ΠΟΛΥΤΕΧΝΕΙΟ
ΚΡΗΤΗΣ

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Analysis of historical data of accidents in oil production and transportation and their environmental impact.

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List of abbreviations

AMF	Automatic Mode Function
API	American Petroleum Institute
BOP	Blow-Out Preventer
BSR	Blind Shear Ram
CAS	Condition Assessment Scheme
CCU	Central Control Unit
CLC	Civil Liability For Oil Pollution Damage
DWH	Deep-Water Horizon
dwt	Deadweight Tonnage
EGIG	European Gas Pipeline Incident Data Group
EMSA	European Maritime Safety Agency
EU	European Union
FPSO	Floating Production Storage And Offloading
GRT	Gross Register Tonnage
HNS	Hazardous & Noxious Substances
IMO	International Maritime Organization
IOPC	International Fund For Compensation For Oil Pollution Damage
ISB	In-Situ Burning
ITOPF	International Tanker Owners Pollution Federation Ltd
LAT	Lead Administrative Trustee
LMRP	Lower Marine Riser Package
MARPOL	The International Convention For The Prevention Of Pollution From S
MEPC	Marine Environment Protection Committee
MEPD	Marine Environment Protection Division
MGS	Mud Gas Separator
MSC	Maritime Safety Committee
NCP	National Contingency Plan
NOAA	National Oceanic And Atmospheric Administration
OCS	Outer Continental Shelf
OILPOL	International Convention For The Prevention Of Pollution Of The Sea
OPA	Oil Pollution Act
OSW	Oil Spill Waste

OSWMP	Oil Spill Waste Management Plan
P&A	Plugged And Abandoned
PHMSA	Pipeline And Hazardous Materials Safety Administration
RITT	Riser Insertion Tube Tool
RMPCS	Regional Marine Pollution Combating Stations
ROV	Remotely Operated Vehicles
SOLAS	Safety Of Life At Sea
THC	Total Hydrocarbon Content
TMR	Triple Modular Redundancy
U.S.	United States
UK	United Kingdom
USA	United States Of America
VLCC	Very Large Crude Carrier

Introduction

In this work are described the most effective oil spill recovery and restoration methods that are used by the industry and the environmental impacts spills. The data that was selected in this work was selected with the criteria to be indicative of the global trends. The term oil spill is used to describe the spill of all petroleum products that may occur in an incident that can potentially harm the environment.

The measurement units were kept unchanged from the initial sources due to the lack of the properties of the fluids.

The biggest challenge in evaluating oil spill data, is the collection of it. There isn't a body or an organization that collects from all the sources worldwide. Even though there are agencies on the national level worldwide, those collect and provide information that is often unconfirmed, an estimation or initial.

It is also described how certain incidents affected the legislation and technology to effectively reduce the number and volume of oil spills, and the current legislation regarding the recovery and response methods.

In the end are given recommendations for Greece.

1. Environmental consequences of oil spills

The portrayal of oil spills is often characterized as “environmental disasters” with major consequences for the marine and coastal flora and fauna, and they can cause an extensive damage for the environment. Depending on the size, type, location and environment of the incident the impact can be from minor to severe, damaging the ecosystems and the people in the area decreasing the quality of life.

Over the past 50 years oil spills are being researched and substantial knowledge have been added to the understanding of oil spills. Subsequently the understanding of the environmental impact of oil spills is better than other types of pollutants (heavy metals, plastic) that can occur in the marine environment.

The variety of consequences of an oil spill includes:

- Physicochemical changes in the natural environment, for example incorporation of the oil mixed with other materials into sediments
- Physical smothering effects on flora and fauna;
- Lethal or sub-lethal toxic effects on flora and fauna;
- Changes in biological communities resulting from oil effects on key organisms, e.g. increased abundance of intertidal algae following death of limpets which normally graze the algae.

There are many factors that play a major role in determining the effect of an incident and the restoration rates. The proven ones are type of oil, volume of oil on the shore or sea, geographical location, weather conditions, flora and fauna in the area and their sensitivity, clean-up methods and response time.

1.1 Oil type

The physicochemical properties can differ extensively from oil to oil and their products. For example aromatic oils with low B.P. (boiling point) have high toxicity and have higher chances to penetrate cell membranes causing great disruptions. Lighter oils have higher toxicity and tend to cause more damage to the flora and fauna. Nonetheless the components with the highest toxicity tend to evaporate fast and the damage is localized and short-term.

The toxicity is lower in heavy oils (crudes and heavy fuel oil) and they can cover area nearshore and in while doing so they kill organisms through smothering. This effect can also take place after the emulsification of water in oil (a “mousse” like substance), and if the emulsified layer is not cleaned up they can get mixed up with sand, gravel and stones and become into a hardened asphalt-like substance.

1.2 Biological characteristics of the area

The impact of oil spills in open seas and their seabed is not that well documented and it is assumed that its low. The vast open area provides a high dilution potential which serves as a mitigation factor. Nevertheless, the organisms that live in surface waters (i.e. planktonic organisms) can be damaged by oil, but lasting effects never have been observed because of the high regeneration of the population and immigration from the polluted area. As a result of that regeneration the food chain is not affected greatly in the affected areas.

There have been raised concerns about the impact in the food chain, for example in the reproduction cycle of different species', for example ichthyoplankton is affected by the toxicity of the oil. Nevertheless, the entire population of those species might not suffer since there are limited effects in the adult population, and the exact effects on large population in the open sea are unknown since there is not sufficient evidence. There is not an argument that oil pollution increases the mortality of eggs and larvae, however the scale of that is low comparted to the mortality because of other factors, such as predation and weather changes.

The animals that most likely will be hurt or die in open waters are sea birds, especially by floating heavy oil slicks. By getting in touch with heavy oil most of the seabirds lose the ability to control the body temperature, fly and/or float so they can drown, and starve since they cannot hunt effectively. The injection of oil has been also observed during preening, which is lethal, it is not as common as the previous causes of death. Although the mortality rate on individual birds is high when they come in contact with oil, there is not sufficient evidence of damage on entire populations, even when the number of deaths is large the effect on the total breeding populations is low.

Sea mammals that live in open waters have lower risk from oil pollution. However marine species that breed nearshore or on shorelines have increased risk of damage, since they will most likely come in contact with oil. Mammal species that depend on temperature regulation also may die when they come in contact with heavy oil.

Oil from an oil spill tends to accumulate in the shorelines, compared to other marine locations, therefore the impact is higher there. The effects on the shoreline vary, the main factor is the oil retention. Marshes, creeks mud flats, hardened shorelines and sandy beaches have different oil retention, the type of the oil plays a major role as well. High viscosity oils are accumulated in higher volume than oils with low viscosity. The tidal range also impacts the oil retention, for example a shoreline with a higher tidal range, disruptions along the shoreline is more likely to hold larger quantities of oil than those with low tidal range and shorelines without any disruptions.

The natural restoration of a shoreline depends mostly on the movement of water (tidal currents and waves) and the rock composition. For example, if the shoreline is composed by sand and its exposed to more frequent wave action and tides will clean faster than those who aren't. Those environments tend to be populated by adaptive species like grazers. In case a high number of grazers is killed due to oil pollution, their food sources (e.g. seaweeds) increases, then there is an increase of the population, this recovery depends on the impact can be achieved from one to five years. This of course is not always the case, in case of a wide polluted area the recolonization rate will be slow and the complete return of the population will take more years.

The viscosity of the oil is the main factor of the sediment penetration. The higher the viscosity the lower the penetration of the oil the sediment. The sediments regardless of their compositions will held large quantities of oil causing long term effects in the area.

The penetration of the oil in coarser sediments is greater than finer (sandy and muddy). Wetlands, which are more sheltered than other shoreline areas, are characterized by finer sediment, and the oil cannot penetrate deep. However, they have greater populations of animals such as birds and they also serve a breeding/nursery place for other species, and in cases when the oil penetrates deeper the self-recovery of the habitats is slower.

In shorelines with fine sediment, the upper littoral fringe consists mainly of saltmarsh and if it is exposed to repeated oilings will take more than ten years to fully recover, but usually is exposed to a single oil oiling. Depending on the cleanup methods used the damage can vary, and in some cases the cleanup has a greater impact than the direct contact with oil. Shoreline areas, that server as habitat areas, such as mangrove swamps in tropical regions have a higher mortality rate, they serve as a coastal protection but if the oiling coat the roots as it penetrates the sediment the damage can take decades to recover. In addition, like in saltmarshes, the cleanup techniques must be selected carefully as the damage can be irreversible.

1.3 Seasons

The impact that an oil spill can cause changes greatly on the season that it takes place, mostly because of the temperature changes. For example, in saltmarshes the flora tends to naturally die in the winter and during the cold period the effect is limited on the surface. Nevertheless, it can affect the seeds, especially during the end of winter and start of spring. The impact is greater during spring or summer when the flora is developing resulting to a lower production of seeds.

The impact on the fauna is depending on the season as well. An oil spill in a breeding area, during mating seasons of birds will affect a large number of hatchlings and reduce the recovery time comparted to a different season. The effects are greater on migratory species on those seasons as well

1.4 Oil cleanup decisions.

Depending on the situation, as it was noted earlier, cleanup methods play a major role in the natural recover of an area, they can improve the recovery rate or do irreversible damage. Each case must be examined thoroughly and be analyzed so the appropriate method is chosen, including not only the environmental but the economic factors as well. In some cases, the recovery of a certain area may have better results without cleanup methods, especially when the natural cleaning process takes a short time. [1]

2. Long term impact of oil spills

Oil spills are presented mainly in small amounts, with no radical consequence, avoiding the impacts of continuing oiling in the same area. Additionally, most of the spills regarding their magnitude and duration are not crucial for the environment, with few cases to have noticeable effects that lasted one or two years. In situations where oil spills were released in big sums, the majority of the marine ecosystem was convalesced quickly. Whilst the remaining effects are limited and concentrated in small areas. In the latter case, the main cause of a long effect is heavy oil, which is persistent and can be incorporated in the sediment by ocean waves or tides. The recovery from a non-persistent oil is generally quick and follows a natural flow. In addition to the causes of chronic effects from an oil spilt is the clean-up process, these activities are intrusive to the life of the marine population, their reproductive patterns are altered or their geographical position isolates them and disturbs the natural circle. The reestablishment of natural process will take place in the end, although many are concerned of the impact that this delay may have. The primer stages of convalescence are clearer, albeit the final stages are difficult to describe accurately. Scientists act in a moderate way when it comes to declare recovery of the natural environment. The main obstacle to this clarification id the lack of a definition for the word “recovery” or “recovered”. Rationally, the term can be used to describe the return to the previous numbers regarding every all species involved. However, it is recognized that biological resources and many environmental factors that characterize biological habitats are in a continuous and largely unpredictable state of flux. In consequence, it is impossible to predict the evolution of the species and how strong was the impact of oil spoil to their development. New definitions of the term “recovery” appear that focus on the function of the ecological system towards itself and the wide perspective of the environment. This definition is based on the two solid and crucial functions, the biodiversity (variability in species) and productivity (abundance of biological matter created in proportional time). Both influencing the ecosystem and communities significantly.[2]

3. Socioeconomic consequences of oil spills

Each incident carries a different gravity regarding the consequences on the environment and the economy of the affected area. To better analyze the economic consequences, the costs are split into cleanup expenses which includes are the expenses used during the cleanup operation, natural resource damages and estimated economic losses of the community that was affected by the incident.

3.1 Cleanup Costs

Depending on the geographical location and its specific characteristics, the type of oil that was spilled (persistent or not) and of course the amount spilt, the cleanup costs differs from case to case.

3.1.1 Location

The prominent factor of the cleanup cost is the location. The simpler the environment the lesser the cost principle can be applied here. Open water areas cost less than complicated geographically locations such as marshlands or mangrove forests. Has to be noted that some areas have organism populations that accelerate significantly the natural degradation of oil, thus reducing the cleanup cost.

The cleanup cost is significantly higher, in tourist destination, animal breeding habitats or protected areas. In those areas, even the media plays a significant roles affecting the cost, as well as the political and social structure, for example a small oil spill that receive a lot of attention can damage the economy of the local population greatly if it relies on tourism. The cost on those areas can skyrocket in case of a major oil spill, and the economy of the area can take many years to recover even after the cleanup.

3.1.2 Oil Type

Generally, the heavier the oil spilled the higher the cleanup cost for the same amount. Lighter oil tends to evaporate leaving only a fraction of the amount spilt to cleanup, whilst heavier (heavy crude oil) have more complicated cleanup methods therefore increasing the cost.

3.1.2 Oil Volume

The amount of spilt isn’t a major factor on calculating the cost, surely the cleanup cost, for all things being equal, will be higher for a higher volume of oil spilt. However, a smaller oil spill in a sensitive area like a coral reef or tourist attraction may have higher costs than a larger oil spill that occurred on open waters.

3.2 Natural Resources Damages

This category of costs relates to the environmental impacts caused by an oil spill. Pursuant to OPA, the party responsible for an oil spill is liable for any loss of natural resources (e.g., fish, animals, plants, and their habitats) and the services provided by the resource (e.g., drinking water, recreation).

When a spill occurs, natural resource trustees conduct a natural resource damage assessment to determine the extent of the harm. Trustees may include officials from federal agencies designated by the President, state agencies designated by the relevant governor, and representatives from tribal and foreign governments. The various trustees assess damages to natural resources under their respective jurisdictions. If multiple trustees are involved, they must select a lead administrative trustee (LAT), who coordinates trustee activities and serves as a liaison between oil spill responders. The LAT need not be from a federal agency; however, only a federal LAT can submit a request to the Oil Spill Liability Trust Fund for the initial assessment funding.

The Oil Pollution Act (OPA) of 1990 states that the measure of natural resource damages includes

- the cost of restoring, rehabilitating, replacing, or acquiring the equivalent of the damaged natural resources;
- the diminution in value of those natural resources pending restoration; and
- the reasonable cost of assessing those damages.

Pursuant to OPA, NOAA developed regulations pertaining to natural resource damage assessments in 1996. Natural resource damages may include both losses of direct use and passive uses. Direct use value may derive from recreational (e.g., boating), commercial (e.g., fishing), or cultural or historical uses of the resource. In contrast, a passive-use value may derive from preserving the resource for its own sake or for enjoyment by future generations.

The damages are compensatory, not punitive. Collected damages cannot be placed into the general Treasury revenues of the federal or state government, but must be used to restore or replace lost resources. NOAA’s regulations focus on the costs of primary restoration—returning the resource to its baseline condition—and compensatory restoration—addressing interim losses of resources and their services.

3.3 Other Economic Costs

Something that is often overlooked is the impact on local businesses. The damage of an oil spill is not only environmental; the reputation of a certain location can be tarnished significantly because of one incident. One industry that is highly affected is the fishing one, even though the effects on the fish population may be insignificant the damage of publicity can be great.

Other businesses that can be impacted are port, harbor operation and local services. Since in local communities the economic life is highly interweaved, because of this an oil spill can also lower the quality of life, for example the flow of trade goods to an island can be reduced due to an oil spill since the main income was from tourism, and this can also halt other operations, like local construction. [3]

The cost of some significant incidents are described below.

The Amoco Cadiz incident that occurred in 1978, took place off the coast of Brittany, France. The total amount spilled was approximately 230.000 tons and the type of fluid mainly light crude oil. The length of the affected areas was 300 km of shoreline. With a total economic cost of $282 million, and $85 million in fines. The environmental effect was significant, 3450 sea birds were killed, and the oil spill affected fisheries, oyster and sea weed beds. The cleanup methods consisted of mechanical removal of oil at the shores, pressure washing with hot water was used as well. For the restoration of the flora and fauna fertilizers were used and artificial bacterial cultures.

The Exxon Valdez incident, 1989, took place in Prince Williams Sound, Alaska, USA. The amount spilled 10.9 million gallons affected 1900 km of coast line. The total economic cost was $9.1 billion, $7 billion of which accounted for fines, penalties and claims. A significant population of seabirds died, an estimation of 250,000, 2800 sea otters, 250 bald eagles and 22 killer whales. The cleanup techniques where mostly unsuccessful due to different factors, such as weather conditions, change in the properties of the oil, in total the means that were used where: booms, dispersants, in-situ burning, sorbents, warm water flushing, bioremediation enhancement agents.

The Sea Empress incident, 1996, took place in Pembrokeshire, Wales. Approximately 70.000 tonnes where spilt affecting 100 km of coast line. The total economic cost was $60 million, of which $37 million was used for cleanup. Approximately 2200 birds were killed, sea weeds and shell fishes were affected. The cleanup at sea occurred by using mechanical means and chemical dispersants, around 50% of the spilt oil dispersed naturally.

The Macondo incident, 2010, took place in the Gulf of Mexico, USA. The estimated amount spilled 4.9 million barrels, without taking into account the quantities of the Taylor oil spill which occurred in the same area, affecting over 790 km of shorelines. The total economic cost was $46,4 billion. As a result of the oil spills 997 birds, 400 sea turtles and 47 mammals were killed. The cleanup methods took place mostly at sea, with the use of booms, skimmer, dispersants controlled burning.[4]

4. Prevention and contingency plans

4.1 Prevention technologies during drilling operations

According to their efficiencies, the response techniques for deep-water blowout accidents can be classified into the relief well technique and rapid response techniques, as shown in Figure 2. A relief well is an offset well drilled to intersect the subsurface formation to combat a blowout. A relief well normally requires several months to fulfill its task. However, the rapid response techniques are capable of completing their missions in several days or weeks. Due to the time constraint, rapid response techniques for deep-water accidents are preferred.

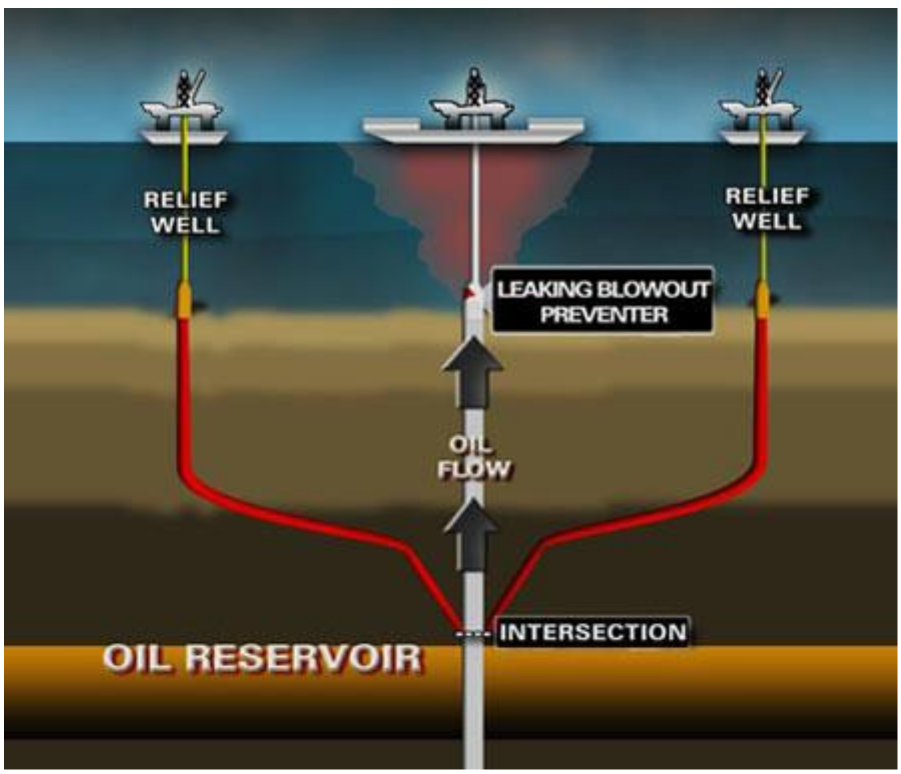

Figure 1 – Relief well sketch

The rapid response techniques employed in the Deepwater Horizon accident represent the state-of-the-art in the offshore oil industry. According to their operating principles and response effectiveness, the rapid response techniques can be categorized into two classes (Figure 2). On the one hand, the temporary control techniques can provisionally stem the blowout flow. On the other hand, the oil recovery techniques can recover partial hydrocarbon from leaked wells without capping them.

