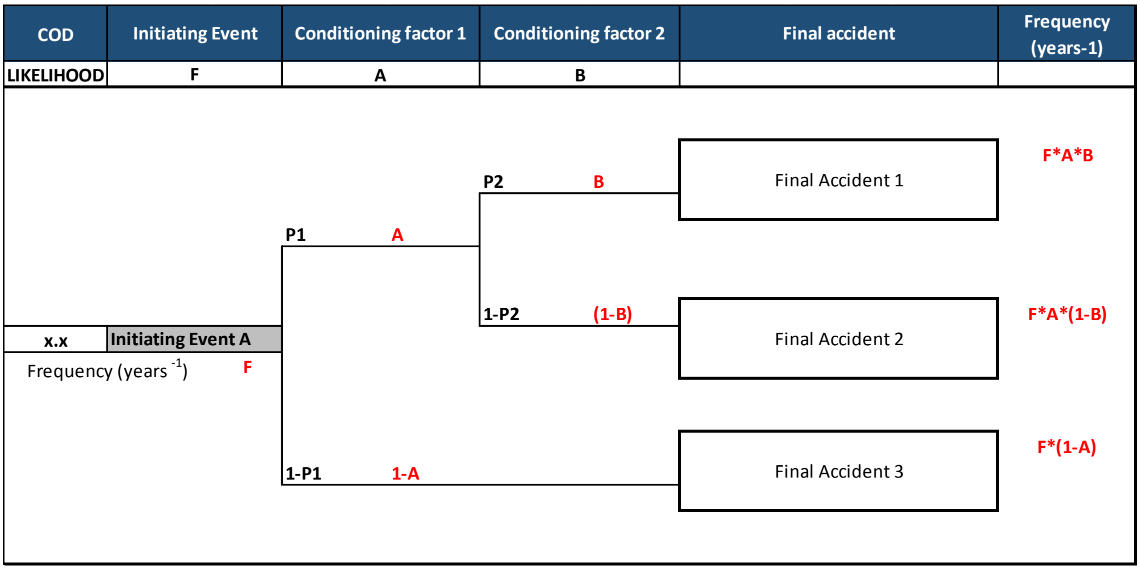

Figure 6 Event tree graphical representation

2.6. Environmental Damage Index (EDI)

The Environmental Damage Index (EDI) assigns an order of magnitude to the damage caused by each accidental scenario presented, It allows rank the importance of each one of the possible damages. Thus, the damage that accumulates 95% of the probability is selected to perform the monetization of damage. [8, 9]

The procedure for calculating the EDI is specified in Royal Decree 183/2015, by amending the Regulation of partial development of the Law 26/2007 of October 23, Environmental Responsibility, approved by Royal Decree 2090/2008 of 22 December.

The EDI methodology is based on an equation which includes a number of input parameters to obtain a Semi-quantitative estimation of the environmental damage. These input parameters depend on the combination of agent injurious and affected natural resource being evaluated. In particular, Royal Decree 183/2015 includes a total of twenty agent-resource partners groups. [8, 9]

$$IDM = \sum_{i=1}^{n}[(ECf + A * Ecu * (B * \alpha * Ec) + p * {M_{acc}}^{q} + C * Ecr) * (1 + Ecc)]_i + (\beta + Eca) \quad \textbf{Ec.1}$$

Where:

Ecf= Fix cost estimation
A. B. C= EDI modificators
Ecu=Unit cost estimation
Macc= Quantitive of resource affected.
q. p= resource EDI modification parameter.
Ecr=Project control and review cost.
Ecc= Reparation consulting cost.
β= Distant from nearest access road.
Eca= Access to the damage area cost.

In order to establish the parameters that affect the calculation of EDI. the Figure 7 shows the relation between damage source agent and the resource.

<table>
<tr><td colspan="3" rowspan="4"></td><td colspan="8">Resource</td></tr>
<tr><td colspan="3">Water</td><td rowspan="3">Marine and continental bed</td><td rowspan="3">Soil</td><td rowspan="3">Sea and river shore</td><td colspan="2">Species</td></tr>
<tr><td rowspan="2">Marine</td><td colspan="2">Continental</td><td rowspan="2">Plants</td><td rowspan="2">Animals</td></tr>
<tr><td>Superficial</td><td>Underground</td></tr>
<tr><td rowspan="15">Damage source agent</td><td rowspan="7">chemical</td><td>Halogenated VOC</td><td rowspan="5">Group 1</td><td rowspan="7">Group 2</td><td rowspan="7">Group 5</td><td></td><td rowspan="7">Group 9</td><td rowspan="5">Group 10</td><td rowspan="7">Group 11</td><td rowspan="7">Group 16</td></tr>
<tr><td>Non halogenated VOC</td><td></td></tr>
<tr><td>Halogenated SVOC</td><td></td></tr>
<tr><td>Non halogenated SVOC</td><td></td></tr>
<tr><td>Diesel and NVOC</td><td rowspan="3">Group 7</td></tr>
<tr><td>Inorganic substances</td><td></td><td></td></tr>
<tr><td>Explosives</td><td></td><td></td></tr>
<tr><td rowspan="3">Physical</td><td>Extraction / Disappearance</td><td></td><td>Group 3</td><td>Group 6</td><td></td><td rowspan="2">Group 3</td><td></td><td>Group 12</td><td>Group 17</td></tr>
<tr><td>Inert spill</td><td></td><td></td><td></td><td>Group 8</td><td></td><td></td><td></td></tr>
<tr><td>Temperature</td><td></td><td>Group 4</td><td></td><td></td><td>Group 4</td><td></td><td>Group 13</td><td>Group 18</td></tr>
<tr><td colspan="2">Fire</td><td></td><td></td><td></td><td></td><td></td><td></td><td>Group 14</td><td>Group 19</td></tr>
<tr><td rowspan="4">Biological</td><td>GMO</td><td></td><td></td><td></td><td></td><td></td><td></td><td rowspan="2">Group 15</td><td rowspan="3">Group 20</td></tr>
<tr><td>Invasive exotic species</td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>Virus and bacteries</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>Insects and fungus</td><td></td><td></td><td></td><td></td><td></td><td></td><td>Group 15</td><td></td></tr>
</table>

100ºC)
SVOC= Semivolatile Organic chemical substance (Boling point between 100 - 325 ºC)
NVOC= Non volatile Organic chemical substance (Boling point > 325 ºC)
GMO= genetically modified organisms

Figure 7 Relative parameters and group combination Resource- Agent

2.7. Environmental Responsibility Offer Model (EROM)

The EROM methodology established the financial guarantee necessary to cover an accidental scenario estimated according to the environmental risk assessment. The procedure by which the amount of the financial guarantee shall be determined by the operator is specified in Article 33 of Royal Decree 183/2015. This process comprises the following steps: [9]

Identify accidental scenarios and determine the likelihood of each scenario.

- Estimation of EDI associated with each accidental scenario following the steps set out in Annex III of Royal Decree 183/2015.
- Calculation of the risk associated to each accidental scenario as the product of the probability of the scenario and the EDI.
- Sort accident scenarios in descending order of EDI and calculate the accumulated risk. The scenario which accumulates 95% of the total risk is selected.
- Finally, the financial guarantee is calculated based on the reference scenario, as indicated in Article 33 of Royal Decree 183/2015.

The EROM procedure performs the task of calculating the replacement value of the natural resources covered by the environmental responsibility law (soil, water, habitat, species and sea and river shore), applying economic methods based on the offer curve. The calculation included the following steps:

2.7.1. Damage Characterization

EROM analyzes the different actions that would be necessary to implement each of the different scenarios of the environmental damage and valorizes their repairing costs. These parameters are divided in 4 blocks: [10]

- **Damage Localization:** in this section EROM established all the characteristic of the affected area such as: permeability, slope, aquifer presence, accessibility, soil use, species, tree age, density, infiltration risk, protected area.
- **Damage source agent:** this part classifies the agent that affect the environment in chemical (Halogenated VOC, Non halogenated VOC, Halogenated SVOC, Non halogenated SVOC, Diesel and NVOC, Inorganic substances, explosives).

physical (extraction/disappearance, Inert spill, Temperature), fire and biological (genetically modified organisms, invasive exotic species, virus and bacteries, insects and fungus).

- **Quantification of Damage:** it is necessary to pin down and estimate the amount of each resource (water, soil, marine bed, river and sea shore, habitat and species) that would be affected by each damage source agent.
- **Reversibility of damage:** EROM performs calculations of the replacement costs separately for reversible damage and irreversible damage, not admitting losses of mixed type. This distinction is made in order to calculate separately primary and compensatory repair.

2.7.2. Reparation techniques

EROM procedure defined control and reparation techniques to be applied in the moment when the reference scenario happens. Reparation techniques aim to recover the soil, water, wildlife, habitats, and the sea and the estuaries of the damage caused by chemical, physical, biological and fire agents, Information on reparation techniques can be obtained simultaneously on two main sources: specialized literature and consultations experts from the Central and Regional Administrations, Some of reparation techniques are: landfarming, mechanical recollection on water surfaces, breeding wildlife rehabilitation centers, soil replacement and others. [10]

2.7.3. Calculation of financial value of Damage

According to EROM methodology, the cost of the project comprise: [10]

- **Budget Elaboration: F**or the reparation cost. EROM includes the following items: consulting cost. access. execution. control and review and security contingency percentage.
- **Cost of prevention and avoidance:** it can be estimated as a percentage of primary repairs, being at least 10%.
- **Cost of remedial measures:** it includes consulting (drafting of repair), access (construction of access roads), execution (implementation of restorative technique) and follow-up (checking and control)

3. OBJETIVES

The main objective of this project is to apply the environmental risk assessment methodology to a liquefied Natural Gas installation according to Spanish legislation, accomplishing the following sub-objectives.

- Identify environmental hazards, initiating events and accident scenarios in a typical LNG installation.
- Apply Environmental Damage Index (EDI) Methodology to estimate the severity of each accident scenario identified.
- Calculate the Risk for each identified scenario and select the reference scenario according to EDI.
- Calculate the financial amount related to the reference scenario using the Environmental Responsibility Offer Model (EROM) methodology.

4. ENVIRONMENTAL RISK ANALISYS

The methodology chosen for the analysis and evaluation of environmental risk assessment has been the UNE 150.008: 2008. The methodology provides two phases for risk analysis: the definition of the initiating event causes and the determination of the accidental scenarios. To complete both phases, the following information must be compiled to perform the evaluation.

4.1. Plant Location

To evaluate the affectation of each possible accident occurring in the plant, it is important to identify the area where the plant is built and the surroundings characteristics. For this study, a LNG plant is taken by example with following environmental specifications:

- Constructed on artificial ground gained to see. Possible seawater affectation but do not affect underground waters and soil.
- Not forest areas near to the site. For this reason, any potential scenario that could affect forest areas is discarded.
- Meteorological condition could not promote the formation of a flammable or toxic cloud that affects surroundings areas like atmosphere or forest.
- There is a Protected Natural Area near from site and some threatened animal species around.

4.2. Area Classification

According to the EDI methodology, in order to identify the most likely causes of accidents, there have been identified potential risk zones, enabling to identify the most relevant sources of hazards that can trigger each event initiator accident. For this reason, the LNG plant was divided as follow:

Table 2 LNG Plant area classification

Area ID	Plant Area	Critical operational activity	Hazardous chemical substance
1	Loading, unloading, THT dosage and natural gas(NG) pipeline network	High pressure process: NG distribution to pipeline network at 80 barg.	Natural Gas and Tetrahydrothiophene (THT)
2	Diesel Storage area	Storage and distribution of diesel to the fire water emergency pumps and emergency electrical power generator.	Diesel
3	LNG tank loading	LNG truck loading with high daily frequency.	LNG
4	Evaporators	LNG phase changing at high pressure (80 barg)	LNG / NG
5	Seawater pumps and electrochlorination plant	Seawater suction from sea. water treatment and electrochlorination system.	Sodium Hypochlorite. sodium bisulfite and hydrochloric acid
6	Compressor room. reliquefier and secondary pumps.	High pressure system and rotative equipments.	LNG / NG
7	Loading / offloading tankers and LNG storage.	Loading and unloading of LNG from/to tankers at cryogenic temperatures.	Hydraulic oil. LNG.
8	Electrical substation, transformers and emergency generator.	Electrical current distribution.	Dielectric oil
9	Chemical substances and lubricants warehouse.	Hazardous chemicals storage.	Hydraulic oil. LNG.

Figure 8 shows the typical layout of a LNG plant with the above mentioned areas.

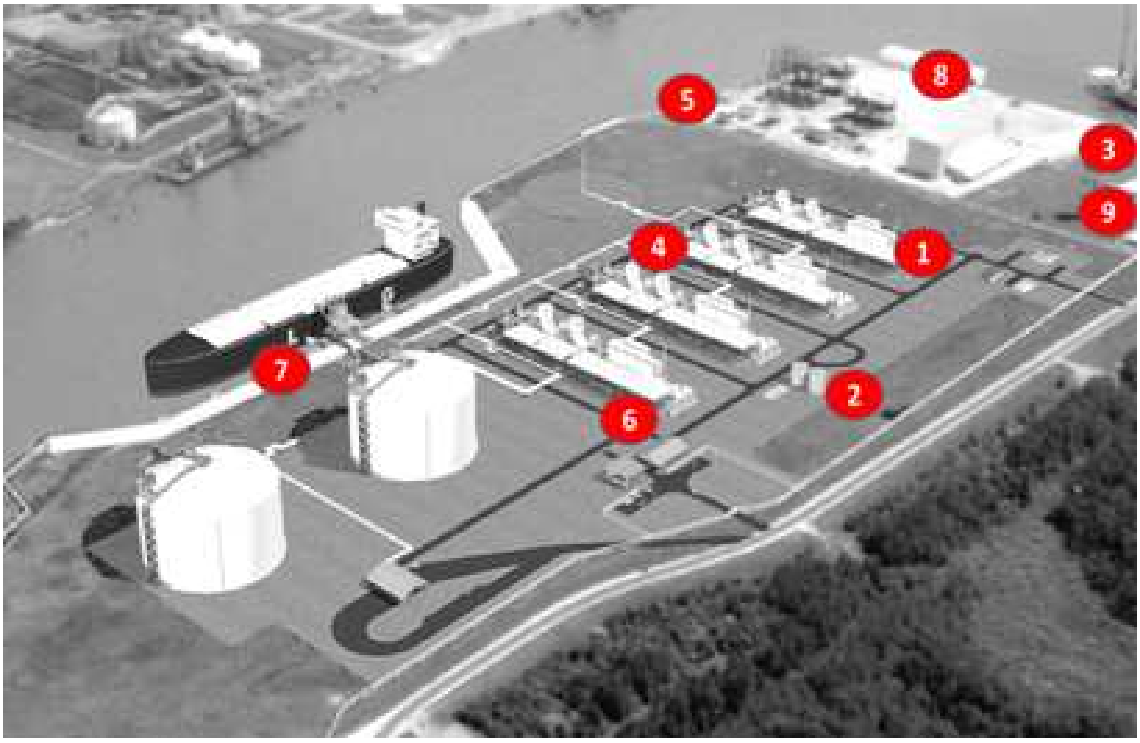

Figure 8 Identification of operational area in a Plant layout example (numeration according plant classification explained before)

4.3. Chemical substances identification

Special attention is given to chemical substances classified as hazardous for the environment (section E) or affected by the 5 "H phrases" of European Regulation 1272/2008 (CLP), which are: H400 (very toxic to aquatic organisms), H410 (very toxic to aquatic life with long lasting effects), H411 (toxic to aquatic life with long lasting effects), H412 (harmful to aquatic life with long lasting effects), H413 (may be harmful to aquatic life with long lasting effects) Table 3 summarizes the hazardous chemical substances identified in the installation.

Table 3 Hazardous Substances identified

Chemical Substance	Hazard Statement	Environmental affectation	Atmosphere	Soil	Water
Natural Gas	H220	Extremely flammable gas, fire or explosions production, Forest fires.	x	--	--
Sodic hypochlorite	H314 H400	Flammable substance, hazardous for aquatic environment, corrosive and harmful.	--	--	x

Table 3 Hazardous Substances identified

Chemical Substance	Hazard Statement	Environmental affectation	Atmosphere	Soil	Water
Sodium bisulfite	H302 H314 H318	Flammable substance, hazardous for aquatic environment, corrosive and harmful.	--	--	x
Diesel, Hydraulic Oil	H226 H304 H332 H315 H351 H411	Flammable liquid and gases, Toxic to aquatic life with long lasting effects and soil affectation.	--	x	x
Hydrochloric Acid	H314 H335 H331	Hazardous for aquatic ecosystems, corrosive and harmful.	--	--	x

Table 4 resumes the hazardous sources identified for each risk area, Usually, a risk scenario involves a chemical substance that could generate an initiating event with the possibility to generate explosive atmospheres, fire or any potential environmental damage condition, Also there are other hazardous condition generators such as: high pressure, electricity or human operations.

Table 4 Hazardous Source Identified by zone

Zone Code	Zone	Hazardous Source
1	Loading, unloading, TSH dosage and sending GN basic gas pipeline network	Natural Gas (NG) Tetrahydrothiophene High pressure system
2	Diesel Storage	Diesel
3	LNG tank loading	Liquefied Natural Gas High pressure process Constant human operational procedure.

Table 4 Hazardous Source Identified by zone

Zone Code	Zone	Hazardous Source
4	Evaporators	NG LNG Phase Change High pressure process
5	Seawater pumps and electrochlorination plant	Diesel HCl (6%) HCl (<3%) NaHSO3 NaOCl Electricity
6	Compressor room, reliquefier and secondary pumps.	Natural Gas Liquefied Natural Gas High Pressure Process
7	Loading / offloading tankers and LNG storage	Natural Gas Liquefied Natural Gas Cryogenic Process
8	Electrical substation, transformers and emergency generator	Diesel Dielectric Oil Electricity
9	Storage of chemicals and lubricants	Various chemicals

4.4. Identifying accident initiating events

The accident initiating events are physical facts able to generate an incident or accident in term of its evolution in space and time.

