ANNEX B

MAPPING OF SAFETY FUNCTIONS AGAINST FUEL PROPERTIES

11/2025

List of Tables

Table 1: Methanol

Safety Function (see main report for definitions)		**Principle References in Methanol Interim guideline MSC.1/ Circ.1621**	**Property**							
			Low flashpoint	**Low Energy Density**	**Density relative to air**	**Solubility in water**	**Flammability / Explosivity**	**Corrosivity**	**Flame Invisibility**	**Toxicity / Environmental impact**
SF1	Layout and arrangement (inc. structure, layout)	Generally covered by Sections 5 and 6		Additional storage space required.			Use dispersion and consequence modelling to inform layout, including avoidance of congestion.			Use dispersion and consequence modelling to inform layout.
SF2	Fuel containment (inc. material compatibility of storage tanks, piping, etc.)	Generally covered by Sections 5, 6 (fuel containment), 7 (materials/piping), 8 (bunkering), 9 (fuel supply), 10 (propulsion). Section 16 covers manufacture, workmanship and testing.	Additional requirements (e.g. for cofferdams) due to low flashpoint.		Provide low-level extraction and no floor recess "pockets"; keep HVAC intakes away from pits/trays; position fixed vapour sensors near grade and in trenches/valve boxes.	Protect coatings/linings from wet/acidified methanol	Treat containment spaces as hazardous zones with Ex-rated equipment; pair alcohol-tuned vapour detection (PID/IR calibrated for methanol) with ESD that stops pumps and isolates; add UV/IR flame detection at vents/transfer skids. Maintain bonding/grounding on tanks, skids, hoses; control flow velocities during transfer; use conductive hoses/liners and verified continuity across joints	Material properties and manufacture (inc. welding)/testing of fuel-containing equipment need to reflect specific properties of methanol. Use alcohol-resistant coatings/linings, keep organics (foam, sealants) chemically compatible, and provide containment coatings in drip areas to prevent under-film creep.	Do not rely on human sight; integrate UV/IR flame detectors and strobe/horn alarms; ensure clear line-of-sight to vent/transfer zones.	Fixed methanol vapour detectors + portable PIDs for crews; interlocks for access control on alarms; closed sampling; splash-resistant trays and guarded transfer points.
SF3	Spill containment and drainage	Sections 5.9, 5.10, 6.4, 6.5, 8.3, 8.5, 15.3, 15.4	Additional requirements due to low flashpoint.		Design trays/sumps with low-level forced extraction and no dead pockets; position alcohol-tuned vapour detectors (PID/IR) at floor level, trenches, and valve boxes; interlock ventilation boost and ESD on alarm.	Use dedicated methanol spill trays/sumps and drain headers—never to common bilge/oily-water. Provide closed, segregated holding tanks for recovered liquid; add water-content sampling points (spills dilute fuel and change hazards). Label drains clearly and lock out cross-connections.	Keep spill zones Ex-classified; integrate UV/IR flame detection overlooking trays and transfer points; on vapour/flame alarm, stop transfer/pumps (ESD) and isolate sources. Stage AR-AFFF for pool-fire control (AFP), but design containment to collect/ventilate, not spread. Bond/ground spill trays, drain piping, and portable recovery systems; use conductive hoses and verify continuity before transfer or clean-up pump-outs.	Build trays, sumps, and drain lines using the right materials - 316/316L, PVDF, PE/PP; avoid copper/brass/galvanized parts. Use alcohol-resistant linings where carbon steel is unavoidable; add corrosion coupons/inspection access.		Spill containment to ensure no release to sea of environmentally damaging liquid. Route drains to closed collection, not overboard; provide fixed vapour detection and local alarm beacons; ensure closed sampling and guarded clean-up points; specify chemical-resistant PPE for spill teams.
SF4	Purging / Inerting	Sections 6.3, 6.4, 6.5, 8.5, 10.4, 13 Section 18.4 covers inerting and purging operations.	Additional requirements due to low flashpoint.		For enclosures, do displacement purges bottom-in / top-out to sweep low pockets; confirm with airflow switches. Place LEL sensors low (trays, trenches) and interlock to ventilation boost during purge.		Use interlocked purge sequences: blowdown → nitrogen inerting (preferred) → verification (O_2 analyser + LEL for methanol) → enable. Enforce proof-of-purge before opening/energizing. Keep cause-&-effect tied to ESD (isolate pumps, close valves) if verification fails. Bond/ground tanks, headers, and hoses; control purge flow/velocity to limit charge; use conductive hoses/liners; verify continuity before purging or line-blow.	Build purge paths and vents from stainless steel 316/316L (or compatible plastics like PVDF/PE/PP); avoid copper/brass/galvanized parts in purge trains. If carbon steel is unavoidable, use alcohol-resistant linings and inspect.	Overlook purge/vent tips with UV/IR flame detection; on flame or LEL alarm, trip ESD, hold purging, and isolate sources; keep Ex-rated fans/equipment in classified envelopes.	Treat purging spaces as restricted access until O_2 normal and LEL≈0; require portable PIDs and O_2 monitors for entrants. Route purge off-gas to safe vent points, not work areas or bilge.
SF5	Gas/vapour detection	Sections 15.3, 15.7, 15.8 and 15.11	Additional requirements for gas vapour/leakage detection.		Place detectors low (trenches, under skids, sumps, valve boxes) and in exhaust/return ducts; avoid floor pockets by design but still assume pockets for coverage calculations; prove capture with smoke/CFD or commissioning tests.	Use sensor heads tolerant to humidity/condensation (heated heads or splash guards where needed); place detectors out of direct wash-down paths; maintain dry ventilation in detection enclosures; include O_2 monitors where inerting may occur.	Gas detectors to be suitable for methanol detection and reflect LFL/LEL Install fixed LEL detectors calibrated for methanol (IR or catalytic) in all fuel spaces; set two alarm levels (e.g., warn ≈10% LEL → ventilation boost/inhibit transfers; trip ≈20–25% LEL → ESD: stop pumps/close valves/shut non-Ex loads).	Specify alcohol-compatible housings, filters, and gaskets; add particulate/condensate traps on sampling systems; schedule frequent bump tests after spill clean-ups or solvent exposure.	Pair vapour detection with UV/IR flame detectors overlooking vents and transfer points; on flame detect, override logic to immediate ESD and muster alarms.	Add ppm-range VOC detection (e.g., PID tuned/CF corrected for methanol) in occupied or adjacent spaces; show exposure alarms locally (beacons/horns) and on HMI; issue portable PIDs to crews for pre-entry checks.