The rapid response techniques for deep-water blowout accidents are

ROV (Remotely Operated Vehicles) intervention is efficient; the capping stack is effective; the top kill technique injects high- pressure mud into wellbores; the static kill usually comes after the wellhead closure. In the oil recovery techniques, the LMRP (Lower Marine Riser Package) cap can effectively recover spilled oil; the RITT (Riser Insertion Tube Tool) can also recover some spilled oil; the containment dome and the top hat method has the risk of hydrate formation which can limit their oil-recovery capacities. [14]

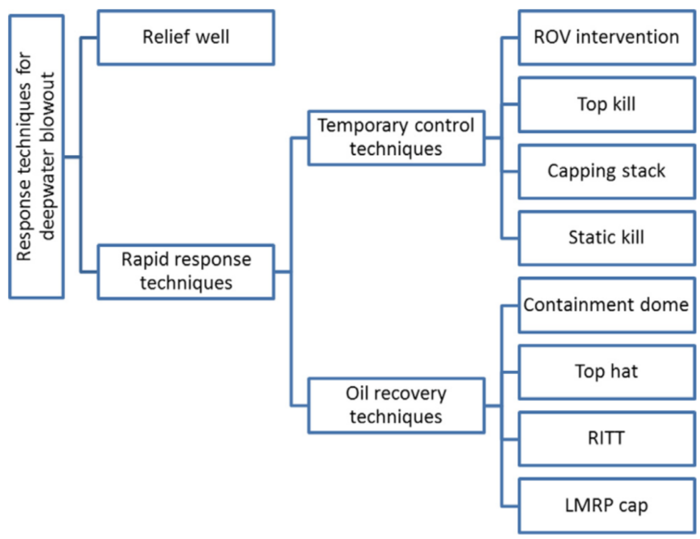

Figure 2 - Classification of response techniques for deep-water blowout accidents.

Blow-out preventer

The subsea BOP system consists mainly of the subsea BOP control system and the subsea BOP stack. A typical subsea BOP system is illustrated in Figure 3.

The subsea BOP control system includes surface and subsea components. The surface components, located in the drilling rig, mainly consist of the central control unit (CCU). It is the kernel of the control system that provides full functional and pressure regulation capability. The CCU is microprocessor-based, and typically utilizes triple modular redundancy (TMR) controllers to transmit commands initiated on the surface to the subsea control pods.

The CCU has three control stations. As the primary control station, driller's panel controls all functions associated with the BOP stack and lower marine riser package (LMRP). The panel design permits well control operations as required, even under adverse conditions. The toolpusher's panel provides the same functionality as the driller's panel, and serves as the secondary control station. It is located in a non-hazardous area away from the drill floor. As the third control station, the work station contains a supervisory control computer and other equipment, such as database servers and network switches.

The subsea components of the control system are two completely independent control pods, the subsea blue pod and the subsea yellow pod, which afford redundant control of all subsea functions. The control pods are the key to system performance. The top section of each pod contains the solenoid-operated shear seal valves and pressure transducers. The lower section contains the subplate-mounted valves, pressure regulators, flow meters, and other associated equipment (Shaughnessy et al., 1999). In addition, each pod includes a subsea electronic module used to receive the command signals initiated on the surface.

Usually, two types of mounting types are used for subsea control pods, retrievable pods and non-retrievable pods (API 16D, 2004). For retrievable pods, surface-controlled locking devices are required to latch the retrievable hydraulic control pods to the LMRP receiver block. Any major problem associated with one pod causes the pod retrieval to the surface for repair, whereas the other one is used to operate all subsea functions, and is unaffected by the disabled one. Non-retrievable pods are the same as the retrievable pods except the pod assembly is fixed to the LMRP. Only when both pods fail are they retrieved for repair.

The configurations of subsea BOP stack vary because of the differences in drilling regions, ocean depths, and so on. Until now, no definite configuration standards have been established.

As secondary barriers during drilling (the primary barrier is the drilling mud), the BOP stack is designed for closing the well annulus or the drill pipe. Two types of preventers, the annular preventer and the ram preventer, are utilized. During deep-water drilling, the BOP stack can be equipped with one or two annular preventers, although usually, the BOP stack is equipped with four or more ram preventers. The different preventer configurations provide different levels of performances for the subsea BOP system. Specifically, a blind shear ram preventer is used to shear the pipe and seal the well, which is regarded as an emergency device. As shown in Figure 3, the typical subsea BOP stack is equipped with two annular preventers and four ram preventers, including a blind shear ram and three pipe rams.

The subsea BOP stack is usually equipped with two hydraulic connectors, the LMRP connector and the wellhead connector. The LMRP connector is located in the middle of two annular preventers, which is used to connect the LMRP to the BOP stack. The wellhead connector is used to connect the BOP stack to the wellhead. Aside from the annular preventers, ram preventers, connectors, and other components such as the flexible joint, choke/kill valves, and choke/kill lines are integrated to form the whole subsea BOP stack.

To simplify the study on subsea BOP stack reliability, the following assumptions were made:

Only the annular preventers, LMRP connector, ram preventers, and wellhead connector of the subsea BOP stack are investigated; the other components such as the flexible joint and choke/kill lines are neglected because the four main components usually cause subsea BOP stack failures, whereas the other components rarely do.

Failure of the upper annular preventer, subsea control pods, or LMRP connector causes the pulling and repair of the complete subsea BOP stack, although either the LMRP or the complete subsea BOP stack may be pulled for repair depending on different practical situations during actual operation.

The annular preventers or ram preventers are assumed to be pulled for repair only when all preventers fail, although the operators may pull and repair the annular preventers or ram preventers when one, two, three, or even all of them fail, depending on the practical situations.

All failed components of the subsea BOP stack have to be repaired after the stack is pulled to the surface, but not on the seafloor because of their complexity, although some minor failures may be repaired using an underwater robot.

The control stations, control pods, annular preventer, and ram preventer are redundantly configured. Therefore, three control stations, two control pods, several annular preventer, and several ram preventer are considered in parallel. The TMR controllers are considered as a unit because the TMR system is usually supplied as a whole by electronics manufacturing service providers. The whole system can be considered as a series composed of control stations, TMR controllers, subsea control pods, annular preventers, LMRP connector, ram preventer, and wellhead connector because the complete failure of each component category causes failure of the subsea BOP system. [13]

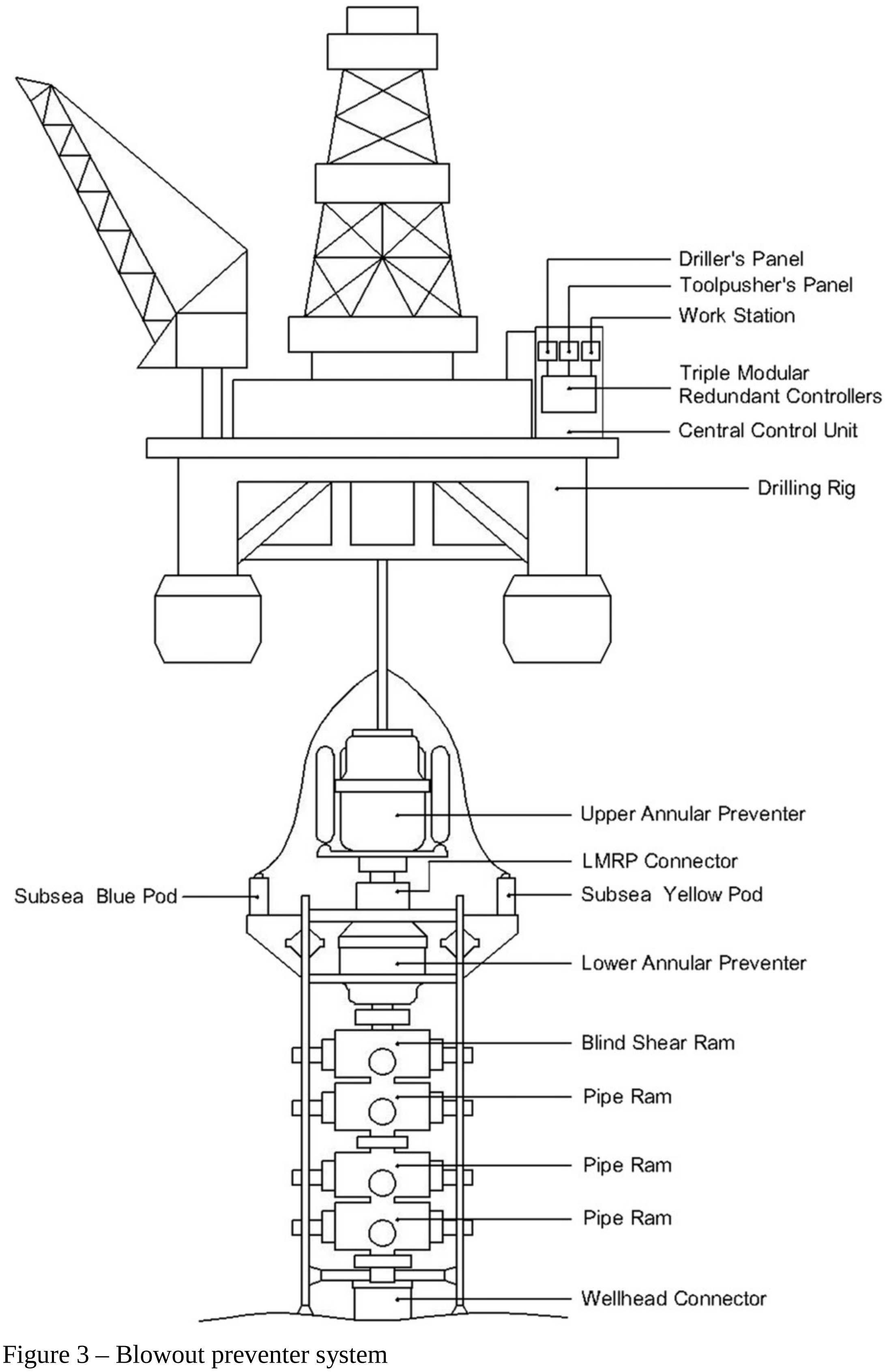

Figure 3 – Blowout preventer system

4.2 Contingency plans

The undergoing national plan of Greece for sea ecosystem pollution in depending from the Marine Environmental Division (MERD) from the ministry of the Trade Marine, managed by the Hellenic Coast Guard. An oil spill is handled by the MEPD in accordance to the emergency level.

The minor incidents are handled by one of the fifty port authorities of the Port Captain, fifteen Regional Marine Pollution Combating Stations (RMPCS) are in use in major ports of Greece, and those are: Alexandroupoli, Chania, Chios, Elefsina, Isthmia, Kavala, Mirina, Neapoli Voion, Patra, Pilos, Piraeus, Rodos, Syros, Thessaloniki, Volos. Local ports would benefit and would be able to coordinate merely the response of larger. MEPD could presume control of large spills and develop natural resources to help the local and regional resources. An Interministerial Committee may be established chaired by the Minister of Mercantile Marine, with representation from the Coast Guard, the Navy, the Institute of Oceanographic & Fishery Research and the Environment Ministry.

All the later mentioned bodies are responsible for the clearance procedure by using their own specific equipment and resources together with the Ministry or immediately with the involved ship-owner. The cleanup of the affected coastlines or shorelines done by contractors or the local authorities, and depending on the incident by both of them, with the contractors usually reporting to the local authorities, backed up by MEPD resources if needed. The majority of the Coast Guard departments have appointed contractors, and in case of unknown origins the cleanup is done by them in accordance of the contingency plan.[5]

5. Recovery and response strategies

There should be a clear prior plan for responding to any oil spill and for making an initial assessment. The primary objective is to minimize the damage.

5.1 Recovery methods

Mechanical containment or recovery is the first line of defense against oil spills. Containment and recovery equipment includes a variety of booms (Figure 4), barriers, and skimmers (Figure 5), just as natural and synthetic sorbent materials. Mechanical deterrent is used to gather and store oil until it can be recycled. [10]

Figure 4 – Oil containment booms

Figure 5 – Oil skimmers

Chemical and biological methods can be used in combination with mechanical means for containing and recycling oil spills. The most useful agents in helping to keep oil from reaching shorelines and other sensitive habitats are dispersing and gelling agents. Biological agents have more potential to assist recovery in sensitive areas. [10]

Oil spill dispersants are mixtures of surface active agents in organic solvents, specifically formulated to enhance the dispersion of oil into the sea-water column by reducing the interfacial tension between oil and water.[17]

Dispersants agents can be applied locally or regionally.

Figure 6 – Use of chemical dispersant

Figure 7 – Ship mounted modern application spraying equipment (source SINTEF)

Significant environmental and economic benefits can be achieved by applying these chemicals to oil spills, when other at-sea response techniques are hampered by the limited availability of resources. Dispersants may provide the means of quickly removing significant quantities of surface oil. The application of these chemicals is intended to minimize the damage. However, the use of dispersants has limitations, and applications require careful planning since it also bring negative consequences to ecosystems. [6]

Biological agents are nutrients, enzymes, or microorganisms that increase the rate at which natural biodegradation occur. Biodegradation is a process by which microorganisms yeasts break down complex compounds into simpler products. The biodegradation of oil is a natural process that slowly breaks down oil. This process can take months or more to occur under natural conditions.

Bioremediation technologies accelerate the biodegradation processes. Bioremediation involves adding microorganisms that increase the rate. When mechanical oil recovery methods have been exhausted, then bioremediation is intended to be used after. There are two bioremediation approaches for oil spill clean-ups - bio stimulation and bio augmentation.

Bio stimulation is the method of adding nutrients to a contaminated environment in order to stimulate the growth of the microorganisms that recycling oil. Limited supplies of these necessary nutrients usually control the growth of native microorganism populations.

Bio augmentation is the addition of microorganisms to the existing native oil-degrading population of microorganisms. Sometimes species of bacteria that do not naturally exist in an area will be added to the native population. Seeding is a technique that is used to increase the population of microorganisms that can biodegrade the spilled oil.

These technologies have been successfully applied to various soil and groundwater contamination problems and are generally considered proven technologies in those applications. Even in these applications represents final stages of remediation because gross oil coverage must first be removed. There is a primarily risk of inhalation and ingestion concern for worker exposure to the biological units. Biological agents can be applied as dusts or can generate aerosols during application. Hence, there is concern for respiratory related illnesses among workers that handle these agents for extended periods of time [6]

Physical methods are used to clean up shorelines. Natural processes can start the cleanup process, but are generally too slow to provide adequate environmental recovery. Physical methods such as wiping with sorbent materials or pressure washing can be used to assist these natural processes. [10]

Figure 8 – Shoreline clean up

A variety of chemical cleaners are used to herd and solidify spilled oil and to cleanse hard surfaces along shorelines that have become contaminated. These chemicals are generally more toxic than dispersants and biological agents. Their methods of applications are manpower intensive and require workers to come into direct contact with liquids.

Workers face exposure through inhalation, ingestion, and skin adsorption. Therefore, appropriate protocols and personal protection are required in application. [6]

Controlled or In-Situ Burning

This alternative countermeasure carries a trade-off in environmental impacts. The trade-off is between continued environmental impacts on marine life and shorelines from the slick and air pollution. [6]

ISB removes spilled oil through a controlled combustion of hydrocarbons. To conduct an ISB, the response conditions must include ignitable hydrocarbon vapor concentrations emitted by the oil, sufficient oil thickness, and an ignition source. When conducted properly, ISB can minimize the spread of spilled oil, reduce or prevent exposure to spilled oil, and reduce the length of a response. In general, most oils on water will burn if slicks are more than 2–4 mm thick. On land or wetlands, the situation is similar, although oil with a thickness of 1 mm or less can be burned in a sustained manner on grassland because of heat from the burning of vegetative fuels. Heavy oils will require a small amount of primer (promoter or accelerant), such as diesel fuel, to start ignition. A promoter or accelerant would be applied to just a few spots on a slick which are judged to be near or on the thickest portion. Easy ignition of the promoter or accelerant can heat the underlying oil and increase its vaporization rate and its potential for ignition. [18]

Figure 9 – Controlled in-situ burning assisted by fire booms

5.2 Final disposal

Some treatments result in the total destruction of the OSW (e.g. co-incineration in cement kiln). However waste treatment often results in the production of an ultimate material that has to be disposed of.

Possible final disposal options comprise:

recycle as alternative fuel source (power plant, refinery, cement works etc.) or raw material, discharge water in natural environment, return sediments on site, use treated material for road fill/construction, storage in landfill or special units/cells.

As for the treatment options, the entry criteria for each final disposal option has to be ascertained, particularly the environmental and technical regulations that apply to the re-use of material and return of treated sediment and water in the environment.

Each country should include in their OSWMP the minimum criteria for returning in the environment (beach, open water, road fill, construction, etc.) of the treated material:

Total Hydrocarbon Content (THC), and other Hazardous and Noxious Substances content.

Treated material that may be used for road fill and/or construction must:

- have geotechnical properties suited to their use e.g.:
    - measurement of the risk of liquefaction in case of seismic solicitation or in presence of vibrations
    - measurement of specific gravity of the treated sediment,
- Comply with the relevant regulations regarding these materials (although special authorization may be delivered).[20]

5.3 Response strategy in Greece

The main recovery method is achieved with mechanical means (skimmers) in the coasts of Greece. Use of oil dispersant is highly regulated and can be used only in open seas outside of protected or sensitive areas. The use of dispersants requires the authorization of MEPD. The approval and testing of oil dispersant is done by accredited departments of universities and/or the state chemical laboratory. As a member of the European Union, Greece can use oil dispersants that have been approved in the European Union although they need to have certification from the State Chemical laboratory. The transportation and disposal of waste from cleanup operations is conducted by authorized companies in approved inland sites.

Equipment

Government

The equipment used by the MEPD consists of two oil spill response vessels, aircraft for surveillance, and two aircrafts for oil dispersant use. The consumables that are used during operations include among others the dispersants and absorbing equipment and it is distributed on regional stations, each regional station has its own trained personnel.