Table 5 shows accident initiating events identified in the plant according to the SEDIGAS methodology [11] given the danger of the substances handled, storage areas and process and operating conditions of the various facilities.

Table 5 Initiating Events identified in each area

Area / System	Initiating Event
Vessel loading / Unloading	LNG leakage during loading/unloading of a methane vessel

Table 5 Initiating Events identified in each area

Area / System	Initiating Event
	Hydraulic oil leakage for rupture of a loading/unloading arm
GNL Storage tanks	LNG leakage from 36" loading pipeline to storage tanks
Secondary Pumps	LNG leakage from 20" secondary pumps manifold
LNG Truck loading system	LNG leakage during loading operation of a cistern truck
NG system (Evaporators, Measurement station)	NG leakage in measurement station pipeline
Odorization System	THT leakage in Odorization system storage tank
	THT leakage in distribution pipeline
	THT leakage during operation of cistern tank unloading
Seawater System	Sodium bisulfite leakage in storage tank
	HCL leakage in storage tank
	Sodium hypochlorite leakage in storage tank
	Diesel leakage in firewater pumps storage tank
Diesel storage	Diesel leakage in storage tank
	Diesel leakage in distribution pipeline
	Diesel leakage during operation of cistern tank unloading
Electrical Station	Dielectric oil leakage in station
	Fire in station
	Diesel leakage in Emergency pumps storage tank
Chemical substances warehouse	Chemical product leakage in warehouse
	Fire in warehouse

4.5. Determination of frequency of initiating events of an accident

Having identified the accident initiating events, the next step is the evaluation of their probabilities of occurrence. Initiating events can be considered as basic or specific, depending of the specialization of the plant or the equipment.

For basic initiator events, the frequency of occurrence can be assessed directly by literature sources without resorting to quantification by fault tree.

Table 6 Frequency of initiating events [7] [6]

Event	Frequency (years^{-1})
1.- Human error / Operator in observation (Not observed)	1.00E-02
2.- Human error / Operator in action (Not act)	1.00E-03
3. - Total pipeline rupture D < 3” (Freq. Length line)	1.00E-06
4. - Total pipeline rupture 3” < D < 6” (Freq. Length line)	3.00E-07
5. - Total pipeline rupture D > 6” (Freq. Length line)	1.00E-07
6.- Instantaneous release of a simple wall atmospheric tank	5.00E-06
7.- Instantaneous release of a double wall atmospheric tank	1.25E-08
8.- Instantaneous release of a pressurized tank	5.00E-07
9.- Instantaneous release of an atmospheric cistern truck	1.00E-05
10.- Instantaneous release of a pressurized cistern truck	5.00E-07
11.- Continuous release orifice	1.00E-04
12.- Release by orifice from underground tank	1.00E-08
13.- Release by orifice from pressurized tank	1.00E-05
14.- Hose rupture (Freq. h-1)	4.00E-06
15.- Arm rupture (Freq. h-1)	3.00E-08
16.- Error in containers manipulation(by Nº of containers)	1.00E-05
17.- Fire in warehouse (Freq. by M2 of warehouse)	1.00E-03
18.- Short circuit (Freq. h^{-1})	1.00E-06
19.- Instrumentation failure (Freq. h-1)	1.00E-06
20.- Pump failure	1.00E-04
21.- Hand valve failure	1.33E-03
22.- Motorized valve	2.63E-03
23.- inadequate construction	1.00E-06

When a specific initiating event needs previously events to occur, involving different types of elements (safety devices, technical components, operators, etc.), a methodology is required to analyze the different mechanisms and to determine the cause and probability of the event happens. In this case the Fault Tree methodology is used for this kind of situations, as it was described in chapter 2.

Figure 9 and Figure 10 show the fault tree used for “Diesel Spill during truck discharges” and “Hydraulic oil leakage for rupture of unloading/loading arm”. Other fault trees used in this study are shown in Appendix II.

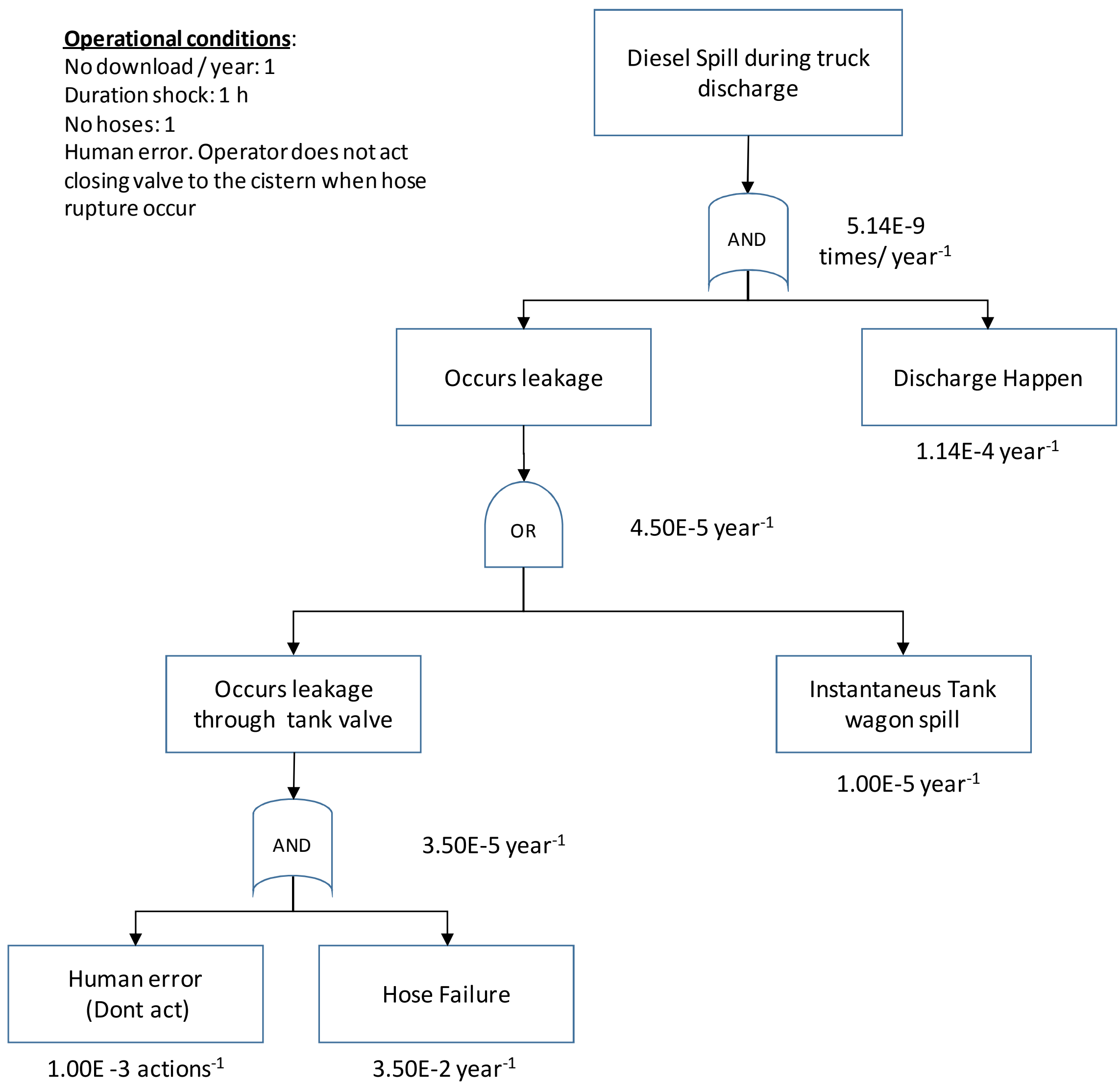

Figure 9 Fault Tree analysis: “Diesel Spill during truck discharges”

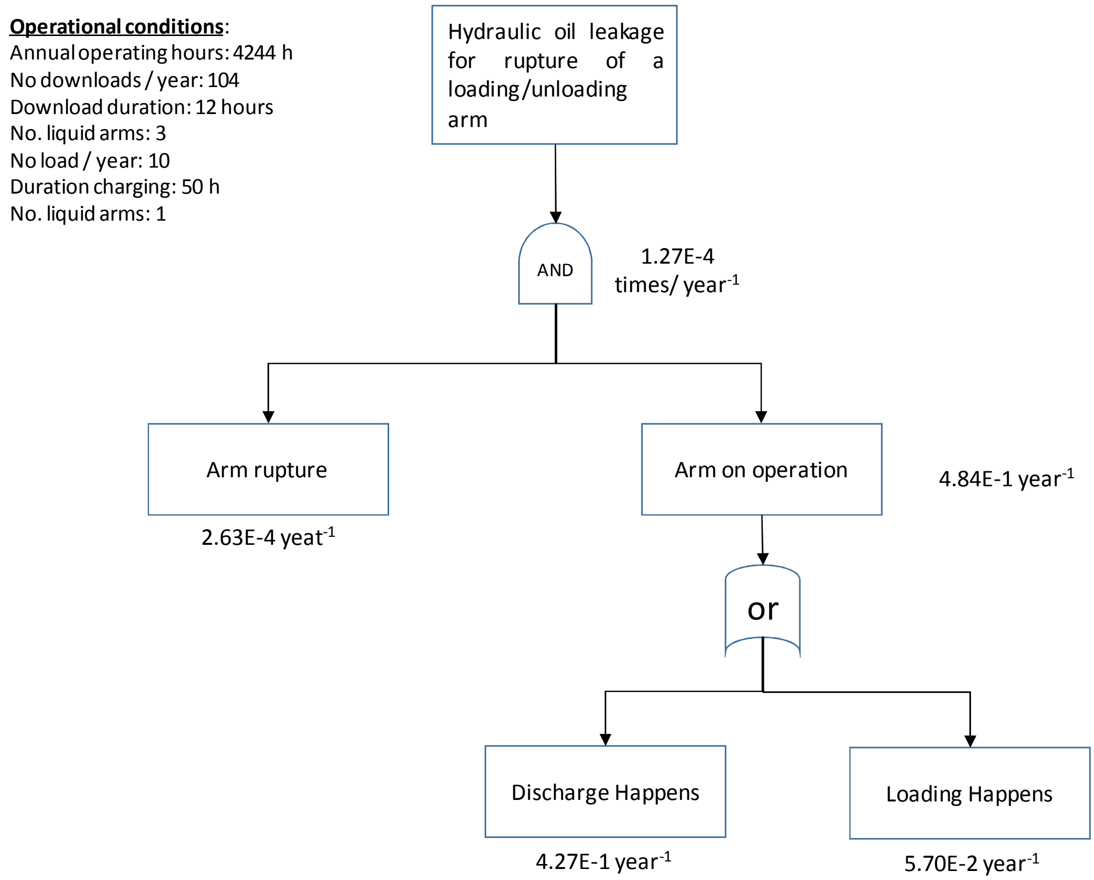

Figure 10 Fault Tree analysis: "Hydraulic oil leakage for rupture of loading/unloading arm"

According to the fault tree analysis, Table 7 shows the frequency calculated for each initiating event. The Appendix III shows the detailed calculation for each initiating event. In all the cases, the procedure was the following:

- Description of initiating event.
- Generic frequency of the initiating event of an accident.
- Features: specific of the process characteristics: annual operating hours, time of the tanker at the facility, average length of a discharge / charge, length of pipe, etc., i.e. data operation installation, which are specified in this section.
- Resulting frequency of the initiating event of an accident.

Table 7 Established scenarios /initiating event frequency calculated

Zone Code	Initiating Event Code	Initiating Event Description	Frequency (times/year)
1	1.1	LNG leakage during loading/unloading of a methane vessel	1.27E-04
	1.2	Hydraulic oil leakage for rupture of a loading/unloading arm	1.80E-04
2	2.1	LNG leakage from 36" loading pipeline to storage tanks	5.98E-07
3	3.1	LNG leakage from 20" secondary pumps manifold	3.70E-06
	3.2	LNG leakage during loading operation of a cistern truck	4.96E-02
4	4.1	NG leakage in measurement station pipeline	1.40E-04
5	5.1	THT leakage in Odorization system storage tank	1.15E-04
	5.2	THT leakage in distribution pipeline	5.00E-05
	5.3	THT leakage during operation of cistern tank unloading	1.74E-09
6	6.1	Sodium bisulfite leakage in storage tank	1.15E-04
	6.2	Sodium bisulfite leakage during operation of cistern tank unloading	1.59E-07
	6.3	HCL leakage in storage tank	5.00E-06
	6.4	Sodium hypochlorite leakage in storage tank	5.00E-06
	6.5	Diesel leakage in firewater pumps tank	1.25E-08
7	7.1	Diesel leakage in main tank	1.15E-04
	7.2	Diesel leakage in distribution pipeline	2.30E-04
	7.3	Diesel leakage during operation of cistern tank unloading	5.15E-09
8	8.1	Diesel leakage in emergency generator tank	1.25E-08
	8.2	Fire in electrical substation	8.76E-03
9	9.1	Fire in warehouse	8.80E-04

4.6. Chemical spilled and firewater volume calculation

After identification of initiating events and visual inspection in the LNG plant installation, it is necessary to determine the spill conditions and firewater volume to calculate the quantity of chemicals that will affect the environment. In this ERA are detailed three substances in order to calculate all the spills and fire scenarios. In case of hazardous inorganic substances (Sodium bisulfite, Sodium Hypochlorite and Hydrochloric acid), the EDI methodology consider the self-regeneration of the marine medium for infinite dilution of the substances [8, 10]. Table 8 shows the properties of hazardous chemical substances to evaluate during the damage quantification.

Table 8 Hazardous Chemical substances properties [1]

Chemical Substance	Density (kg/m^3)	Combustion rate ($kg/m^2.s$)	Flash Point (ºC)
THT	1000	0.052	13
Diesel	850	0.081	52
Hydraulic oil	868	No evaluated	>55

The magnitude of the accident scenarios is associated with the amount of hazardous chemical substances spilled to seawater.

The calculation was made taking into account the following considerations:

- Volume determination of lines, reservoirs and storage tanks where the spill scenarios is estimated.
- Volume determination of cistern truck leakage during unloading of dangerous chemicals (THT and diesel).
- Calculation of water volume required for each fire accident where the hazardous substance could be dragged to sea by the fire-water.

4.6.1. Pipelines volume calculation

To calculate the volume release in each accidental scenario where the initiating event is a pipeline rupture, the following criteria have been considered:

- THT pipeline: total release of the entire pipeline volume between main tank and daily tank.
- Diesel pipeline: Total distribution diesel system pipeline.

- Hydraulic oil Circuit: total circuit discharge.

The following tables show the calculated volume for initiating event:

Table 9 Calculated volume of pipeline systems

Code	Initiating event	Length (m)	Diameter (in)	Volume (m^3)
5.2	THT leakage in distribution pipeline	50	0.75	0.01
7.2	Diesel leakage in distribution pipeline	230	2	0.47

Table 10 Volume of a hydraulic system in a LNG Plant.

Code	Initiating event	Volume (m^3)
1.2	Hydraulic oil leakage for rupture of a loading/unloading arm	0.45*

*Hydraulic oil volume of the LNG plant under analysis.

4.6.2. Cistern tank volume

Cistern tank volume estimation is taken by reference of common tanks used in Spain for this activity. Table 11 shows the volumes taken as a reference for this study:

Table 11 Typical volume of cistern tank of THT and Diesel

Code	Initiating event	Volume (m^3)
5.3	THT leakage during operation of cistern tank unloading	15
7.3	Diesel leakage during operation of cistern tank unloading	15

4.6.3. Firewater volume calculation

In case of pool fire of flammable chemical spill, fire water was calculated according to the technical note “NTP 40” published by the Spain National Institute of Safety and Health at Work (INSHT), which sets the minimum water flow firefighting 4-20 liters/min/ m2. [12].

If the hazardous chemical leak occurs inside the tank dike, the area of fire is estimated like the free area where the substance is exposed to the atmosphere. Otherwise, if the hazardous chemical leak occurs in unconfined area, it has been considered a thickness of 10 mm of the puddle until reaching the spill, and its area can be calculated by Ec.1. Table 12 shows the area calculated for each initiating event where occurring as unconfined spill.

$$SpillArea = A = V/h \quad \textbf{Ec.2}$$

Where:

A= Spill Area (m^2)
h= Spill thickness (m)
V= Spill volume (m^3)

Table 12 Area calculated for unconfined spill of THT and Diesel

Code	Initiating event	Spill Area (m^2)
5.2	THT leakage in distribution pipeline	1.43
5.3	THT leakage during operation of cistern tank unloading	1500
7.2	Diesel leakage in distribution pipeline	46.62
7.3	Diesel leakage during operation of cistern tank unloading	1500

Also the calculated free areas for the spills that occur inside the dike of the storage tank are shown in Table 13.

Table 13 Dike area calculation for confined spills.

Tank	Tank volume (m^3)	Average filling level (*) (%)	Tank Diameter (m)	Dike surface (m^2)	Free Dike surface (m^2)	Dike Volume (m^3)
THT	20.98	50	2	39.13	39.13*	25.43
Diesel	44	40	3	49	41.93	43.61

**Cylindrical tank over the ground.*

The duration of fire is calculated according to the formula [12]:

$$T(s) = \frac{Mp}{Ad * Vc} \quad \textbf{Ec.3}$$

Where:

T (s) = Fire duration, seconds.
Mp = Mass of chemical spilled, kg.
Ad = Surface area of the basin or spill, m2.
Vc = Burning rate, kg/m2.s

Firewater volume is calculated according to the formula [12]:

$$Vol(m^3) = Ad * T * 20 \frac{l}{min.m^2} \quad \textbf{Ec.4}$$

Where:

T(s) = Fire duration, seconds.
Ad = Spill Surface or tank basin free area where fire is happened m^2.

