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ESCAPE-EVACUATION-RESCUE RESPONSE IN ICE-COVERED REGIONS

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ABSTRACT

Emergency response planning incorporates several key factors, including the credible hazards that might precipitate an emergency at a given installation, the weather conditions that can be expected to prevail and shape the physical environment in the region, the safety measures and equipment alternatives that may be used, the people who have to escape and respond, and the interaction of these factors. Emergency response is examined in the context of offshore industry activities and shipping in ice-covered regions. The aim is to identify key issues relating to escape, evacuation and rescue in cold regions where sea ice occurs.

KEY WORDS: escape, evacuation, rescue, emergency, offshore, ice, safety

INTRODUCTION AND SCOPE

Emergency response on an offshore petroleum installation or ship involving escape, evacuation and rescue (EER) is a low frequency event, but one with potential for severe consequences. Given the prospects of significant increases in offshore petroleum exploration and production in the cold regions of the world, and corresponding increases in marine support and transportation activities, it is worth considering the demands of emergency escape, evacuation and rescue in the context of operations in cold regions and sea ice. The demands include those on personal protection, escape routes and procedures, evacuation systems and their capabilities, and means of rescue and associated support.

The aims of this paper are to highlight the broad goals and expectations of EER, identify the key factors involved in EER, and focus on the impact of the cold environment in light of the interaction between the goals and expectations and key factors.

GOALS OF EER

Overall, the key goal of EER is that, in the event of an emerging hazard scenario that requires an emergency escape, evacuation and rescue response, all personnel on board should have a reasonable expectation of avoiding harm in environmental conditions that can be reasonably expected to occur during operations. We can consider the expectations of each stage of escape, evacuation and rescue in turn.

Escape

Starting with escape, the main goal is that all personnel have recourse to provisions that allow them to escape from the potential harm posed by the emerging hazard and go to a place of relative safety. Corresponding expectations include that there be appropriate alarms to warn personnel of the circumstances, and means of communications throughout the response process; personal protective equipment, such as immersion suits (ISO 2002), warm clothing and breathing apparatus; and escape routes, muster areas, temporary refuges and embarkation stations, all with sufficient redundancy and protection.

Evacuation

The main goal of evacuation, should a decision be taken to abandon the installation, is to move all personnel, including injured people, off the installation and away from the emerging hazard in a controlled procedure. Normally, there is an expectation that a means of evacuation that is resourced external to the installation be available for all personnel. In the offshore industry, this is typically provided by helicopter. Recognizing that helicopters or other externally resourced means are not likely to always be available in adequate numbers and within response time requirements, there is an expectation that an alternative means of evacuating all personnel be available, independent of external resources. In current practice, this implies an installation-based system or systems that can operate in the local marine and sea ice conditions. Such means of evacuation should facilitate safe embarkation and launch from the installation, be able to clear the installation and hazard immediately after launch, and survive until the occupants are transferred to a place of relative safety. These procedures must be practicable in the environmental conditions that prevail at the time, within the weather and environmental limits of the equipment.

Rescue

An emergency EER response ends when personnel are transferred to a safe place where appropriate medical assistance is available. The corresponding expectations include that means of rescue be available, that these be compatible with the means of evacuation, and that all personnel have a reasonable probability of reaching a safe place within a reasonable time under the prevailing weather conditions and emerging hazards that can credibly be anticipated.

Safety management system

Emergency EER response planning and management should be addressed explicitly in the context of an overall safety management system. Identification of credible major hazards and hazard scenarios that might necessitate an escape, evacuation and rescue response is an important basis of such a plan, establishing the potential exposure of personnel and equipment to consequences such as physical harm and impairment. Application of ALARP (as low as reasonably practicable) principles to identified hazards and consequences is also expected through the safety management system, which will influence the emergency response plan. The response plan is also expected to incorporate command, control and communications issues, include arrangements between the operator and others who might be involved in a planned emergency response, identify emergency procedures and required personnel competencies, as well as specify the equipment to be used in the response. Foreknowledge of the physical environment and weather is also expected, along with knowledge of corresponding capabilities and limitations of the installation, EER equipment, and people.