Private

Under the legislation, all coastal facilities must be in accordance to the national plan and have a local contingency plan. Based on that each facility should have the response personnel and equipment ready for an incident, this is achieved by frequent evaluations of the spill response capability. The training and evaluation is done by private companies.

The Ministry of Mercantile Marine and the Marine Rescue Coordination Centre are the main authorities in every case of pollution in the marine environment (including shorelines) that involves hazardous and noxious substances (HNS). The national contingency plan (NCP) includes the response of HNS pollution. Based on the NCP, a National Advisory Committee was created, consisting of representatives from all the bodies involved. Scientific personnel often advise the committee during incidents. The oil spill response equipment is often used for incidents involving HNS. Despite the fact that HNS pollution are included in the NCP there is a shortage of specialized equipment and cleanup know-how. The Hellenic Centre for Marine Research (HCMR) can provide scientific advice on HNS. Base on the European Maritime Safety Agency, Greece never had an incident of pollution involving HNS. [5]

6. Historical data of Oil spills

6.1 Pipeline oil spills

6.1.1 Europe

Two bodies, EGIG and Concawe, have done statistical analysis of the pipeline spillage in Europe, both used data from 1971 until 2016 and 2017 respectively. EGIG focused on gas pipelines whilst Concawe on oil pipelines.

EGIG is comprised by European Gas Companies, DGC (Denmark), ENAGAS S.A (Spain), EUSTREAM (Slovak Republic), Fluxys (Belgium), Swedegas A.B. (Sweden), Gas Networks Ireland (Ireland), Gasum (Finland), GRT Gaz (France), National Grid (UK), Gasunie (Operating in Netherlands and Germany), NET4GAS (Czech Republic), Open Grid Europe (Germany), REN Gasodutos S.A. (Portugal), Gasconnect (Austria), Snam Rete Gas (Italy), SWISSGAS (Switzerland), TIFG (France)

The total length of the European gas transmission pipelines system in EGIG has remained at approximately the same level since the last six years. [12]

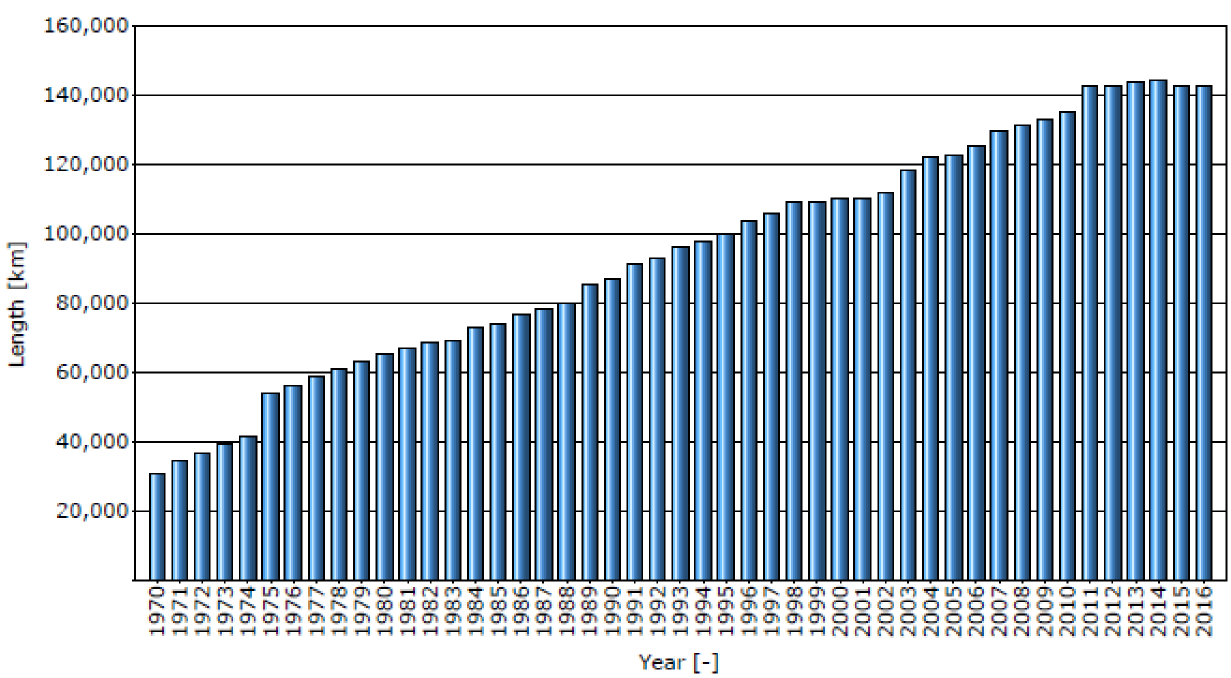

Figure 10 – Changes in the length of the transmission system in Europe during the period 1970-2016

For the period from 1970 to 2016 there were recorded a total of 1366 incidents on the gas network according to the 9th EGIG report. In Figure 11 is shown the number of recorded incidents per year and is observed a decline compared to the first decades of available data. In Figure 12 is shown the cumulative number of incidents and a slowdown is observed.

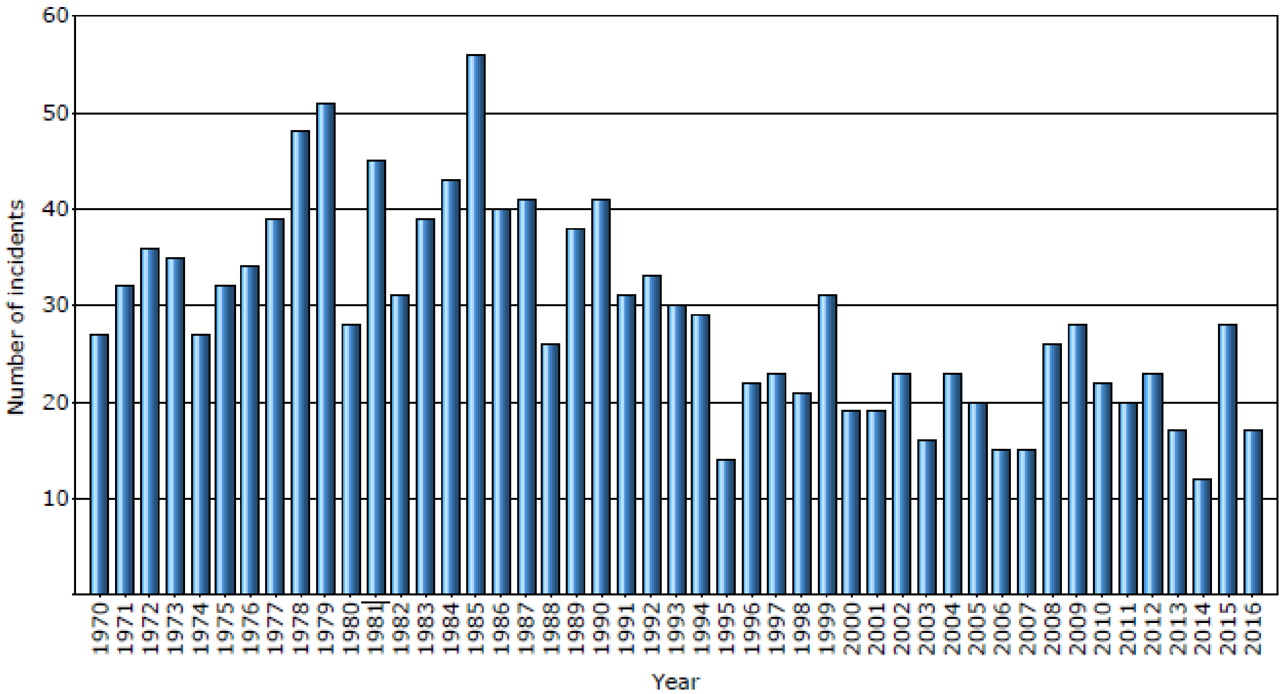

Figure 11 – Number of incidents in Europe

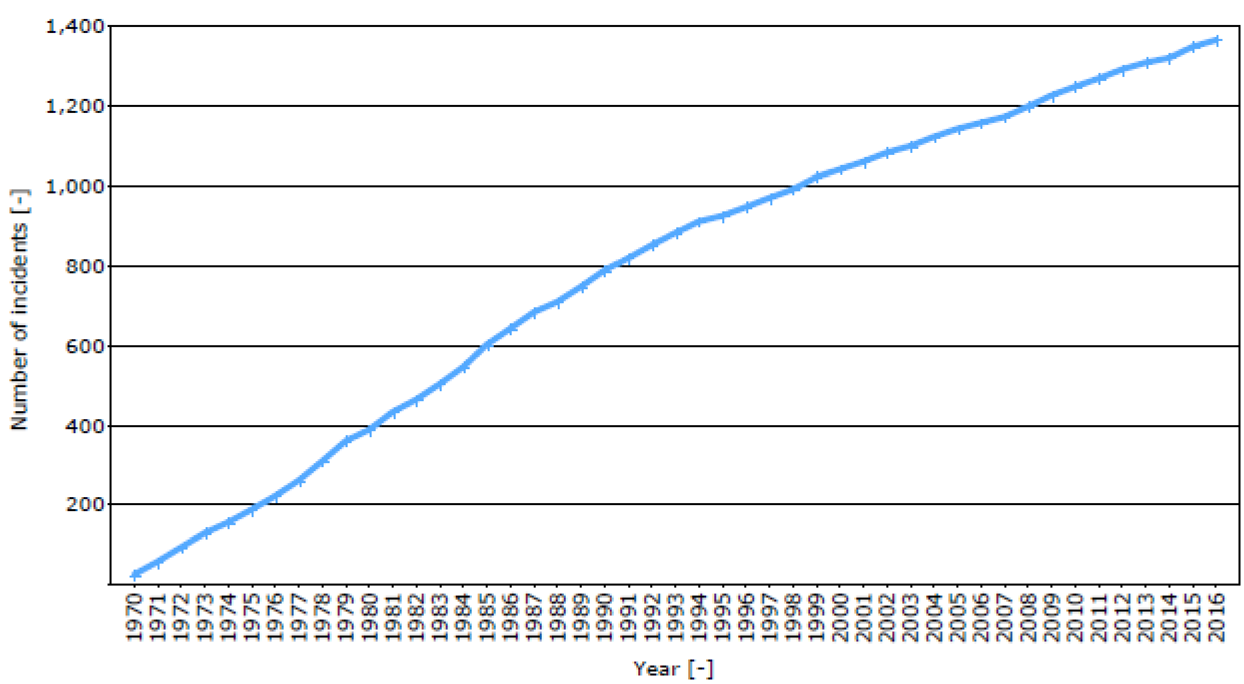

Figure 12 – Cumulative number of incidents in Gas pipelines in Europe

Fortunately, not every gas release ignites, which limits the consequences of the incidents. For the observed period of 1970-2016 only a fraction of gas releases ignited, according to EGIG that is 5%.

The main causes of the incidents are:

- External interference:

  Cause mainly from activities near or on the pipelines (pilling, digging, groundworks) by the used equipment (bulldozers, excavators) that damaged or reduced the safety of the pipeline. With proper training and safety protocols incidents caused by external interference can be reduced.

- Corrosion:

  Corrosion is can be found both internally and externally, with the main factor being the location. This cause can be prevented with regular inspections.

- Construction defect/material failure:

  The material used to construct the pipeline must be carefully selected to avoid defects.

- Ground movement:

  The type of ground movement can have different effects on the pipelines, bet generally it reduces the integrity of the pipelines be it a landslide or floods. Those factors are not always considered and can change overtime depending not only on the human activity on the region.

- Other and unknown:

There are other sub-causes that are difficult to control and sometimes the cause of an incident is not clear, such as human error on maintenance or design, or extreme weather conditions.

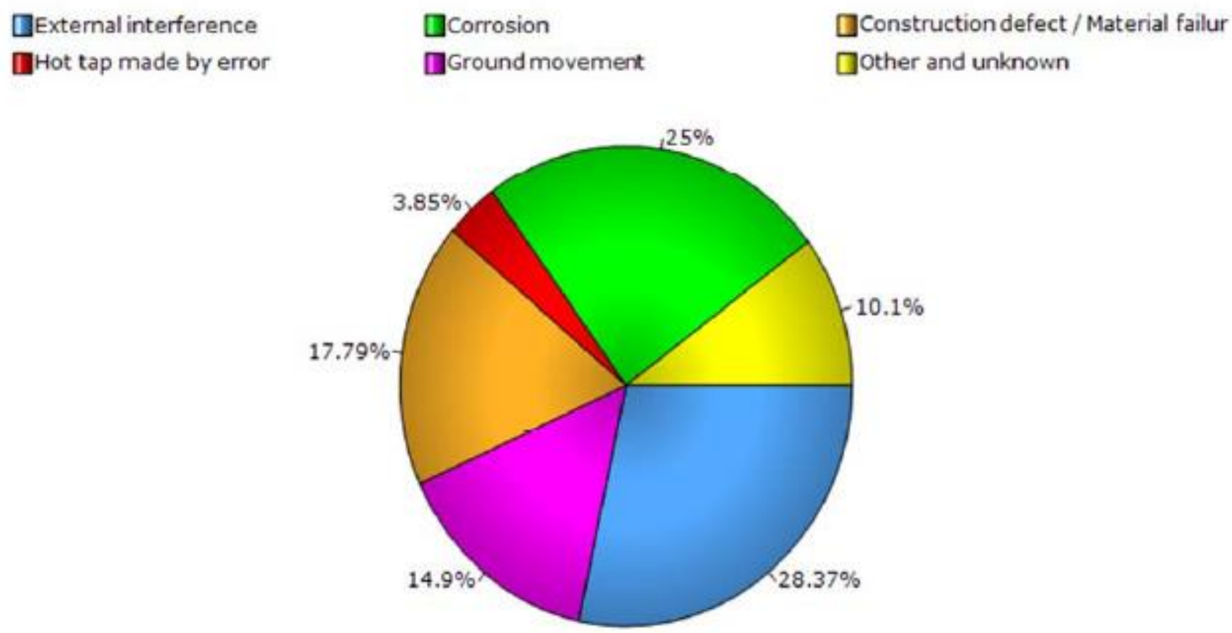

Figure 13 – Distribution of incidents (2007-2016)

The Concawe consists of 76 companies and agencies operating a total of 35,312 km of oil pipelines in Europe and are currently listed for the annual survey.

According to a study done by Concawe over the 47 years' survey period there have been a total of 754 spillage incidents, 496 when excluding theft.

Spilled volume is generally difficult or impossible to determine in the case of theft-related events as spillage may have occurred over a period of time and one cannot determine how much was spilled or indeed how much was stolen. [11]

In the history of the survey only one spillage affected more than 100,000 m^2, although the gross volume spilt was relatively modest. For all other spillages, there appears to be a direct relationship between spill size and area affected, with the area affected increasing slowly at first and then more rapidly where the average spill volume exceeds 100 m^3. This suggests that very large spills behave differently to smaller releases, which could happen, for example, if product escaping at a high flow rate was to migrate across the surface, rather than in the subsurface.

It should be noted that small spillage volumes can affect larger areas of the surface if fine sprays are directed upwards and spread around by winds, or if material is spread over larger areas by flowing water. Conversely, comparatively large spills, particularly those that occur over extended periods of time and in the lower quadrants of the pipeline circumference, can have their main effect underground with relatively little impact on the surface. Porous ground and hot, arid conditions can also lead to the surface consequences being limited. Distribution of spillage causes in oil pipelines Figure 14.

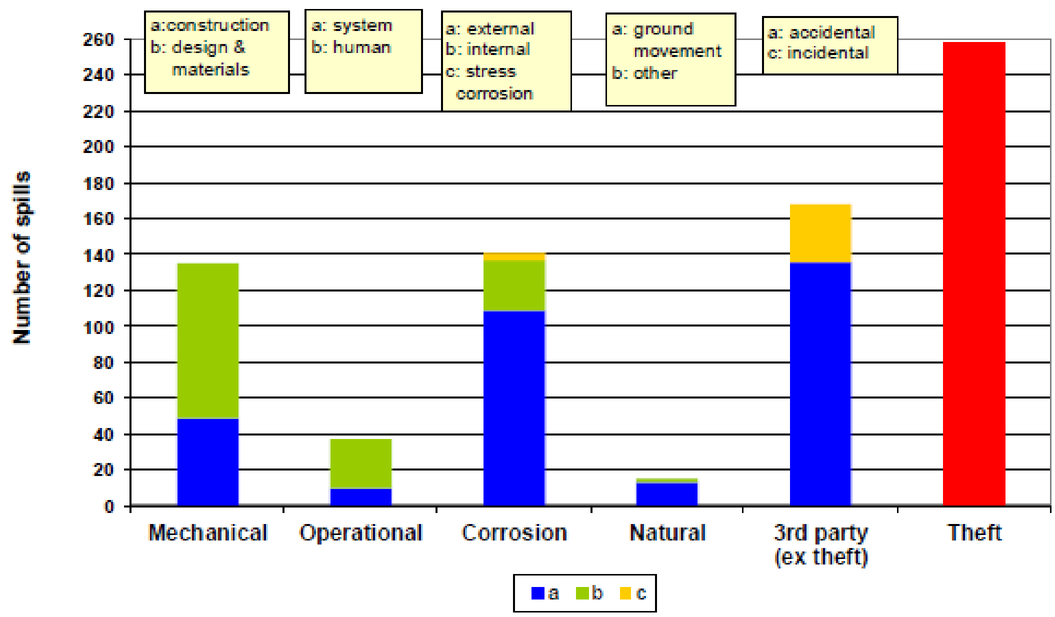

Figure 14 – Distribution of spillage causes for all oil pipelines

6.1.2 USA

From 1964 to 2015, the oil and gas industry produced over 20.6 Bbbl of crude oil in the U.S. OCS. In addition, Anderson et al. estimate that 95% of all crude oil produced in the OCS each year was transported by pipeline. [15]

Since 1991, pipelines have annually spilled 37 times as much as tankers. The change in the proportion U.S. pipeline spillage is largely due to the fact that since 1990, pipelines transport more oil across more miles than water carriers though the actual pipeline mileage has not increased appreciably. U.S. pipelines now carry 69.3% of oil transported, compared to 30.3% carried by vessels (tankers and barges). The annual number of pipeline spills has decreased by 500% over the last 30 years (Figure 15). Spill amounts are dominated by a small number of large events. Over 74% of pipeline spills involve 100 gallons or less, while spills in these smaller size classes contribute only 0.8% of the total amount spilled. 90% of spills are under 1,000 gallons. Overall, the amount spilled has decreased (Figure 16).[15]