Consequently the spilled volume is calculated as follow:

$$\text{Firewater + Chemical substances discharge into sea } (m^3) = \text{Chemical Substance Spilled } (m^3) + \text{Firewater volume } (m^3) - \text{Dike Volume } (m^3) \quad \textbf{Ec.5}$$

Table 14 Firewater calculation for each initiating event

COD	Initiating Event	Chemical Substance Spilled (m^3)	Fire Duration (min)*	Firewater volume (m^3)	Firewater + Chemical substances discharge into sea
4.1	NG leakage in measurement station pipeline (THT tank affectation, jetfire)	10	82.46	65.82	50.39
4.1	NG leakage in measurement station pipeline (Diesel tank affectation. jetfire)	18	75.08	64.22	38.61
5.1	THT leakage in Odorization system storage tank	10	82.46	65.82	50.39
5.2	THT leakage in distribution pipeline	0.01	-	-	-
5.3	THT leakage during operation of cistern tank unloading	15	3.23	2.58	-
6.4	Diesel leakage in firewater pumps tank	9	2.058	-	-
7.1	Diesel leakage in main tank	18	75.08	64.22	38.61
7.2	Diesel leakage in distribution pipeline	0.47	0.1	-	-
7.3	Diesel leakage during operation of cistern tank unloading	15	60	-	-
8.1	Diesel leakage in emergency generator tank	2.7	1.75	-	-

*According to NTP 40, the firewater is calculated when the fire duration is more than 60 minutes [12].

4.7. Evolution of initiating event into environmental accident

This section is intended to quantify the probability of environmental accidents coming from the evolution of initiating event by event tree.

- Ignition probability: is the probability of a direct or indirect ignition. For this. TNO has specified the classification according to substance category, see Table 15.
- Human intervention: in case of the event happens, is the probability that the operator can apply procedures to avoid the final accident. For TNO 1.00 E-3 [7]
- Fire system activation: 95% of availability [7].

Table 15 Ignition likelihood according substance category [7, 6]

Substance Category	Continuous flow source	Instantaneous source	Probability immediate ignition
Category 0 Average / High Reactivity	< 10 kg/s 10 - 100 Kg/s > 100 kg/s	< 1000 kg 1000 - 10000 kg > 10000 kg	0.2 0.5 0.7
Category 0 Low reactivity	< 10 kg/s 10 - 100 Kg/s > 100 kg/s	< 1000 kg 1000 - 10000 kg > 10000 kg	0.02 0.04 0.09
Category 1	All flow range	All leakage quantities	0.065
Category 2	All flow range	All leakage quantities	0.01
Category 3.4	All flow range	All leakage quantities	0

Continuing to the event tree progress, follow figures show an event tree for each representative initiating event. Other event trees are shown in Appendix IV.

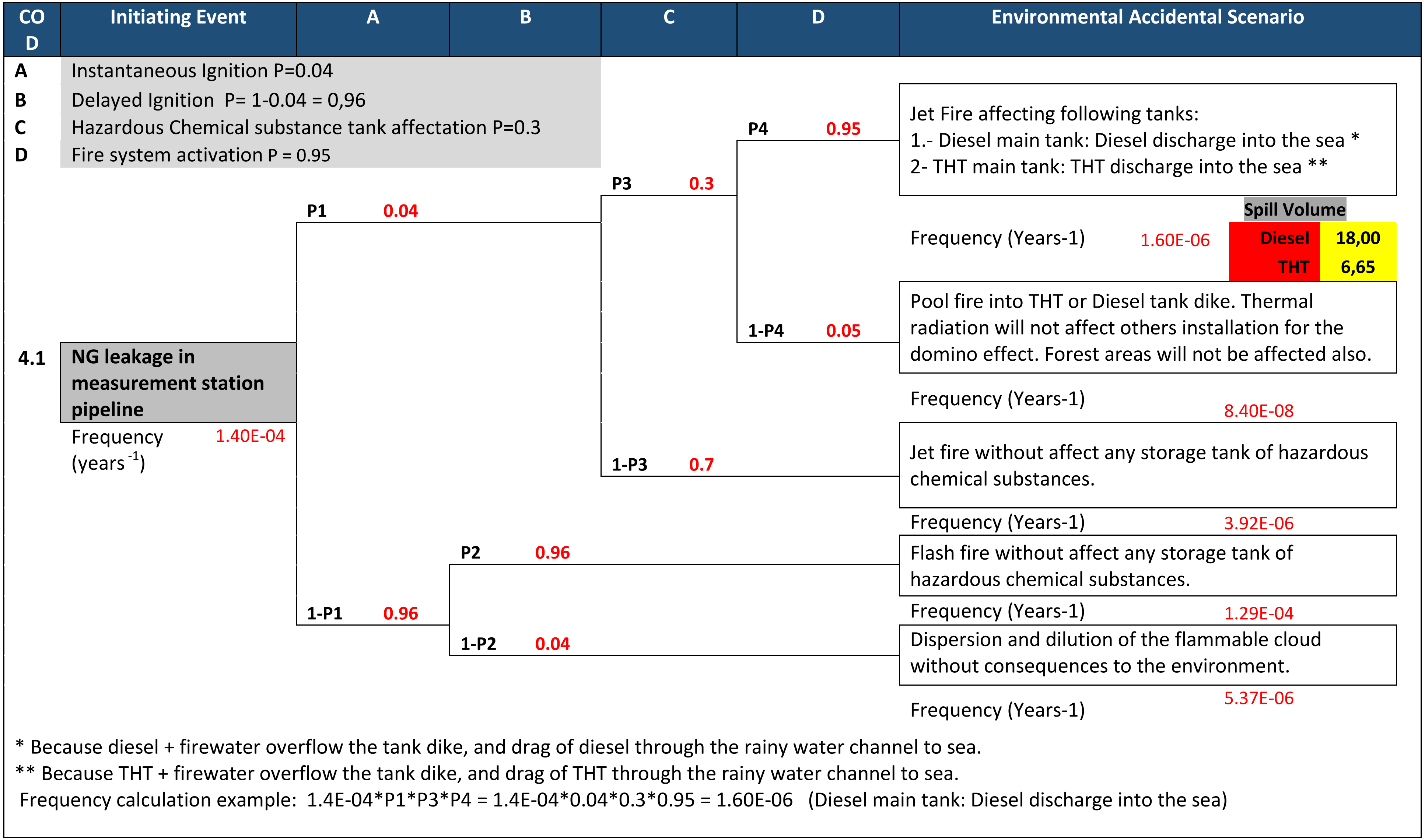

Figure 16 NG leakages in measurement station pipeline event tree

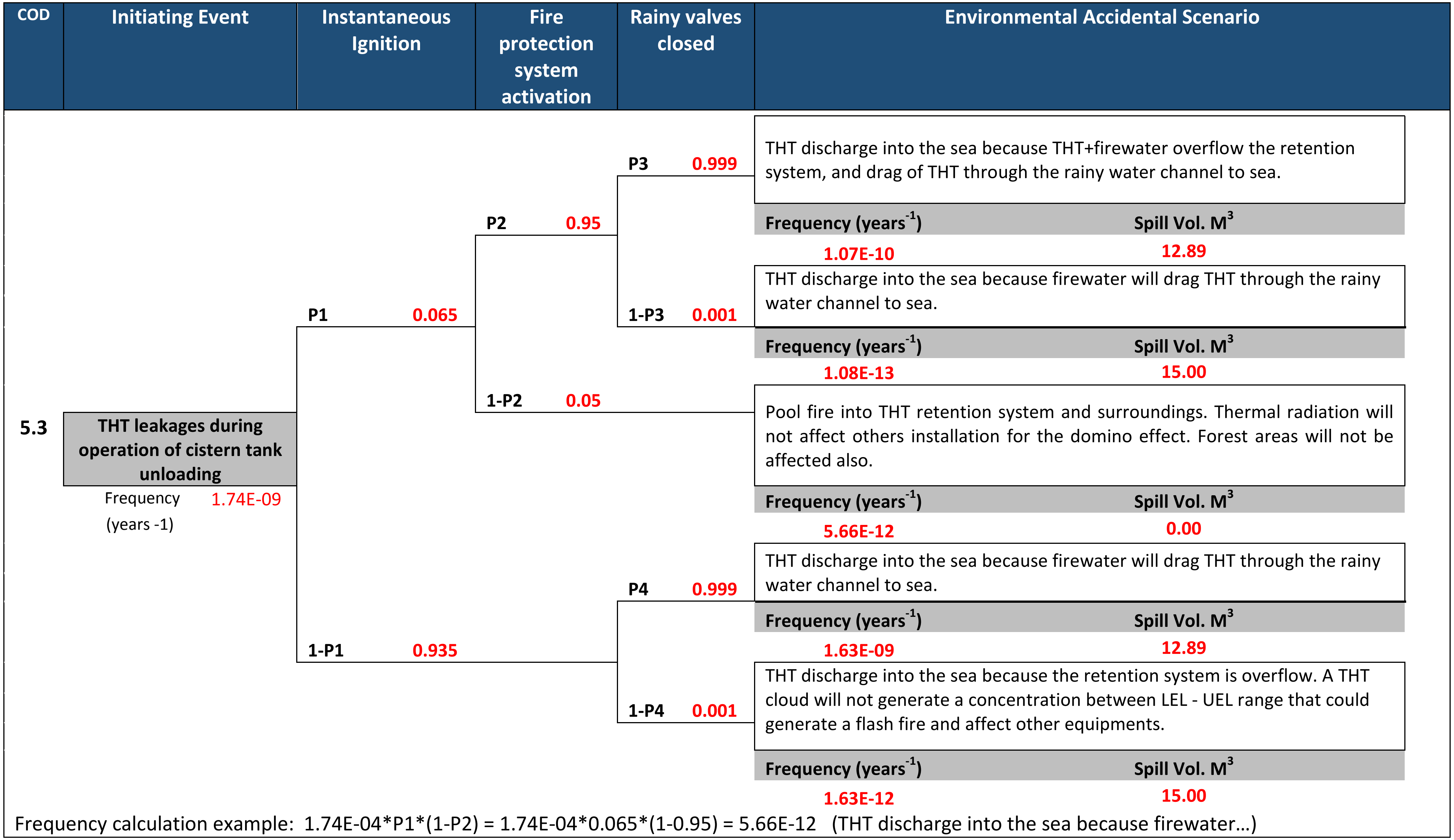

Figure 17 THT leakage during operation of cistern tank unloading Event Tree

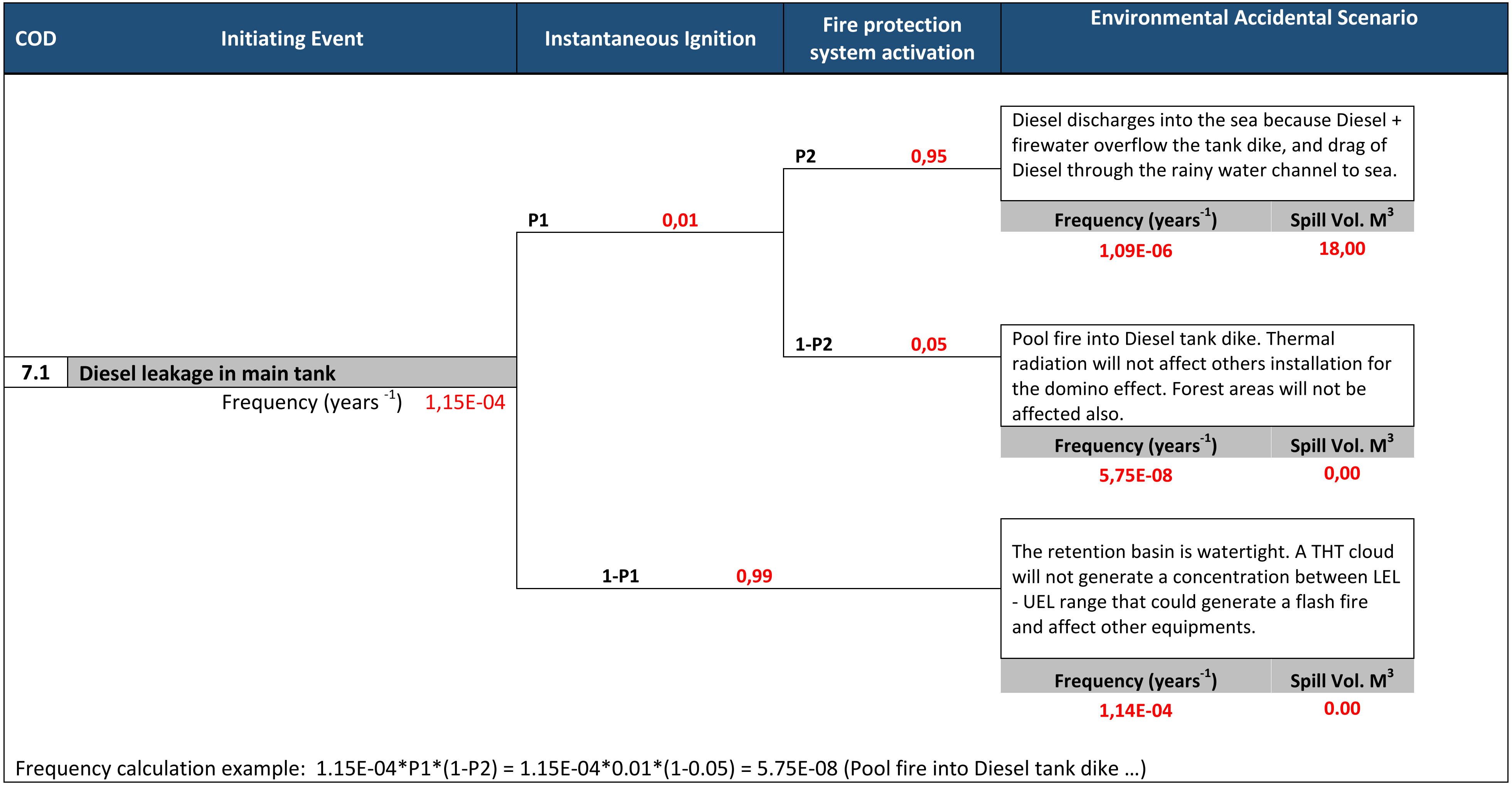

Figure 18 Diesel leakages in main tank Event tree

After developing each event tree according an initiating event selected. Table 16 shows the environmental accidental scenarios founded and their Frequency and probability of occurrence.

Table 16 Environmental Accidental Scenarios Identified

COD	Initiating Event	Frequency (years^{-1})	EAS COD	Environmental Accidental Scenario (EAS)	EAS Frequency (times/ year)	Spill Vol. (m3)
1.2	Hydraulic oil leakage for rupture of a loading/unloading arm	1.80E-04	1.2.A	Hydraulic oil spill to the sea	1.80E-04	0.45
4.1	NG leakage in measurement station pipeline	1.40E-04	4.1.A	Jet Fire affecting following Diesel main tank: Diesel discharge into the sea	1.60E-06	18.00
			4.1.B	Jet Fire affecting THT main tank: THT discharges into the sea	1.60E-06	6.65
5.1	THT leakage in Odorization system storage tank	1.15E-04	5.1.A	THT discharges into the sea because THT+ firewater overflow the tank dike and drag of THT through the rainy water channel to sea.	7.10E-06	6.65
5.2	THT leakage in distribution pipeline	5.00E-05	5.2.A	THT discharges into the sea because firewater will drag THT through the rainy water channel to sea.	3.09E-06	0.01
			5.2.B	THT discharges into the sea through the rainy water channel. A THT cloud will not generate a concentration between LEL - UEL range that could generate a flash fire and affect other equipments.	4.68E-05	0.01
5.3	THT leakage during operation of cistern tank unloading	1.74E-09	5.3.A	THT discharges into the sea because THT + firewater overflow the retention system and drag of THT through the rainy water channel to sea.	1.07E-10	12.89
			5.3.B	THT discharges into the sea because firewater will drag THT through the rainy water channel to sea.	1.08E-13	15.00
			5.3.C	THT discharges into the sea because firewater will drag THT through the rainy water channel to sea.	1.63E-09	12.89

Table 16 Environmental Accidental Scenarios Identified

COD	Initiating Event	Frequency (years^{-1})	EAS COD	Environmental Accidental Scenario (EAS)	EAS Frequency (times/ year)	Spill Vol. (m3)
				THT discharges into the sea because the retention system is overflow. A THT cloud will not generate a concentration between LEL - UEL range that could generate a flash fire and affect other equipments.	1.63E-12	15.00
6.2	Sodium bisulfite leakage during operation of cistern tank unloading	1.59E-07	6.2.A	Sodium bisulfite discharges into the sea	1.59E-10	15.00
6.5	Diesel leakage in firewater pumps tank	1.25E-08	6.5.A	Diesel discharges into the sea because firewater will drag Diesel through the rainy water channel to sea.	1.19E-10	9.00
			6.5.B	Diesel discharges into the see through rainy channels. A diesel flammable cloud will not generate a concentration between LEL - UEL range that could generate a flash fire and affect other equipments.	1.24E-08	9.00
7.1	Diesel leakage in main tank	1.15E-04	7.1.A	Diesel discharges into the sea because Diesel+ firewater overflow the tank dike and drag of Diesel through the rainy water channel to sea.	1.09E-06	18.00
7.2	Diesel leakage in distribution pipeline	2.30E-04	7.2.A	Diesel discharges into the sea because firewater will drag Diesel through the rainy water channel to sea.	2.19E-06	0.47
			7.2.B	Pool fire in surroundings. Thermal radiation will not affect others installation for the domino effect. Forest areas will not be affected also.	1.15E-07	0.00
			7.2.C	Diesel discharges into the sea through the rainy water channel. A cloud will not generate a concentration between LEL - UEL range that could generate a flash fire and affect other equipments.	2.28E-04	0.47

Table 16 Environmental Accidental Scenarios Identified

COD	Initiating Event	Frequency (years^{-1})	EAS COD	Environmental Accidental Scenario (EAS)	EAS Frequency (times/ year)	Spill Vol. (m3)
7.3	Diesel leakage during operation of cistern tank unloading	5.14E-09	7.3.A	Diesel discharges into the sea because firewater will drag Diesel through the rainy water channel to sea.	4.88E-11	15.00
			7.3.B	Diesel discharges into the see through rainy channels. A diesel flammable cloud will not generate a concentration between LEL - UEL range that could generate a flash fire and affect other equipments.	5.09E-09	15.00
8.1	Diesel leakage in emergency generator tank	1.25E-08	8.1.A	Diesel discharges into the sea because firewater will drag Diesel through the rainy water channel to sea.	1.19E-10	9.00
			8.1.B	Diesel discharges into the see through rainy channels. A diesel flammable cloud will not generate a concentration between LEL - UEL range that could generate a flash fire and affect other equipments.	1.24E-08	9.00

5. ENVIRONMENTAL DAMAGE INDEX ESTIMATION

Environmental Damage Index (EDI) assigns an order of magnitude to the damage caused by each accidental scenario presented. Thus it allows ranking the importance of each potential damage.