KEY FACTORS

Two key factors that shape decision-making in emergency response planning are credible hazard scenarios and the physical environment, including the weather. Another two key factors in emergency EER are the people and the design of safety measures and equipment.

Environmental conditions have a general influence on the design of any installation or ship. For example, operations in cold regions will require specific winterization measures for equipment and systems, as well as protection of personnel from cold temperatures. Likewise, hazards can arise without invoking a full emergency EER. The focus here is on the intersection of hazards arising from accidents in cold environment conditions that necessitate an escape, evacuation and rescue response.

Environmental conditions can be highly variable on annual, seasonal, and daily time scales. Potential hazard types and their likelihoods change with the phase of operations, from exploration and construction, development drilling and production, on to decommissioning. Consequently, the overall risk profile is dynamic, changing broadly with operational phase and prevailing environmental conditions. This broad conceptual framework is illustrated in Figure 1.

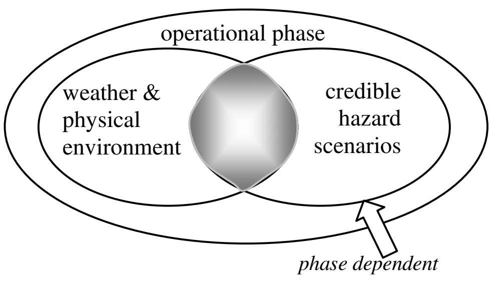

Figure 1. Credible hazard scenarios & environmental conditions.

Hazards

Typical major hazards associated with offshore petroleum installations are uncontrolled releases, such as blowouts and process equipment leaks, explosions, fires, smoke and toxic gas. In addition, collisions with vessels, and transportation and construction accidents all pose hazards that can lead directly, or through an escalation of events, to losing watertight integrity, flooding and eventually sinking, or to losing stability and capsizing. Loads due to interaction with ice features, such as a consolidated multi-year ice ridge or a piece of glacial ice, which can result in loss of structural integrity, are analogous to the more familiar environmental hazards such as large waves, earthquakes and geotechnical hazards.

Weather and the physical environment

The physical environment and weather conditions are clearly at issue in the planning and execution of emergency response in cold, ice-covered, and often remote regions. Sea ice, wind, waves, currents and tides, snow, rain and fog, cold temperatures, light levels and icing conditions are described below, along with some potential impacts on EER goals and expectations.

Sea ice cover

Ice conditions tend to be different in one way or another from region to region. Even within a given area, ice conditions are highly variable over time and length scales. Foreknowledge of the expected ice conditions in a given location should be a key element in any EER planning exercise. There are standard descriptions of sea ice cover, such as the nomenclature used by the WMO (Anon. 1970).

Sea ice in the form of intact level ice, broken pack in varying concentrations, compressed fields with embedded rafting, ridging or rubbling, and brash ice in broken fairways all pose different challenges to evacuation and rescue (see e.g. Timco *et al*. 2006, and Timco & Dickins 2005). Typically, these ice forms are present in some combination, and are accompanied by additional relevant environmental factors, such as cold temperatures, high winds, marine and atmospheric icing, snow storms, and fog. Sea ice cover conditions can also be highly dynamic under the driving influence of winds, waves and currents. This dynamic situation is exacerbated during the fall freeze-up and spring break-up, when the features are not only moving, but changing quickly over large and local scales. The physical characteristics of ice, such as thickness, floe size, and strength, are also significant.

Evacuation and rescue solutions have to be able to function in the full range of anticipated local conditions. This is a critical environmental factor. For example, evacuation systems designed for open water can have reasonably high utility in low ice concentrations. However, such means are unsuitable in high ice concentrations and ice fields under pressure, where they lack sufficient power and strength to operate (Simões Ré & Veitch 2007a). A displacement vessel used for either evacuation or rescue in heavier ice conditions would have to be substantially heavier and more highly powered than any existing conventional evacuation vehicle, to the point where it could break and transit ice cover (Johansson 2006). Any marine evacuation (or rescue) system may be prone to interaction between its propulsion system components and submerged pieces of ice. The system must be designed to suit, by having adequately strengthened propeller blades, hubs, and shafts, and appropriately arranged shaft brackets, propeller nozzles, and inlets to avoid ice blockages (Veitch *et al*. 2004).