Safety Function (see main report for definitions)		Principle References in Methanol Interim guideline MSC.1/ Circ.1621	Property							
			Low flashpoint	Low Energy Density	Density relative to air	Solubility in water	Flammability / Explosivity	Corrosivity	Flame Invisibility	Toxicity / Environmental impact
SF6	Fire detection	Sections 11.7, 15.9, 15.11			Fires/ignitions tend to start low. Aim flame/heat detector fields of view at low elevations (near floors, sumps, trenches, under skids). Add low-mounted LEL sensors to catch pre-ignition vapour (flame + gas as a system).	Use heated/hooded detector heads in damp areas; set environmental blanks to reduce false trips; keep detectors clear of steam reliefs and spray patterns.	Use of suitable fire detection for methanol fires. Place wide-angle, overlapping flame detectors covering pan/tray surfaces and bunded areas. Validate coverage maps (no blind spots behind pumps/valves). Use 2ooN voting for actuation where false alarms are a concern; keep short verification delays.	Specify alcohol-resistant housings, windows, and gaskets for detectors; fit drip shields and keep optics out of wash-down impact. Add inspection/cleaning intervals after spills or maintenance.	Use UV/IR (dual-band) flame detectors validated for alcohol flames; avoid IR-only where possible. Overlook transfer skids, pump rooms, vent areas, trays/sumps, and along likely jet/pool fire paths. Provide beacons/horns and CCTV viewpoints—do not rely on human sight. Due to low soot/smoke production do not depend on smoke detection for first pickup. Pair flame detection with rate-of-rise heat detectors in enclosed spaces; keep smoke heads as secondary where required by rules.	
SF7	Ignition Source Control (inc. hazardous area classification and Ex-rating of equipment etc.)	Section 12					Area classification and associated methodology must reflect properties of methanol. Classify spaces conservatively (e.g., Zone 1 at pumps/ transfer/vents; Zone 2 surrounding). Use Ex-rated equipment appropriate to methanol's gas group, with a temperature class that keeps surface temperatures well below auto-ignition. Tie gas alarms → de-energise non-Ex loads in the zones. Minimize potential ignition sources: intrinsically safe instrumentation where practicable, no arcing contacts in zones, and ESD that rapidly isolates pumps/valves and removes non-essential power on low LEL trip. Bond/ground tanks, skids, trucks/shore, and hoses; verify continuity before transfer; limit flow/velocity during purging/filling; mandate antistatic PPE/footwear and Ex-certified portable gear (radios, lights, meters). Limit surface temperatures inside zones via shielding/insulation; specify Ex motors/fans and certified couplings; manage alignment/bearing condition to avoid frictional heating; no hot work without permits and continuous gas monitoring.	Use alcohol-compatible cable jackets, seals, and coatings so deterioration does not expose conductors or loosen glands. Inspect/replace any softened gaskets that could lead to sparking at loose joints. Avoid Cu/Zn alloys; prefer 316/316L in wetted service to prevent corrosion-driven hot spots or poor connections. Implement periodic torque/IR scans on electrical terminations near methanol areas.	Do not rely on human perception—pair ignition control with UV/IR flame detection and low-level LEL sensors; auto-trigger ignition source cut-off (non-Ex loads, hot surfaces) and ESD.	

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SF8	Pressure Relief	Section 6.7, 6.9, 10.5			Keep vent tips high and clear of HVAC intakes/occupied decks; prohibit relief to enclosed headers or near-deck terminations; add low-level LEL detectors in areas that could see secondary accumulation.	Segregate relieved liquid to a closed contaminated-methanol tank—never to bilge/oily-water. Provide closed-loop sampling and capacity for firewater dilution from a relief event.	Size fire-case PRVs on tanks and pump skids; route discharges to elevated safe vent points with Ex zoning around tips; interlock ESD so pump/transfer isolation accompanies any relief event.	Specify 316/316L PRV bodies/internals (or proven compatible materials), avoid brass/bronze/galvanized parts; if CS is unavoidable, use alcohol-resistant linings and set inspection intervals for seats/nozzles. Choose PTFE/PFA/FFKM soft goods where required; prefer metal-seated designs for hot/dirty service; define tightness class and pop/reseat requirements; plan functional tests and post-event inspections.	Provide UV/IR flame detection at vent tips; bond/ground vent stacks; maintain standoff distances and passive shielding so a stable flare-like burn (if it ignites) remains aloft and away from structure.	
SF9	Ventilation (HVAC)	Section 13	Additional requirements for ventilation system to avoid vapour accumulation.		Provide low-level extraction with make-up air high, sweeping trenches, under-skid spaces, and sumps; eliminate floor pockets. Put LEL heads low and interlock boost/exhaust on warn, ESD + intake closure on trip.	Keep fuel spaces dry-ventilated; shield detectors from wash-downs; route condensate from coils/exhausts to segregated contaminated-water systems, never to common bilge.	Treat fuel spaces as once-through, negative-pressure zones—no recirculation to safe areas. Locate fans/motors outside the hazardous airflow or use Ex-certified non-sparking designs; de-energise non-Ex HVAC on gas alarm. Bond/ground metallic ducts and equipment; limit air velocities in extract near high vapour zones; use conductive flexible connectors with verified continuity.	Build ducts, fans, and grilles from 316/316L or compatible plastics; avoid copper/brass/galvanized parts in methanol airstreams. Use alcohol-resistant sealants/gaskets at duct joints. Specify solvent-resistant coatings inside drip areas and intakes; guard optics/sensors; schedule cleaning/inspection after spills.		Location of ventilation inlets/outlets to take account of possible hazardous releases. Add ppm-range VOC monitoring (PID) in adjacent/occupied spaces and return plenums; on alarm, shut dampers, stop recirc, and pressurize safe spaces away from the hazard.
SF10	Process Control and Monitoring	Section 15	Generally, parameters and executive actions for process control need to reflect process and fuel properties.		Low-mounted LEL heads with fast scan rates; on warn → ventilation boost; on trip → ESD + intake/damper closure. Prove low-level airflow (switches) before enabling transfer.	Water-content trending for tanks/headers; dry-gas inert padding where specified; humidity-tolerant detectors (heated heads/splash guards). Route condensate to segregated systems.	Generally, parameters and executive actions for process control need to reflect process and fuel properties. Low alarm thresholds and tight permissives (no start unless LEL≈0 and vents/HVAC proven). Interlocked sequences for transfer/start/stop tied to ESD (isolate pumps/close valves/de-energise non-Ex loads). Bonding/grounding continuity checks as permissives; flow-rate limits on purges/transfers; alarms on loss of continuity.	Instrument wetted service with 316/316L-compatible sensors and seal packs; corrosion coupons/thickness trending; alarms on vacuum/inert loss that could pull humid air. Use alcohol-compatible analysers, tubing, filters. Sampling knock-out pots and coalescers on analyser lines; maintenance alarms for filter ΔP/fouling.	Integrate UV/IR flame detection with gas detection in the cause-and-effect: flame detect → immediate ESD, ventilation logic, AFP call.	Generally, parameters and executive actions for process control need to reflect process and fuel properties. ppm-range VOC (PID) monitoring in occupied/adjacent spaces and HVAC returns; access interlocks (no entry if PID high). Display exposure alarms locally (beacons/horns) and on HMI.
SF11	Emergency Shutdown	Sections 5.4, 5.6, 8.5, 9.4, 10.3, 10.4, 10.5, 14.3, 15 Shutdown via SSL described in Sections 8.5.7 and 18.	Generally, parameters and executive actions for ESD need to reflect fuel properties. Process system should be subject to HAZOP to identify need for safeguarding systems.		On alarm, shut low-level HVAC intakes/close dampers, maintain once-through extraction, and lock out access to near-floor zones. Place emergency stops and beacons at height/clear of plumes.	Maintain inert padding on tanks during/after trips; interlock N_2 supply low as an ESD cause; prevent automatic water deluge onto spills (handled by AFP/ER procedures) but allow exposure cooling where required.	Generally, parameters and executive actions for ESD need to reflect fuel properties. Process system should be subject to HAZOP to identify need for safeguarding systems. Implement two-tier logic from gas detection: Warn (LEL low) → ventilation boost, inhibit starts; Trip (LEL high or flame detect) → isolate fuel (stop pumps, close ROVs/ESDVs), de-energise non-Ex loads, and halt transfers. ESD sequence verifies bonding/grounding status for transfer skids/hoses; inhibit restart if continuity fails. Limit restart flow ramps (anti-static ramping).	Use fail-closed, spring-return valves with alcohol-compatible soft goods or metal seats; partial-stroke test routinely; treat seat leakage as an ESD-reportable fault requiring inspection before reset.	Tie UV/IR flame detection + LEL directly into ESD cause-and-effect for instant isolation without operator confirmation; latch trips and require gas-free/ proof-of-purge to reset. Trigger muster alarms and access interlocks.	Generally, parameters and executive actions for ESD need to reflect fuel properties. Process system should be subject to HAZOP to identify need for safeguarding systems. On trip, deny entry (door mag-locks/beacons), enforce SCBA-only for response into alarmed spaces, and announce locally via horns/strobes; keep portable PIDs as part of the reset/permitting sequence.