The EDI calculation procedure is specified in Royal Decree 183/2015, which modified the law 26/2007 of Environmental Responsibility, developed by Royal Decree 2090/2008.

As explained in chapter 2, the EDI methodology is based on a mathematical equation that provides semi-quantitative estimation of environmental damage. The input parameters are function of the combination damage source agent – natural resource being evaluated. In particular, Royal Decree 183/2015 shows a total of twenty one groups of Hazard - natural resource partners.

According to event trees where marine water is polluted by hazardous substance such as THT, diesel and hydraulic oil. EDI methodology defines groups 1 (Marine water –chemical substances) to develop the calculation, as shows in Figure 7 (Chapter 2). Also, group 16 (Animal Species/Chemical substances) is included in the EDI evaluation because it is estimated to affect seabird species in surrounding.

5.1. EDI parameters selection and calculation procedure

As shown in chapter 2, EDI formula is defined as follow:

$$EDI = \sum_{i=1}^{n}[(ECf + A * Ecu * (B * \alpha * Ec) + p * {M_{acc}}^{q} + C * Ecr) * (1 + Ecc)]_i + (\beta + Eca) \quad \textbf{Ec.1}$$

Ecf= Fix cost estimation
A. B. C= EDI modificators
Ecu=Unit cost estimation
Macc= Quantitive of resource affected.
q. p= resource EDI modification parameter.
Ecr=Project control and review cost.
Ecc= Reparation consulting cost.
β= Distant from nearest access road.
Eca= Access to the damage area cost.
n= groups evaluated

To apply the EDI calculation comprises the following steps:

- Select the damage source agent / Resource affected (group)
- Choose all the parameters values and calculate the modifiers A,B and C.
- Identify Ecu, α, β, Macc, Ecr, Ecc and Eca for each group.
- For each group affected and variables selected, apply EDI formula.
- Sum each EDI results and obtained the global EDI value for the accidental scenario selected.
- Apply this procedure for each accidental scenario.

The parameters to evaluate each environmental accident identified in EDI Methodology are given bellow:

Table 17, Table 18 and Table 19 show the basic parameters defined to group 1 and 16.

Table 17 *Group 1(Marine Water – Chemical Substances) equation coefficients and modifiers [13]*

Agent	Coefficients									Modifiers		
	Ecf	Ecu	α*	Ec	Ecr	Ecc	p	M_{acc}	q	MA	MB	MC
VOC & SVOC	0	866	$M_{spilled}$	1	1934	0.03	0	0	0	-	M_{B1} M_{B12} M_{B18}	M_{C1}
Fuel oil and NVOC	0	3648	$M_{spilled}$	1	1934	0.03	0	0	0			

***Mspilled:** ton of chemical substance spilled

Table 18 Group 16 (Animal Species/Chemical substances)equation coefficients and modifiers [13]

Resource	**Coefficients**									**Modifiers**		
	Ecf	Ecu	α	Ec	Ecr	Ecc	p	M_{acc}	q	MA	MB	MC
Threat bird Species	0	11866	R	0.5	6027	0.03	0	0	0	M_{A2}	M_{B1} M_{B2} M_{B15}	M_{C5}
Not Threat bird Species	0	2373	R	1	6027	0.03	0	0	0			

Table 19 Calculation range of R coefficient to estimate α value in group 16 [13]

Resource	Range*	R
Threat bird Species	0 ≤ Vspill ≤ 25	2xVspill
	Vspill > 25	50
Not Threat bird Species	0 ≤ Vspill ≤ 25	2xVspill
	Vspill > 25	50

***Vspill:** volume of chemical substance spilled

After select the principal parameters of EDI equation, Table 20 shows the necessary values to calculate A. B and C modificators.

Table 20 Modifiers selected for EDI calculation of each environmental accidental scenario [8]

Category	Description	Modifier	Value
Protected Natural Area affectation MA2	Protected Natural Area affected	M_{A2}	1.25
	Protected Natural Area unaffected	M_{A2}	1.00
Substance biodegrability MB1 **	Low	M_{B1}	1.00
	Average	M_{B1}	0.90
	High	M_{B1}	0.80
Animal Population Density MB2	High Dense (Many references about species presence in the area)	M_{B2}	2.00
	Average (some references about species presence in the area)	M_{B2}	1.50
	Sparse Average (few references about species presence in the area)	M_{B2}	1.00
Solubility MB12	Insoluble	M_{B12}	1.00
	Low solubility (Water solubility 20ºC between 0.1 - 10 mg/l)	M_{B12}	0.90
	High Solubility (Water solubility at 20ºC > 10 mg/l)	M_{B12}	0.80
Toxicity MB15	High (More than 50% of population affectation)	M_{B15}	2.00
	Average (10-50% of population affectation)	M_{B15}	1.50
	Low (Less than 1% of population affection)	M_{B15}	1.00
Volatility MB18	Low (PE > 325ºC)	M_{B18}	1.00
	Average (Bp 100 - 325 ºC)	M_{B18}	0.90
	High (Bp < 100 ºC	M_{B18}	0.80
Duration 1 MC1 (Time lapse for water recovery)	High (> 1 year)	M_{C1}	1.25
	Medium (6 month - 1 year)	M_{C1}	1.10
	Low (< 6 month)	M_{C1}	1.00
Duration 5 MC5 (Time lapse for animal species recovery)	High (mammals affectation)	M_{C5}	1.25
	Low (other species affectation)	M_{C5}	1.00

** Biodegradability parameter is evaluated according external information included in European Chemical Substances Information System.

Choosing the hazardous substances involved in the study. Table 21 shows the parameters relative to damage agent.

Table 21 Parameter relative to damage agent

Substance	EDI Agent*	biodegradability MB1	Solubility MB12	Toxicity MB15	Volatility MB18
THT	SVOC	Low	Insoluble	High	Medium
Diesel	NVOC	Low	Insoluble	High	Low
Hydraulic Oil	NVOC	Low	Insoluble	High	Low

***SVOC:** Semivolatile organic chemical substance. **NVOC:** No volatile organic chemical substance

Afterward, the possibility to affect a protected natural area (M_{A2}) and seabird species (M_{B2}) are expressed as:

Table 22 Characteristic Parameters relative to surroundings *[8]*

Parameter	Value	Justification
Possible affectation of a protected natural area (M_{A2})	No	Spill scenario occurs inside the port area. It is not estimated to affect any protected natural area in surroundings. It is estimated affect seabirds related to this area.
Population density (M_{B2}) (Apply to seabird population)	Very dense	The standard ES0000148 and ES0000470 have not information about population density of seabirds in this environment. To establish a principle of prudence. the population density is taken as " very dense " to encompass the scene of involvement completely [14]

Finally, modifiers for Groups 1 and 16 estipulate the duration parameters: " duration 1" (MC1) and “duration 5" (MC5), where collected the estimate time to recover the affected area or animal species.

Table 23 Damage estimation parameter *[8]*

Parameter	Value	Justification
Duration 1 (M_{C1}) Group 1 (Time lapse for water recovery)	Low (< 6 month)	It is estimated hazardous substance affectation bellow 6 month of recuperation. See Table 20 classification
Duration 5 (M_{C5}) Group 16 (Time lapse for animal species recovery)	Low (other species affectation)	It is estimated affectation to seabirds. See Table 20 classification

Taking an example of EDI calculation, Table 24 shows the parameters selection and EDI evaluation for accidental scenario 7.1 “Diesel leakage in main tank”. The other EDI calculation reports are shown in appendix V

Table 24 EDI Calculation for 7.1 Scenario (Diesel Leakage in main tank)

Scenario		7.1.A Diesel leakage in main tank		
EDI Substance		Diesel		
EDI Resource		Marine Water	Threat bird Species	Not Threat bird Species
EDI Group		1	16	16
EDI Parameters	Ecf	0.00	0.00	0.00
	Ecu	3648	11866	2373
	α	15.53	36.00	36.00
	Ec	1.00	0.50	1.00
	Ecr	1.934	6027	6027
	Ecc	0.03	0.03	0.03
Marine bed Parameters	P	0.00	0.00	0.00
	Macc	0.00	0.00	0.00
	q	0.00	0.00	0.00
Modifiers MA	MA2	0.00	1.00	1.00
	A	1.00	1.00	1.00
Modifiers MB	MB1	1.00	1.00	1.00
	MB2	0.00	2.00	2.00
	MB12	1.00	0.00	0.00
	MB15	0.00	2.00	2.00
	MB18	1.00	0.00	0.00
	B	1.00	4.00	4.00
Modifiers MC	MC1	1.00	0.00	0.00
	MC5	0.00	1.00	1.00
	C	1.00	1.00	1.00
EDI Combination by resource		**58353**	**886190**	**358171**
EDI Scenario		**1302715**		

After EDI calculation, Table 25 shows the results of frequency, Spill volume and EDI value for each accidental scenario.

Table 25 EDI calculation for each environmental scenario

COD	Initiating Event	ID	Environmental Accidental Scenario (EAS)	EAS Frequency (times/year)	Spill Vol. (m^3)	EDI
1.2	Hydraulic oil leakage for rupture of a loading/unloading arm	1.2.A	Hydraulic oil spill to the sea	1.80E-04	0.45	51431
4.1	NG leakage in measurement station pipeline	4.1.A	Jet Fire affecting following tanks: 1.- Diesel main tank: Diesel discharge into the sea	1.60E-06	18.00	1302715
		4.1.B	Jet Fire affecting following tanks: 1- THT main tank: THT discharge into the sea	1.60E-06	6.65	499731
5.1	THT leakage in Odorization system storage tank	5.1.A	THT discharge into the sea because THT + firewater overflow the tank dike and drag of THT through the rainy water channel to sea.	7.10E-06	6.65	499731
5.2	THT leakage in distribution pipeline	5.2.A	THT discharge into the sea because firewater will drag THT through the rainy water channel to sea.	3.09E-06	0.01	21946
		5.2.B	THT discharge into the sea through the rainy water channel. A THT cloud will not generate a concentration between LEL - UEL range that could generate a flash fire and affect other equipments.	4.68E-05	0.01	21946
5.3	THT leakage during operation of cistern tank unloading	5.3.A	THT discharge into the sea because THT + firewater overflow the retention system and drag of THT through the rainy water channel to sea.	1.07E-10	12.89	915196
		5.3.B	THT discharge into the sea because firewater will drag THT through the rainy water channel to sea.	1.08E-13	15.00	1053684
		5.3.C	THT discharge into the sea because firewater will drag THT through the rainy water channel to sea.	1.63E-09	12.89	915196

Table 25 EDI calculation for each environmental scenario

COD	Initiating Event	ID	Environmental Accidental Scenario (EAS)	EAS Frequency (times/year)	Spill Vol. (m^3)	EDI
		5.3.D	THT discharge into the sea because the retention system is overflow. A THT cloud will not generate a concentration between LEL - UEL range that could generate a flash fire and affect other equipments.	1.63E-12	15.00	1053684
6.5	Diesel leakage in firewater pumps tank	6.5.A	Diesel discharges into the sea because firewater will drag Diesel through the rainy water channel to sea.	1.19E-10	9.00	659125
		6.5.B	Diesel discharge into the see through rainy channels. A diesel flammable cloud will not generate a concentration between LEL - UEL range that could generate a flash fire and affect other equipments.	1.24E-08	9.00	659125
7.1	Diesel leakage in main tank	7.1.A	Diesel discharge into the sea because Diesel+ firewater overflow the tank dike and drag of Diesel through the rainy water channel to sea.	1.09E-06	18.00	1303842
7.2	Diesel leakage in distribution pipeline	7.2.A	Diesel discharges into the sea because firewater will drag Diesel through the rainy water channel to sea.	2.19E-06	0.47	37203
		7.2.B	Diesel discharge into the sea through the rainy water channel. A cloud will not generate a concentration between LEL - UEL range that could generate a flash fire and affect other equipments.	2.28E-04	0.47	37203
7.3	Diesel leakage during operation of cistern tank unloading	7.3.A	Diesel discharges into the sea because firewater will drag Diesel through the rainy water channel to sea.	4.88E-11	15.00	1089550
		7.3.B	Diesel discharge into the see through rainy channels. A diesel flammable cloud will not generate a concentration between LEL - UEL range that could generate a flash fire and affect other equipments.	5.09E-09	15.00	1089550

Table 25 EDI calculation for each environmental scenario

COD	Initiating Event	ID	Environmental Accidental Scenario (EAS)	EAS Frequency (times/year)	Spill Vol. (m^3)	EDI
8.1	Diesel leakage in emergency generator tank	8.1.A	Diesel discharges into the sea because firewater will drag Diesel through the rainy water channel to sea.	1.19E-10	9.00	659125
		8.1.B	Diesel discharge into the see through rainy channels. A diesel flammable cloud will not generate a concentration between LEL - UEL range that could generate a flash fire and affect other equipments.	1.24E-08	9.00	659125

According to the results obtained and shown in Table 24 and Table 25, it is important to emphasize the relation between EDI value and damage source agent. EDI values are directly proportional to the amount of damage source agent spilled (THT. diesel). In addition, threat species (seabird) gives highest EDI values because the possible disappearance of the species and irrecoverable damage to the ecosystem. Finally, Spain LNG industry has just been started to apply this EDI methodology in 2015 for this reason; there are not environmental risk assessment done to compare the results obtained.

6. REFERENCE ACCIDENTAL SCENARIO SELECTION AND FINANCIAL GUARANTEE ESTIMATION

This section details the methodology develop to search the reference scenario and its financial guarantee estimation.

6.1. Selection of environmental accidental reference scenario

The procedure to estimate the amount of the financial guarantee is specified in article 33 of Royal Decree 183/2015, Environmental Responsibility. This process comprises the following steps:

- Identification of accident scenarios and determination of the probability of occurrence of each scenario.
- Estimation of environmental damage index (EDI) associated to each environmental accidental scenario. EDI assigns a magnitude of the environmental impacts for each scenario (see Chapter IV).
- Risk calculation associated to each accidental scenario as the product of the probability of the scenario and the EDI value.

$$Risk = EDIxFrequency$$ **Ec.6**

- Sort accident scenarios in descending order of EDI and calculate accumulated risk. Subsequently the reference scenario is that accumulating 95% of the total risk.
- Finally, the amount of the financial guarantee of the reference scenario is calculated as indicated in Article 33 of Royal Decree 183/2015.

Table 26 shows the resume of risk calculation and the reference scenario selection.

Table 26 Reference scenario identification according EDI Methodology

Code	Chemical Substance	EDI (dimensionless)	Frequency (times/year)	Risk (times/year)	Relative Risk	Accumulate Risk %	Vol. Spilled (m^3)
7.1.A	**Diesel**	**1.302.715**	**1.09E-06**	**1.42E+00**	**5.32%**	**100.00%**	**18.00**
4.1.A	Diesel	1.302.715	1.60E-06	2.08E+00	7.77%	94.68%	18.00
7.3.A	Diesel	1.089.550	4.88E-11	5.32E-05	0.00%	86.91%	15.00
7.3.B	Diesel	1.089.550	5.09E-09	5.55E-03	0.02%	86.91%	15.00
5.3.B	THT	1.053.684	1.08E-13	1.13E-07	0.001%	86.89%	15.00
5.3.D	THT	1.053.684	1.63E-12	1.72E-06	0.002%	86.89%	15.00
5.3.A	THT	907.579	1.07E-10	9.75E-05	0.004%	86.89%	12.89
5.3.C	THT	907.579	1.63E-09	1.48E-03	0.01%	86.89%	12.89
6.5.A	Diesel	659.125	1.19E-10	7.83E-05	0.003%	86.88%	9.00
6.5.B	Diesel	659.125	1.24E-08	8.16E-03	0.03%	86.88%	9.00
4.1.B	THT	499.731	1.60E-06	7.97E-01	2.98%	86.85%	6.65
5.1.A	THT	499.731	7.10E-06	3.55E+00	13.26%	83.87%	6.65
1.2.A	Hydraulic Oil	51.431	1.80E-04	9.25E+00	34.56%	70.61%	0.45
7.2.A	Diesel	37.203	2.19E-06	8.13E-02	0.30%	36.05%	0.47
7.2.B	Diesel	37.203	2.28E-04	8.47E+00	31.66%	35.75%	0.47
5.2.A	THT	21.946	3.09E-06	6.78E-02	0.25%	4.09%	0.01
5.2.B	THT	21.946	4.68E-05	1.03E+00	3.83%	3.83%	0.01
			Total Risk	**2.68E+01**			

According to all above mentioned, 7.1.A scenario "Diesel leakage in principal tank "is selected to calculate the financial amount of guarantee.

Table 27 Reference scenario selected

COD	Initiating Event	Environmental Accidental Scenario (EAS)	EAS Frequency (times/year)	1.09E-06
7.1.A	Diesel leakage in main tank	Diesel discharge into the sea because Diesel + firewater overflow the tank dike and drag of Diesel through the rainy water channel to sea.	**EDI**	1.303.842
			RISK	1.42E+00

6.2. Financial valuation of reference scenario

The damage foreseen in the reference scenario should be valued economically to estimate the reparation scope and calculate the financial guarantee.