Evacuation craft designed to travel on the ice, rather than go through it, have to be light enough to remain supported by the ice, which imposes a weight restriction that is governed by the ice strength and thickness. Such craft also have to be able to deal with the variations in ice terrain, from level ice and rafted ice, to rough, broken ice in ridges and rubble. Broken ice features such as ridges can impose severe restrictions on surface vehicles, requiring them to detour, or blocking progress entirely.

Snow accumulation

Not only can snow accumulation on sea ice effectively reduce the unevenness of broken ice terrain, it can also increase the friction with surface vehicles. Snow accumulation on installations can obstruct mobility, for example along access ways, escape routes, stairs and handrails, and cause slips, trips and falls. It can also obstruct visibility by covering equipment and signage. It can directly impair visibility if it accumulates on the windows of evacuation equipment.

Atmospheric and marine icing

Icing results in slippery surfaces on access ways, escape routes, stairs and handrails, which can cause slips and falls. Iced surfaces will impair the escape process (and any other deck procedure) where personnel are required to be outside. Icing can also impair equipment to the point where it becomes inoperable or unavailable. For example, the access hatches of the means of evacuation can freeze shut due to icing, window wipers can freeze to windows, and icing on windows can restrict visibility.

Accumulation of ice can also reduce the stability of floating vessels due to the rise in centre of mass. This can be particularly important for small marine vehicles. In addition to its effect on stability, icing results in a reduction in payload (or freeboard) due to additional weight. Both considerations are relevant to marine evacuation.

Cold temperatures

Cold air temperature and wind chill have impacts on both personnel and equipment. Exposure to cold temperature and wind chill can lead to hypothermia, frostbite, fatigue, shivering, cramping, and breathing difficulties (Bercha *et al.* 2003, Bercha 2007). Protective clothing is required against the effects of cold, but can result in impaired general mobility, impaired dexterity (due to gloves), and obstructed vision and hearing (due to head and face protection). Head and face protection may also interfere with breathing apparatus and means of communication. Many of these considerations are generally relevant in cold regions, and require specific attention to details with respect to EER.

Spaces on board require adequate heating and insulation to ensure protection of personnel from cold temperatures and wind chill. These include escape route arrangements, muster areas and embarkation points. Heating and insulation is again a requirement within the means of evacuation, which has to protect its occupants from the elements. Air supply, air quality and condensation are related issues, as such equipment normally has to be effectively sealed to prevent ingress of toxic gas and smoke.

Air temperature and wind chill also influence the design of systems and equipment. For example, cold temperatures can cause fluids to freeze in various systems. Winterization measures, such as insulation, can be used to protect fire mains, cooling and other water piping systems, and hydraulic lines. Starting systems under cold temperatures can also be problematic, which can be dealt with, for example, by providing special heaters or batteries. Cold air and water temperatures also influence the choice of materials. For example, steel with sufficient ductility is required to avoid brittle fracture associated with low grade steels under low temperatures. Special structural design considerations are also required to withstand concentrated ice loads. Finally, the design of equipment that is exposed to the cold should account for the reduced mobility and dexterity of its operators. Class societies and the IMO have also provided guidance on winterization measures for ships (e.g. IMO 2002).

Waves and wind (open water)

Open water conditions occur for some portion of the year at many sites associated with sea ice cover. Waves and wind give rise to motions on floating installations that can cause motion sickness and motion induced interruptions, which can increase fatigue and impair situational awareness. These are not particular to emergency situations, but are relevant to them. With respect to the means of evacuation, high seas and wind reduce the performance of conventional evacuation craft (Simões Ré & Veitch 2007b) and can prevent rescue operations. Exposure of personnel to cold water due to immersion can lead to rapid hypothermia or drowning.

