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Research Article

Blowout Accident Impact Analysis Method for the Siting of Offshore Floating Nuclear Power Plant in Offshore Oil Fields

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Focused on the utilization of nuclear energy in offshore oil fields, the correspondence between various hazards caused by blowout accidents (including associated, secondary, and derivative hazards) and the initiating events that may lead to accidents of offshore floating nuclear power plant (OFNPP) is established. The risk source, risk characteristics, risk evolution, and risk action mode of blowout accidents in offshore oil fields are summarized and analyzed. The impacts of blowout accident in offshore oil field on OFNPP are comprehensively analyzed, including injection combustion and spilled oil combustion induced by well blowout, drifting and explosion of deflagration vapor clouds formed by well blowouts, seawater pollution caused by blowout oil spills, the toxic gas cloud caused by well blowout, and the impact of mobile fire source formed by a burning oil spill on OFNPP at sea. The preliminary analysis methods and corresponding procedures are established for the impact of blowout accidents on offshore floating nuclear power plants in offshore oil fields, and a calculation example is given in order to further illustrate the methods.

1. Introduction

The development of OFNPPs has attracted attention in the nuclear industry for a long time. The original intention of the OFNPP proposal is that OFNPP could be an effective solution for the scarcity of land site for nuclear power plants. Klepper et al. [1] made a survey of the availability and characteristics of offshore sites in the US for OFNPPs. Zhang et al. [2] performed safety analysis of a 300 MWe OFNPP in the marine environment by investigating the effects of motions for the six degrees of freedom on the engineered safety systems of the OFNPP. Buongiorno et al. [3] presented a new offshore floating nuclear plant (OFNP) concept with high potential for attractive economics and an unprecedented level of safety. Akademik Lomonosov, the only floating nuclear power plant today, is constructed in Russia with two 35 MWe reactors mounted on a barge to be moored at a harbor to supply energy and heat generated by the offshore units to the remote city of Pevek.

A large amount of electricity, heat, and fresh water is required for the development of offshore oil and gas fields. Normally, oil-gas turbines and heating boilers are commonly used in oil fields to provide electricity and heat for oil and gas production. However, the equipment will not only occupy much platform space, thereby increasing the cost of platform construction, but also produce a large amount of CO_2 and other harmful gases during their operation. As a low-carbon clean energy, OFNPP can not only provide energy for offshore oil production but also meet the needs of clean production and emission reduction. It uses small integrated PWR, which saves space and has better flexibility.

OFNPP consists of floating platform, reactor, steam generator system, drainage and heat dissipation system, power transmission system, and safety facilities. The function of safety facilities is to prevent rare and extreme accidents of OFNPP from further evolving into serious accidents beyond the design basis, similar as those of nuclear power plants on land.

In order to ensure the safety of power supply, especially the power cable, disconnectable SPM (single point mooring) or spread mooring will be used to anchor OFNPP on-site as shown in Figure 1. Those mooring system are so complex that the disconnection of OFNPP from them would be a

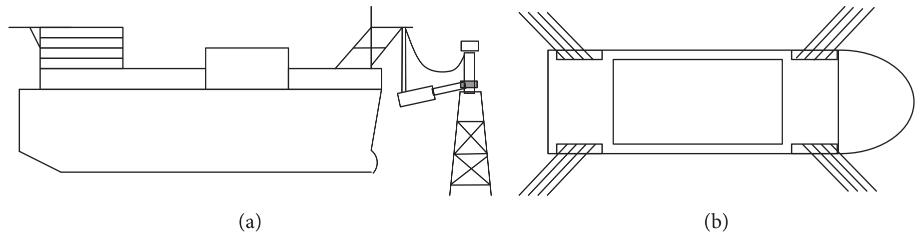

Figure 1: Feasible mooring scheme of OFNPP: (a) single point mooring and (b) spread mooring.

time-consuming process (normally it takes 2 days from preparation to completion to disconnect from SPM).