6.2.1. Economic valuation of environmental damage

Due to Royal Decree 183/2015, monetization of environmental damage will be made from the primary restoration project cost. Environmental, food and agriculture Spain Ministry (MAGRAMA) offers the Environmental Responsibility Offer Model (EROM) to determine the financial evaluation of the potential environmental damage founded (Reference scenario). [10]

In addition to the parameters defined in the EDI methodology, calculation of the financial by EROM must consider the following parameters:

- Polluted water quantity
- Proper technique to collect the hazardous substances in the sea.
- Animal species affected.

6.2.1.1. Polluted water quantity

Polluted seawater calculation is estimated by the equilibrium characteristic of the spill on the water surface. USEPA (2001) suggests an average equilibrium thickness of oil over sea surface slick in temperate waters about 1E-3 inches. Finally, to calculate the volume of contaminated seawater, it is estimated 1 cm of depth under the spill surface.

Table 28 Polluted seawater calculation

Parameter	Value	Unit
Spilled volume	18	m^3
Thickness film	0.001	in
Affected surface	7.08E04	m^2
Depth affected	0.01	m
Seawater affected	708	m^3

6.2.1.2. Recovery Technique

For the damage caused by the chemical substance spilled. EROM procedure established the mechanical recollection like the best technique to apply in sceneries where the substance is not miscible with water. For EROM tool, the recovery of 18 m3 of diesel spilled on sea takes less than one month. [10]

6.2.1.3. Animal species affected

To estimate animal affectation, it is taken like reference a natural protected area to calculate approximately the population and common species that being part of this ecosystem. Marjal dels Moros is the selected area to study animal population and it is included in the Red Natura 2000 of Spain having a special normative for its conservation [15]. It is a special protected area located near from Puerto Sagunto, in Valencia Community.

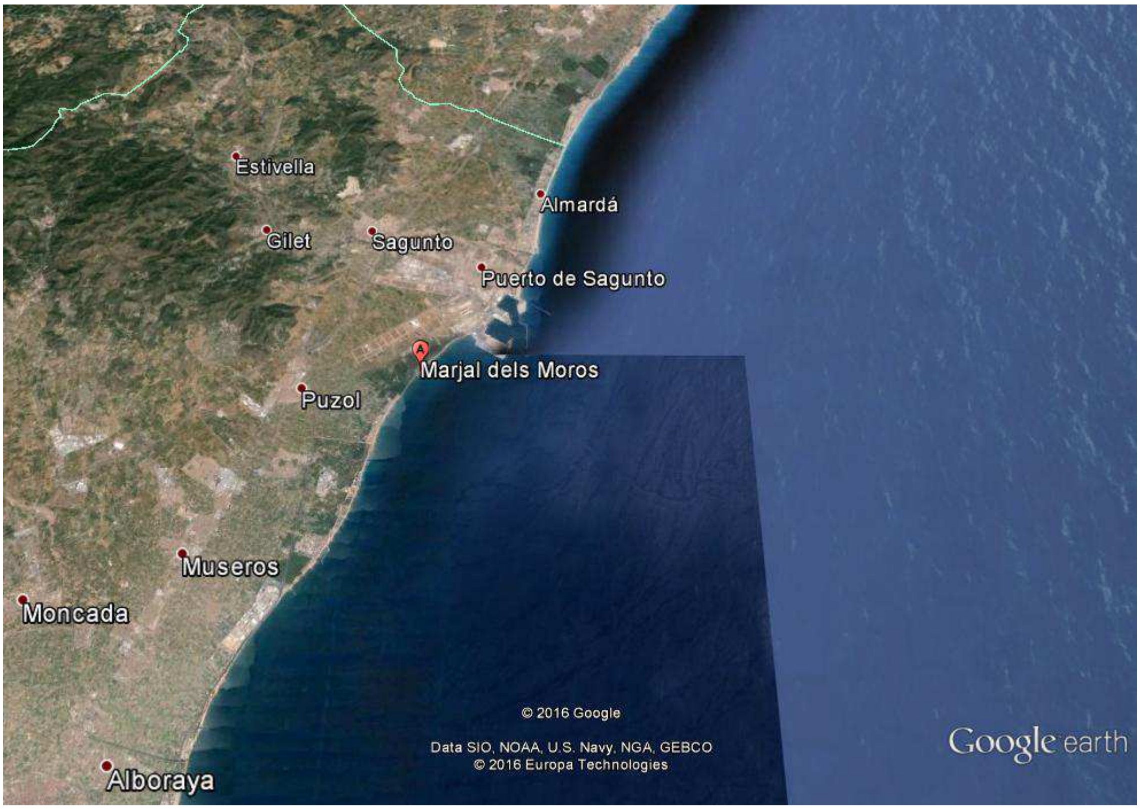

Figure 14 Marjals dels Moros location. Source: Google Earth

For diesel spill on water surface, only marine birds are affected in the surrounds of Marjals dels Moros. Other species like mammals, reptiles or ground birds are not selected because their presence is not relevant in the marine water in this area. The Table 29 shows the population of ground and sea bird in the Marjals of Moros.

Table 29 Ground Bird and seabird species identified in Marjal dels Moros *[15]*

Specie	Population		
	Sedentary	Reproductive	Wintering
Carricerín real	40- 75p		
Common Martín Pescador	P		
Garza Imperial		4 - 12p	
Garcilla cangrejera		2p	
Chorlitejo patinegro		6 - 15p	
Fumarel cariblanco		40 - 200p	
Aguilucho lagunero occidental			0 - 9i
Aguilucho cenizo			
Garceta grande			0 - 1i
Common Garceta			3 - 50i
Focha moruna		0 - 1p	0 - 5i
Common canastera		38 - 100p	
Common cigüeñuela		16 - 48p	0 - 2i
Common avetorrillo		19 - 52p	
Aguja colinta			0 - 21i
Cerceta pardilla		0 - 2p	
Malvasía cabeciblanca		0 - 2p	
Common flamenco			0 - 30i
Common Morito			
European chorlito dorado			0 - 158i
Common Calalmón	29-58p		14-73i
Common avoceta		2-4p	
Common charrancito		60-163p	
Common charrán		50-200p	
Charrán patinegro			R

P: Pairs; i: Individual; R: scarce

Continue to the species identification according to the Marjal dels Moros normative [15], seabird species identified are Cerceta pardilla, Malvasía cabeciblanca, Fumarel cariblanco, common Charrancito, common Charrán and Charrán patinegro. For the damage quantification, it is assumed that threatened species are affected in their entirety and non-threatened species are affected by 25%. To cover the worst case scenario, it is assumed that 100% of affected birds die on contact with the spilled substance. EROM estimated six months to recover the damage caused. This time comprises the incubation period, birth and release from captivity of the species concerned to restore. Table 30 shows the seabird population affected by the diesel spilled on sea water.

Table 30 Potential Affected Bird species in Marjal dels Moros area

Species	Reference population (Individual)		Average (individual)	Affected Population (individual)
	Minimum	Maximum		
Cerceta pardilla (Mamaronetta angustirosris)	0	4	2	2
Malvasía cabeciblanca (Oxyura leucocephala)	0	4	2	2
Total Threatened species affected				4
Fumarel cariblanco (Chlidonias hybrida)	80	400	240	60
Common Charrancito (Sternula albifrons)	120	326	223	56
Common Charrán (Sterna hirundo)	100	400	250	63
Charrán patinegro	-	-	-	-
Total Non-Threatened species affected				178

As required by the regulations, the amount of financial guarantee is related to the estimated cost of primary and compensatory repairs. The calculation performed by EROM methodology proposes the financial budget showed in Table 31 to recover the estimated damage caused. Appendix VI shows the complete calculation report by EROM tool.

Table 31 Scope estimation by EROM Tool [10]

Combination Agent - Resource	Repairs	Amount
Fuel oil and NVOC non biodegradable - Marine Water	Primary repair	329.131.98 €
	Compensatory repair	329.131.98 €
	Total damage repairs	658.263.96 €
Fuel oil and NVOC non biodegradable - Marmaronetta angustirostris (Dead)	Primary repair	38.046.35 €
	Compensatory repair	25.558.97 €
	Total damage repairs	63.605.32 €
Fuel oil and NVOC non biodegradable -Non-Threatened birds (Dead)	Primary repair	27.891.51 €
	Compensatory repair	25.482.60 €
	Total damage repairs	53.374.11 €
Total damage repairs		775.243.39 €
Total financial guarantee		775.243.39 €

As shown in Table 31, the financial guarantee is 775243.39 €. This amount represents the obligatory financial guarantee that the operator has to constitute according to the Royal Decree 183/2015.

Additionally, financial guarantee shows the combination agent-resource most relevant to the study. Figure 15 demonstrates that marine water affectation cover

84.91% of the total guarantee estimation, representing the relevant damage to the environment. The operator has to prepare all emergency operational procedure to act in case of an accidental spill and cover the biggest affectation of the environment.

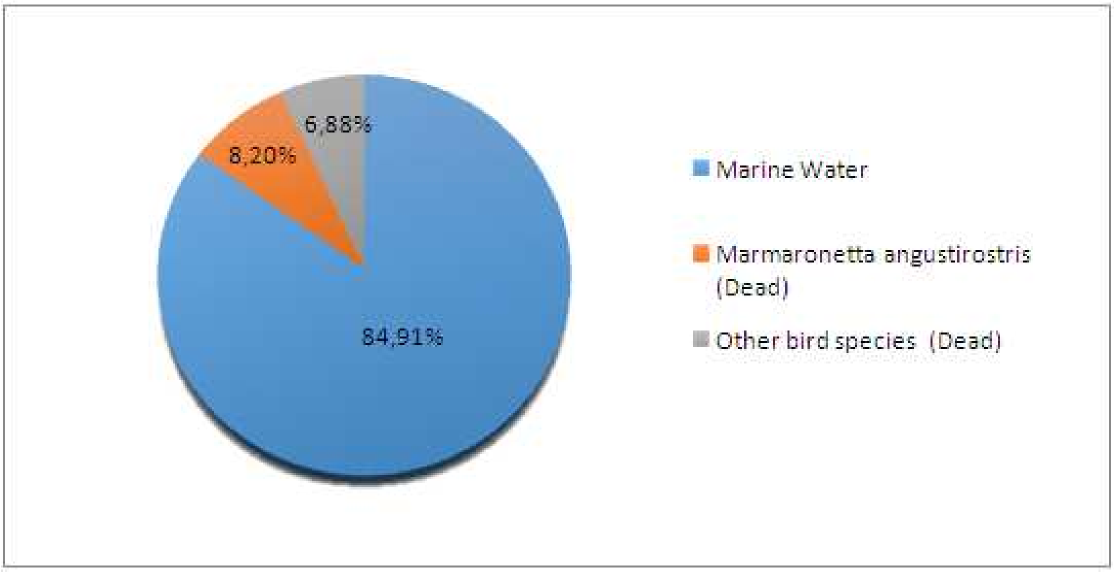

Figure 15 Financial guarantee distribution of Resource affectation by diesel spill.

Finally, prevention and mitigation actions have to be included. Article 33 of Royal Decree 183/2015 sets the value of 10% of primary repair to calculate final value of the financial guarantee. Table 32 shows the financial guarantee of the regasificacion natural gas plant.

Table 32 Financial Guarantee of the reference scenario

Repair	Amount
Prevention and mitigation	39.506.98 €
Primary Reparation	395.069.84 €
Financial Guarantee	**434.576.82 €**
Compensatory reparation	380.173.55 €
Financial Guarantee	**814.750.37 €**

The financial guarantee of 814.750.37€ comprises the range established by the RD 183/2015 between 300k – 200M Euros, which established the exemption of the financial guarantee if the company has implemented an environmental management system such as UNE-EN ISO 14001 or EMAS.

7. CONCLUSIONS

The environmental risk assessment of a liquefied natural gas drives to the following conclusions:

- Initiating events identified in the installation are related to pipe rupture, storage tank failure and cistern tank leakage.
- Scenario 7.1.A. "*diesel discharges into the sea because diesel + firewater overflowing the tank dike*" is the reference scenario identified by the EDI methodology. This scenario comprised the 5.32% of the total risk scenarios and the highest environmental damage with an EDI value of 1303842.
- Diesel, THT and hydraulic oil were the relevant dangerous substances identified that could affect the environment in a LNG plant. Other inorganic substances such as sodium bisulfite or sodium hypochlorite are not included in the evaluation because EDI methodology established infinite dilution if exist a spill of these substances into the sea.
- Even natural gas is the most dangerous substance in the installation is not the most relevant substance affecting the environment. Natural gas is important for its affectation to other installations in case of deflagration, fire, jet fire and explosion by the domino effect, releasing dangerous substances from storage tanks or main pipelines.
- Environmental evaluation identifies the affectation of 708 m^3 of marine water, 4 threatened and 178 non-threatened seabird species.
- The financial guarantee estimation demonstrates that marine water affectation cover 84.91% of the total guarantee estimation, representing the most relevant damage to the environment by diesel spill.

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APPENDIX

APPENDIX I: ACRONYMS

A. B. C= EDI modificators

Ad = Surface area of the basin or spill. m2.

AENOR=Spanish Association for Normalization and Certification.

EAS: Environmental Accidental Scenario.

Eca= Access to the damage area cost.

Ecc= Reparation consulting cost.

Ecf= Fix cost estimation

Ecr=Project control and review cost.

Ecu=Unit cost estimation

EDI=Environmental Damage Index.

ERA= Environmental Risk Assessment.

EROM =Environmental Responsibility Offer Model.

GMO= genetically modified organisms

HCl: Hydrochloric Acid

INSHT=Spain National Institute of Safety and Health at Work.

LNG: Liquefied Natural GAS.

Macc= Quantitive of resource affected.

MAGRAMA=Environmental, food and agriculture Spain Ministry.

Mp = Mass of chemical spilled, kg.

NaHSO3: Sodium Bisulfite

NaOCl: Sodium Hypochlorite

NG: Natural Gas

NVOC= Non volatile Organic chemical substance

q. p= resource EDI modification parameter.

SVOC= Semivolatile Organic chemical substance

T (s) = Fire duration, seconds.

THT: Tetrahydrothiophene.

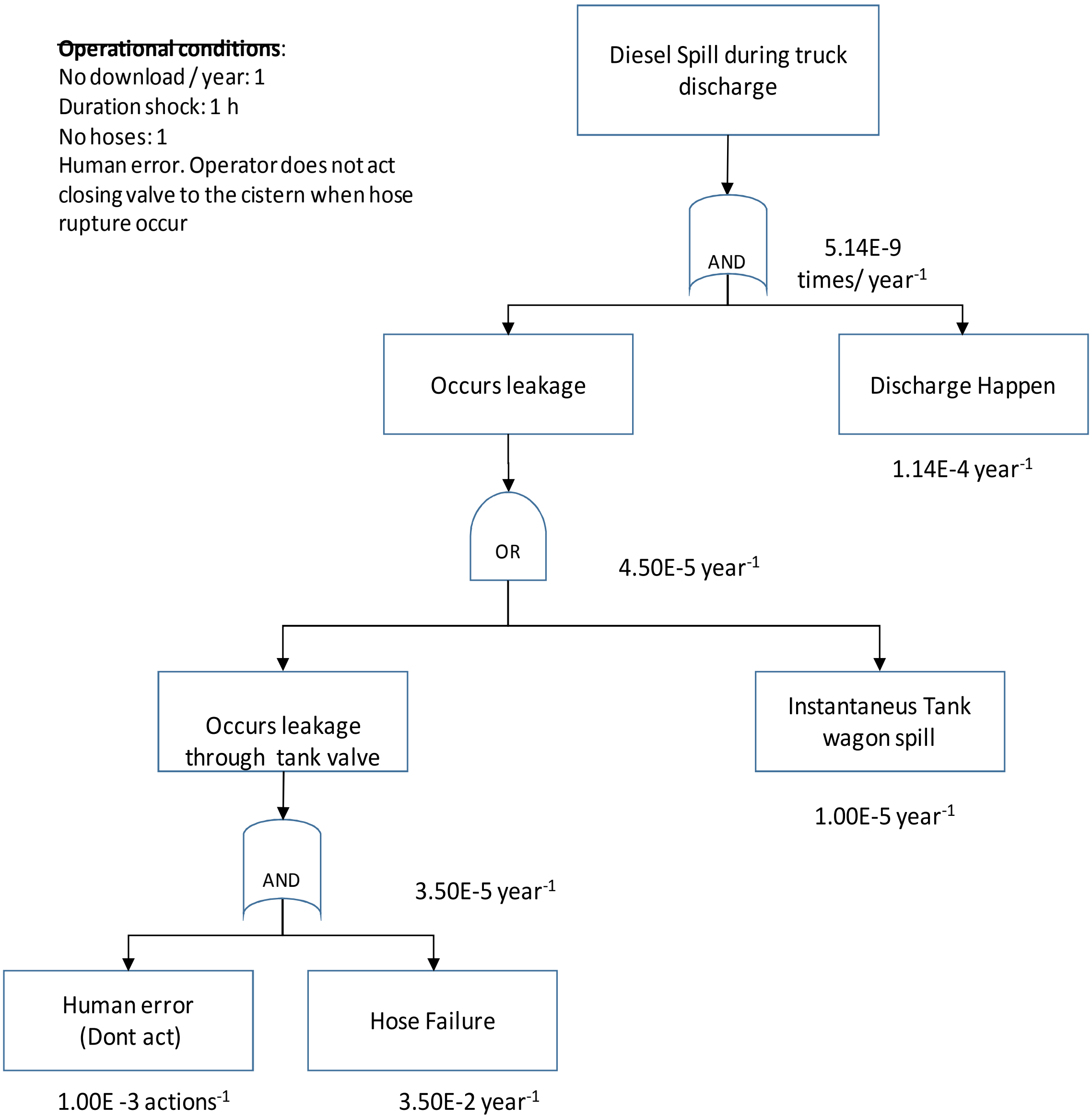
USEPA United States Environmental Protection Agency

Vc = Burning rate, kg / m2.s

β= Distant from nearest access road.