Currents, tides, water depth

Currents and tides drive ice cover movements, so are of general operational interest. They are also of particular interest in the wake of an evacuation that requires a search and rescue response. Water depth is relevant to evacuation and rescue if it is shallow and imposes vessel draft restrictions. Even if the water depth is not shallow enough to limit the draft of evacuation and rescue vessels, it may be relevant in terms of shallow water waves and the potential for grounding of ice. Grounded ice features in shallow water and subsequent ice accumulation may prevent launching of evacuation vehicles.

Light level

Low light conditions and prolonged periods of darkness associated with northern latitudes require that adequate lighting be provided, including emergency lighting systems for escape routes, muster stations and embarkation points. Darkness also complicates rescue operations and again requires that adequate search and other lighting be available on rescue vessels.

Snow, rain, fog

Snow, rain and fog all reduce visibility, sometimes severely, which can impair all stages of EER and endanger personnel. Impaired visibility can be especially detrimental to rescue operations, as prolonged delays in recovery can result in extended exposure of evacuees to the elements, which can have severe consequences under cold conditions.

Remote location

The cold regions at issue here are often remote from supporting infrastructure. Potential psychological impacts arise from the isolation associated with remote locations, accentuated by periods of prolonged darkness. There are additional issues related to routine transportation risks. Another relevant impact of remoteness is the overall logistical challenge, including requirements for mounting search and rescue operations. As the distance between the installation site and external infrastructure increases, the less tenable it may become to rely on resources external to the operator, which may, in the extreme case, lead to a fully independent, locally-based rescue capability.

Design and equipment

The integration of safety measures into the design of the installation, and the design of safety equipment itself, whether used during escape, evacuation or rescue, must be effective in the range of environmental conditions that are likely to occur, and under the various credible hazard scenarios, including those particular to a given operational phase. Changes in operational phase may also be accompanied by changes in the installation, support vessels, and associated marine transport, and in the number and competencies of the people working offshore.

Personnel

People are the focal point of the escape, evacuation and rescue plan. The relevant human factors include organizational management, procedures and training, through to physiological and psychological issues. With reference to cold environment scenarios, human factors related to cold temperatures, prolonged periods of darkness, low visibility, fatigue, isolation and related stress are all relevant to EER system design and operations. Personnel and their required competencies are also likely to change from one phase of operations to the next. Consequently, the risk profile associated with EER changes over time as safety equipment and personnel factors interact with the various combinations of credible hazards and environmental conditions.

INTERACTION OF KEY FACTORS AND GOALS

So far in this paper, key factors of emergency EER response have been identified as hazards, the physical environment, people, and installation design and equipment. As well, the main goals of EER and key expectations arising from these goals have been presented. Next we will consider the interaction of these factors with a focus on how EER expectations might be impacted by the cold environment. Although in-depth assessment of different scenarios is beyond the scope of the paper, such considerations can help inform the development of performance standards that may be suitable for a particular situation. By identifying key impacts at the very early stages of design, it is more likely that decisions can be taken that will result in inherently safer design and operation.

Escape

The expectations associated with achieving the escape goal successfully include alarms and communications, personal protective equipment, and escape routes leading to temporary refuges and embarkation points.

With particular focus on impacts from factors associated with the physical environment, visual alarms may be obstructed from view by snow accumulation and icing, or by falling snow or fog. Audible alarms and means of communication can be muffled by personal protective clothing, or masked by high levels of ambient noise, such as that arising from high winds. To mitigate these impacts, visible alarms might be heated to avoid snow and ice build-up. Similarly, sound alarms can be made louder than the expected ambient noise. Clothing can be designed to protect against cold and avoid impairing hearing. Likewise, means of communication can be designed to suit the ambient noise conditions, and be integrated into protective clothing and equipment, such as immersion suits and possibly breathing apparatus.

Personal protective equipment such as breathing apparatus will be used only in circumstances where toxic gas and smoke might occur. Still, if required, it has to be complementary to clothing, such as face and head protection. This is a small detail, as are many of the points raised here, but becomes important in the event.