Located nearby offshore oil fields with high-risk operation, and dozens of kilometers away from the coast, OFNPP will face some special risks different from those of onshore nuclear power plants, for example, the threat of rough sea conditions, the collision of operating vessels, the impact of crashed helicopter in oil field operation on OFNPPs, explosion of nearby offshore oil and gas facilities, and release of dangerous substances. These risks must be fully taken into account in site selection.

Blowout accident in offshore oil fields is one of the most serious environmental and safety risks in oil and gas development activities. The process and impact of blowouts of offshore oil fields are more complicated compared with those of onshore oil fields due to the fluidity and complexity of the marine environment. Offshore blowout can trigger a variety of associated, secondary, and derivative risks, which constitute a series of external events of nuclear power plant site selection, and therefore should be the key point to be considered for the siting of OFNPPs in offshore oil fields.

2. Sources of Blowout Accidents during Offshore Oil and Gas Development

A blowout is an accident where formation fluid flows out of the well or between formation layers after all the predefined technical well barriers or the activation of the same has failed. Blowout can happen during different operational phases. SINTEF technology and society have analyzed 642 offshore blowout/blowout events worldwide from 1955 to 2016, as well as the overall exposure data of the Gulf of Mexico, the Outer Continental Shelf, and the North Sea of the United States, and formed a comprehensive blowout event database (the latest database is confidential and only accessible for sponsors). According to the database, the blowout frequency is between 10^{-5} and 10^{-3} [4] (Table 1 for details) and much larger than design basis probability value (DBPV, 10^{-6}per reactor-year [5, 6]) for siting an onshore nuclear power plant. Therefore, it is necessary to make detailed evaluations of this external event [6]. In order to correctly analyze the impacts of blowout on an OFNNP in the vicinity of the offshore oil fields, comprehensive evaluation methods should be established to assess the direct, secondary, associated, and derivative risks caused by blowouts on OFNPP in the vicinity of the offshore oil fields.

Offshore well blowouts can occur during different operation phases such as drilling, well testing, well completion, production, and workover. Once out of control, blowouts will lead to serious damage to the surrounding environment and safety [7].

3. Hazards of Blowout Accidents in Offshore Oil Fields and External Human-Induced Events Triggered by the Blowout Accidents

When blowout accidents occur in offshore oil and gas fields, a large number of crude oil and flammable and explosive gases will be released from wellhead. For high sulfur oil and gas fields, the gas will also contain a large number of hydrogen sulfide toxic gases. Flammable and explosive gases emitted directly form dangerous gas clouds. The spilled crude oil contains a large number of volatile substances, which will also form flammable and explosive dangerous gas clouds after volatilization. The above flammable and explosive gases will burn and form jet combustion at wellhead if they are exposed to open fire and even explode if they reach the limit of explosion concentration. Shock waves and projectiles produced by explosions can also cause continuous accidents such as fires and explosions of oil field production facilities, causing secondary damage and forming the “domino effect” of disasters, which may pose an immediate threat to nearby OFNPP.

Crude oil spilled on the sea surface has physicochemical characteristics of floatability, fluidity, volatility, flammability, explosiveness, and even toxicity. Evaporation of volatile components in oil spills may form dangerous vapor cloud over the sea surface where oil spill occurs. In case of open fire, these vapor clouds may burn and explode, posing an immediate threat to nearby OFNPP. Combustion and explosion of vapor clouds may ignite oil spills on the sea surface, which will pose a threat to nearby OFNPP over time. Oil spills caused by blowouts may also cause sea water pollution in large areas. The evaporation of volatile components in oil spill will also leads to the change of oil spill characteristics, which will increase the density and viscosity of oil spill remaining on the sea surface and cause it to sink below the water surface. If the sinking spilled oil drifts to the vicinity of an OFNPP, it may cause harm to the water intake of the OFNPP, pollute the heat exchanger, and then become a sustained damage affecting the safety of nuclear power facilities. The poisonous gas emitted, once invading the nearby OFNPP, may cause bodily harm to the staff and then affect the safe operation of nuclear power facilities, causing safety accidents.