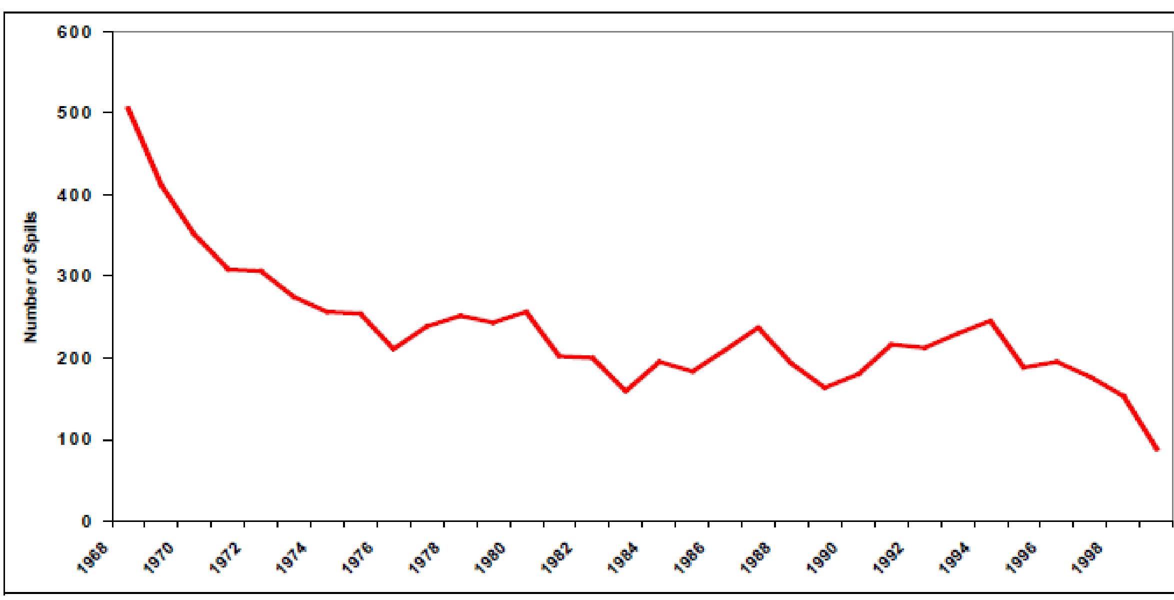

Figure 15 - Number of oil transport pipeline spills in United States [21]

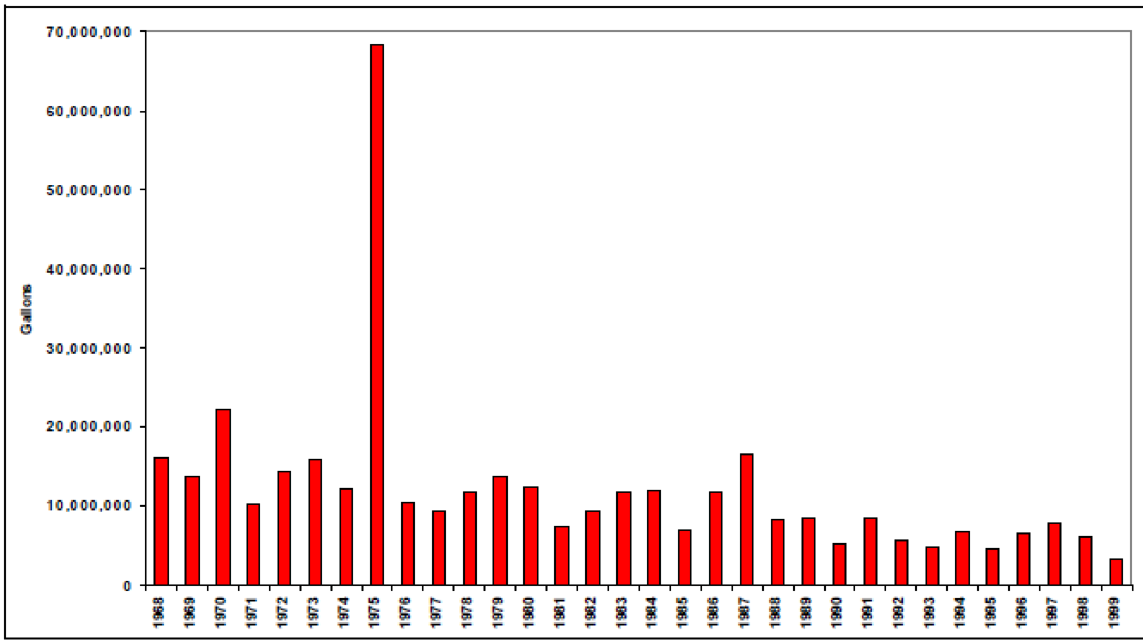

Figure 16 - Amount of oil spilled from U.S. oil transport pipelines [21]

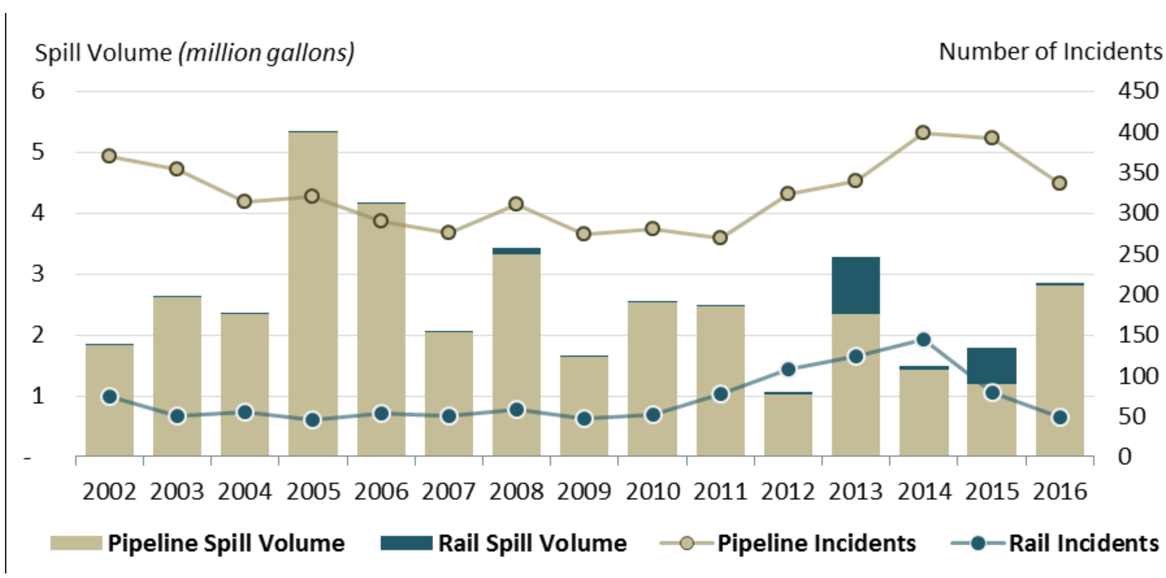

Figure 17 – Incidents occurred in Oil Pipelines and during Rail Transportation: 2002 2016

6.2 Spills during production operations

6.2.1 USA

A national assessment of oil spill volume and frequency necessitates data collection from different agencies, including the U.S. Coast Guard and the Department of Transportation's Pipeline and Hazardous Materials Safety Administration (PHMSA). The combinations of the date from those sources is often problematic, because there may be repetition of data and sources, the purpose of the collected data may be different and the collection of the data may vary.[3]

Oil spills on land facilities. From Figure 18 is shown a decrease in aqueous environments from land based facilities (excluding pipelines) since 1991, following a similar trend with spills from other causes. Even though the number of smalls spills is greater the total amount of volume spilled is smaller than the larger oil spills. Large oil spills of over 100 gallons, represent only 8.46% of the spill number, account for 98% of the amount of oil spilled between 1987 and 1999 (Figure 19).

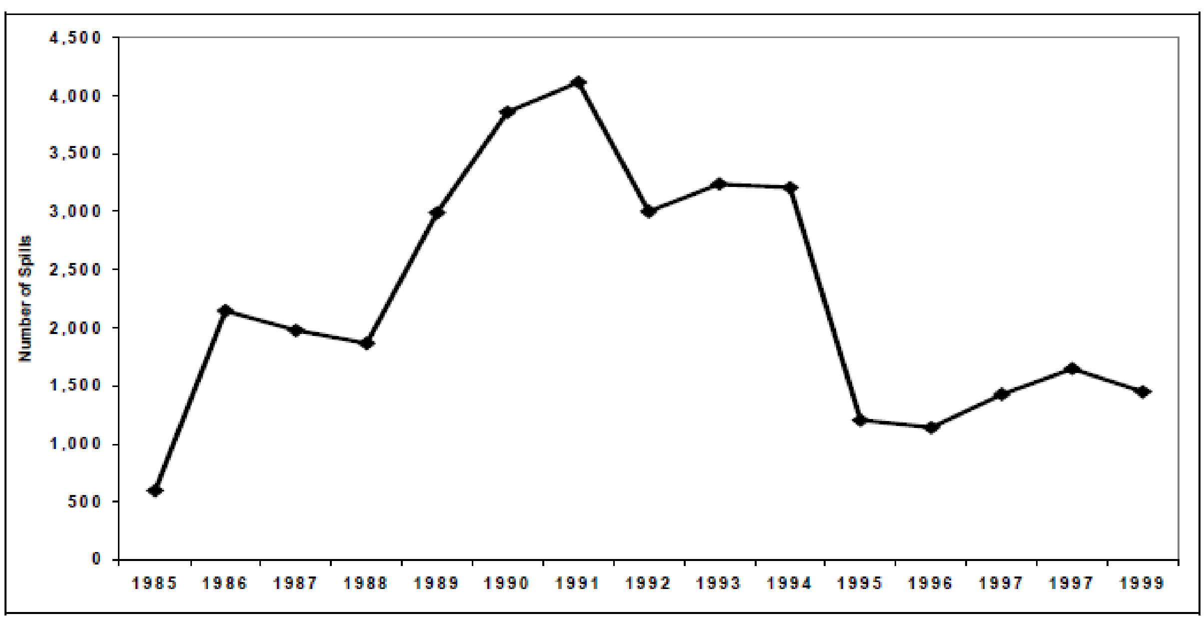

Figure 18 – Number of land-based facility spills

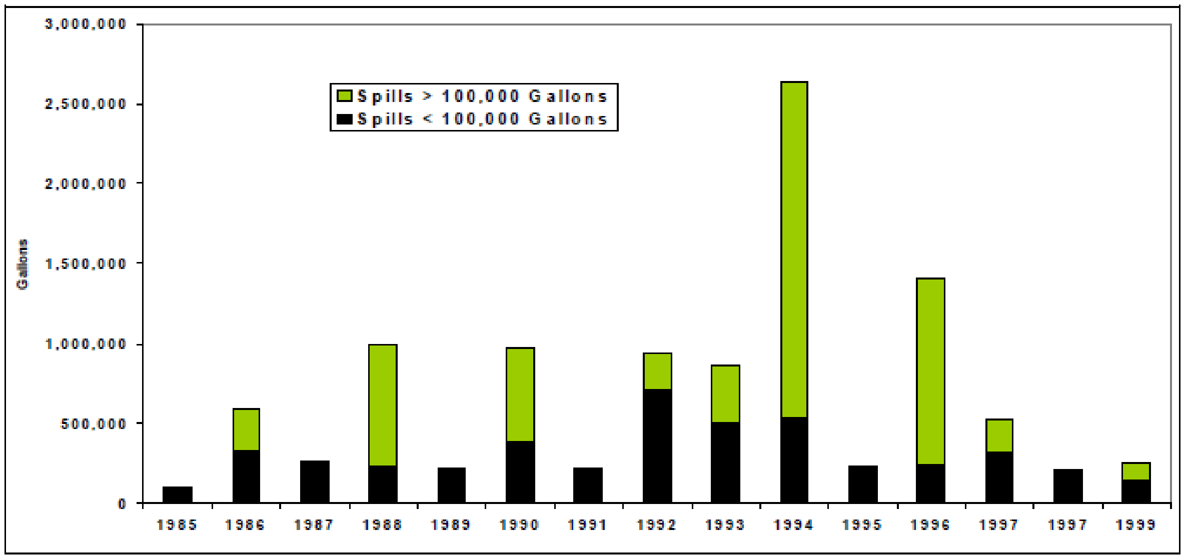

Figure 19 - Annual amount of oil spilled from facilities (excluding pipelines) into U.S. waters

6.3 Oil spills from tankers

ITOPF is a non-profit organization and is considered the most reliable source for the oil spill data from tankers, excluding oil spills that were a result from acts of war.

Then annual report of ITOPF shows the record of oil spills from tankers from its establishment in 1968.

To represent the data, the spills are mainly categorized by the volume of oil spilled, into 3 categories, smaller than 7 tons, between 7 and 700 tons, and larger than 700 tons, or their barrel equivalents of >50, 50-5000, <5000 bbls respectively. ITOPF collects data from tank vessels, floating production storage and offloading vessels and barges. This data includes the volume spilled of the incidents, location, type of oil (heavy, light), vessels and cause of the incident.

The information is gathered from a combination of sources, from parties directly involved in the incident like the vessels, P&Is and publicly available sources and it is combined with the experience of ITOPF. The information from publicly available sources mostly is related to large spills, often resulting from collisions, groundings, structural damage, fires or explosions whilst smaller incidents are overlooked.

For the volume spilt ITOPF uses the initial oil in each vessel, including the oil that was still a sunken vessel or burned during the incident, the estimation of the volume from the recovered oil is highly uncertain.

The accuracy of the information can vary from case to case, as there may be differences in the volume reported from each source. For each annual report, newly discovered information is evaluated and is added to the previous data to keep the information as precise as possible. Knowing that the data presented below should be seen with caution and that it can be changed with new information

6.3.1 Major Tanker Oil Spills in History

The twenty biggest tanker oil spills after 1967 (SS Torrey Canyon oil spill) are summarized in Table 2 and their relatives volumes and locations can be seen in Figure 20. It has to be noted that the majority of the largest oil spills (19 out of 20) happened before 2000. In addition, the newest oil spill in that list (SHANCHI) had the lower environmental impact compared to the other incidents. Despite being the top twenty list, not all incidents affected coastlines and some of them occurred in open waters, for that reason in Table 1 is a comparison with more “famous” incidents like EXXON VALDEZ, HEBEI SPIRIT and PRESTIGE.

Figure 20 – Worldwide location of significant oil spills

Table 1 - Major oil spills from vessels since 1967 (rounded to nearest thousand)

Position	Vessel name	Year	Country of incident or location	Spill size (tonnes)
1	SS Atlantic Empress	1979	Tobago Island near Venezuela	287,000
2	MV ABT Summer	1991	Angola	260,000
3	MT Castillo de Bellver	1983	South Africa	252,000
4	AMOCO CADIZ	1978	France	223,000
5	MT Haven Oil Spill	1991	Genoa, Italy	144,000
6	ODYSSEY	1988	Canada	132,000
7	SS Torrey Canyon	1967	United Kingdom	119,000
8	MV Sea Star	1972	Gulf of Oman	115,000
9	SANCHI	2018	China	113,000
10	IRENES SERENADE	1980	Greece	100,000
11	URQUIOLA	1976	Spain	100,000
12	MV Hawaiian Patriot	1977	United States of America, Hawaii	95,000
13	MT Independența	1979	Turkey	95,000
14	JAKOB MAERSK	1975	Oporto, Portugal	88,000
15	MV Braer	1993	United Kingdom	85,000
16	AEGEAN SEA	1992	Spain	74,000
17	MV Sea Empress	1996	United Kingdom	72,000
18	KHARK 5	1989	Morocco	70,000
19	NOVA	1985	Iran	70,000
20	KATINA P	1992	Mozambique	67,000
21	MV Prestige +	2002	Spain	63,000
36	EXXON VALDEZ+	1989	United States of America, Alaska	37,000
132	MT Hebei Spirit	2007	South Korea	11,000

6.3.2 Worldwide trend of oil spill incidents

The record shows that, since 1973 the amount of oil spill incidents follows a negative trend as it is shown below. Only incidents of 7 tonnes are considered.

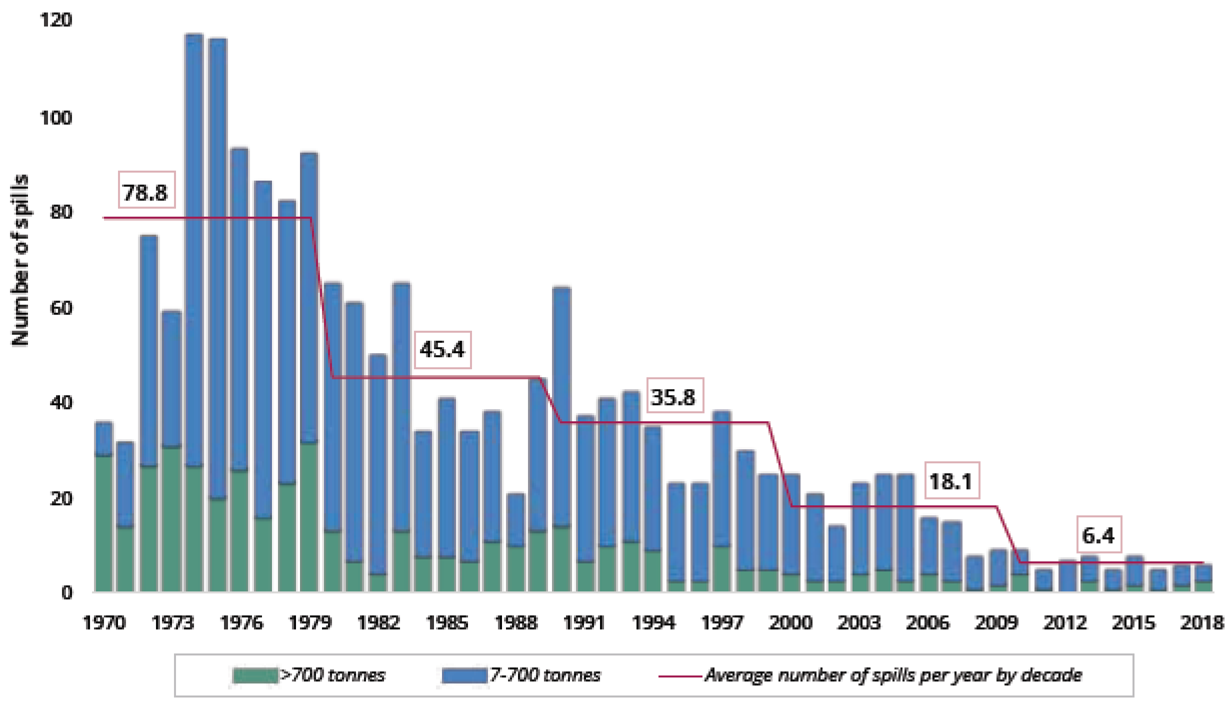

Figure 21 – Number of spills (>7 tonnes) from 1970-2018

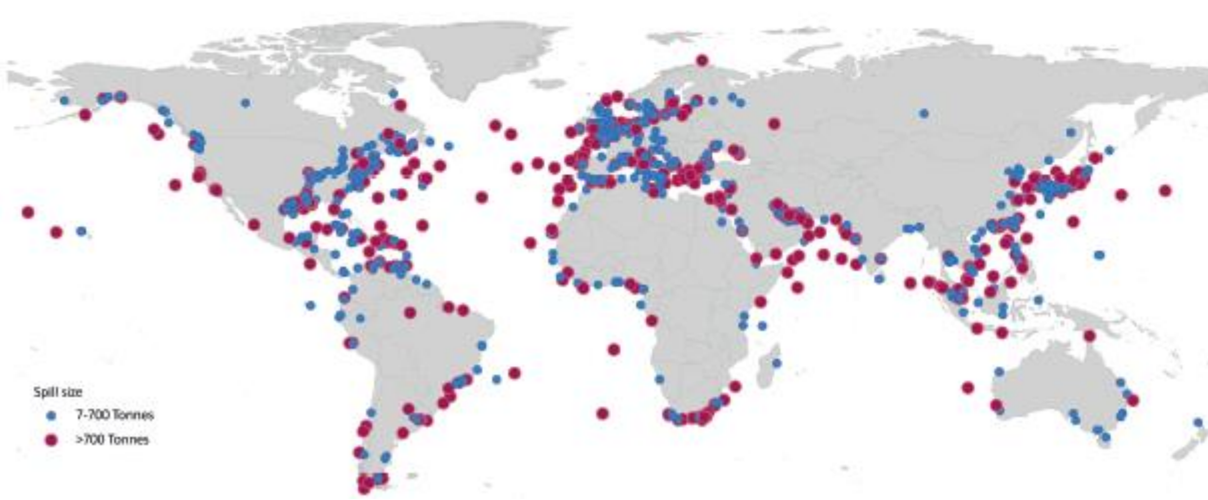

Figure 22 – Location of spill >7 tonnes* from 1970 to 2018

6.3.3 Amount of Oil Spills

The number of large oil spills (bigger than 700 tons) is low, which makes the statistical analysis difficult and inaccurate (insufficient data), therefore the data is used to identify trends to reveal patterns.