Clothing, such as immersion suits, designed to protect personnel from the cold environment, can impair mobility and dexterity. To mitigate this impact, equipment should be designed to accommodate the reduced physical capabilities of personnel. This may apply to the arrangement of controls on equipment that will be operated by people wearing such clothing, as well as to the basic design of things like stairs, ladders, and handrails. Indeed, the ergonomics associated with protective clothing is pervasive, extending from the escape process, to the operations associated with the means of evacuation (e.g. negotiating access hatches and seating arrangements), right through to the rescue process (mobility during transfer operations).

Escape routes that are exposed to the elements are prone to snow and ice accumulation, which can slow escape procedures, or even block passage. Icing can result in slippery surfaces that can slow the progress of escapees and cause slips and falls. Also, exposed routes leave personnel relatively unprotected from cold temperatures and wind chill. Protective clothing is meant to guard against the effects of cold, although, as discussed above, it can have effects, such as on mobility, that require mitigation. Non-slip surfaces on exposed decks and stairs, along with boots with traction, can help reduce the likelihood of slips and falls. Snow and ice accumulation can be limited by aggressive manual procedures or by heating. A more fundamental approach is to design escape routes and other access ways with a high degree of weather sheltering to allow personnel to avoid exposure to the elements and the associated reduction in their performance. Interior muster and embarkation stations and enclosed stowage arrangements for evacuation craft would further reduce exposure of personnel to the elements during the escape process. Enclosed stowage spaces would also protect evacuation craft from the normal degradation associated with exposure to the marine environment and prevent equipment from incurring the consequences of icing. Furthermore, an interior stowage arrangement would facilitate maintenance on evacuation equipment, which is an important practical matter in the life of an installation.

Evacuation

Ergonomic issues associated with cold weather clothing and the design of equipment and controls accompany personnel into the means of evacuation. In addition, many of the general winterization issues identified above, such as those regarding materials, propulsion systems, insulation, heating and air quality, apply to evacuation craft. Similarly, icing and associated visibility concerns, as well as deluge system functionality, can be mitigated with appropriate heat tracing. As noted above, an internally stowed evacuation craft will be free of environment-related impairment, at least before launch.

The physical environment has a profound impact on evacuation craft, which merits particular attention here (see Timco & Dickins 2005). Remoteness adds to the demands on the means of evacuation in terms of the duration of the evacuation stage and the distance the vehicle may have to travel. There is no general purpose evacuation vehicle that has proven itself capable in the wide range of ice conditions that prevail in the cold regions of the world: innovative solutions may be required if the goal of evacuation is to be met.

Helicopters
Helicopters are generally preferred as a means of evacuation, but are practically available only in precautionary down-manning scenarios. It is unlikely that helicopters would be available in sufficient capacity and within required time constraints to respond as a primary means of evacuation or rescue in a large scale emergency event. Weather conditions that reduce visibility, such as snow and fog, or cause icing risk, such as atmospheric icing, can render helicopters unavailable. Furthermore, emerging hazards involving fire and smoke or toxic releases may prevent helicopters from approaching and landing on a platform.

Conventional lifeboats

Open water and broken sea ice cover in low concentrations can be navigated by conventional marine vessels, such as TEMPSC lifeboats. These are typical IMO governed products with minimum prescribed standards set in SOLAS and LSA regulations, none specifically related to ice capability (IMO 2003, 1974). The capabilities of conventional davit launched TEMPSC are severely limited in ice, where they can be lowered into the water and make way in open pack in concentrations less than about $7/10^{ths}$ coverage (Simões Ré & Veitch 2007a). As such vessels are typically not strengthened for ice, their structural integrity is at risk even in low concentrations of ice. This risk includes exposure to ice impacts in waves. In heavy pack ice, lifeboats will be grounded if lowered onto the ice. They cannot navigate through heavy ice nor extract themselves from a compressive ice field.