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			Low flashpoint	Low Energy Density	Density relative to air	Solubility in water	Flammability / Explosivity	Corrosivity	Flame Invisibility	Toxicity / Environmental impact
SF12	Active Fire Protection	Sections 11.4 to 11.6			Aim low-elevation foam discharge and mist curtains across floor level; protect trenches/valve boxes; coordinate with low-level extraction so AFP sprays do not push vapour into occupied zones.	Favour AR foam for extinction/vapour suppression; use water mist/deluge primarily for exposure cooling (adjacent equipment, structure) rather than as the primary extinguishing agent on the pool. Route AFP runoff/foam solution to segregated contaminated-liquid tanks (not bilge/oily water); provide capacity for firewater + foam volumes; use quick-closing scuppers to prevent overboard discharge.	Active fire protection should be suitable for methanol fires. Training for firefighting needs to reflect specific properties of methanol. Provide fixed foam systems specifically alcohol-resistant (AR-AFFF/AR-FFF) for bunds, trays, and transfer areas; include foam pourers/monitors and proportioners sized for spill and tank top scenarios. Tie foam release to ESD (isolate pumps/close valves) so fuel is stopped as foam blankets are applied. Bond/ground foam skids, monitors, and deluge piping; verify continuity of flexible connections; limit jet velocities near vapour clouds where practicable. Treat fuel isolation as the primary extinguishing action. AFP logic: flame detect → ESD isolate → foam/mist auto-start for exposure control and final knockdown; retain post-fire cooling timers to prevent reflash.	Build AFP wet parts from 316/316L or compatible plastics; specify alcohol-compatible elastomers (PTFE/EPDM/FFKM) in foam valves/pumps; protect detector lenses/nozzles with drip shields and solvent-resistant coatings.	Auto-actuate AFP from UV/IR flame + LEL detection; provide beacons/horns and CCTV viewpoints over spill areas; do not wait for visual confirmation.	Design AFP operation to be remote-first: remote foam monitors, remote deluge valves, and locally unoccupied actuation points; integrate muster alarms and access interlocks on AFP start.
SF13	Passive Fire and Explosion Protection	Section 11.3			Design pocket-free geometry at floor level (no unvented pits); build passive low-level relief openings/louvres in enclosures (with flame/jet splash protection) to prevent vapour accumulation; shield escape routes with low baffles/curbs from floor-level flames.	Route passive runoff to segregated contaminated-liquid tanks (not bilge); specify coatings/linings under containment areas that resist alcohol/wet exposure; avoid materials that blister/undermine PFP when wetted with methanol.	Provide physical segregation (bunds/curbs/cofferdams) sized for credible spill volumes; protect nearby load-bearing steel, cable trays, and penetrations with pool-/jet-fire–rated PFP (intumescent/insulation) based on heat-flux calculations; keep fire divisions (e.g., A-60) between fuel areas and accommodation/MCCs. Minimize congestion and confinement; where enclosures are unavoidable, incorporate explosion relief (panels/vents) with directed, obstruction-free discharge away from routes/intakes; avoid long ducting that adds inertia/overpressure. Integrate bonding & lightning protection into passive features (vent stacks, blast/fire walls, foam monitor towers) so the structure doesn't become an ignition site during a release.	Build passive barriers—bunds, trays, drain lines, scuppers—from 316/316L or compatible plastics; avoid copper/brass/galvanized items in wetted zones that could degrade and compromise barriers; include inspection access for under-insulation corrosion checks around PFP.	Size PFP by calculated heat load, not visual cues; add thermal shields (non-combustible splash guards) between spill zones and critical structure/cables; use fire-stops and rated penetration seals to prevent undermining divisions.	Use passive separation distances and blast/fire walls to keep occupied areas and muster points out of spill/fire envelopes; provide natural ventilation paths to atmosphere from enclosures (no recirculation paths through safe spaces).
SF14	Emergency Response (includes muster, escape and rescue and environmental response)	Section 6.2 refers to availability of systems following loss of fuel containment. Section 17 covers drills and exercises.	Locations and arrangements to be based on consequence modelling and risk assessment results, so that muster stations, escape routes and LSA are available following a hazardous event. Emergency response plans, training and emergency plans to be based on the specific hazards.							