The amount of oil spills has been decreasing since 1970 and as of 2010 it averages 1.9/year. The majority (53%) of the large spills that were recorded occurred from 1970 to 1980. Because of the number of incidents to show up trends each decade is combine, and can be seen that there is a significant reduction in the number of large oil spills, it has to be noted that the volume of seaborne crude oil trade hasn't decreased from 1986 and continues to grow since then.

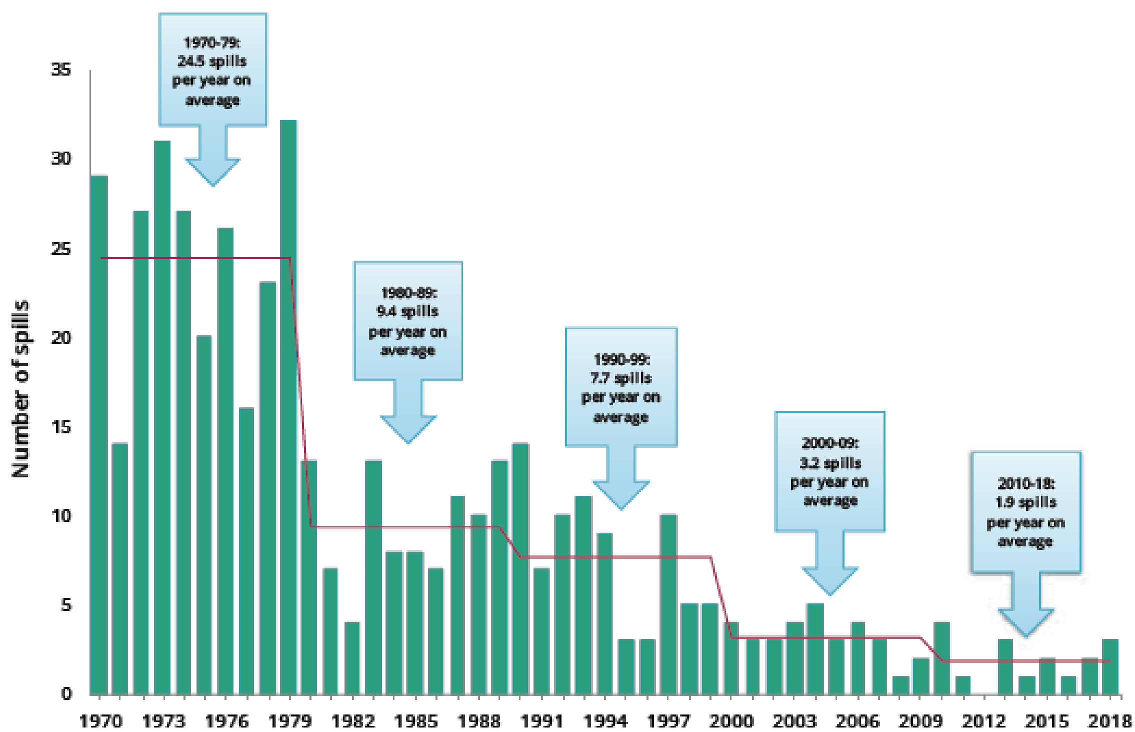

Figure 23 – Amount of large spills (>700 tonnes) during the period of 1970-2018

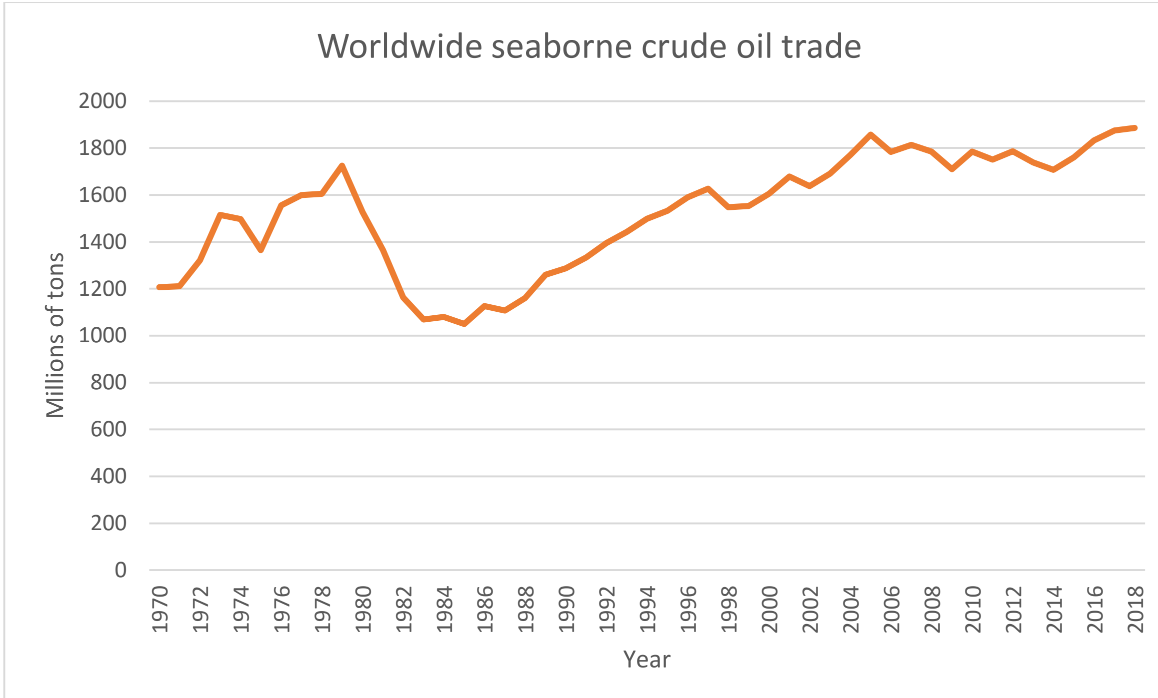

Figure 24 - Worldwide seaborne crude oil trade [35]

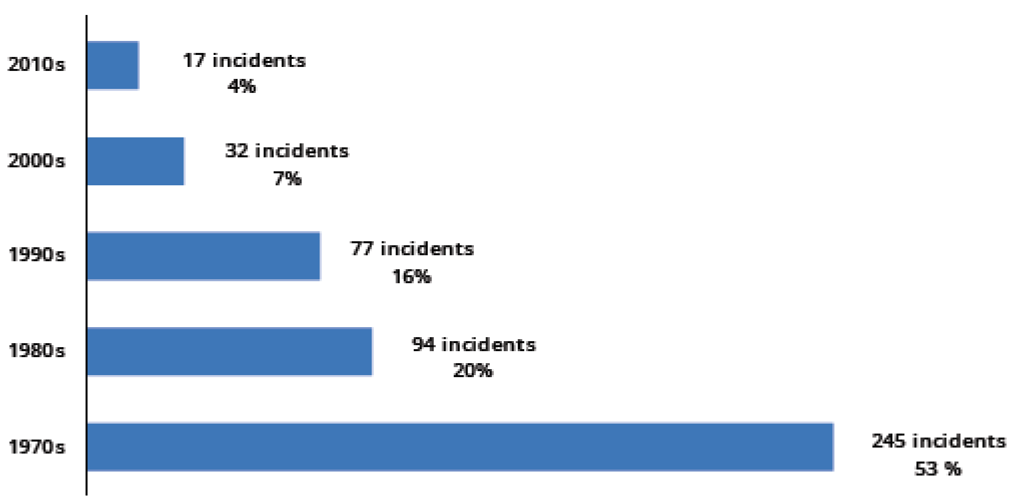

Figure 25 – Percentage of large oil spill per decade for the period 1970-2018

The amount of medium oi spills has been also been decreasing (7-700 tones) as shown in Table 2 and Figure 26. Averaging 28.1/year for the 1990s decade, a decrease to 14.9/year in the 2000s and it is currently 4.7/year 2010s (not a complete decade).

The majority of incidents (more than 80%) that have been recorded since 1970 are small spills. However, the available data isn't complete for the small spills, and they are underreported.

Table 2 – Number of oil spills per year

Year	Medium oil spills	Large oil spills
1970	7	29
1971	18	14
1972	48	27
1973	28	31
1974	90	27
1975	96	20
1976	67	26
1977	70	16
1978	59	23
1979	60	32
Total	543	245
Average	54.3	24.5
Year	Medium oil spills	Large oil spills
1980	52	13
1981	54	7
1982	46	4
1983	52	13
1984	26	8
1985	33	8
1986	27	7
1987	27	11
1988	11	10
1989	32	13
Total	360	94
Average	36	9.4
Year	Medium oil spills	Large oil spills
1990	50	14
1991	30	7
1992	31	10
1993	31	11
1994	26	9
1995	20	3
1996	20	3
1997	28	10
1998	25	5
1999	20	5
Total	281	77

Average	28.1	7.7
Year	Medium oil spills	Large oil spills
1990	50	14
1991	30	7
1992	31	10
1993	31	11
1994	26	9
1995	20	3
1996	20	3
1997	28	10
1998	25	5
1999	20	5
Total	281	77
Average	28.1	7.7
Year	Medium oil spills	Large oil spills
2000	21	4
2001	18	3
2002	11	3
2003	19	4
2004	20	5
2005	22	3
2006	12	4
2007	12	3
2008	7	1
2009	7	2
Total	149	32
Average	14.9	3.2
Year	Medium oil spills	Large oil spills
2010	5	4
2011	4	1
2012	7	0
2013	5	3
2014	4	1
2015	6	2
2016	4	1
2017	4	2
2018	3	3
Total	42	17
Average	4.7	1.9

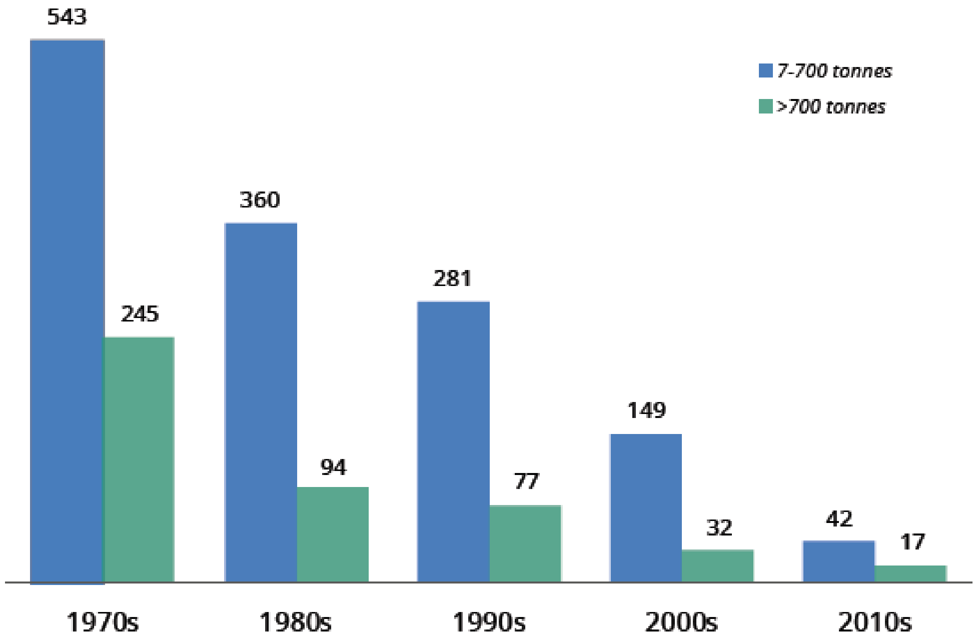

Figure 26 – Amount of oil spills larger than 7 tonnes per decade

During 2018, there were recorded three large spills (>700 tonnes) and three medium spills (7-700 tonnes).

The 1st large spill was the oil tanker SANCHI and it took place early in the new year when it collided with a bulk carrier CF CRYSTAL resulting in a fire and as a result it sank in the East China Sea. In the Persian Gulf a tanker sunk, resulting the 2nd large spill of 2018, it had on board over 1000 tons of cargo. The collision of two tankers in Chine became the 3rd large oil spill.

During a ship to ship transfer a medium sized oil spill occurred in Gulf of Guinea in February. In June of the same year a collision in the Port of Rotterdam occurred, resulting the 2nd medium oil spill. The collision of two tankers in Nigerian waters resulted in the 3rd medium oil spill in November.

6.3.4 Quantities of Oil Spilt

Most of the incidents are >7 tons and are considered small, but due to difficulties on collecting the data of those spills and assessing their reliability often proves difficulty the quantity of total oil spilt may differ greatly from the reality. Data from medium and major incidents is more reliable and the quantity spilt oil is presented on Table 3 (rounded)).

For the period of 1970-2018, approximately 6 million tonnes have been lost because of incidents involving tankers. However, the quantity spilt have been reduced significantly since 1970 Today, the quantity of oil lost in accidents is only a tiny fraction of the quantity that is delivered to its destination each year. From Table 3 it is observed that an amount greater than the total quantity of oil spilt during 2000-2009 (196,000 tonnes) was spilt in several single years in earlier decades.

In 2018, around 116,000 tonnes were spilt, as it was recorded, and the bulk of that volume is due to the incident in the East China Sea, MT SANCHI, (Table 3).

Table 3 – Volume of oil spilt per year

Year	Quantity (Tonnes)
1970	383,000
1971	144,000
1972	313,000
1973	159,000
1974	174,000
1975	352,000
1976	365,000
1977	276,000
1978	393,000
1979	636,000
Total	3,195,000
Year	Quantity (Tonnes)
1980	206,000
1981	48,000
1982	12,000
1983	384,000
1984	29,000
1985	85,000
1986	19,000
1987	38,000
1988	190,000
1989	164,000
Total	1,175,000
Year	Quantity (Tonnes)

1990	61,000
1991	431,000
1992	167,000
1993	140,000
1994	130,000
1995	12,000
1996	80,000
1997	72,000
1998	13,000
1999	28,000
Total	1,134,000
Year	Quantity (Tonnes)
2000	14,000
2001	9,000
2002	66,000
2003	43,000
2004	17,000
2005	15,000
2006	12,000
2007	15,000
2008	2,000
2009	3,000
Total	196,000
Year	Quantity (Tonnes)
2010	12,000
2011	2,000
2012	1,000
2013	7,000
2014	5,000
2015	7,000
2016	6,000
2017	7,000
2018	116,000
Total	163,000

6.3.5 Influence of Large Spills on Quantities of Oil Spilt

As it is shown in Figures 27 and 28, a high percentage of oil spilt comes from large spills but they are much less than small or medium. For example, in more recent decades the following can be seen (Figure 27):

• During the 1990s, 358 medium and large oil spills were recorded, a total of 1.134.000 tonnes of oil was spilt, the majority (73%) is accredited only to 10 incidents.

• During the 2000s, 181 medium and large oil spills were recorded, a total of 196.000 tonnes of oil was spilt, the majority (75%) is accredited only to 10 incidents.

• During 2010-2018, 59 medium and large oil spills were recorded, a total of 163.000 tonnes of oil was spilt, the majority (92%) is accredited only to 10 incidents. It has to be noted that 70% of the total oil spilt for that period was from one incident.

The trends of the spilt quantity can significantly change just by a single large incident as it shown in Figure 28.