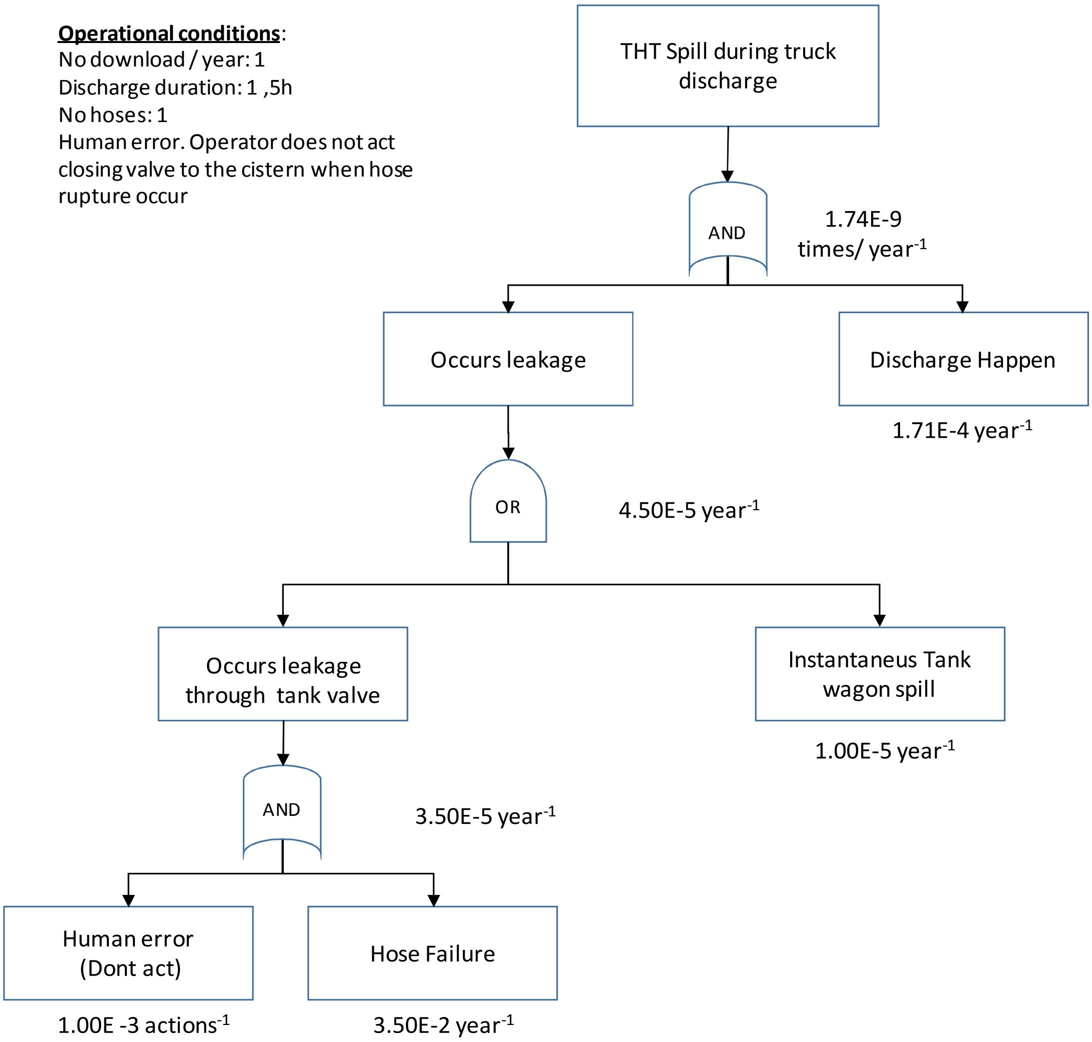
APPENDIX II: FAUL TREES

II.1. Diesel spill during truck discharge

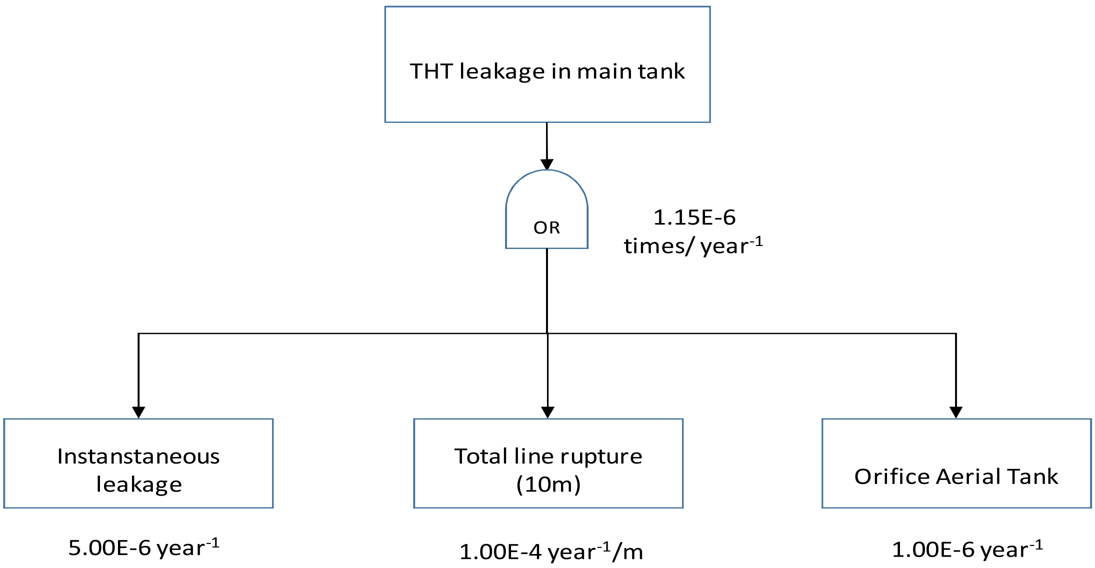


II.2. THT spill during truck discharge

Operational conditions:
No download / year: 1
Discharge duration: 1 ,5h
No hoses: 1
Human error. Operator does not act closing valve to the cistern when hose rupture occur

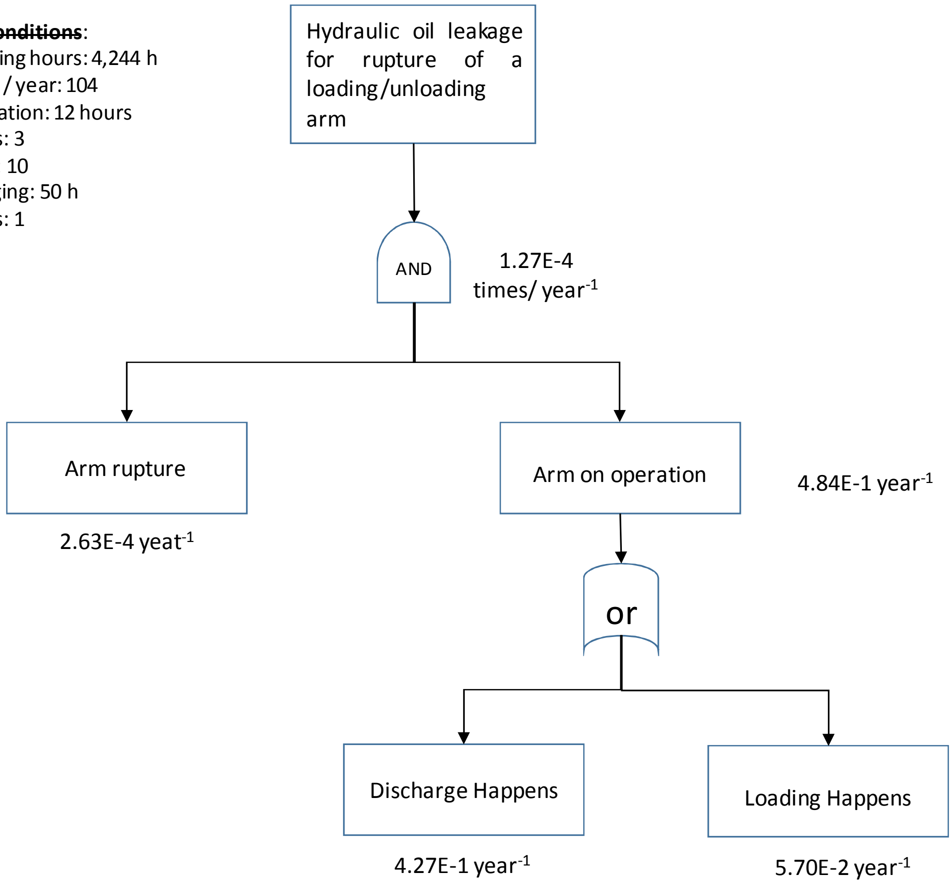


II.3. THT leakage in main tank

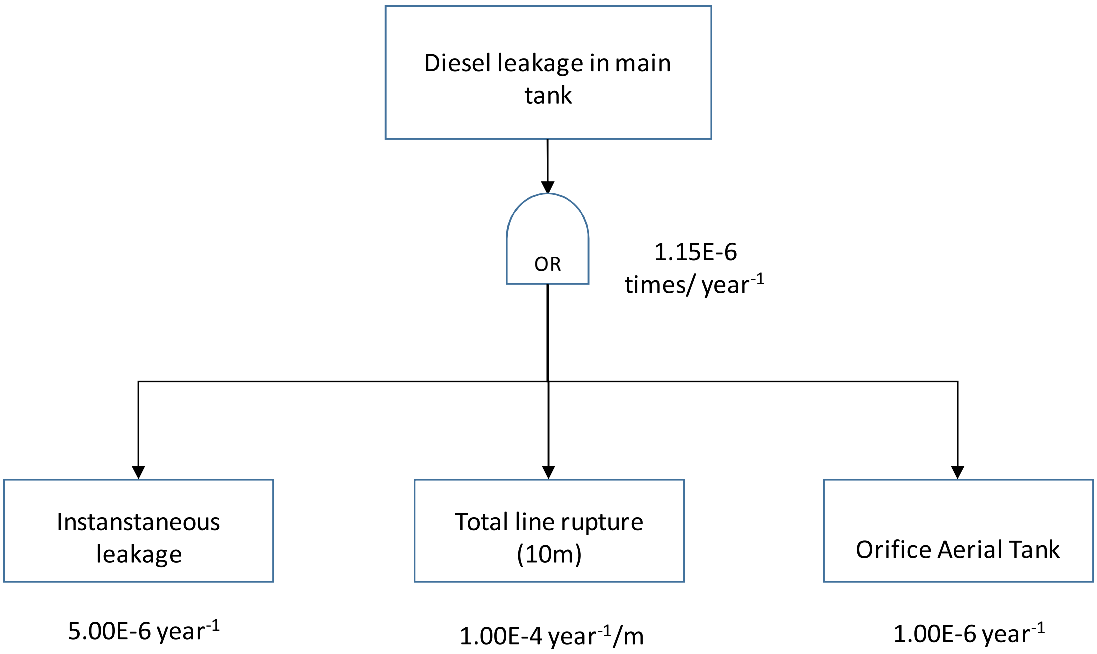


II.4. Hydraulic oil leakage for rupture of loading/unloading arm

~~**Operational conditions**~~:
Annual operating hours: 4,244 h
No downloads / year: 104
Download duration: 12 hours
No. liquid arms: 3
No load / year: 10
Duration charging: 50 h
No. liquid arms: 1

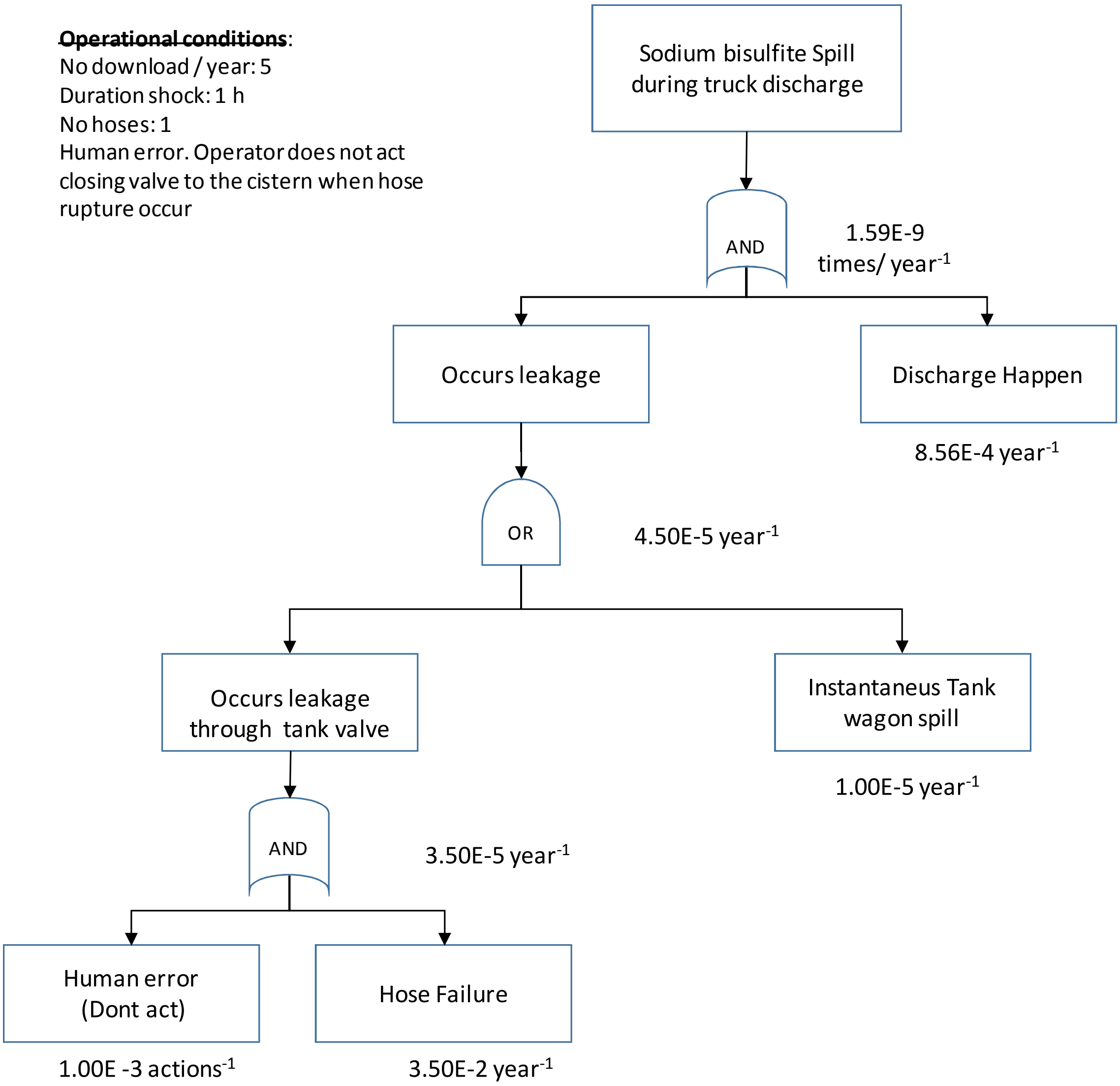


II.5. Hydraulic oil leakage for rupture of loading/unloading arm



II.6. Sodium bisulfite spill during truck discharge

Operational conditions:
No download / year: 5
Duration shock: 1 h
No hoses: 1
Human error. Operator does not act closing valve to the cistern when hose rupture occur