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			Low flashpoint	Low Energy Density	Density relative to air	Solubility in water	Flammability / Explosivity	Corrosivity	Flame Invisibility	Toxicity / Environmental impact
SF15	Personal Protective Equipment (PPE)				Require personal monitors worn near the breathing zone; position muster/egress routes away from low pockets. Face shields over chemical splash goggles for work near trays/sumps.	Use water rinse for decontamination of PPE/skin, then soap and water—collect runoff to segregated containment. Provide absorbent pads compatible with alcohols; prohibit dry sweeping that can aerosolize.	Mandate flame-resistant (FR) outerwear (treated cotton/wool or equivalent)—no meltable synthetics. Use antistatic garments and conductive footwear in transfer zones; bond/ground personnel where practicable. Require antistatic PPE, conductive footwear, and Ex-safe portable devices (radios, lights, meters). Verify hose/personnel bonding before transfers.	Specify gloves and suit materials proven for methanol: butyl rubber or laminated film (e.g., SilverShield/4H) preferred; nitrile/neoprene only with short breakthrough times and frequent changeout; avoid PVC and unqualified FKM/Viton. Document breakthrough times in the PPE matrix. Avoid PPE components with exposed metal fittings that corrode; select alcohol-resistant fasteners/zips; inspect and retire PPE that shows stiffening, swelling, or seam degradation.	Do not rely on seeing a fire—tie entry controls to gas/flame detection alarms. Equip helmets with high-vis beacons for low-light operations; prioritize remote operations over close approach.	Additional requirements for eye wash/shower facilities. Possible requirements for PPE and breathing apparatus. Emergency response procedures need to cover spill of methanol to sea. Issue personal VOC monitors (PID) for work in/near fuel spaces; require SCBA for entries into alarmed or poorly ventilated areas (no half-mask for emergency). For routine low-level tasks, allow air-purifying respirators with organic-vapour cartridges only when concentrations are confirmed below limits and oxygen is normal. Provide chemical-splash goggles + full face shield, chemical apron, sleeves, and splash boots for sampling/connection tasks. Emergency eyewash and showers within 10 s travel; enforce glove-change rules after contamination.
	Collision Protection	Generally covered by Section 5.3 and 6.4 and various requirements for different areas.	Because methanol spreads quickly, forms low-lying flammable vapour, burns with a hard-to-see flame, is toxic, water-miscible, and materials-selective, collision protection must combine inboard/double-hull placement, crashworthy guards, immediate isolation at the tank, liquid-tight spill control with segregated drainage, high venting, low-level detection/extraction, and bonded/compatible hardware—so a breach is contained, directed, and isolated fast, keeping people, intakes, and ignition sources out of harm's way.							

Table 2: Ammonia

Safety Function (see main report for definitions)		Principle References in Interim guideline MSC.1/Circ.1687	Property									
			Flammability / Explosivity	**Flame invisibility**	**Corrosivity**	**Refrigerated storage ~−33 °C) or ambient pressurized storage (≈10–18 bar)**	**Solubility in water**	**Density relative to air**	**Reactivity**	**Asphyxiation**	**Odour**	**Toxicity / Environmental impact**
SF1	Layout and arrangement (inc. structure, layout)	Generally covered by Sections 5 and 6	Use dispersion and consequence modelling to inform layout., including avoidance of congestion. Layout focuses on toxic-cloud control, not hydrocarbon-style hazardous zoning. Still keep potential igniters (motors/lighting) outside likely plume paths or Ex/non-sparking if they must be within the envelope; prioritize fast isolation and ventilation, not flare-type strategies.		Corrosion depends on water/oxygen content (anhydrous on CS generally benign; wet/ oxygenated aggressive).		Keep ammonia areas roofless or well-vented; if using water curtains/scrubbers as mitigation, provide segregated neutralisation/collection tanks (no bilge), splash shields, and alkali-resistant coatings. Arrange graded decks, curbs, and grated trays so runoff is captured and routed away from personnel routes.	Use dispersion and consequence modelling to inform layout., including avoidance of congestion. Use high vent masts and high-level extraction for normal leaks; avoid overhead pockets. For refrigerated or large releases, shape decks with open, unobstructed pathways that let a plume rise while barriers/curbs deflect and prevent downwash into intakes, doors, or stair towers; keep intakes high and cross-wind.			Put fixed NH_3 detectors high (and low near transfer/skids for cold plumes), at HVAC intakes, and inside escape passages; route detector/alarm beacons to doors and ladders; design “gas-tight refuge” options (bridge/CCR) with pressurisation.	Use dispersion and consequence modelling to inform layout. Place all ammonia equipment on open deck or in dedicated, gas-tight, ventilated compartments far from accommodation/bridge/air intakes. Provide gas-tight boundaries to people spaces, protected escape routes (two ways out), muster points upwind, and abundant eyewash/showers at access points. Provide double barriers and cofferdams below tanks/valve boxes; segregate all ammonia drains to neutralisation/holding; keep overboard scuppers normally closed in ammonia zones.

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			Flammability / Explosivity	Flame invisibility	Corrosivity	Refrigerated storage ~−33 °C) or ambient pressurized storage (≈10–18 bar)	Solubility in water	Density relative to air	Reactivity	Asphyxiation	Odour	Toxicity / Environmental impact
SF2	Fuel containment (inc. material compatibility of storage tanks, piping, leak detection etc.)	Generally covered by Sections 5, 6 (fuel containment), 7 (materials/piping), 8 (bunkering), 9 (fuel supply), 10 (propulsion). Section 16 covers manufacture, workmanship and testing.	Focus detection/ESD on toxic thresholds; still apply Ex/non-sparking equipment within potential plume footprints and keep igniters (hot surfaces, motors) out of vent paths.		Material properties and manufacture (inc. welding)/testing of fuel-containing equipment need to reflect specific properties of ammonia. Use carbon steel (NH_3-rated) or 304/316 stainless for tanks/lines; ban Cu/Zn/galvanized parts (incl. small items like fittings/gratings). Select seals/liners/hoses PTFE, EPDM, FFKM; avoid NBR, PVC, and most FKM in wetted service. Keep an on-board seal kit of approved materials. Control water content and exclude air: closed handling, dry-gas padding, desiccants on vents where applicable. Add corrosion coupons/thickness monitoring in wet-risk locations; avoid mixed-metal pairs that drive galvanic materials in condensate. Provide liquid leak detection in trays/cofferdams; segregate drains to neutralisation units; design graded, pocket-free floors so liquids do not pond near doors or egress.	Use low-temperature-rated steels, insulated/segregated supports, cold shields/drip trays, and verify thermal contraction loads; size relief/BOG handling and monitor temperature/level/pressure closely. Pressurized: provide impact/fragment standoff, snag protection, and fire-case PRVs with direct lines to safe discharge/scrubbers.	Build secondary containment (cofferdams, curbed/grated trays) and segregated neutralisation/holding tanks—never to common bilge. Use alkali-resistant coatings and splash shields; keep eyewash/showers at entries.	Place detectors high generally and low near transfer/skids and cold sources. Design high-level extraction plus low-level pull in spill areas. Route relief/purge to elevated vent masts; keep HVAC intakes outside modelled plume envelopes.				Treat toxicity as the primary hazard. Use fixed NH_3 detectors (ppm range) in tank rooms, valve boxes, ducts, and near intakes; set two alarm tiers (warn → ventilation/ access control; trip → ESD isolate, muster, HVAC shut/pressurize refuges). Provide gas-tight valve boxes with extraction and remote sample points. Keep short, straight relief lines to high masts; where appropriate, vent via packed/aqueous scrubbers (with segregated effluent tanks). Add standoff shields to protect walkways/egress from accidental impingement.

