

Quantitative Approach to the Preliminary Risk Analysis of Environmental Contamination Caused by Oil Spills from Offshore Oil and Gas Installations

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S1. Oil Spill Risk Assessment (OSRA) methods: source-based methods, exposure-based methods, and damage-based methods

A large number of Oil Spill Risk Assessment (OSRA) methods is available in the technical literature. Focusing only on those OSRA approaches taking into account both the frequencies and the consequences of spills, it is useful to consider the three categories into which they can be classified, in increasing order of complexity [41], as explained below: 1) source-based methods; 2) exposure-based methods; 3) damage-based methods.

When considering source-based procedures, an initial rough attempt to define the risk of environmental pollution caused by oil spills at sea is described in [69], where curves showing the relationship between the occurrence frequency and the size of oil spills are introduced, in the form of graphs where the cumulated frequency of oil accidents is plotted versus the spill volume. Unquestionably, the consequences of an oil spill strongly depend on the source term, i.e., on the amount of oil spilled. However, as already evidenced in the study, this approach does not consider the interaction between the oil and the environment, which has as well a strong influence on the fate of the spill. Nevertheless, several years later, plots reporting the cumulated frequency versus the spill size were adopted as the metrics for expressing the risk to the environment (e.g., in [96]).

A step forward with respect to this source-based approach has been proposed by the ISO 17776 guideline [41], where it is recognized that the assessment of environmental risk can be carried out via exposure-based or damage-based procedures. To better understand the peculiar features of these methods, it is necessary to remark that, in order to obtain both exposure- and damage-based risk indexes, as a first step the fate of the spilled oil has to be determined for each release scenario through oil weathering and drift models, resulting in maps of the oiled zones. For this evaluation, in addition to the rate and duration of the leakage event, information about the oil type, the depth of the spill, the position of the spill site, the morpho-bathymetric features of the area, and the metocean

conditions are required. Successively, the information about the oil presence has to be overlapped to maps reporting the vulnerability of the area, expressed by the spatial and temporal distribution of the valuable resources, as endangered species, sensitive natural habitats, sites important from the cultural, economic, and recreational points of view (for instance, fisheries, water intakes, historical sites, and tourist resorts on the coast) [46].

By this approach, it is possible to carry out a qualitative evaluation of the exposure, defined as the environmental impact of an oil spill on the ecological resources, by assigning it to one of the impact categories which can be defined on the basis of the density of the high value targets in the affected area and of the amount of oil impacting them. The availability of estimates of the environmental impact represents the input to the Net Environmental (and economic) Benefit Analysis (NEBA) of the response strategies which could be used in order to contrast the oil spill. A NEBA study may be performed qualitatively. Alternatively, a semi-quantitative approach may be applied as, for instance, the Spill Impact Mitigation Assessment (SIMA) method [72, 97].

As a further step, after estimating the exposure, it is possible to evaluate the environmental damage, considering how long the environmental impact on the more vulnerable marine populations will last. In fact, the damage is usually expressed in terms of recovery time, i.e., the time necessary for the living organisms exposed to the oil to revert to the conditions existing prior to the spill event. Usually, a predefined limited number of time ranges, spanning from a few months to several years, are considered to categorize the environmental damage.

In both the exposure- and the damage-based procedures, the results of the risk assessment can be reported on a risk matrix, in which the oil spill occurrence frequency - assigned to some predefined categories - is reported versus the environmental consequences, expressed in terms of environmental impact in the exposure-based risk approaches, and of recovery time in the damage-based methods. As an example, the exposure-based approach proposed in [46] adopts a risk matrix with five categories for the spill frequency f , ranging from likely (equal or higher than 10^{-2} ev/y) to remote (equal or lower than 10^{-6} ev/y) and five categories for the exposure, ranging from low to disastrous environmental impact. Differently, the Norwegian methodology MIRA [45] and its extension to the marginal ice zone [47], up to now in use for the installations of the Norwegian Continental Shelf, are damage-based procedures, using a risk matrix with five categories for the spill frequency and four categories for the environmental damage, ranging from one month to 20 years. More in detail, in the Norwegian approach the probability distribution of the recovery time for the different ecological components in the oiled area is determined, considering the oil amount and the vulnerability to oil of each species. The recent ERA Acute methodology, intended to substitute the MIRA procedure in the future, is also damage-based, addressing the sensitive habitats and populations of the marine environment more systematically than MIRA [38, 50, 98].