From the above analysis, it can be seen that blowout accidents in offshore oil and gas development may trigger a

Table 1: The blowout frequencies during the different operational phases (data based on the experience from US GoM OCS, UK, and Norway in the period 1980-01-01–2005-01-01).

Operational phase	No. of operations	No. of incidents	No. of operations per incident	No. of incidents per operation
Development drilling	22833	57	401	$2.50E-03$
Exploration drilling	13762	71	194	$5.16E-03$
Completion	20328	15	1302	$7.70E-04$
Production	211142	10	21114	$4.70E-05$
Well workover	19920	37	538	$1.86E-03$
Wire line	358941	8	44868	$2.20E-05$

series of initial events regarding the external events of site selection for nuclear power plant, such as the release of flammable and explosive gas clouds, combustion, explosion, dangerous liquid leaks, and projectile impact. The correspondence between them can be seen in Figure 2.

4. Analysis Methods of External Human-Induced Events Triggered by the Blowout Accidents

It can be seen from the above description that the typical hazard forms caused by offshore oil and gas blowouts may include jet combustion, hazardous gas cloud explosion, oil spill combustion, large-scale oil spill pollution, and H_2S gas diffusion for high-sulfur fields. The specific hazards to OFNPP may include shock waves, projectile impact, thermal radiation, the effect of toxicity on the human body, and seawater pollution.

4.1. Blowout-Induced Jet Combustion and Oil Spill Combustion. Blowout on offshore oil platforms may cause two kinds of fires, one is the fire of oil platform facilities, and the other is the fire of oil spills around platforms.

Blowout may trigger platform fire which may cause scorching fire flame hazard to nearby facilities. According to the technical guide "External human induced events in site evaluation for nuclear power plant" (HAD 101-04), when the distance between the object and the fire source is several times larger than the square root of the fire source area, the heat flow does not pose a scorching threat to the object. Usually, the sizes of most offshore platforms are less than 50 m ∗ 50 m in size; therefore, the distances of hundreds of meters away from the oil platforms are enough for OFNPP to avoid the scorching fire flame hazard of platform flames. This means that the screening distance of 1~2 km from the fire source for onshore nuclear power plants can also be adapted to the fire of offshore oil platforms caused by blowout.

As to the fire of oil spills around platforms, due to the fluidity of seawater, it forms mobile fire. Therefore, the screening distance of fire sources for OFNPP should not simply copy that for onshore nuclear power. The effect of possible mobile fire sources caused by blowout-induced oil spill should also be assessed.

It has been proven that the basic condition for the effective and sustained combustion of oil spills on the water surface is that the thickness of the burning oil film is greater than 2~3 mm, which can be used as thickness limit for the burning oil film on sea surface. This is because when the thickness of oil film is lower than this thickness, the oil temperature will drop below evaporation temperature due to the rapid heat loss of oil film, which will cause the combustion to stop [8].

According to the Fay model combined with the elliptical expansion model of Lehr et al. [9], the quantitative relationship between the oil film thickness and the duration is derived as follows [10]:

$$h_1(t) = \left(\frac{-179 \times U_w^{4/3} \times t \sqrt{\left(179 \times U_w^{4/3} \times t\right)^2 + 30940 \times t^{1/2} \times S}}{15470 \times t^{1/2}} \right)^3 \times \frac{\rho_0, T}{(\rho_w - \rho_0, T) \times S}, \tag{1}$$

where S is the oil spill area (m^2), U_w is the wind speed (m/s), t is the oil spill duration (min), $h_1(t)$ is the oil film thickness (mm), ρ_w is the seawater density (g/m^3), and $\rho_{o,T}$ is the crude oil density (g/m^3) at the corresponding temperature T (°C). Assuming the oil spill volume to be V_o (m^3), the oil spill thickness can be derived from formula (1) as shown below:

$$h_1(t) = \frac{30940 \times V_o}{t^{1/2}} \times \frac{1}{\left[15470 \times \left(\left(V_o \times \left(\rho_w - \rho_{o,T}\right)\right)/\rho_{o,T}\right)^{1/3} + 179 \times U_w^{4/3} \times t^{1/2}\right]^2 - 179^2 \times U_w^{8/3} \times t}. \tag{2}$$