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			Flammability / Explosivity	Flame invisibility	Corrosivity	Refrigerated storage ~−33 °C) or ambient pressurized storage (≈10–18 bar)	Solubility in water	Density relative to air	Reactivity	Asphyxiation	Odour	Toxicity / Environmental impact
SF3	Spill containment and drainage	Sections 5.9, 5.10, 6.4, 6.5, 8.3, 8.5, 15.3, 15.4			Build wetted spill hardware from NH_3-compatible CS/316L or plastics (HDPE/PP/PVDF); ban Cu/Zn/galv in trays, gratings, and fasteners. Specify PTFE/EPDM/FFKM seals for drain valves and sumps. Keep spill areas dry by design (roofless/open deck, high natural ventilation). Where persistent moisture is likely, add coupon/UT monitoring on trays/sumps and set inspection intervals for under-film attack.	Use cryogenic-tolerant materials for trays/sumps; design slopes and non-plugging strainers so ice cannot block drains. Protect structural steel with cold shields where impingement is credible.	Segregate all drains from bilge/oily water to a neutralisation/holding system sized for worst-case wash/curtain flows. Use alkali-resistant coatings in trays/sumps; add splash shields and drip lips around manifolds/valve boxes. If using water curtains/scrubbers, ensure segregated neutralisation capacity and level alarms; provide backflow prevention so caustic does not migrate to other systems. Clearly separate firewater/ER drains from bilge.	Build open, grated spill trays and pocket-free decks with directed falls to guarded sumps. Provide dual-level gas detection (high for warm gas, low near cold sources) and interlock to ventilation boost/ESD. Keep HVAC intakes and doors above and cross-wind of spill pathways.				Spill containment to ensure no release to sea of environmentally damaging liquid. Treat any spill area as a toxic zone. Mark temporary exclusion cones; fit local beacons/horns on leak detect. Provide eyewash/showers at entries and route their runoff to segregated tanks (not bilge). Keep overboard scuppers normally closed in ammonia zones; install quick-closing valves to lock down deck drainage on alarm. Provide sample points and pH monitoring on the neutralisation header.
SF4	Purging / Inerting	Sections 6.3, 6.4, 6.5, 8.5, 10.4, 13 Section 18.4 covers inerting and purging operations.	Use nitrogen inerting to keep O_2 below target and prevent entry into the flammable band during startups/shutdowns. Require proof-of-purge: O_2 analyser ok + NH_3 below threshold before enabling fuel/transfer.		Build purge/inert headers from NH_3-compatible CS/304/316; ban copper/brass/galv. Specify seals PTFE/EPDM/FFKM. Keep spare seal kits for purge valves.	Do not use CO_2 for inerting ammonia systems. Standardize on dry nitrogen; tag connections to prevent wrong-gas tie-in. Control cool-down/warm-up ramp rates, verify material low-temp limits, and instrument temperature/pressure with rate-of-change alarms. Avoid cold plugs by ensuring dry N_2 purges before introducing/withdrawing NH_3.	Keep purge gas dry; prevent humid air ingress. Route purge and any condensate to segregated neutralisation/holding, not bilge. Place splash shields at purge outlets where liquid carryover is possible. Do not use CO_2 for inerting ammonia systems. Standardize on dry nitrogen; tag connections to prevent wrong-gas tie-in.	Configure displacement purges to sweep both high points (warm gas) and low points (cold plumes)—e.g., bottom-in/top-out in warm service and add low-level draw near refrigerated equipment. Confirm airflow with switches.		Asphyxiation risk from inert gases (N_2) - O_2 monitoring in purge areas, access interlocks (no entry during active purges), local beacons/horns, and SCBA requirements for any emergency intervention.	Odour is not reliable; human senses poor - Pair fixed NH_3 detectors (ppm) and portable meters with purge logic. Alarms latch; reset requires documented gas-free (NH_3 ppm + O_2 normal).	Make toxicity the primary criterion for “gas-free.” Interlock purge sequences to verify NH_3 ppm below entry limits (fixed + portable sensors) and confirm purge routing to safe vent/scrubber before opening any volume. Do not use CO_2 for inerting ammonia systems. Standardize on dry nitrogen; tag connections to prevent wrong-gas tie-in. Purge to elevated masts or packed/aqueous scrubbers with segregated effluent; overboard scuppers normally closed in NH_3 zones. Add pH/level alarms on neutralisation tanks. Asphyxiation risk from inert gases (N_2) - O_2 monitoring in purge areas, access interlocks (no entry during active purges), local beacons/horns, and SCBA requirements for any emergency intervention.

Safety Function (see main report for definitions)		Principle References in Interim guideline MSC.1/Circ.1687	Property									
			Flammability / Explosivity	Flame invisibility	Corrosivity	Refrigerated storage ~−33 °C) or ambient pressurized storage (≈10–18 bar)	Solubility in water	Density relative to air	Reactivity	Asphyxiation	Odour	Toxicity / Environmental impact
SF5	Gas/vapour detection	Sections 15.3, 15.7, 15.8 and 15.11	Gas detectors to be suitable for ammonia detection and reflect LFL/LEL Prioritize ppm-level toxic detection; optionally add %LEL heads where flammability could be credible (e.g., enclosed machinery). Tie both to interlocked responses; keep non-Ex loads de-energised in alarmed zones.		Specify detector housings, sinter filters, and sampling lines in 316/304 SS or PTFE/PVDF; ban copper/brass/galv in wetted parts. Choose seals PTFE/EPDM/FFKM; keep approved sensor protectors and spares. NH_3 is more corrosive in wet/oxygenated conditions; can poison or drift some sensors. Prefer electrochemical NH_3 cells (ppm toxic monitoring) and photoacoustic IR/NDIR or MOS where suited; manage cross-sensitivities via correction factors. Enforce bump-tests and calibrations at defined intervals (increase frequency after exposures).		Use splash/condensate guards and heated or hooded heads to prevent fouling; fit particulate/coalescing filters on any sampling systems; route condensate to neutralisation, not bilge. Plan cleaning intervals after spray/wash events.	Place sensors high for warm-gas accumulation and low near transfer/skids and refrigerated equipment for cold plumes. Verify coverage of overhead pockets and floor recesses; prove capture with commissioning tests/smoke or CFD.			Provide local beacons/horns at entries and along routes; integrate alarms to bridge/CCR with muster prompts. Require portable NH_3 meters for pre-entry and post-event gas-freeing.	Design for instrumented detection, not smell. Install fixed NH_3 detectors (ppm range) in tank rooms, valve boxes, duct returns, near air intakes, and along escape paths. Use two alarm tiers (warn → ventilation boost/access control; trip → ESD isolate, HVAC closure/pressurisation of refuges, muster). Interlock damper closure/recirc lockout on alarms; keep hazardous spaces once-through, negative pressure to safe areas. Prove pressure cascades and airflow on commissioning and routine tests.