Lifeboats strengthened for ice

The capabilities of a conventional TEMPSC lifeboat could be extended by strengthening the hull to resist some level of ice load and by increasing the power so that it could navigate through broken pack. However, even substantial increases in power and hull strength are likely to yield only marginal improvements to conventional lifeboats (Simões Ré & Veitch 2007a). Kendrick *et al.* (2006) also concluded from some unmanned trials of a TEMPSC in pack ice that ice-strengthening a conventional TEMPSC is unlikely to be worthwhile.

Lifeboats with ice-going capability

For a lifeboat to have additional ice-going capability, it requires some degree of icebreaking capacity, which really means that the means of evacuation becomes a small icebreaking vessel. To break even thin ice requires a vessel significantly larger, heavier and more highly powered than any conventional TEMPSC. Johansson (2006) described an interesting concept design for an icebreaking lifeboat, which had an estimated required minimum weight of 200 tonnes and installed power of 1MW. His concept design was large enough to accommodate 250 people. Stowing and launching such a vessel on an installation may be problematic, but it could be an attractive option for operations involving large numbers of personnel. Stowing and launching difficulties could be avoided by configuring the means of evacuation as a dedicated stand-by emergency response vessel, rather than as an evacuation vessel based on the installation.

Stand-by emergency response rescue vessel

Configured as a stand-by vessel, this option would effectively become a resource external to the platform and would require some means to transfer personnel from the installation to the vessel in the event of an anticipated or emerging hazard event. Such use would be limited to scenarios that do not expose the vessel and its crew to high risk. Still, such a vessel could be designed to have icebreaking capabilities in conditions that are typically problematic for evacuation craft, such as thin ice that cannot support surface vehicles, heavy brash, and high concentrations of broken pack. This type of vessel could perform ice management and escort duties in the vicinity of a platform, and escort evacuation vessels and rescue personnel in an emergency. As such, it is not really an evacuation craft, but rather a rescue vessel.

Surface craft - amphibious tracked vehicles

An amphibious vehicle, Arktos, was originally developed for use in the Canadian Arctic and as such is the first modern, purpose-designed cold region evacuation craft. It is driven by tracks when on ice or land, and by waterjets when in water. It appears to be an effective vehicle for transiting thick, intact ice. It is enclosed so can provide protection from the elements and from fire and toxic plumes. Arktos may be a useful option in some scenarios, particularly where there are fairly large numbers of personnel to evacuate. As it is relatively large, special arrangements would likely be necessary for storing it on board and launching it, making it less suitable for floating, than for low freeboard caisson structures or islands.

Surface craft – air cushion craft

Hovercraft have been used for operations in ice for some time, including by the Canadian Coast Guard. These craft can be effective on level intact ice and are capable of making the transition between level ice and open water, as long as the freeboard of the ice edge is not large. Uneven ice terrain, such as rubble fields and ridged ice, can prevent their progress or require detours. In open water conditions, hovercraft are not well suited to rough seas. Piloting skills and maintenance are relatively specialized for hovercraft, and require special training. Indeed, the same is true, to a greater or lesser extent, of all the means of evacuation discussed here. A large hovercraft would have the same limitations as the stand-by emergency response rescue vessel described above in the sense that it would likely be impractical to store it on an installation, which would make such a vehicle an option for response and rescue, but perhaps not for dedicated evacuation. Still, smaller hovercraft may usefully be configured as evacuation craft.

Surface craft – sledded fanboats

Small shallow draft fanboats have been used in many regions of the world in a variety of configurations. Indeed, several versions have been used in ice covered waters (e.g. Schulte 1998), including for search and rescue operations. Existing fanboats are relatively small, typically designed for just a few people. These are, or can be, amphibious craft, like hovercraft and Arktos, and are propelled by air propellers, thereby avoiding ice interaction with the propulsion system. This concept could be adapted for use as an evacuation craft for cold regions. It would have to have an appropriately modified cabin to offer protection from hazards and the elements, the minimum standards for which are described by SOLAS. Further, the hull form could be modified from the typically flat bottomed planing form seen in most fanboats, to a form more suitable for transiting level ice and uneven ice terrain, such as the traditional sleds (kometik) used by Inuit in the Arctic. Surface operations of such a vehicle would be limited by weight considerations that would consequently limit the capacity in terms of personnel and other relevant payload items, including fuel and power.