The combustion experiment of oil spill on sea surface shows that the combustion rate is about 2~3 mm/min. The rate does not change significantly with the type and the weathering degree of oil spill [11]. Therefore, the thickness reduction of the oil spill due to combustion can be described by using the following formula:

$$\Delta h(t) = C \times t, \tag{3}$$

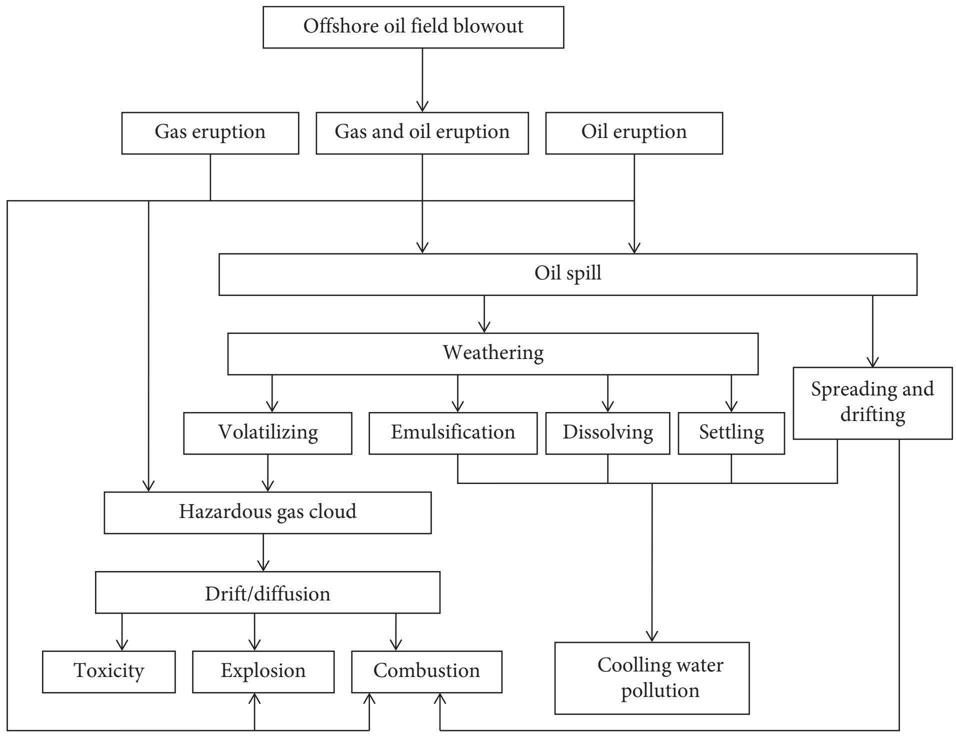

Figure 2: Direct, secondary, and derived hazards from the blowouts of offshore oil fields.

where $\Delta h(t)$ is the thickness reduction of the oil spill due to combustion (mm), C is the reduction rate of the thickness of the burning oil film on the sea surface per unit time, with a value of 2~3 mm/min, and t is the duration of combustion (min).

Combining the two equations (2) and (3), the residual thickness of the burning oil film $H(t)$ (mm) can be estimated with the following formula:

$$H(t) = h(t) - \Delta h(t), \tag{4}$$

where $H(t_c) = 2$ mm can be used as a condition to obtain the corresponding combustion duration t_c (min), beyond which the burning of oil spill will be terminated. Figure 3 shows the relationship between the volume of oil spill and the duration of combustion when the oil spill is burning on sea surface.