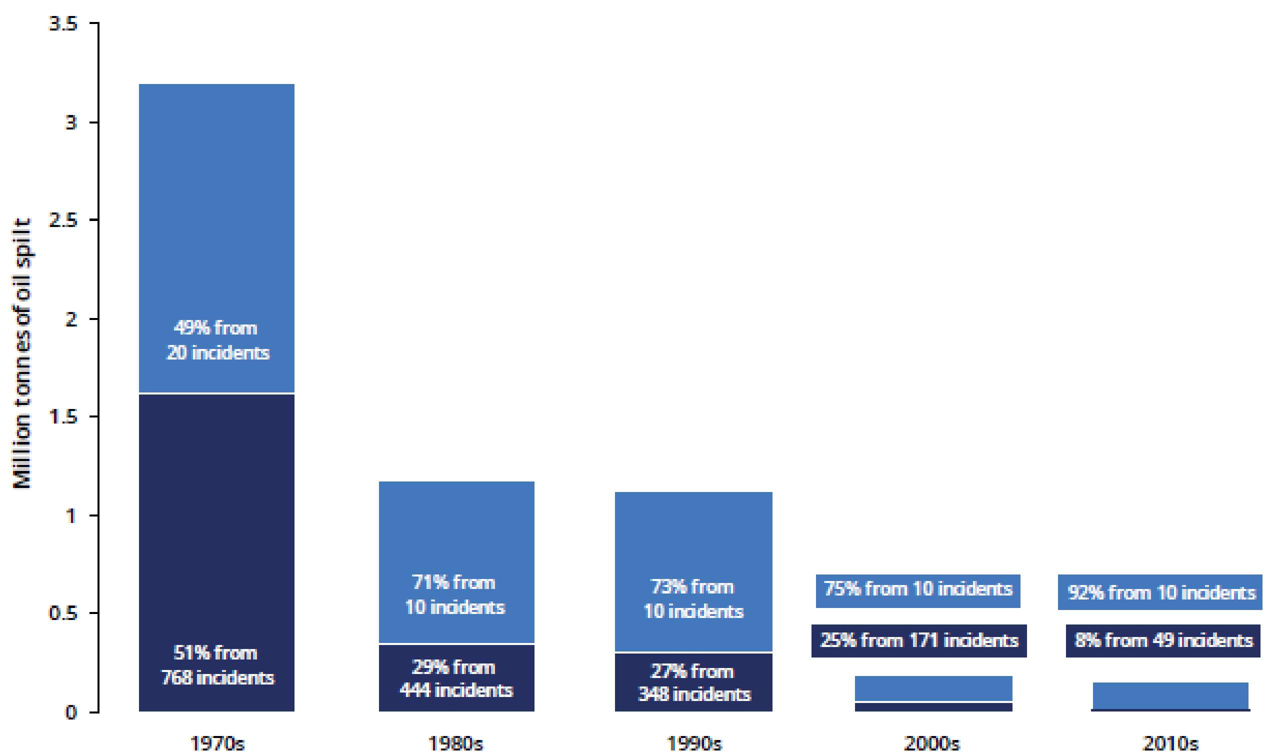

Figure 27 – Medium and Large oil spills, indicating the importance of large oil spills

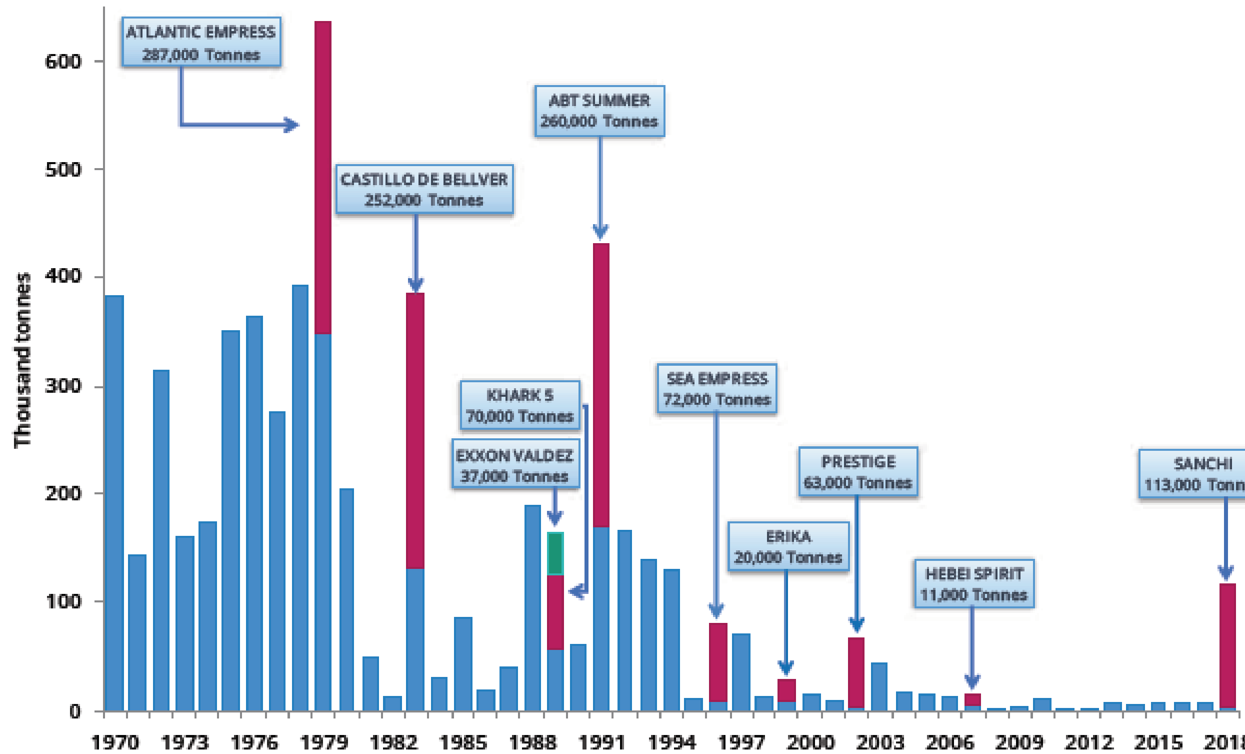

Figure 28 – Quantities of medium and large incidents during 1970-2018

6.3.6 Tanker Spills versus Seaborne Oil Trade

Seaborne oil trade has been increasing steadily since 1970 (Figure 29), excluding a decrease in 1981 due to an economic recession. This increase implies a significant risk from oil pollution, and It should follow a similar patter, but due to measure taken throughout the years there is a decrease in the frequents of incidents for the same time period

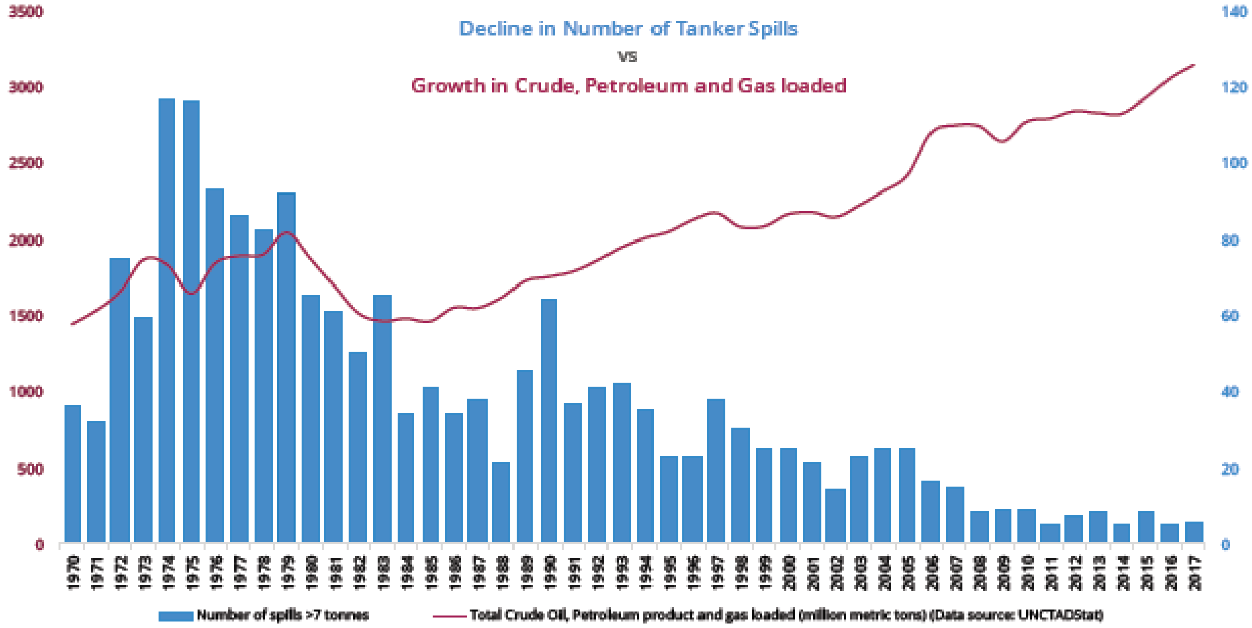

Figure 29 – Seaborne trade (crude, petroleum, gas) and number of oil spills

6.3.7 Causes of Oil Spills

One of the main problems analyzing the causes of oil spills is the available data, especially for small spill. However, every piece of information contains significant knowledge because the causes and circumstance of oil spills differ greatly from case to case.

From the available data, there have been created several categories of the primary causes: Allisions/Collisions, Groundings, Hull Failures, Equipment Failures, Fires and Explosions, Others and Unknown (Figure 30). Has to be noted that weather conditions and human error have been added as Other. Oil spills where the data isn't available or there are significant gaps are added as Unknown and are excluded from the analysis, however they are reported.

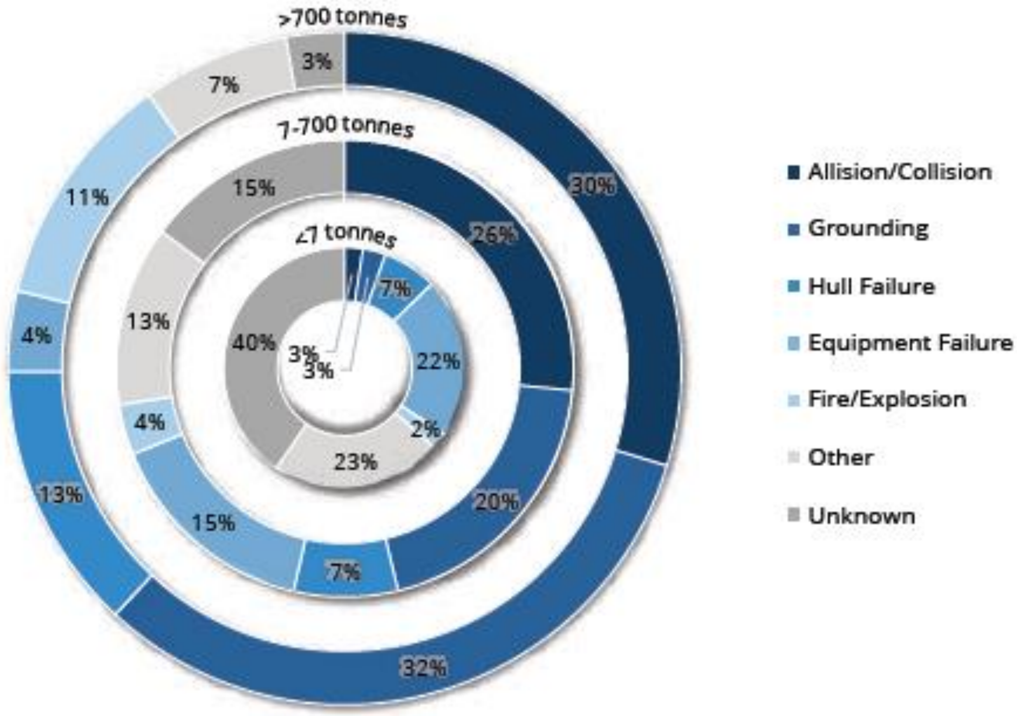

Figure 30 – Causes of spills, 1970-2018

The analysis below is using the information from medium and large oil spills, excluding those with the unknown cause.

The cause of the majority of those oil spill incident for the recorded period was Allisions/Collisions and Groundings. The percentage of oil spills from Allisions/Collisions has increased, and from Ground has decreased. Has to be noted that there is a significant reduction of the percentage of oil spills caused by Hull Failure since the 1990s (Figure 31)

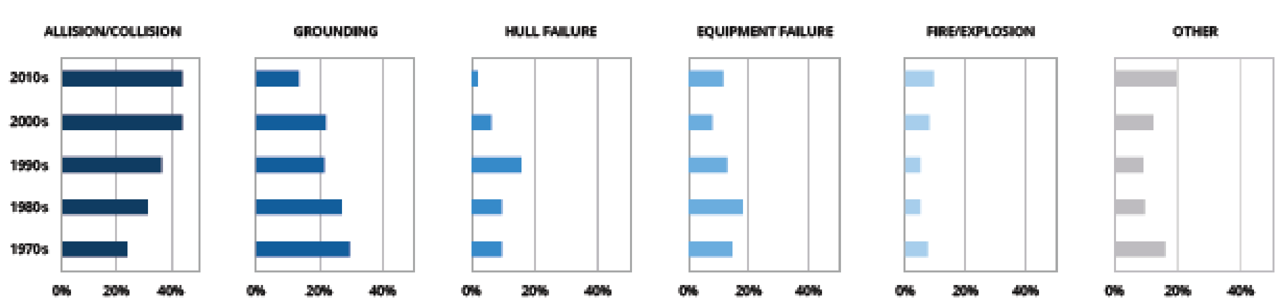

Figure 31 – Cause of spills per decade, for the recorded period

Below is analyzed the main cause of the oil spill, in regard the operations that were taking place by the vessels that caused the incident.

As it was mentioned before the unknown causes are not included. The primary causes are specified above.

To conclude better results, the operations have summarized to Loading/Discharging, Bunker, Other Operation and Unknown Operations. Ballasting, de-ballasting and tank cleaning are incorporated into the Other Operations. This was done due to the lack of information on small and medium spills. The analysis of large spills has a detailed vessel operation characterization since they contribute additional data. Accordingly, the operations are organized into Loading/Discharging, Bunkering, At Anchor (Inland/Restricted waters), At Anchor (Open water), Underway (Inland/Restricted waters), Underway (Open water), Other Operations and Unknown Operations.

The majority of the recorded incidents (95%) are small and medium oil spills. Due to the lack of information the exact causes of the incidents for many cases are unknown. Nevertheless, it can be shown that 40% of small oil spills are caused during Loading/Discharging, and 29% of medium oil spills are caused during the same operation. These operations take place in ports and oil terminals (Figure 32).

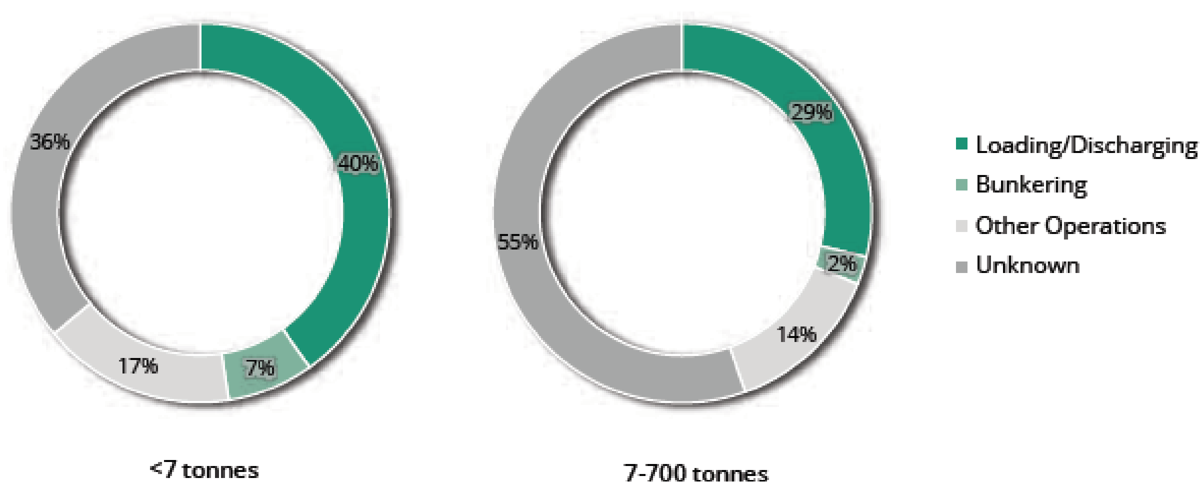

Figure 32 – Small and medium oil spills during for the recorded period

According the available data on small and medium soil spills, for which the main cause is established, equipment failure accounts for approximately 45% for small oil spills, and 50. However, there is a significant difference in Allision/Collision when comparing the main cause during Other operations in small and medium spills which is 4% and 35% respectively.

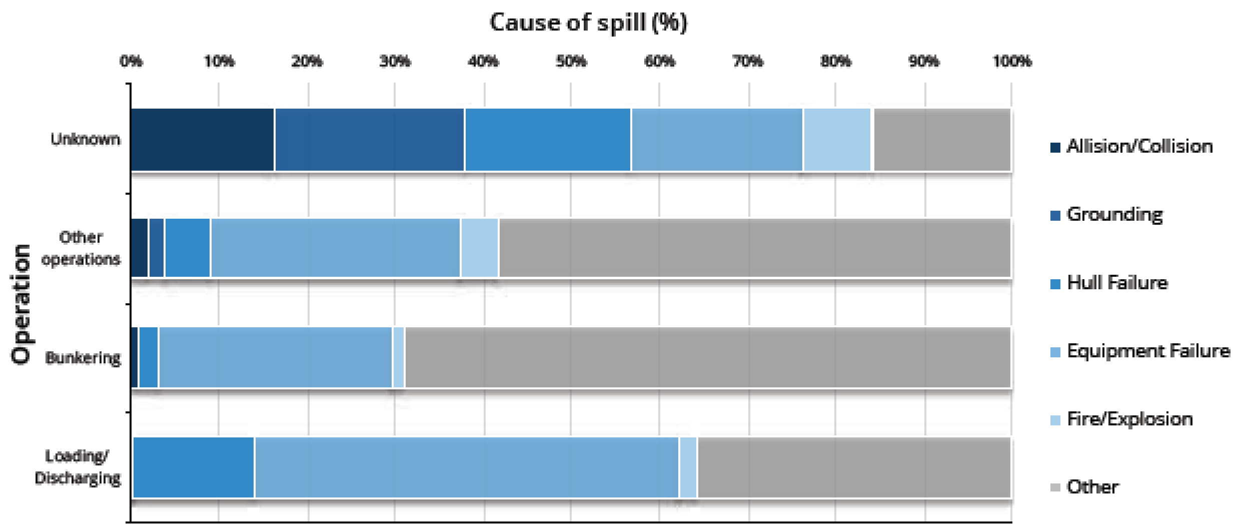

Figure 33 – Percentage of primary cause of small oil spills during each operation

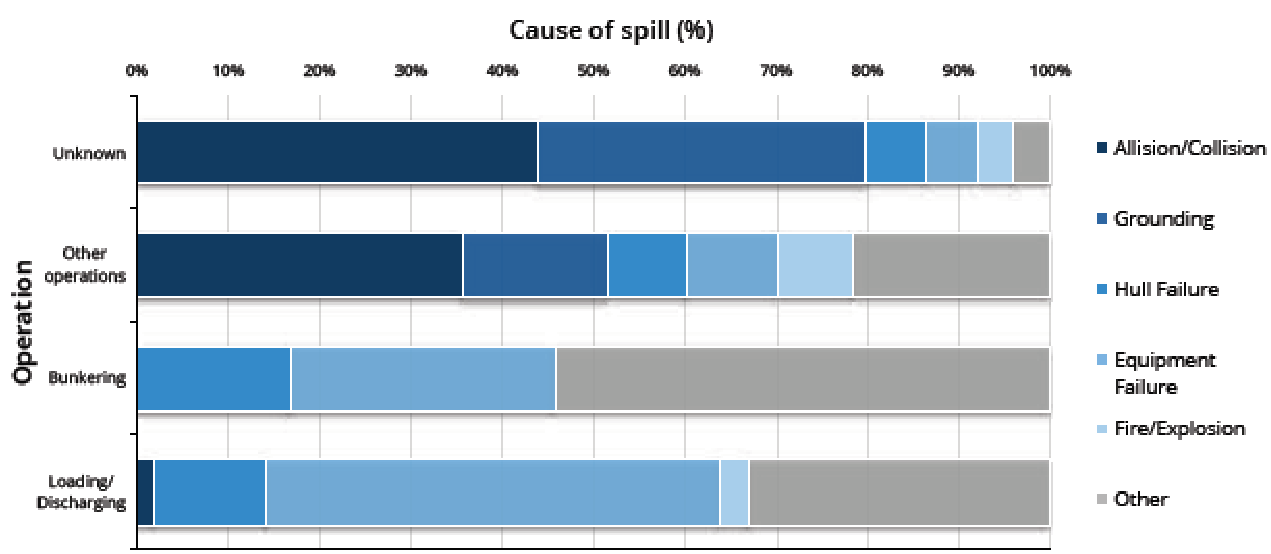

Figure 34 – Percentage of primary cause of medium oil spills during each operation

Even though there is more available data for large oil spills, a significant portion (18%) of operations is Other/Unknown. 50% the incidents took place on open waters when the vessel was Underway, with the main causes being Allision/Collision and Grounding, 28% and 30% respectively. As it was expected those are the primary causes when the vessel was underway (inland/restricted) accounting for 41% for Allision/Collision and 58% for Grounding.