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Safety Function (see main report for definitions)		**Principle References in Interim guideline MSC.1/Circ.1687**	**Property**									
			Flammability / Explosivity	**Flame invisibility**	**Corrosivity**	**Refrigerated storage ~−33 °C) or ambient pressurized storage (≈10–18 bar)**	**Solubility in water**	**Density relative to air**	**Reactivity**	**Asphyxiation**	**Odour**	**Toxicity / Environmental impact**
SF6	Fire detection	Sections 11.7, 15.9, 15.11	Use of suitable fire detection for ammonia. Make toxic-gas detection the primary trigger; treat flame detection as a confirmatory/secondary channel. Tie either flame or high toxic alarm to ESD isolate, HVAC isolation, and muster. High jet momentum when pressurized → small jet fires at seals/PRVs. Increase detector density around seal packs, flange clusters, PRV outlets, and breakaway couplings; validate coverage maps so short, directional jets cannot bypass fields of view. Potential H_2 presence where cracking/mixed fuels are used (H_2 flames are near-invisible). In systems with NH_3-to-H_2 cracking or mixed fuels, require hydrogen-capable UV/IR detectors and place heads to cover both NH_3 and H_2 vent paths; integrate H_2 gas detection as a pre-ignition channel.	Use UV or UV/IR dual-band flame detectors validated for NH_3 fires; avoid IR-only heads. Overlook vent masts, PRVs, transfer skids, valve boxes, compressor modules, and potential jet paths with overlapping fields of vision and short actuation delays. Potential H_2 presence where cracking/mixed fuels are used (H_2 flames are near-invisible). In systems with NH_3-to-H_2 cracking or mixed fuels, require hydrogen-capable UV/IR detectors and place heads to cover both NH_3 and H_2 vent paths; integrate H_2 gas detection as a pre-ignition channel.	Choose 316/304 SS or coated aluminium for detector housings/brackets; PTFE/EPDM seals; avoid Cu/Zn/galv near optics; provide anti-corrosion mounting and easy service reach.	High vapour pressure; leaks can be intermittent and jet-like. Increase detector density at likely leak sources (seals, flanges, PRVs, breakaways). Monitor valve boxes and double-wall annuli; sample HVAC returns serving adjacent spaces; add fast-response voting (e.g., 1ooN warn / 2ooN trip with short time filters).		Aim detector views at high elevations and low elevations near cold sources; add rate-of-rise heat or linear heat at low level inside enclosures and below skids to catch shielded/low fires.	Water-reactive; sprays/washdowns form caustic aerosols/salts (can foul optics). Specify heated/hooded flame detector heads with sacrificial windows or wipers where exposure is likely; plan inspection/cleaning intervals after washdowns or rain; place optics out of direct spray trajectories.			Pair flame detection with ppm NH_3 gas detectors and loud/visual beacons at entries and routes; ensure alarms drive access interlocks (no entry without gas-free confirmation/SCBA).

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SF7	Ignition Source Control (inc. hazardous area classification and Ex-rating of equipment etc.)	Section 12	Area classification and associated methodology must reflect properties of ammonia. Classify hazardous areas conservatively where an NH_3/air mix could form (transfer skids, valve boxes, enclosed machinery). Use Ex-rated equipment with a temperature class comfortably below ammonia's auto-ignition temperature; set ESD logic so gas alarms de-energise non-Ex loads and inhibit restarts. Keep potential igniters out of jet impingement paths; shield hot surfaces; place breakaway couplings and non-return devices to prevent backflow. Validate standoff distances to electrical gear. Bond/ground tanks, skids, hoses, and vent stacks; verify continuity before bunkering; limit flow/velocity ramps; require antistatic PPE/footwear and Ex-certified portable radios/lights/meters. Lightning/stray currents at tall vent masts - Provide bonding/lightning protection on vent stacks and metallic barriers; maintain equipotential bonding during ship–shore connections. Hot-surface/mechanical-spark sensitivity in the mix band - Limit surface temperatures via insulation/shrouds; specify non-sparking fan wheels and Ex motors; implement condition monitoring (alignment/bearings) to prevent frictional heating; no hot work without permits and continuous gas monitoring.	Do not rely on human perception—tie UV/IR flame and ppm toxic gas detection to automatic ignition-source cut-off (kill non-Ex loads, stop fans in zone, isolate heaters/hot surfaces).	Avoid materials that degrade into loose/hot connections (no copper/brass/galv). Use NH_3-compatible CS/304/316 for supports/enclosures; schedule torque/IR scans of terminals in NH_3 zones; specify alkali-resistant gaskets/cable glands. Protect electrics with NEMA/IP enclosures suited for caustic splash; locate gear above splash lines; plan wash-down/neutralisation procedures that don't drive mist into fans or busbars.	Pressurized systems → high-velocity jets (seal/PRV/connection failures) - Keep potential igniters out of jet impingement paths; shield hot surfaces; place breakaway couplings and non-return devices to prevent backflow. Validate standoff distances to electrical gear.		Zone both overhead (warm plume) and near-floor (cold plume) regions. Keep motors, lamps, and hot surfaces outside plume footprints where possible, or Ex/non-sparking if they must be inside. Interlock HVAC intake closure on toxic gas alarm. Keep hazardous spaces once-through, negative pressure; fit automatic fire/gas dampers and recirc lockout to prevent carrying vapour to non-rated equipment; keep pressurized refuges (bridge/CCR).				