Dedicated refuge

An alternative concept to evacuation vehicles is a dedicated refuge, separate from the main installation. The installation and dedicated refuge would be connected by some form of link, which would be configured differently depending on whether the installation and refuge were floating or fixed. For example, in deep water, a floating production installation could be accompanied by a floating safe refuge, either dedicated to emergency evacuation or integrated with accommodations. In the former configuration, the concept is not unlike an emergency response stand-by vessel, although it could be moored in position on a continuous basis, rather than simply in stand-by mode. In shallow water, both the installation and dedicated refuge might be bottom-founded. This type of alternative would have a high level of independence and reliability compared to some of the alternatives, and could very well be an option in some circumstances.

Rescue

As with the escape and evacuation stages, the human factors associated with cold environments are important in the rescue stage as well. Many of the design and equipment issues identified in the discussion of escape are also relevant to rescue, as both typically involve relatively large, dedicated platforms, whether a petroleum installation (or ship) or a rescue vessel. In addition to the risks posed to the evacuees, consideration must be given to the welfare of the rescuers.

Again, the physical environment dominates the rescue issue as much as it does evacuation. Specifically, the means of rescue must be capable in the conditions that may prevail. From the discussion in the previous section on possible means of evacuation, vessels such as hovercraft and dedicated icebreaking emergency response vessels were identified as being more likely to be useful in rescue roles than for evacuation. The demands imposed by large distances, difficult environmental conditions, and supporting logistics provided some rationale to an option that effectively eliminates conventional response and rescue by situating an independent refuge on site.

SUMMARY & DISCUSSION

Key factors impacting on escape, evacuation and rescue were viewed through the lens of the goals and expectations of the EER response, with a view to highlight important issues and identify gaps. The discussion of cold environment impacts on the escape stage of EER focused on human factors arising from the cold temperatures, and on design of safety measures and equipment on board. Interaction between personnel and the safety equipment during escape procedures underlined several concerns, and steps to mitigate risks associated with these impacts were suggested, some of which led into detailed design issues. One of the measures proposed to increase the inherent safety of escape was to enclose the means of evacuation and the corresponding embarkation points so that the equipment and personnel are protected from the elements as much as possible in the escape procedure. Training for emergencies is also of general importance throughout the EER process. Scenario-based training, including cold environment factors, can capture specific training objectives.

Human factors and design measures were also recognized as important in the discussions of environmental impacts on evacuation and rescue. However, without diminishing these types of issues, it was also recognized that the physical environment feature that dominates both evacuation and rescue is sea ice. The remoteness factor adds to the challenges of evacuation and rescue.

To meet the goal of evacuation and rescue, personnel have to move through, on or over sea ice and water, and to reach a place of safety. Several existing options and proposed enhancements were discussed in the paper, serving to highlight the need for innovation and development in this area. There is currently no single operational evacuation craft suitable for the wide range of conditions that can reasonably be expected to occur in regions with ice-covered waters. Given the wide variability in the physical environment, as well as specific logistical, operational, and regional conditions, it is likely that evacuation and rescue solutions will have distinguishing design characteristics from one installation to the next, even if this is only in the mixture of evacuation and rescue assets that are deployed at different sites.

Design considerations in this context include the time to embark and launch the means of evacuation, its launch arrangements and any restrictions imposed by the environment, its capacity, both in terms of personnel and outfit, its endurance, including power and fuel capacity considerations, its survivability with respect to hazards and protection from the environment, and its operability, especially in terms of its ease of use and corresponding training requirements (Warrillow *et al.* 2007). Integration of the means of evacuation and means of rescue is another consideration, as is the impact of the response measures on the environment. General availability of the means of evacuation and rescue are also at issue, which draws attention to matters such as environmental limits on the equipment, maintenance requirements, and remoteness.

The demands of EER for offshore petroleum installations and ships in cold regions present a challenging design space. A good solution to the challenge will address the various design considerations and synthesize them in a coherent design that will be part of an overall safety management system.

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