By comparing the causes of small and medium oil spills with the causes of large, it can be seen that 36% of large oil spills were caused by fires and explosions, whilst 4% percent of small and medium were caused for the same reason. However, the gap is small when comparing the

Equipment failure cause which accounts for 31% for large, 50% for medium and 48% for small oil spills.

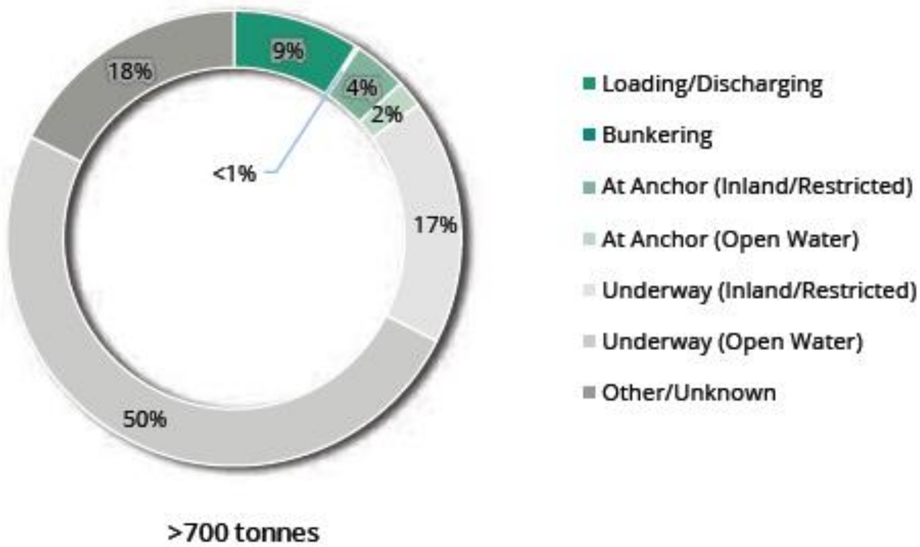

Figure 35 – Percentage of operations during the occurrence of large oil spills

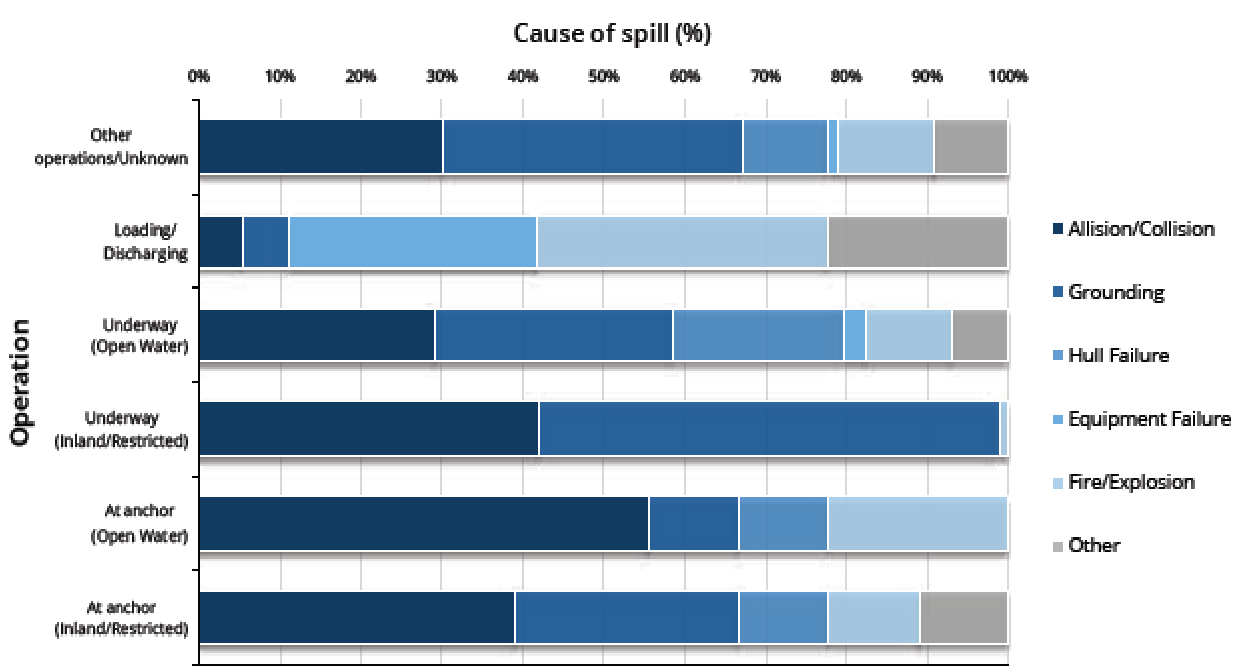

Figure 36 – Percentage of primary cause of large oil spills during each operation

On tables 4 and 5 are shown the number of causes and the operations that the vessels were undergoing at the time of medium and large oil spills for the recorded period.

Table 4 – Number of primary causes and operations for medium oil spill

Causes	Operations				Total
	Loading/ Discharging	Bunkering	Other Operations	Unknown	
Allision/Collision	5	0	61	299	365
Grounding	0	0	27	244	271
Hull Failure	37	4	15	45	101
Equipment Failure	147	7	17	39	210
Fire/Explosion	9	0	14	26	49
Other	98	13	37	28	176
Unknown	99	9	14	81	203
Total	*395*	*33*	*185*	*762*	1375
Percentage (%)	29	2	14	55	

Table 5 – Number of primary causes and operations for large oil spill

	Operations							
Causes	At anchor (Inland/Restricted)	At anchor (Open Water)	Underway (Inland/Restricted)	Underway (Open Water)	Loading/Discharging	Bunkering	Other Operations/ Unknown	**Total**
Allision/Collision	7	5	34	67	2	0	23	**138**
Grounding	5	1	46	68	2	0	28	**150**
Hull Failure	2	1	0	49	0	0	8	**60**
Equipment Failure	0	0	0	6	11	0	1	**18**
Fire/Explosion	2	2	1	25	13	1	9	**53**
Other	2	0	0	16	8	0	7	**33**
Unknown	0	0	0	1	6	0	6	**13**
Total	**18**	**9**	**81**	**232**	**42**	**1**	**82**	**465**
Percentage (%)	4	2	17	50	9	0	18	

[7]

6.4 Major spills

Gulf War oil spill: 1,360,000 -1,500,000 tons

The second worst oil spill in history, the Gulf War oil spill spewed an estimated 8 million barrels of oil into the Persian Gulf after Iraqi forces opened valves of oil wells and pipelines as they retreated from Kuwait in 1991. The oil slick reached a maximum size of 101 miles by 42 miles and was five inches thick. It was revealed that in a last-ditch attempt to prevent U.S. forces from landing on the beaches of Kuwait, Iraqi forces intentionally dumped oil into the Persian Gulf. They released oil from eight oil tankers, a refinery, two terminals, and a tank field. Since the Iraqis anticipated an amphibious invasion, they also dug long trenches down the coastline and filled them with oil. The entire act of environmental terrorism released a total of 11 million barrels of crude oil into the Gulf, resulting in the largest oil spill in history.[25] For the next three months, oil continued to spill into the Gulf at a rate of up to 6,000 barrels a day.[24] Furthermore, while the Iraqis were retreating they set ablaze a reported 732 oil wells. When the Kuwait Oil Company first announced this in May of 1991, they calculated the oil wells were burning as many as 6 million barrels a day. [23]

Deepwater Horizon – est. 550,000 to 750,000 tons

During the final phases of drilling the exploratory well at Macondo, a geyser of seawater erupted from the marine riser onto the rig, shooting 73 m into the air. This was soon followed by the eruption of a slushy combination of drilling mud, methane gas, and water

Eight key findings related to the causes of the accident emerged

1. The annulus cement barrier did not isolate the hydrocarbons. The day before the accident, cement had been pumped down the production casing and up into the wellbore annulus to prevent hydrocarbons from entering the wellbore from the reservoir. The annulus cement that was placed across the main hydrocarbon zone was a light, nitrified foam cement slurry. This annulus cement probably experienced nitrogen breakout and migration, allowing hydrocarbons to enter the wellbore annulus. The investigation team concluded that there were weaknesses in cement design and testing, quality assurance and risk assessment.

2. The shoe track barriers did not isolate the hydrocarbons. Having entered the wellbore annulus, hydrocarbons passed down the wellbore and entered the 9 7/8 in. x 7 in. production casing through the shoe track, installed in the bottom of the casing. Flow entered into the casing rather than the casing annulus. For this to happen, both barriers in the shoe track must have failed to prevent hydrocarbon entry into the production casing. The first barrier was the cement in the shoe track, and the second was the float collar, a device at the top of the shoe track designed to prevent fluid ingress

into the casing. The investigation team concluded that hydrocarbon ingress was through the shoe track, rather than through a failure in the production casing itself or up the wellbore annulus and through the casing hanger seal assembly. The investigation team has identified potential failure modes that could explain how the shoe track cement and the float collar allowed hydrocarbon ingress into the production casing.

3. The negative-pressure test was accepted although well integrity had not been established. Prior to temporarily abandoning the well, a negative-pressure test was conducted to verify the integrity of the mechanical barriers (the shoe track, production casing and casing hanger seal assembly). The test involved replacing heavy drilling mud with lighter seawater to place the well in a controlled underbalanced condition. In retrospect, pressure readings and volume bled at the time of the negative-pressure test were indications of flow-path communication with the reservoir, signifying that the integrity of these barriers had not been achieved. The Transocean rig crew and BP well site leaders reached the incorrect view that the test was successful and that well integrity had been established.

4. Influx was not recognized until hydrocarbons were in the riser. With the negative-pressure test having been accepted, the well was returned to an overbalanced condition, preventing further influx into the wellbore. Later, as part of normal operations to temporarily abandon the well, heavy drilling mud was again replaced with seawater, under balancing the well. Over time, this allowed hydrocarbons to flow up through the production casing and passed the BOP Indications of influx with an increase in drill pipe pressure are discernable in real-time data from approximately 40 minutes before the rig crew took action to control the well. The rig crew's first apparent well control actions occurred after hydrocarbons were rapidly flowing to the surface. The rig crew did not recognize the influx and did not act to control the well until hydrocarbons had passed through the BOP and into the riser.

5. Well control response actions failed to regain control of the well. The first well control actions were to close the BOP and diverter, routing the fluids exiting the riser to the Deepwater Horizon mud gas separator (MGS) system rather than to the overboard diverter line. If fluids had been diverted overboard, rather than to the MGS, there may have been more time to respond, and the consequences of the accident may have been reduced.

6. Diversion to the mud gas separator resulted in gas venting onto the rig. Once diverted to the MGS, hydrocarbons were vented directly onto the rig through the 12 in. goosenecked vent exiting the MGS, and other flow-lines also directed gas onto the rig. This increased the potential for the gas to reach an ignition source. The design of the MGS system allowed diversion of the riser

contents to the MGS vessel although the well was in a high flow condition. This overwhelmed the MGS system.

7. The fire and gas system did not prevent hydrocarbon ignition. Hydrocarbons migrated beyond areas on Deepwater Horizon that were electrically classified to areas where the potential for ignition was higher. The heating, ventilation and air conditioning system probably transferred a gas-rich mixture into the engine rooms, causing at least one engine to overspeed, creating a potential source of ignition.

8. The BOP emergency mode did not seal the well. Three methods for operating the BOP in the emergency mode were unsuccessful in sealing the well.

- The explosions and fire very likely disabled the emergency disconnect sequence, the primary emergency method available to the rig personnel, which was designed to seal the wellbore and disconnect the marine riser from the well.
- The condition of critical components in the yellow and blue control pods on the BOP very likely prevented activation of another emergency method of well control, the automatic mode function (AMF), which was designed to seal the well without rig personnel intervention upon loss of hydraulic pressure, electric power and communications from the rig to the BOP control pods. An examination of the BOP control pods following the accident revealed that there was a fault in a critical solenoid valve in the yellow control pod and that the blue control pod AMF batteries had insufficient charge; these faults likely existed at the time of the accident.
- Remotely operated vehicle intervention to initiate the autoshear function, another emergency method of operating the BOP likely resulted in closing the BOP's blind shear ram (BSR) 33 hours after the explosions, but the BSR failed to seal the well. [26]

Ixtoc I oil well: 454,000 tons

Ixtoc (ISH-tok) 1 was an exploratory oil well being drilled in the southwestern Gulf of Mexico by Mexico's government-owned oil company Pemex in 1979. On June 3, circulation of drilling mud to the well failed, causing a blowout, explosion, and fire that resulted in the destruction and sinking of the rig.

For nearly ten months, the well poured oil into the Gulf at a rate initially estimated to be 30,000 barrels per day. That was later reduced by about one-third by pumping nearly 100,000 metal balls into the well. [27]

Atlantic Empress/Aegean Captain: 287,000 ton

In July 1979, a Greek oil tanker called the Atlantic Empress collided with another ship, the Aegean Captain, during a tropical storm off of the island of Tobago in the Caribbean Sea. The Atlantic Empress disaster killed 26 crew members and is the largest ship-based oil spill.[28]

Fergana Valley: 285,000 tons

The Fergana Valley, one of Central Asia's most densely populated agricultural and industrial areas, was the site of the largest inland oil spills in history in 1992. The Fergana Valley oil spill happened when the Mingbulak oil field had a blow out at well number 5.[29]

Nowruz oil field: 260,000 tons

On February 10, 1983, a tanker collided with a platform. January 1983, oil began to discharge from a well in the Nowruz oil field, in Iranian territorial waters. Between January and October 1983, an estimated 42 million gallons of oil were spilled into the Persian Gulf, primarily from several spills associated with the Iran-Iraq War. Wave action and corrosion apparently caused the riser to collapse into the well-head causing a spill of approximately 1,500 barrels per day. The platform burned and spilled oil at an initial rate of approximately 5,000 barrels per day. It is estimated that the rate of oil leaking into the Persian Gulf in Mid-May of 1983 was between 4,000 and 10,000 barrels per day due to more war-related activity or the collapse of burning platforms. [30]

ABT Summer: 260,000 tons

On the morning of 28 May 1991, the Liberian oil tanker ABT Summer exploded 1,287 km off the coast of Angola (Africa). It was transporting 260,000 tonnes of heavy Iranian crude. In the afternoon, 7 vessels arrived onsite to rescue the crew. 27 people were rescued, however one person was killed and 4 went missing.

Two tugs, the Red Kestrel and the Red Robin, as well as a plane attempted to fight the fire onboard the ship.

On 29 May, the flames were still raging onboard the ABT Summer and an oil slick was beginning to form around the ship (32 km long by 7 km wide). The tanker burnt for 3 days before sinking on 1st June.

In June, the response team attempted to track down signs from the ABT Summer to locate the wreck, in vain. The wreck has never been found since. [31]

Castillo de Bellver: 252,000 tons

In August 1983, a fire aboard the Castillo de Bellver led to an explosion that caused the tanker to break in two. Oil spilled into the sea 24 miles off the coast of Cape Town, marking the largest spill to date in South Africa. Luckily, the oil caused minimal environmental damage as the direction of the wind moved the oil slick offshore, where it dissipated naturally. The tanker, of 263 031 GRT,was owned by the Empressa Nacional Elcano, the Spanish Government Shipping Line. It was en route from the Persian Gulf to Spain with 250 000 tons of crude oil although initial estimates were 160000 to 190000 tons. [32]

The Amoco Cadiz: 230,000 tons

Stormy weather drove the Amoco Cadiz VLCC aground on the Portsall Rocks, a 90-foot deep outcrop off the coast of Brittany, France, in 1978. The ship split in two and quickly sank before its 1,604,500 barrels of oil load could be pumped from the wreck. [33]

The Haven: 145,000 tons

A violent explosion aboard the Cyprus-based tanker the Haven killed six members of the crew and spilled 145,000 tons of oil off the coast of Italy in April 1991. About 70 percent of the oil burned in the ensuing fire. In most oil spills, oil remains near the surface of the water, but in this spill some of it sank. Oil from the Haven was later found in ocean beds at depths of up to 500 meters. [34]

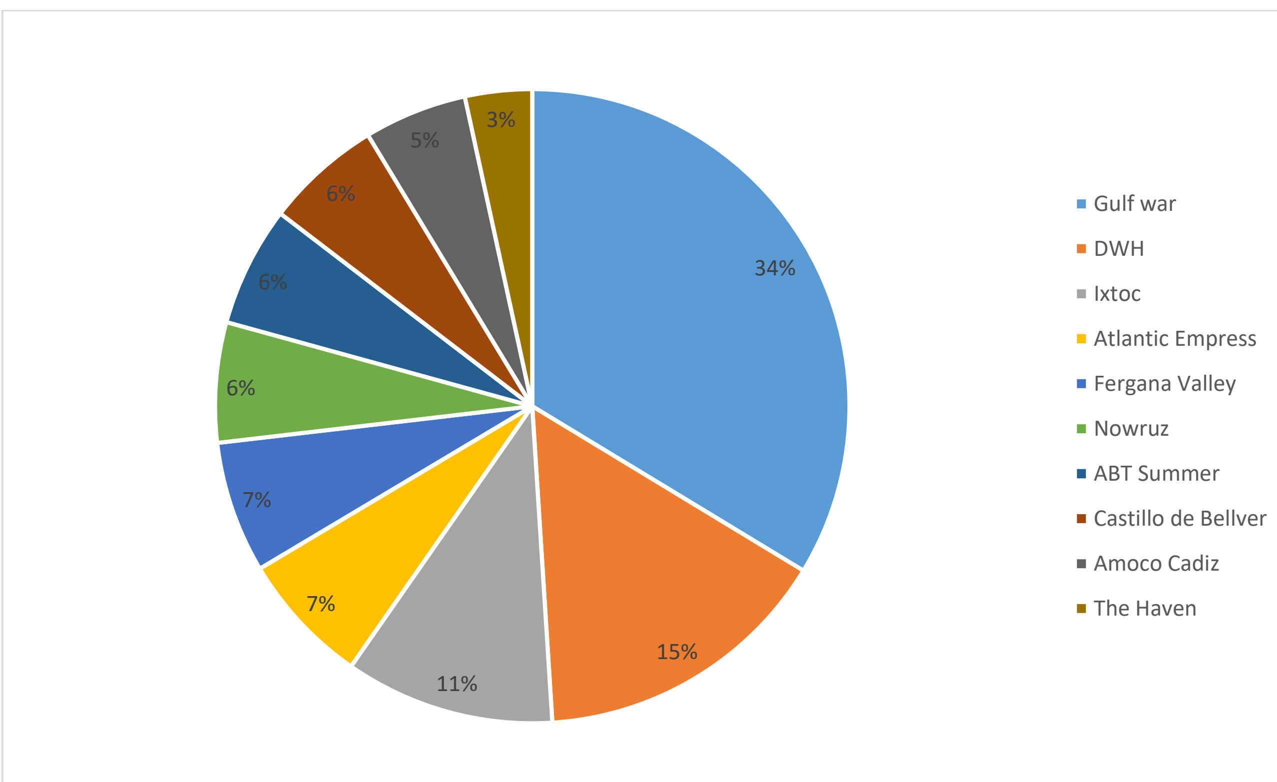

Figure 37 – Oil spill distribution in major accidents

7 Legal framework

The potential of oil tanker to pollute the environment was noted by the IMO and several laws were implemented beginning with OILPOL 1954 and updated later on.