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SF8	Pressure Relief	Section 6.7, 6.9, 10.5	Pressurized systems → high-momentum jets (reaction loads, noise) - Verify stack bracing and supports for thrust; analyse acoustic exposure and set exclusion zones. Bond/ground stacks and provide lightning protection. Include fire-case PRV sizing for tanks and bullets. Keep Ex-classified envelopes around vent tips; fit UV/IR flame detection overlooking masts (treat as confirmatory—toxicity still drives response).		Specify CS (NH_3-rated) or 304/316 SS bodies/internals; ban Cu/Zn/galv anywhere in relief and stack assemblies. Choose soft goods PTFE/EPDM/FFKM; document tightness class, set pressure, blowdown/reseat requirements.	Use cold-rated materials for PRVs/nozzles/stacks; provide ice/drip shields and layouts that will not plug with frost. Keep vent lines short, straight, sloped, and free of water seals that can freeze or trap liquid. Pressurized systems → high-momentum jets (reaction loads, noise) - Verify stack bracing and supports for thrust; analyse acoustic exposure and set exclusion zones. Bond/ground stacks and provide lightning protection.	If using water scrubbers/curtains, size neutralisation/holding tanks for peak flow; segregate effluent (no bilge). Materials in wetted relief trains need alkali-resistant coatings and corrosion allowance.	Keep vent tips high, clear, and unobstructed; avoid near-deck terminations. Add knock-out/demist stages before masts to strip liquid carryover; provide dual-level toxic detection around discharge zones.	CO_2 reactivity (carbamate formation/fouling) - Do not manifold ammonia relief into CO_2-containing systems; avoid CO_2 quench streams in scrubbers. Keep relief headers single-service to prevent cross-contamination/backflow.			Size relief for credible overpressure but route all discharges to elevated vent masts or packed/aqueous scrubbers (preferred near people). Interlock ESD/muster/HVAC isolation on lift confirmation; mark and cordon plume exclusion cones. Overboard paths normally closed in NH_3 areas; continuous pH/level monitoring on neutralisation tanks; sample points for post-event verification.
SF9	Ventilation (IHVAC)	Section 13	Fire risk is secondary, but possible in confined mixes. Place fans/motors outside the hazardous airstream where practicable; otherwise use non-sparking/Ex-certified equipment within classified envelopes. On alarm, de-energise non-Ex loads in affected zones.		Build airstream parts from 316/304 SS or compatible plastics (PP/HDPE/PVDF/FRP). Ban Cu/Zn/galv in ducts, coils, and fasteners in NH_3 zones. Specify alkali-resistant sealants/gaskets and corrosion-resistant fan housings/impellers.	Ensure ice-tolerant exhausts: short, direct runs; no water seals; heat-trace or insulate where freezing is possible. Keep grilles and screens non-plugging; add icing alarms where warranted. Pressurized systems → jet releases can enter intakes - Keep HVAC intakes outside modelled vent/relief envelopes; interlock automatic intake closure on NH_3 alarms. Provide local extract hoods over valve boxes and breakaway points.	Use demisters/coalescers at exhaust pickups where spray is credible. Route condensate/drainage to neutralisation/holding, never to bilge. Avoid water mists inside HVAC except in engineered scrubbers; prevent carry-over into ducts.	Implement dual-elevation strategy: high-level extraction for warm gas + low-level pull around transfer/refrigerated equipment. Eliminate ceiling pockets and floor recesses; prove capture with commissioning tests/CFD. Site fresh-air intakes high, upwind, and clear of vent cones.				Location of ventilation inlets/outlets to take account of possible hazardous releases. Design ventilation as a primary life-safety layer. Keep ammonia spaces once-through and negative to adjacent areas—no recirculation. Tie ppm NH_3 detection to boost on warn and HVAC intake/damper closure + ESD + muster on trip. Provide pressurized refuges (bridge/CCR) with monitored over-pressure. Segregate all HVAC condensate/exhaust washdowns to neutralisation; overboard scuppers normally closed in NH_3 areas. Provide pH/level monitoring on the neutralisation header.

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			Flammability / Explosivity	**Flame invisibility**	**Corrosivity**	**Refrigerated storage ~−33 °C) or ambient pressurized storage (≈10–18 bar)**	**Solubility in water**	**Density relative to air**	**Reactivity**	**Asphyxiation**	**Odour**	**Toxicity / Environmental impact**
SF10	Process Control and Monitoring	Section 15	Generally, parameters and executive actions for process control need to reflect process and fuel properties. Fire is secondary but possible in confined mixes - Integrate UV/IR flame detection as confirmatory with fast trip; flame or high toxic alarm → ESD, HVAC isolation, AFP call for exposure cooling.		Instrument with NH_3-compatible metallurgy; trend corrosion coupons/thickness at wet-risk spots; alarm on oxygen ingress (e.g., pad pressure low) that could drive corrosion; planned IR/torque checks on electricals in NH_3 zones.	Continuous P/T/level/vacuum monitoring with rate-of-change alarms; enforce cool-down/warm-up ramp limits via interlocks; trips on vacuum-loss or rapid $\Delta T/\Delta P$; verify BOG/relief availability before transitions. High vapour pressure; rapid jet/leak dynamics - Increase detector density at seals/PRVs/manifolds; fast scan rates and short alarm delays. Validate ESD valve stroke times (partial-stroke tests) and log closing confirmation.	Trend neutralisation tank pH/level, alarm on capacity; route condensate/washdowns to segregated systems. Use heated/hooded sensors and fouling alarms; schedule post-wash bump tests.	Monitor dual elevations (high + low near refrigerated/transfer areas). Prove airflow (switches) at both elevations before enabling transfers; interlock intake closure and zone pressurisation on trip.	Block CO_2 as an inerting gas in logic/permits; tag connections; interlock N_2-only supply permissive for purge/inert sequences.		Human senses unreliable (SCBA, sleep); need deterministic logic - Latched trips with clear reset criteria (NH_3 < limit, O_2 normal where inerted, proof-of-purge); alarm rationalisation to avoid nuisance; clear cause-&-effect matrix visible at CCR.	Generally, parameters and executive actions for process control need to reflect process and fuel properties. Make ppm NH_3 detection the primary process variable for safety. Two alarm tiers: warn → ventilation boost, access control; trip → ESD isolate, HVAC intake/damper closure, muster. Display alarms on bridge/CCR and locally with beacons/horns; require portable NH_3 meters for entry/reset. Monitor overboard valves (normally closed), prove segregated drain valves positions, and alarm on unauthorized openings; log effluent sampling events.
SF11	Emergency Shutdown	Sections 5.4, 5.6, 8.5, 9.4, 10.3, 10.4, 10.5, 14.3, 15 Shutdown via SSL described in Sections 8.5.7 and 18.	Generally, parameters and executive actions for ESD need to reflect fuel properties. Process system should be subject to HAZOP to identify need for safeguarding systems. Narrow flammability range (≈15–28% vol); higher MIE than hydrocarbons - Toxic trip is primary but still tie UV/IR flame or %LEL (where applicable) to instant isolation and AFP exposure-cooling. De-energise non-Ex loads automatically in alarmed zones.		Specify NH_3-compatible valve metallurgy and soft goods; treat seat leakage as an ESD-reportable fault. After any trip, enforce post-event tightness tests before reset.	Interlock cool-down/warm-up ramp limits; on trips, start safe blowdown/BOG handling (to mast/scrubber), protect against cold-plug/ice conditions, and verify vacuum integrity for double-wall equipment before transitions. High vapour pressure; jet-like leaks; rapid concentration rise - Use fast-acting, fail-closed valves (spring return), partial-stroke tested; confirm closed position in logic. Configure local ESD pushbuttons (ship-side, escape routes) hardwired to isolation.	On trip, route all drains/eyewash/shower runoff and any quench/scrubber effluent to neutralisation/holding (no bilge). Monitor pH/level and inhibit restart if capacity is low.	Vote high and low elevation detectors into ESD tiers. On trip, close low intakes/doors, hold negative pressure in hazard spaces, and lock out access to near-floor zones; keep emergency stops and beacons out of plume footprints.	ESD logic blocks CO_2 as an inerting/blanket medium; permissive requires dry N_2 available for purge/isolation sequences.			Generally, parameters and executive actions for ESD need to reflect fuel properties. Process system should be subject to HAZOP to identify need for safeguarding systems. Make toxic gas the primary trip. Two tiers: warn (ppm low) → ventilation boost, inhibit starts, access control; trip (ppm high or flame) → isolate fuel (shut pumps/compressors, close ROV/ESDVs), HVAC intake/damper closure, pressurize refuges, and muster. Alarms latch; reset only after documented gas-free. Close overboard scuppers on trip in NH_3 zones; verify segregated drain valves positions; log effluent sampling before restart.