When the distance D between the OFNPP and the burning oil spill meets the following formula: $D \gg V_o \times t_c$, where V_o is the oil drift velocity, it can be concluded that the flame will extinguish automatically before the burning oil spill has arrived at OFNPP, and it will not cause combustion or thermal radiation impact on OFNPP.

4.2. Hazardous Gas Cloud Explosion Caused by Well Blowout. If the dangerous gas cloud caused by blowout explodes, it may pose an immediate threat to nearby OFNPP. The hazardous gas cloud caused by the blowout consists of two parts: one is the natural gas directly ejected from the oil and gas well, and the other is the vapor cloud formed by the evaporation of the blowout oil spill. The amount of gas cloud directly ejected in blowout can be calculated by using the following formula:

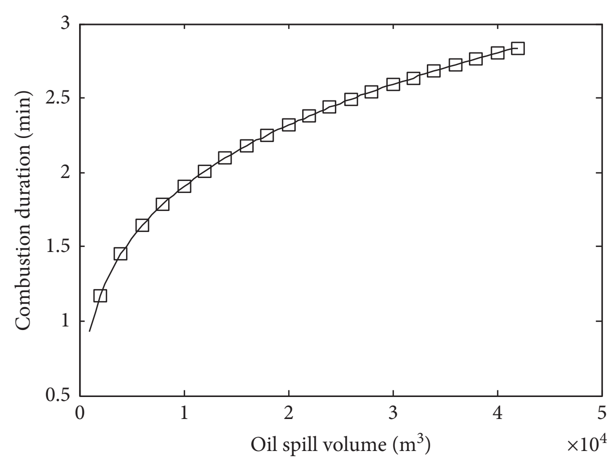

Figure 3: The burning duration t_c versus the volume of burning oil spill on sea surface under combined action of spreading and combustion.

$$Q_{UVEC} = C \times Q_{AOF} \times t, \tag{5}$$

where C is the volume fraction of the explosive gas in the blowout gas (%), t is the eruption duration (min), and Q_{AOF} is the absolute open flow of the blowout well (m^3/min), which is related to parameters such as reservoir permeability, reservoir thickness, viscosity, the type of well, the effective radius, formation pressure, and formation temperature [12]. Normally, if a natural gas well that has a blowout cannot be killed within 15 minutes of blowout, it would normally be ignited and discharged. Therefore, the 15 min blowout volume can be used for the accident consequence assessment in such case.

The mass of the directly erupted explosive gas (kg), W_C, is determined by using the following formula:

$$W_C = \rho \times Q_{UVE}, \quad (6)$$

where ρ is the density of the erupted explosive gas (kg/m^3).

As to the vapor cloud formed by the evaporation of the blowout oil, the evaporation amount can be derived from the Stiver and Mackay [13] models and is determined by using the following formula:

$$F_v = \frac{T}{B' \times T_G} \times \ln\left[1 + B' \times \frac{T_G}{T} \times K_2 \times A \times \frac{t}{V_0} \times \exp\left(A' - B' \times \frac{T_0}{T}\right)\right], \quad (7)$$

where F_v is the oil vapor evaporation volume fraction; T is the ambient temperature (K); A', B', T_0, and T_G are oil-related constant ($A' = 6.3$, $B' = 10.3$, T_0 is the initial boiling point temperature (K) of the oil, and T_G is the gradient of the distillation curve. T_0 and T_G can be calculated from the specific gravity index (API degree).); A is the oil film area (m^2); V_0 is the initial volume (m^3) of the oil spill; t is the evaporation time (s); and K_2 is the air end mass transfer coefficient (m/s) which can be determined by using the following empirical formula:

$$K_2 = 2.5 \times 10^{-3} U_w^{0.78}, \quad (8)$$

where U_w is the wind speed 10 m above the sea surface (m/s).