APPENDIX III INITIATING EVENT FREQUENCY CALCULATION

Table III.1 Initiating event frequency calculation

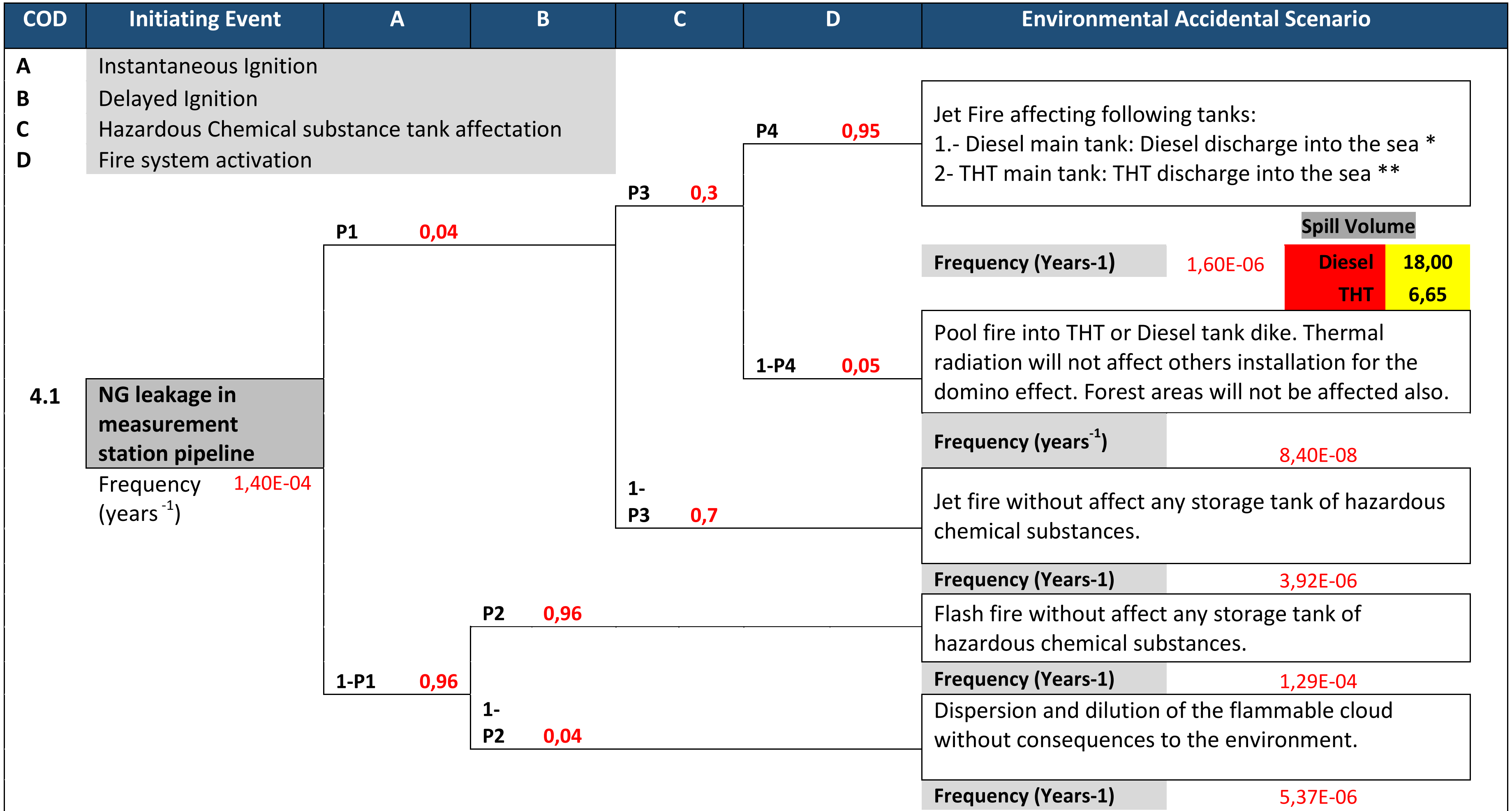
Initiating event	Basic failure element	Operational Conditions	Basic Frequency (year-1)	Initiating event frequency (times/year)
LNG leakage during loading/unloading of a methane vessel	Total pipeline rupture D > 6" (Freq. Length line)	Operation hours = 104*12*4 104 unloading/years Arm 12 hours/discharge 4 arm h = 10*50*2 10 loading/years Arm 50 hours/discharge 2 Arm	1.00E-07	5.99E-04
Hydraulic oil leakage for rupture of a loading/unloading arm	Arm rupture (Prob h-1)	Operation hours = 104*12*4 104 unloading/years 4 Arm 12 hours/discharge 4 arm h = 10*50*2 10 loading/years Arm 50 hours/discharge 2 Arm	3.00E-08	1.80E-04
LNG leakage from 36" loading pipeline to storage tanks	Total pipeline rupture D > 6" (Freq. Length line)	Length= 42 m Operation Year = 1248/(365*24)	1.00E-07	5.98E-07
LNG leakage from 20" secondary pumps manifold	Total pipeline rupture D > 6" (Freq. Length line)	Length = 37 m Year = 8760/(365*24)	1.00E-07	3.70E-06
LNG leakage during loading operation of a cistern truck	Hose rupture (Prob h-1)	hours = 12.410	4.00E-06	4.96E-02
NG leakage in measurement station pipeline	Total pipeline rupture D > 6" (Freq. Length line)"	Length= 60 m diameter= 16" Hours./year: 7800 h	2.62E-06	1.40E-04
THT leakage in Odorization system storage tank	Instantaneous leakage in single wall atmospheric tank	- Length= 10m	5.00E-06	1.15E-04
	Continuous release orifice		1.00E-04	

Table III.1 Initiating event frequency calculation

Initiating event	Basic failure element	Operational Conditions	Basic Frequency (year-1)	Initiating event frequency (times/year)
	Total line rupture D < 3”		1,00E-06	
THT leakage during operation of cistern tank unloading	Instantaneous release of an atmospheric cistern truck	-	1,00E-05	1,74E-09
	Hose rupture (Prob. h-1)		3,50E-02	
	Human error / Operator in action (Not act)		1,00E-03	
	Discharge happens	1 discharge/year 1,5 hours/discharge	1,71E-04	
THT leakage in distribution pipeline	Total line rupture D < 3”	Length = 50 m	1,00E-06	5,00E-05
Sodium bisulfite leakage in storage tank	Instantaneous leakage in single wall atmospheric tank	-	5,00E-06	1,15E-04
	Aerial tank orifice leakage		1,00E-04	
	Total line rupture D < 3”	Length= 10m	1,00E-06	
Sodium bisulfite leakage during operation of cistern tank unloading	Atmospheric cistern tank leakage	-	1,00E-05	1,59E-07
	Hose rupture (Prob. h-1)		3,50E-02	
	Human error (Act)		1,00E-03	
	Discharge happens	5 discharge/year 1 hours/discharge	8,56E-04	
Sodium hypochlorite leakage in storage tank	Instantaneous leakage in single wall atmospheric tank	-	5,00E-06	5,00E-06
HCL leakage in storage tank	Instantaneous leakage in single wall atmospheric tank	-	5,00E-06	5,00E-06
Diesel leakage in storage fire pump	Instantaneous leakage in double wall atmospheric tank	-	1,25E-08	1,25E-08

Table III.1 Initiating event frequency calculation

Initiating event	Basic failure element	Operational Conditions	Basic Frequency (year-1)	Initiating event frequency (times/year)
Diesel leakage in main tank	Instantaneous leakage in single wall atmospheric tank	-	5,00E-06	1,15E-04
	Aerial tank orifice leakage	-	1,00E-04	
	Total line rupture D < 3”	Length = 10 m	1,00E-06	
Diesel leakage in distribution pipeline	Total line rupture D < 3”	Length = 230 m	1,00E-06	2,30E-04
Diesel leakage during operation of cistern tank unloading	Instantaneous release of an atmospheric cistern truck		1,00E-05	5,14E-09
	Hose rupture (Prob. h-1)		4,00E-06	
	Human error (Act)		1,00E-03	
	Discharge happens	1 discharge/year 1 hours/discharge	1,14E-04	
Diesel leakage in emergency generator tank	Instantaneous leakage in double wall atmospheric tank	-	1,25E-08	1,25E-08
Fire in electrical substation	Short circuit (Freq. h^{-1})	h = 365*24 All year operation	1,00E-06	8,76E-03



* Because diesel+firewater overflow the tank dike, and drag of diesel through the rainy water channel to sea.

** Because THT+firewater overflow the tank dike, and drag of THT through the rainy water channel to sea.

Figure IV.1 NG leakage in measurement station pipeline Event Tree

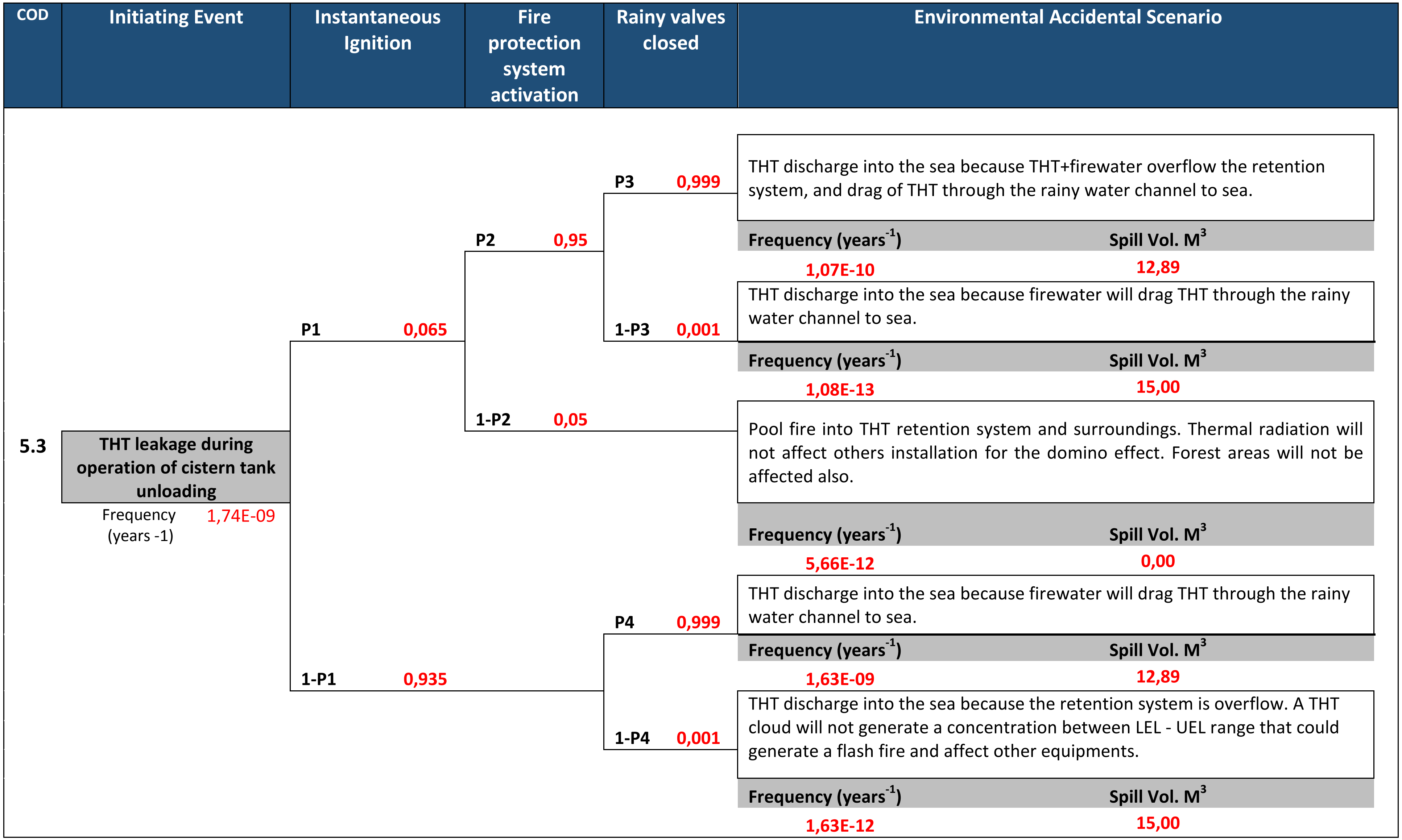


Figure IV.2 THT leakage during operation of cistern tank unloading Event Tree

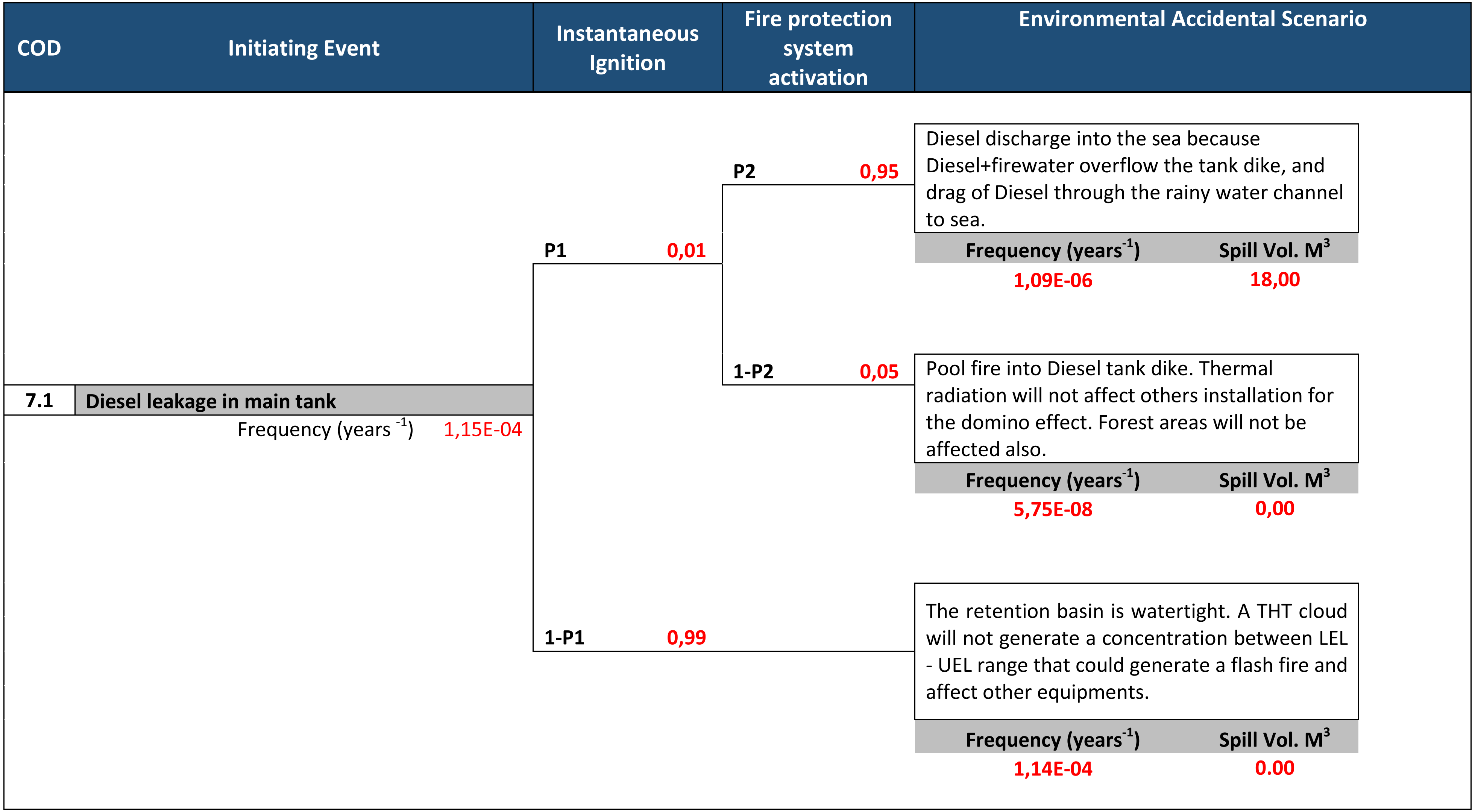


Figure IV.3 Diesel leakage in main tank Event tree

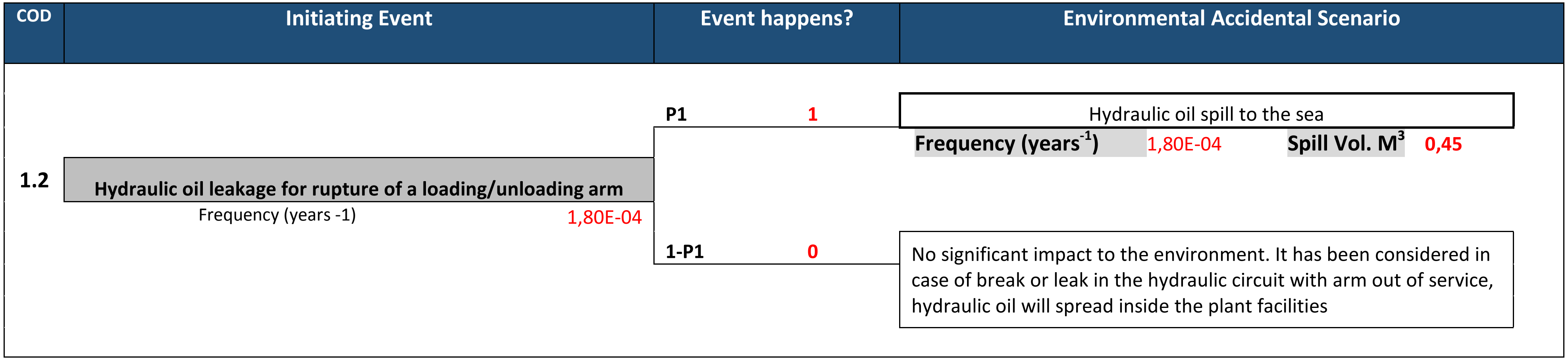


Figure IV.4 Hydraulic oil leakage for rupture of a loading/unloading arm event tree

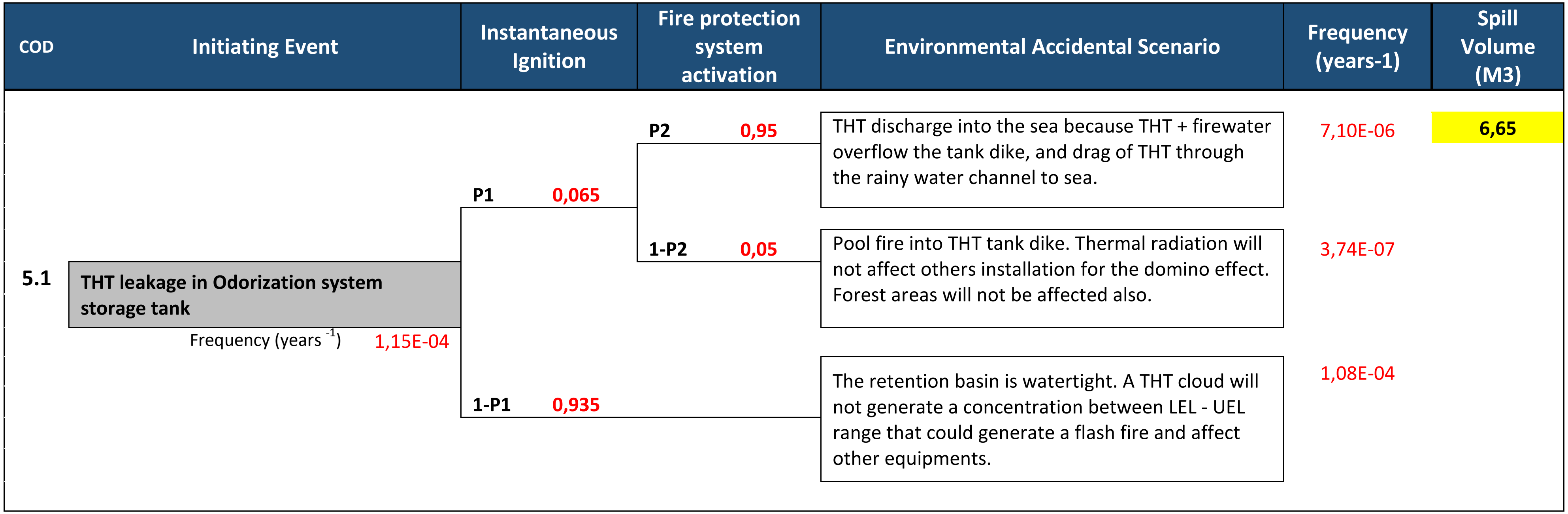


Figure IV.5 THT leakage in Odorization system storage tank event tree

	Initiating Event	Instantaneous Ignition	FPS activation	Environmental Accidental Scenario	Frequency (years-1)	Spill Volume (M^3)
5.2	**THT leakage in distribution pipeline** Frequency (years $^{-1}$) 5,00E-05	**P1** 0,065	**P2** 0,95	THT discharge into the sea because firewater will drag THT through the rainy water channel to sea.	3,09E-06	**0,01**
			1-P2 0,05	Pool fire in surroundings. Thermal radiation will not affect others installation for the domino effect. Forest areas will not be affected also.	1,63E-07	
		1-P1 0,935		THT discharge into the sea through the rainy water channel. A THT cloud will not generate a concentration between LEL - UEL range that could generate a flash fire and affect other equipments.	4,68E-05	**0,01**