Torrey Canyon disaster

Although the OILPOL Convention had been ratified, pollution control was at the time still a minor concern for IMO, and indeed the world was only beginning to wake up to the environmental consequences of an increasingly industrialized society.

The incident of 1967 of the Torrey Canyon that spilled 120,000 tons of crude oil in the sea alerted the world for the impact of the oil spilled into the marine environment, Emerging questions and worries regarding the marine ecosystem. Leading eventually to the establishment of the MARPOL protocol, as well as a host of Conventions in the field of liability and compensation.

The board of IMO selected the issue with a plan with practical and legal perspectives for future incidents. Whilst accidents are still possible the operational pollution are the most crucial pollution and how to reduce the impact of these incidents.

Two years after the Canyon incident a new technique was introduced “load on top” where oil was saved whilst reduced pollution was achieved. Where during the travel the terminal oil and water are separated, the water is pumped overboard, and the terminal oil left in the tank.

Simultaneously, the increase of oil transport, tankers, and chemicals created concern on the ecosystem, leading to the fact that 1954 OILPOL guideline is inadequate to cover the present needs.

Thus, a complementary version of the OILPOL 1954 was conducted in 1969 by the IMO Assembly. Alongside, the Sub-Committee on Oil Pollution was altered to Sub-Committee on Marine Pollution, to wide its perspective, thus becoming the Marine Environment Protection Committee (MEPC), dealing with all the issued regarding the pollution of the marine ecosystem.

The conference was set for October-November 1973, and preparatory meetings began in 1970.

Meanwhile, in 1971 IMO adopted amendments to OILPOL 1954, which limited the size of cargo tanks in all tankers ordered after 1972. The intention was that given certain damage to the vessel, only a limited amount of oil could enter the sea.

1973 International Convention for the Prevention of Pollution from Ships

The 1973 conference in October-November 1973 incorporated much of OILPOL 1954 and its amendments into Annex I, covering oil, while other annexes covered chemicals, harmful substances carried in packaged form, sewage and garbage.

Annex I expanded and improved on OILPOL in several ways. It specified requirements for continuous monitoring of oily water discharges and included the requirement for Governments to provide shore reception and treatment facilities at oil terminals and ports. It also established a number of Special Areas in which more stringent discharge standards were applicable, including the Mediterranean, Red Sea and Gulf, and Baltic Seas. These special areas would be implemented when the littoral States concerned had provided adequate reception facilities for dirty ballast and other oily residues.

An important regulation of Annex I was Regulation 13 which required segregated ballast tanks on new tankers over 70,000 deadweight tonnes. The aim was to ensure that ballast water (taken on board to maintain stability, such as when a tanker is sailing empty to pick up cargo) is never going to be contaminated by oil carried as cargo or fuel.

As it turned out, there was slow progress at ratifying the Convention (partly due to technical problems in ratifying Annex II) and the non-ratification of MARPOL became a major concern.

At the same time, a series of tanker accidents in 1976-1977, mostly in or near United States waters and including the stranding of the Argo Merchant, led to demands for more stringent action to curb accidental and operational oil pollution. The Argo Merchant ran aground off Massachusetts in December 1976. It was a small tanker, carrying 27,000 tons of oil, but caused huge public concern as the oil slick threatened New England resorts and Georges Bank fishing ground.

The United States took the lead in asking the IMO Council, in May 1977, to consider adopting further regulations on tanker safety. The Council agreed to convene a Conference in February 1978 - the Conference on Tanker Safety and Pollution Prevention.

A working group met in May, June and July, and a combined MSC/MEPC met in October, to prepare basic documents for the Conference.

1978 Conference on Tanker Safety and Pollution Prevention

The Conference, in February 1978, adopted a protocol to the 1973 MARPOL Convention, absorbing the parent Convention and expanding on the requirements for tankers to help make them less likely to pollute the marine environment.

The Protocol expanded the requirements for segregated ballast tanks to all new crude oil tankers of 20,000 dwt and above and all new product carriers of 30,000 dwt and above. The Protocol also required segregated ballast tanks to be protectively located, in other words, placed in areas of the ship where they will minimize the possibility of and amount of oil outflow from cargo tanks after a collision or grounding.

To reduce the amount of oil that remains on the vessel after discharge, tanker with capacity over 20,000 DWT are required to be equipped with oil washing systems with the use of high-pressure jets.

The same Protocol introduced requirements for tanker over 40,000 DWT to be equipped with washing systems or ballast tanks. In addition, the Protocol allowed tanker the use of ballast tanks for an interim period.

Additional measures for tanker safety were incorporated into the 1978 Protocol to the International Convention for the Safety of Life at Sea (SOLAS), 1974. These included the requirement for inert gas systems (whereby exhaust gases, which are low in oxygen and thus incombustible, are used to replace flammable gases in tanks) on all new tankers over 20,000 dwt and specified existing tankers. The SOLAS Protocol also included requirements for steering gear of tankers; stricter requirements for carrying of radar and collision avoidance aids; and stricter regimes for surveys and certification.

In order to speed up implementation of MARPOL, the Conference allowed that the Parties "shall not be bound by the provisions of Annex II of the Convention for a period of three years" from the date of entry into force of the Protocol, so that countries could accept Annex I and have three years to implement Annex II.

Both the 1978 MARPOL and SOLAS Protocols were seen as major steps in raising construction and equipment standards for tankers through more stringent regulations.

If the world needed further reminder of the need for strict regimes to control oil pollution, it got it just one month after the 1978 Conference, when the Amoco Cadiz ran aground off Brittany, giving France its worst oil spill ever. The tanker, filled with 223,000 tons of crude oil, lost its entire cargo, covering more than 130 beaches in oil. In places, the oil was up to 30 cm thick.

Sufficient States had ratified MARPOL by October 1982, and the MARPOL 1973/78 Convention entered into force on 2 October 1983.

Since the Convention entered into force, there have been a number of amendments to the Convention – see MARPOL

Exxon Valdez incident

It was another tanker accident which led to one of the most important changes to be made to Annex I of the Convention since the adoption of the 1978 Protocol.

In March 1989, the Exxon Valdez, loaded with 1,264,155 barrels of crude oil, ran aground in the northeastern portion of Prince William Sound, spilling about one-fifth of its cargo. It was the largest crude spill, to date, in US waters and - probably the one which gained the biggest media coverage to date. The U.S. public demanded action - and duly got it.

The United States introduced its Oil Pollution Act of 1990 (OPA 90), making it mandatory for all tankers calling at U.S. ports to have double hulls.

The United States also came to IMO, calling for double hulls this time to be made a mandatory requirement of MARPOL. The implications of the Exxon Valdez spill were not lost on IMO Members, and the MEPC began discussions on how the U.S. proposals could be implemented.

As on previous occasions, there was some resistance on the part of the oil industry to double hulls being made mandatory, due mainly to the cost of retrofitting existing tankers.

At the same time, several of IMO's Member States said that other designs should be accepted as equivalents and that measures for existing ships should also be contemplated. In 1991 a major study into the comparative performances of the double-hull and mid-height deck tanker designs was carried out by IMO, with funding from the oil and tanker industry.

It concluded in January 1992 that the two designs could be considered as equivalent, although each gives better or worse outflow performance under certain conditions.

Eventually, the MEPC agreed to make mandatory double hulls or alternative designs "provided that such methods ensure the same level of protection against pollution in the event of a collision or stranding". These design methods must be approved by the MEPC.

1992 “double hull” amendments

The amendments introducing double hulls (or an alternative) were contained in old Regulation 13F - (now Regulation 19) prevention of oil pollution in the event of collision or stranding. The amendments were adopted in March 1992 and entered into force in July 1993.

Regulation 13F applies to new tankers - defined as delivered on or after 6 July 1996 - while existing tankers must comply with the requirements of 13F not later than 30 years after their date of delivery.

Tankers of 5,000 dwt and above must be fitted with double bottoms and wing tanks extending the full depth of the ship's side. The regulation allows mid-deck height tankers with double-sided hulls as an alternative to double hull construction.

Oil tankers of 600 dwt and above but less than 5,000 dwt, must be fitted with double bottom tanks and the capacity of each cargo tank is limited to 700 cubic meters, unless they are fitted with double hulls.

The MEPC also adopted Regulation 13G (now Regulation 20), concerned with existing tankers, which makes provision for an enhanced programme of inspections to be implemented, particularly for tankers more than five years old.

Regulation 13G also allowed for future acceptance of other structural or operational arrangements - such as hydrostatic balance loading - as alternatives to the protective measures in the Regulation.

The Erika incident

The sinking of the Erika off the coast of France in December 1999 led to a new, accelerated phase-out schedule for single-hull tankers - the revision of old regulation 13G of MARPOL. The investigations into the Erika incident carried out by the French government and the Maltese maritime authority concluded that age, corrosion, insufficient maintenance and inadequate surveys were all strong contributing factors to the structural failure of the ship.

There was a wide consensus that the Erika and other the recent accidents involving oil tankers pointed to a need for additional international measures to eradicate substandard vessels, particularly substandard oil tankers given the catastrophic impact such ships may have on the marine environment in the case of an accident.

Besides the revised phase-out scheme for single-hull tankers, IMO also adopted other measures in response to the incident:

- Amendments adopted by IMO in October 2000 to raise by 50 percent the limits of compensation payable to victims of pollution by oil from oil tankers under the International Convention on Civil Liability for Oil Pollution Damage (CLC Convention) and the International Convention on the Establishment of an International Fund for Compensation for Oil Pollution Damage (IOPC Fund).
- IMO's Maritime Safety Committee (MSC) in December 2000 adopted amendments to the guidelines on the enhanced programme of inspections during surveys of bulk carriers and oil tankers (resolution A.744(18)) with relation to the evaluation of the longitudinal strength of the hull girder of oil tankers.
- Furthermore, IMO has taken action on several other operational matters based on a list of measures aimed at enhancing safety and minimizing the risk of oil pollution, drawn up in response to the Erika incident.

The Prestige incident

The Prestige incident of November 2002 led to further calls for amendments to the phase-out schedule for single hull tankers.

The MEPC at its 49th session in July 2003 agreed to an extra session of the Committee, to be convened in December 2003, to consider the adoption of proposals for an accelerated phase-out scheme for single hull tankers, along with other measures including an extended application of the Condition Assessment Scheme (CAS) for tankers.[8]

In Greece the following laws are implemented for regulating oil pollution in marine environment.

- N.Δ. 4529/1966 (ΦΕΚ 154/A/10-08-1966) Oil spill prevention convention OILPOL 54.
- N. 314/1976 (ΦΕΚ 106/A/05-05-1976). Reviewed on 02-05-1997 (ΦΕΚ 146/A/10-07-1997 International Convention on Civil Liability for Oil Pollution Damage.
- N.855/1978 (ΦΕΚ 235/A/23-12-1978) Dumping protocol of the United nations.
- N.1638/1986 (ΦΕΚ 108/A/18-07-1986) International Convention on the Establishment of an International Fund for Compensation for Oil Pollution Damage. Reviewed on 02-05-1997 (ΦΕΚ 146/A/10-07-1997)
- Π.Δ. 81/1989 (ΦΕΚ 36/A/07-02-1989) Changes on the Convection on Civil Liability
- N.2252/1994 (ΦΕΚ 192/A/18-11-1994) International Convention on Oil Pollution Preparedness, Response and Co-operation
- N.2321/1995 (ΦΕΚ 136/A/23-06-1995) Based on the United Nations convention on the Law of the Sea
- Π.Δ.197/1995 (ΦΕΚ 106/A/13-06-1995) Convention on Civil Liability 92
- Π.Δ. 270/1995 (ΦΕΚ 151/A/26-07-1995) Review International Convention on the Establishment of an International Fund for Compensation for Oil Pollution Damage
- N.3022/2002 (ΦΕΚ 144/A/19-06-2002) Changes on the Barcelona convention 1976
- Π.Δ. 286/2002 (ΦΕΚ 256/A/22-10-2002) Changes on the Convention on Civil Liability
- N.3100/2003 (ΦΕΚ 20/A/29-01-2003) Protocol on preparedness, cooperation and response 2000 HNS-OPRC 90
- Π.Δ. 291/2003 (ΦΕΚ 247/A/29-10-2003) Review International Convention on the Establishment of an International Fund for Compensation for Oil Pollution Damage
- N.3482/2006 (ΦΕΚ 163/A/02-08-2006) Protocol on establishing a supplementary fund for compensation from oil spills [9]

Conclusions

Based on the collected data there is a general decrease in the number of incidents that occur every year, this is due to the improvement of technology and legislation. There are exceptions from this general trend mainly because of uncontrollable circumstances (ex. Hurricanes), and there is only case (DWH) were all the prevention methods failed, which resulted to one of the biggest oil spills in history.

The following years the number on oil spills is expected to decrease even more because of newly integrated systems of monitoring (satellite, drones) which in some cases can improve the inspection rates and prevent accidents, it should be noted that to keep that trend the existing infrastructure (pipelines, production facilities) must be maintained and monitored.

Potential spill sources may be the plugged and abandoned wells since the life time of many offshore platforms and wells comes to an end the following years.

Oil spill recovery methods are improving as well and the percentage of recoverable oil is increasing.

For the region of Greece, it is recommended international cooperation between Greek authorities and EGIG to monitor and prevent spill incidents in newly constructed pipeline projects, as well as future projects such as the floating storage regasification unit.

There should be also the creation of an annual report of the occurring incidents based on the Digital Waste Registry from the Greek authorities to keep track and improve on methods of collection oil spill waste.

References

1. THE ENVIRONMENTAL IMPACT OF MARINE OIL SPILLS -Effects, Recovery and Compensation, Dr. Brian Dicks, Technical Team Manager, International Tanker Owners Pollution Federation Ltd, International Seminar on Tanker Safety, Pollution Prevention, Spill Response and Compensation, 6th November 1998, Rio de Janeiro, Brazil

2. Impacts of oil spills on marine ecology, Good practice guidelines for incident management and emergency response personnel, IOGP Report 525, International Association of Oil & Gas Producers, 2015

3. Congressional Research Service, Oil Spills: Background and Governance, 09/15/2017

4. Journal of Environmental Management, A sustainable approach to controlling oil spills, Abdul Aziz Al-Majed, Abdulrauf Rasheed Adebayo, M. Enamul Hossain, 2 October 2012

5. http://www.itopf.org/knowledge-resources/countries-territories-regions/countries/greece/ (checked 16/09/2019)

6. Emergency Response Management of Offshore Oil Spills, Guidelines for Emergency Responders, Nicholas P. Cheremisinoff, Anton Davletshin, 2011, ISBN 978-0-470-92712-0

7. Oil Tanker Spill Statistics 2018, January 2019, International Tanker Owners Pollution Federation Limited

8. http://www.imo.org/en/OurWork/Environment/PollutionPrevention/OilPollution/Pages/Background.aspx (15/01/2020)

9. http://www.ypeka.gr/ (12/01/2020)

10. https://www.epa.gov/emergency-response/epas-response-techniques (01/01/2020)

11. Performance of European cross-country oil pipelines Statistical summary of reported spillages in 2017 and since 1971

12. 10th Report of the European Gas Pipeline Incident Data Group (period 1970 – 2016)

13. Journal of Petroleum Science and Engineering, Performance evaluation of subsea blowout preventer systems with common-cause failures, Baoping Cai, Yonghong Liu n, Zengkai Liu, Xiaojie Tian, Yanzhen Zhang, Jing Liu ,April 2012

14. Safety Science. An oil recovery technique for emergency response in deepwater blowout accidents, Huixing Meng, Guoming Chenc, Xiuquan Liuc’, Yuan Zhuc, March 2019

15. 2016 Update of Occurrence Rates for Offshore Oil Spills, Bureau Ocean Energy Management, ABS CONSULTING INC.

16. https://www.phmsa.dot.gov/data-and-statistics/pipeline/data-and-statistics-overview (03/01/2020)

17. Guidelines for the use of dispersants for combating oil pollution at sea in the Mediterranean region, Part II: Basic information on dispersants and their application, REMPEC, MEDITERRANEAN ACTION PLAN

18. Controlled in-situ burning of spilled oil, International Association of Oil & Gas Producers, 2016

19. International Tanker Owners Pollution Federations Limited, HANDBOOK 2011/12

20. Mediterranean Oil Spill Waste Management Guidelines, REMPEC, May 2011

21. http://www.environmental-research.com/index.php (12/01/2020)

22. Etkin, Dagmar. (2001). Analysis of oil spill trends in the United States and worldwide. International Oil Spill Conference Proceedings. 2001. 10.7901/2169-3358-2001-2-1291.

23. C. C. Joyner and J. T. Kirkhope, "The Persian Gulf War Oil Spill: Reassessing the Law of Environmental Protection and the Law of Armed Conflict," Case W. Res. J. Intl. Law 24, No. 1, 29 1992.

24. J. Michel, "1991 Gulf War Oil Spill," in Oil Spill Science and Technology, ed. by M. Fingas (Gulf Professional Publishing, 2010)

25. T. M. Hawley, Against The Fires of Hell: The Environmental Disaster of the Gulf War (Harcourt Brace Jovanovich, 1992).

26. DEEPWATER HORIZON ACCIDENT INVESTIGATION REPORT https://www.sec.gov/Archives/edgar/data/313807/000119312510216268/dex993.htm (11/09/2019)

27. https://www.whoi.edu/oil/ixtoc-I

28. Hooke, N. (1997) Maritime casualties, 1963-1996. 2nd edition, LLP Limited, London

29. Oil & Gas Resources of the Fergana Basin (Uzbekistan, Tadzhikistan, & Kyrgyzstan). Collingdale, PA: Diane Pub. 1995.

30. Pashaei, Reza & Gholizadeh, Mortaza & Hanifi, Ahad & jodeiri iran, Keyvan. (2015). The Effects of Oil Spills on Ecosystem at the Persian Gulf. 10.13140/RG.2.1.2239.3684.

31. https://wwz.cedre.fr/en/Resources/Spills/Spills/ABT-Summer (12/12/2020)

32. Some aspects of the Castillo de Bellver oil spill, A.G.S. Moldan L. F. Jackson S. McGibbon J. Van Der Westhuizen, Sea Fisheries Research Institute, Private Bag X2, 8012 Roggebaai, South Africa,Marine Pollution Bulletin,Volume 16, Issue 3, March 1985, Pages 97-102

33. The Amoco Cadiz oil spill—At a glance, Knut Lehre Seip, Marine Pollution Bulletin, Volume 15, Issue 6, June 1984, Pages 218-220

34. https://safety4sea.com/cm-mt-haven-the-worst-oil-spill-ever-in-the-mediterranean/

35. https://stats.unctad.org/handbook/MaritimeTransport/WorldSeaborneTrade.html