Thus, the amount of oil spill evaporation Q_S (m^3) can be obtained by using the formula $Q_S = F_V \times V_0$, and the mass of the evaporated oil spill W_S (kg) can be obtained by using the formula $W_S = \rho \times Q_S$, where ρ is the density of oil spill vapor (kg/m^3).

The total amount of explosive gas which can then be converted into TNT equivalent W_{TNT} (kg) with the following formula:

$$W_{TNT} = \alpha \times (W_C + W_S) \times \frac{Q_C}{Q_{TNT}}, \quad (9)$$

where α is the percentage of gaseous fuel involved in the gas cloud explosion, ranging from 0.01 to 0.1, with an average of 0.04; Q_C is the combustion heat of the explosion gas involved in the gas cloud explosion (J/kg); and Q_{TNT} is the TNT explosive heat, with a value of 4.52×10^6 J/kg.The safety distance, which is corresponding to 7 kPa normal incidence peak overpressure, can be calculated with the following formula recommended by technical standard HAD 101-04:

$$R = K \times W_{TNT}^{1/3}, \quad (10)$$

where R is the safety distance (m) and K is the safety factor and usually takes the value of 18 (m·kg^{-1}).

When the distance between the OFNPP and the gas cloud is greater than R, the gas cloud explosion will not have a safety impact on the nuclear power plant. Otherwise, the external event of the gas cloud explosion should be considered as a design basis event.

In addition, the meteorological data such as dominant wind direction, atmospheric stability, and diffusion coefficient should be combined with the atmospheric diffusion model to further analyze spatial-temporal variation of the concentration distribution of hazardous gas cloud drifting to the OFNPP so as to get a more accurate risk assessment.

4.3. Poisonous Gas Cloud Caused by Well Blowout. A large amount of hydrogen sulfide will be released during blowout in high sulfur oil and gas fields, which is a typical case of toxic gas release caused by blowout. The erupted H_2S gas will form drifting toxic gas cloud. Once it enters the OFNPP, it will pose a threat to personnel's life and health, affect the habitability of the control room and other important plant areas, and thus prevent operators from fulfilling safety functions of the OFNPP.

The total amount of poisonous gas released during the blowout accident is determined by using the following formula:

$$Q_{H_2S} = Q_{AOF} \times C_{H_2S} \times t, \quad (11)$$

where C_{H_2S} is the volume fraction of H_2S and t is the blowout accident duration.

The Gaussian plume model can be used to calculate the concentration of poisonous air cloud diffusing to the OFNPP by using the following formula:

$$C(x, y, z) = \frac{Q}{2\pi u \sigma_y \sigma_z} \times \left\{\exp\left(\frac{-(z-h)^2}{2\sigma_z^2}\right) + \exp\left(\frac{-(z+h)^2}{2\sigma_z^2}\right)\right\} \times \exp\left(\frac{-(y)^2}{2\sigma_y^2}\right), \quad (12)$$

where $C(x, y, z)$ is the concentration of toxic gases in the air at coordinates (x, y, z), Q is the emission rate of toxic gases, and σ_y and σ_z are the atmospheric diffusion parameters in the direction of y and z, respectively.

The NRC RG1.78-2001 standard [14] gives the threshold of toxicity limit concentration for the impact of leakage accidents of fixed and mobile hazardous chemical sources on nuclear power plants. This toxicity limit is based on the maximum concentration that adults can withstand before being incapacitated within 2 minutes of exposure. For H_2S, the concentration threshold is 150 mg/m^3 [14]. If the calculated concentration of the blowout H_2S diffused to the site is greater than or equal to the above concentration, the H_2S poisonous gas produced by blowout should be taken as the design basis event [15]. The relationship between the minimum safety distance and the concentration of H_2S in blowout is shown in Figure 4.