Figure IV.6 THT leakage in distribution pipeline event tree

COD	Initiating Event	Rainy valves closed Human Error (Don't Act)	Environmental Accidental Scenario	Frequency (years-1)	Spill Volume (M^3)
6.2	**Sodium bisulfite leakage during operation of cistern tank unloading** Frequency (years $^{-1}$) 1,59E-07	**P1** 0,999	Sodium bisulfite spill without consequences to the environment.	1,58E-07	
		1-P1 0,001	Sodium bisulfite discharge into the see	1,59E-10	**15,00**

Figure IV.7 Sodium bisulfite leakage during operation of cistern tank unloading event tree

COD	Initiating Event	Instantaneous Ignition	FPS activation	Environmental Accidental Scenario	Frequency (years-1)	Spill Volume (M^3)
FPS: Fire Protection System Activation						
7.2	**Diesel leakage in distribution pipeline** Frequency (years $^{-1}$) 2,30E-04	P1 0,01	P2 0,95	Diesel discharges into the sea because firewater will drag Diesel through the rainy water channel to sea.	2,19E-06	0,47
			1-P2 0,05	Pool fire in surroundings. Thermal radiation will not affect others installation for the domino effect. Forest areas will not be affected also.	1,15E-07	
		1-P1 0,99		Diesel discharge into the sea through the rainy water channel. A cloud will not generate a concentration between LEL - UEL range that could generate a flash fire and affect other equipments.	2,28E-04	0,47

Figure IV.8 Diesel leakage in distribution pipeline event tree

COD	Initiating Event	Instantaneous Ignition	FPS activation	Environmental Accidental Scenario	Frequency (years-1)	Spill Vol (M3)
FPS: Fire Protection System Activation						
7.3	**Diesel leakage during operation of cistern tank unloading** Frequency (years $^{-1}$) 5,14E-09	P1 0,01	P2 0,95	Diesel discharges into the sea because firewater will drag Diesel through the rainy water channel to sea.	4,88E-11	15,00
			1-P2 0,05	Pool fire in spill area. Thermal radiation will not affect others installation for the domino effect. Forest areas will not be affected also.	2,57E-12	
		1-P1 0,99		Diesel discharge into the see through rainy channels. A diesel flammable cloud will not generate a concentration between LEL - UEL range that could generate a flash fire and affect other equipments.	5,09E-09	15,00

Figure IV.9 Diesel leakage during operation of cistern tank unloading Event tree

COD	Initiating Event	Instantaneous Ignition	FPS activation	Environmental Accidental Scenario	Frequency (years-1)	Spill Vol (M3)
FPS: Fire Protection System Activation						
8.1	**Diesel leakage in emergency generator tank**	**P1** 0,01	**P2** 0,95	Diesel discharges into the sea because firewater will drag Diesel through the rainy water channel to sea.	1,19E-10	**2,70**
			1-P2 0,05	Pool fire in spill area. Thermal radiation will not affect others installation for the domino effect. Forest areas will not be affected also.	6,25E-12	
		1-P1 0,99		Diesel discharge into the see through rainy channels. A diesel flammable cloud will not generate a concentration between LEL - UEL range that could generate a flash fire and affect other equipments.	1,24E-08	**2,70**

Figure IV.10 Diesel leakage in emergency generator tank event tree

APPENDIX V: EDI CALCULATION

Table V.1 EDI Calculation for scenario 1.2.A Hydraulic oil spill to the sea

Scenario		1.2.A Hydraulic oil spill to the sea		
EDI Substance		Hydraulic Oil		
EDI Resource		Marine Water	Threat bird species	Not Threat bird species
EDI Group		1	16	16
EDI Parameters	Ecf	0.00	0.00	0.00
	Ecu	3648	11866	2373
	α	0.50	1.00	1.00
	Ec	1.00	0.50	1.00
	Ecr	1.934	6027	6027
	Ecc	0.03	0.03	0.03
Marine bed Parameters	P	0.00	0.00	0.00
	M_{acc}	0.00	0.00	0.00
	q	0.00	0.00	0.00
Modificators Ma	M_{A2}	0.00	1.00	1.00
	A	1.00	1.00	1.00
Modificators M_B	M_{B1}	1.00	1.00	1.00
	M_{B2}	0.00	2.00	2.00
	M_{B12}	1.00	0.00	0.00
	M_{B15}	0.00	2.00	2.00
	M_{B18}	1.00	0.00	0.00
	B	1.00	4.00	4.00
Modificators Ma	M_{C1}	1.00	0.00	0.00
	M_{C5}	0.00	1.00	1.00
	C	1.00	1.00	1.00
EDI Combination		1880.71	30651.77	15984.57
EDI Scenario		48517		

Table V. *2*EDI Calculation for scenario NG leakage in measurement station pipeline 4.1.A and Diesel leakage in main tank 7.1.A

Scenario		**4.1.A** Jet Fire affecting following tanks: Diesel main tank: Diesel discharge into the sea **7.1.A** Diesel discharge into the sea because Diesel+ firewater overflow the tank dike and drag of Diesel through the rainy water channel to sea.		
EDI Substance		Diesel		
EDI Resource		Marine Water	Threat bird species	Not Threat bird species
EDI Group		1	16	16
EDI Parameters	Ecf	0.00	0.00	0.00
	Ecu	3648	11866	2373
	α	15.53	36.00	36.00
	Ec	1.00	0.50	1.00
	Ecr	1.934	6027	6027
	Ecc	0.03	0.03	0.03
Marine bed Parameters	P	0.00	0.00	0.00
	M_{acc}	0.00	0.00	0.00
	q	0.00	0.00	0.00
Modificators Ma	M_{A2}	0.00	1.00	1.00
	A	1.00	1.00	1.00
Modificators M_B	M_{B1}	1.00	1.00	1.00
	M_{B2}	0.00	2.00	2.00
	M_{B12}	1.00	0.00	0.00
	M_{B15}	0.00	2.00	2.00
	M_{B18}	1.00	0.00	0.00
	B	1.00	4.00	4.00
Modificators Ma	M_{C1}	1.00	0.00	0.00
	M_{C5}	0.00	1.00	1.00
	C	1.00	1.00	1.00
EDI Combination		58353.62	886190.37	358171.17
EDI Scenario		**1302715**		

Table V. ***3*** EDI Calculation for scenarios NG leakage in measurement station pipeline 4.1.B / THT leakage in Odorization system storage tank 5.1.A

Scenario		**4.1.B** Jet Fire affecting following tanks: THT main tank: THT discharge into the sea **5.1.A** THT discharge into the sea because THT + firewater overflow the tank dike and drag of THT through the rainy water channel to sea.		
EDI Substance		THT		
EDI Resource		Marine Water	Threat bird species	Not Threat bird species
EDI Group		1	16	16
EDI Parameters	Ecf	0.00	0.00	0.00
	Ecu	866	11866	2373
	α	7.03	14.06	14.06
	Ec	1.00	0.50	1.00
	Ecr	1.934	6027	6027
	Ecc	0.03	0.03	0.03
Marine bed Parameters	P	0.00	0.00	0.00
	M_{acc}	0.00	0.00	0.00
	q	0.00	0.00	0.00
Modificators Ma	M_{A2}	0.00	1.00	1.00
	A	1.00	1.00	1.00
Modificators M_B	M_{B1}	1.00	1.00	1.00
	M_{B2}	0.00	2.00	2.00
	M_{B12}	1.00	0.00	0.00
	M_{B15}	0.00	2.00	2.00
	M_{B18}	1.00	0.00	0.00
	B	1.00	4.00	4.00
Modificators Ma	M_{C1}	1.00	0.00	0.00
	M_{C5}	0.00	1.00	1.00
	C	1.00	1.00	1.00
EDI Combination		6271.32	349818.99	143640.70
EDI Scenario		**499731**		

Table V. *4*EDI Calculation for scenarios THT leakage in distribution pipeline 5.2.A / 5.2.B

Scenario		**5.2.A** THT discharge into the sea because firewater will drag THT through the rainy water channel to sea. **5.2.B** THT discharge into the sea through the rainy water channel. A THT cloud will not generate a concentration between LEL - UEL range that could generate a flash fire and affect other equipments.		
EDI Substance		THT		
EDI Resource		Marine Water	Threat bird species	Not Threat bird species
EDI Group		1	16	16
EDI Parameters	Ecf	0.00	0.00	0.00
	Ecu	866	11866	2373
	α	0.14	0.27	0.27
	Ec	1.00	0.50	1.00
	Ecr	1.934	6027	6027
	Ecc	0.03	0.03	0.03
Marine bed Parameters	P	0.00	0.00	0.00
	M_{acc}	0.00	0.00	0.00
	q	0.00	0.00	0.00
Modificators Ma	M_{A2}	0.00	1.00	1.00
	A	1.00	1.00	1.00
Modificators M_B	M_{B1}	1.00	1.00	1.00
	M_{B2}	0.00	2.00	2.00
	M_{B12}	1.00	0.00	0.00
	M_{B15}	0.00	2.00	2.00
	M_{B18}	1.00	0.00	0.00
	B	1.00	4.00	4.00
Modificators Ma	M_{C1}	1.00	0.00	0.00
	M_{C5}	0.00	1.00	1.00
	C	1.00	1.00	1.00
EDI Combination		124.58	12926.40	8895.02
EDI Scenario		**21946**		

Table V. *5* EDI Calculation for scenarios THT leakage during operation of cistern tank unloading 5.3.A / 5.3.C

Scenario		**5.3.A** THT discharge into the sea because THT + firewater overflow the retention system and drag of THT through the rainy water channel to sea. **5.3.C** THT discharge into the sea because firewater will drag THT through the rainy water channel to sea.		
EDI Substance		THT		
EDI Resource		Marine Water	Threat bird species	Not Threat bird species
EDI Group		1	16	16
EDI Parameters	Ecf	0.00	0.00	0.00
	Ecu	866	11866	2373
	α	13.02	26.04	26.04
	Ec	1.00	0.50	1.00
	Ecr	1.934	6027	6027
	Ecc	0.03	0.03	0.03
Marine bed Parameters	P	0.00	0.00	0.00
	M_{acc}	0.00	0.00	0.00
	q	0.00	0.00	0.00
Modificators Ma	M_{A2}	0.00	1.00	1.00
	A	1.00	1.00	1.00
Modificators M_B	M_{B1}	1.00	1.00	1.00
	M_{B2}	0.00	2.00	2.00
	M_{B12}	1.00	0.00	0.00
	M_{B15}	0.00	2.00	2.00
	M_{B18}	1.00	0.00	0.00
	B	1.00	4.00	4.00
Modificators Ma	M_{C1}	1.00	0.00	0.00
	M_{C5}	0.00	1.00	1.00
	C	1.00	1.00	1.00
EDI Combination		11616.31	642768.90	260810.79
EDI Scenario		915196		

Table V. *6* EDI Calculation for scenarios THT leakage during operation of cistern tank unloading 5.3.B / 5.3.D

Scenario		**5.3.B** THT discharge into the sea because firewater will drag THT through the rainy water channel to sea. **5.3.D** THT discharge into the sea because the retention system is overflow. A THT cloud will not generate a concentration between LEL - UEL range that could generate a flash fire and affect other equipments.		
EDI Substance		THT		
EDI Resource		Marine Water	Threat bird species	Not Threat bird species
EDI Group		1	16	16
EDI Parameters	Ecf	0.00	0.00	0.00
	Ecu	866	11866	2373
	α	15.02	30.04	30.04
	Ec	1.00	0.50	1.00
	Ecr	1.934	6027	6027
	Ecc	0.03	0.03	0.03
Marine bed Parameters	P	0.00	0.00	0.00
	M_{acc}	0.00	0.00	0.00
	q	0.00	0.00	0.00
Modificators Ma	M_{A2}	0.00	1.00	1.00
	A	1.00	1.00	1.00
Modificators M_B	M_{B1}	1.00	1.00	1.00
	M_{B2}	0.00	2.00	2.00
	M_{B12}	1.00	0.00	0.00
	M_{B15}	0.00	2.00	2.00
	M_{B18}	1.00	0.00	0.00
	B	1.00	4.00	4.00
Modificators Ma	M_{C1}	1.00	0.00	0.00
	M_{C5}	0.00	1.00	1.00
	C	1.00	1.00	1.00
EDI Combination		13397.97	740418.64	299867.39
EDI Scenario		**1053684**		

Table V. *7* EDI Calculation for scenarios Diesel leakage in firewater pumps tank 6.5.A / 6.5.B

Scenario		**6.5.A** Diesel discharges into the sea because firewater will drag Diesel through the rainy water channel to sea. **6.5.B** Diesel discharge into the see through rainy channels. A diesel flammable cloud will not generate a concentration between LEL - UEL range that could generate a flash fire and affect other equipments.		
EDI Substance		Diesel		
EDI Resource		Marine Water	Threat bird species	Not Threat bird species
EDI Group		1	16	16
EDI Parameters	Ecf	0.00	0.00	0.00
	Ecu	3648	11866	2373
	α	7.85	18.04	18.04
	Ec	1.00	0.50	1.00
	Ecr	1.934	6027	6027
	Ecc	0.03	0.03	0.03
Marine bed Parameters	P	0.00	0.00	0.00
	M_{acc}	0.00	0.00	0.00
	q	0.00	0.00	0.00
Modificators Ma	M_{A2}	0.00	1.00	1.00
	A	1.00	1.00	1.00
Modificators M_B	M_{B1}	1.00	1.00	1.00
	M_{B2}	0.00	2.00	2.00
	M_{B12}	1.00	0.00	0.00
	M_{B15}	0.00	2.00	2.00
	M_{B18}	1.00	0.00	0.00
	B	1.00	4.00	4.00
Modificators Ma	M_{C1}	1.00	0.00	0.00
	M_{C5}	0.00	1.00	1.00
	C	1.00	1.00	1.00
EDI Combination		29482.63	447094.67	182547.69
EDI Scenario		**659125**		

Table V. *8* EDI Calculation for scenarios Diesel leakage in distribution pipeline 7.2.A / 7.2.B

Scenario		**7.2.A** Diesel discharges into the sea because firewater will drag Diesel through the rainy water channel to sea. **7.2.B** Diesel discharge into the sea through the rainy water channel. A cloud will not generate a concentration between LEL - UEL range that could generate a flash fire and affect other equipments.		
EDI Substance		Diesel		
EDI Resource		Marine Water	Threat bird species	Not Threat bird species
EDI Group		1	16	16
EDI Parameters	Ecf	0.00	0.00	0.00
	Ecu	3648	11866	2373
	α	0.30	0.69	0.69
	Ec	1.00	0.50	1.00
	Ecr	1.934	6027	6027
	Ecc	0.03	0.03	0.03
Marine bed Parameters	P	0.00	0.00	0.00
	M_{acc}	0.00	0.00	0.00
	q	0.00	0.00	0.00
Modificators Ma	M_{A2}	0.00	1.00	1.00
	A	1.00	1.00	1.00
Modificators M_B	M_{B1}	1.00	1.00	1.00
	M_{B2}	0.00	2.00	2.00
	M_{B12}	1.00	0.00	0.00
	M_{B15}	0.00	2.00	2.00
	M_{B18}	1.00	0.00	0.00
	B	1.00	4.00	4.00
Modificators Ma	M_{C1}	1.00	0.00	0.00
	M_{C5}	0.00	1.00	1.00
	C	1.00	1.00	1.00
EDI Combination		1131.85	23105.02	12966.13
EDI Scenario		**37203**		

Table V. *9* EDI Calculation for scenarios Diesel leakage during operation of cistern tank unloading 7.3.A / 7.3.B

Scenario		**7.3.A** Diesel discharges into the sea because firewater will drag Diesel through the rainy water channel to sea. **7.3.B** Diesel discharge into the see through rainy channels. A diesel flammable cloud will not generate a concentration between LEL - UEL range that could generate a flash fire and affect other equipments.		
EDI Substance		Diesel		
EDI Resource		Marine Water	Threat bird species	Not Threat bird species
EDI Group		1	16	16
EDI Parameters	Ecf	0.00	0.00	0.00
	Ecu	3648	11866	2373
	α	13.07	30.04	30.04
	Ec	1.00	0.50	1.00
	Ecr	1.934	6027	6027
	Ecc	0.03	0.03	0.03
Marine bed Parameters	P	0.00	0.00	0.00
	M_{acc}	0.00	0.00	0.00
	q	0.00	0.00	0.00
Modificators Ma	M_{A2}	0.00	1.00	1.00
	A	1.00	1.00	1.00
Modificators M_B	M_{B1}	1.00	1.00	1.00
	M_{B2}	0.00	2.00	2.00
	M_{B12}	1.00	0.00	0.00
	M_{B15}	0.00	2.00	2.00
	M_{B18}	1.00	0.00	0.00
	B	1.00	4.00	4.00
Modificators Ma	M_{C1}	1.00	0.00	0.00
	M_{C5}	0.00	1.00	1.00
	C	1.00	1.00	1.00
EDI Combination		49103.88	740532.99	299913.13
EDI Scenario		**1089550**		