As also, the above technical method can be used for risk assessment of other blowout toxic gases.

4.4. Harm of Seawater Pollution Caused by Blowout Oil Spill to OFNPP. If a blowout accident of the offshore oil field cannot be controlled quickly, a large amount of crude oil will be

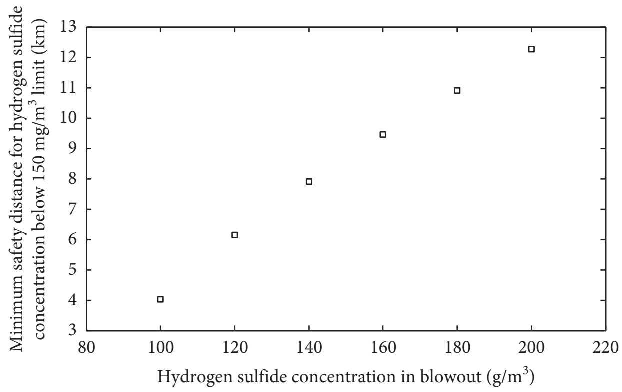

Figure 4: The relationship between the minimum safety distance and the concentration of H_2S in blowout.

discharged into the sea, causing serious marine environmental pollution accidents.

Oil spills in marine water environment will undergo three types of changes: diffusion, transportation, and weathering under the combined action of complex physical, chemical, and biological processes. In the processes, the oil spill will exist in four forms: oil film floating on the sea surface, dissolved oil spill, emulsified oil spill, and coalesced oil slick. Some types of oils, especially those with asphaltene content greater than 0.5%, tend to absorb water to form a water-in-oil emulsion, which is usually very viscous and does not easily dissipate. The emulsified particles of the oil will enter the sea water under the action of the wave and the ocean current shearing, causing vertical mixing of the emulsified oil and further causing rising or settling of the emulsified oil depending on its density change during weathering process. Oils with high viscosity, such as heavy crude oils and heavy fuel oils, tend to form thick oil layers that are not easily dispersed and can remain on sea surface for several weeks.

It can be known from the above analysis that the oil spill, if not treated in time, will probably pollute the quality of the seawater around the cooling water intake and cause the cooling water pipe of the power generation cooling device of OFNPP polluted and damaged, or even worse, clog the water inlets, which will furthermore reduce the heat transfer efficiency and affect the normal operation of the power generation device. Therefore, if the OFNPP is built in the vicinity of an offshore oil field with a risk of blowout, the oil spill model should be employed to finally determine whether it can affect the normal operation of the OFNPP.

4.5. Example Case Calculation. Suppose that the maximum blowout volume of an offshore oil field is 10×10^4 cubic meters, of which 80% (8×10^4 cubic meters) is gas, 20% (2×10^4 cubic meters) is oil, and 120 grams per cubic meter is H_2S. The density $\rho_{o,T}$, initial boiling point temperature T_0, and gradient of the distillation curve T_G of spilled oil are 0.83 g/cm^3, 517 K, and 140 K, respectively.

4.5.1. Safety Distance for Blowout-Induced Jet Combustion and Oil Spill Combustion. As to the fire on platform caused by well blowouts, assuming the size of oil platform where blowout occurred is about 50 m × 50 m, safety distance of 200~300 m, which is 4~6 times the square root of the ignition area, should be enough to prevent heat flow damage from oil platform fire. As to the blowout-induced oil spill combustion, if the spilled oil is in a combustion state, the combustion duration can be calculated by using formulas (2) and (3) for about 2.8 minutes. Assuming the maximum current speed of sea water in the oil field is 1.5 m/s, the drift distance of the oil spill from burning to self-extinguishing is 256 m.

4.5.2. Safety Distance for Hazardous Gas Cloud Explosion Caused by Well Blowout. According to formula (6), we can calculate that mass of the blowout gas W_c equals 57.4 ton, and mass of the evaporated oil spill W_s equals 0.15 ton. According to formula (9), equivalent W_{TNT} equals 28313 kg. Using formula (10), safety distance can be calculated to be 549 m.

4.5.3. Safety Distance for Poisonous Gas Cloud Caused by Well Blowout. For the blowout-induced release of toxic gases, the most conservative meteorological conditions for atmospheric pollution are adopted as follows: (1) taking Guifford–Pasquill stability class F for atmospheric stability; (2) taking 1 m/s for wind speed; (3) assuming the wind direction is directed from the blowout platform to OFNPP during the blowout accident.

Minimum safety distance for H_2S concentration below 150 mg/m^3 limit can be calculated by using formula (12) for about 6.1 km.

Table 2 is a summary of safe distances for different threats induced by blowout. Among these different safety distances in the example, the maximum should be chosen as the required distance of the OFNPP from the offshore oil and gas platform. It can be seen that the safety distances of toxic gases are the largest in this example, which means the required distance is at least 6 km. As can be seen from Figures 3 and 4, the safe distances are proportional to the amount of blowout and the concentration of toxic gas released, which means that the safe distances are determined by the blowout property of an oil field, or in other words, they are oil field specific, so it is necessary to analyze each oil field separately. As to oil fields that do not release toxic gases, 2~3 km away from oil platform should be an appropriate safe distance.

5. Special Risks of Blowout-Induced Failures of OFNPP Installations

If the nuclear power vessel maintains enough safe distance greater than mentioned above from the offshore oil field where blowout occurs, blowout will not cause damage to the facilities of the nuclear power vessel. If it fails to meet the requirement of safe distance, serious blowout may cause damage to OFNPP, especially when the hull is seriously damaged, which will lead to the sinking of OFNPP. If radioactive substances leak into sea water at the same time and

Table 2: Summary of safe distances for different threats induced by blowout in the example.

Safety distance for platform fire caused by blowout (km)	0.2~0.3
Safety distance for drifting burning oil spill caused by blowout (km)	0.26
Safety distance for hazardous gas cloud explosion caused by well blowout (km)	0.55
Safety distance for poisonous gas cloud caused by well blowout (km)	6.1

drift with the current, it will cause radioactive pollution to the surrounding oil fields and fishery resources and harm the workers of the oil field and the public. Therefore, a joint emergency response mechanism must be established between the nuclear power ship and the oil field so that both sides can inform each other in time when an accident occurs, share information, and take joint measures to deal with it.

Because OFNPP uses low-power and small integrated PWR and is located near offshore oil and gas fields, dozens of kilometers away from the coast, it will not have a serious impact on the onshore installations and the public.

6. Conclusion

Offshore oil field blowout is a sort of accident of high-risk and malignance, and it is also one of the most serious characteristic risks in the development of oil and gas fields. Once it is out of control, it will cause serious consequences. From correspondence between various hazards caused by blowout accidents (including associated, secondary, and derivative hazards) and the initiating events that may lead to accidents of offshore floating nuclear power plant (OFNPP), the blowout accident of the offshore oil and gas development may cause a series of external events such as hazardous gas cloud, combustion, explosion, and hazardous liquid release. Therefore, when OFNPP is located near an offshore oil field to supply energy to offshore oil platforms, the blowout must be analyzed and assessed as a main characteristic risk in the site selection stage. Much attention should be paid to the jet combustion and oil spill combustion caused by the blowout, the drift and explosion of the explosive gas cloud formed by the blowout, the seawater pollution caused by the blowout oil spill, and the hazardous toxic gas cloud caused by the blowout. Since the burning oil spill will form a moving fire source, the evaluation should also focus on the oil spill combustion caused by the blowout.

Data Availability

The data in Table 1 are available from SINTEF Technology and Society on reasonable request. All other data used to support the findings of this study are available from the corresponding author upon request.

Conflicts of Interest

The author declares that there are no conflicts of interest.

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