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SF12	Active Fire Protection (AFP)	Sections 11.4 to 11.6	Active fire protection should be suitable for ammonia fires. Training for firefighting needs to reflect specific properties of ammonia. Make fuel isolation and toxic dispersion control the priority. Auto-trigger AFP from ppm NH_3 and/or flame to ESD isolate, then use AFP primarily for exposure cooling and plume control—not “flame knockdown” alone. Fire is secondary but credible in confined mixes / cracking systems (H_2 present) - Where H_2 may exist (ammonia cracking/mixed fuel), ensure hydrogen-capable UV/IR coverage and treat AFP as exposure cooling + isolation first; dry chemical may help very small, localized flames only once fuel is isolated. Pressurized systems → high-momentum jets, strong local heat flux when burning. Add zoned deluge rings and remote monitors to cool structural steel, cable trays, and equipment facing vent/PRV cones. Verify standoff so streams do not impinge directly on a jet and cause flame attachment.	Use UV/IR flame detection to auto-start water mist/deluge for adjacent equipment and structural cooling around PRVs, seals, and valve boxes. Keep short actuation delays and ensure overlapping nozzle coverage along likely jet paths.	Build AFP wetted parts from 304/316 SS or compatible plastics; specify alkali-compatible seals (PTFE/EPDM/FFKM). Protect detector optics with drip shields and plan clean-and-test intervals after spray use.	Fit heated/hooded spray nozzles and ice-tolerant deluge hardware near cold sources; protect supports and cables with water spray cooling while avoiding ice bridges that block drains. Keep non-plugging strainers and clear spill paths. Pressurized systems → high-momentum jets, strong local heat flux when burning - Add zoned deluge rings and remote monitors to cool structural steel, cable trays, and equipment facing vent/PRV cones. Verify standoff so streams do not impinge directly on a jet and cause flame attachment.	Any AFP water used for curtains/scrubbing or post-event wash must drain to segregated neutralisation/holding tanks (not bilge). Size runoff capacity, add pH/level monitoring, and provide alkali-resistant coatings around discharge areas.	Provide water curtains/spray lines at deck edge and around transfer skids to steer/dilute cold plumes away from intakes and routes (tactics plan). Coordinate sprays with high/low ventilation extraction so you do not drive vapour into occupied spaces.				

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SF13	Passive Fire and Explosion Protection	Section 11.3	Possible risk reduction measure for mitigation of explosions. Prioritize toxic-cloud management over flame radiation. Use separation distances, gas-tight divisions, and pressurized refuges (bridge/CCR). Treat PFP as life-safety shielding for escape routes and control spaces. Size PFP by calculated heat-flux/jet-fire scenarios, not visual cues. Install jet-fire-rated cladding/insulation for nearby steel, supports, cable trays, and penetrations around PRVs/vents/valve boxes. Pressurized systems → potential for confined explosions if vapour accumulates -Minimize congestion and confinement (short valve boxes, smooth internals). Where enclosures are unavoidable, provide explosion relief (panels/hinged louvres) with directed, obstruction-free discharge away from people/intakes; avoid long vent ducts that add inertia/overpressure. Lightning/stray currents on tall metallic features - Integrate bonding/lightning protection into vent masts, fire/blast walls, and monitor towers so passive features don't become ignition sites.	Size PFP by calculated heat-flux/jet-fire scenarios, not visual cues. Install jet-fire-rated cladding/insulation for nearby steel, supports, cable trays, and penetrations around PRVs/vents/valve boxes.	Passive fire protection requirements to be based on consequence modelling and risk assessment. Wet NH_3 corrodes CS; can attack Al in alkaline condensate) - Build passive hardware—bunds, trays, scuppers, louvers, guards—from NH_3-compatible materials (304/316 SS, FRP, PP/HDPE/PVDF). Ban Cu/Zn/galv in wetted or fume-exposed parts; design inspection access for under-insulation corrosion (UIC).	Low boiling point (−33 °C); icing/cold impingement - Keep structural steel off cold plume lines or shield it; use ice-tolerant gratings/drains and layouts that cannot plug. Allow thermal gaps and sliding supports where cold shrinkage can load structure. Pressurized systems → potential for confined explosions if vapour accumulates - Minimize congestion and confinement (short valve boxes, smooth internals). Where enclosures are unavoidable, provide explosion relief (panels/hinged louvres) with directed, obstruction-free discharge away from people/intakes; avoid long vent ducts that add inertia/overpressure.	All spill surfaces liquid-tight with alkali-resistant coatings. Route passive runoff to segregated neutralisation/holding (not bilge). Protect cable/penetrations so caustic does not undermine PFP or divisions. Relief/vent plumes: high momentum, highly irritating; water creates more caustic liquid - Place tall vent masts with passive standoff shields (no walkways beneath). If a scrubber is part of the philosophy, ensure passive containment and materials compatibility for effluent paths.	Design pocket-free geometry: no ceiling traps or floor recesses. Provide open, grated decks and high/low natural vents so clouds can relieve to atmosphere instead of accumulating in enclosures. Shield stair towers and doors with baffles.				Prioritize toxic-cloud management over flame radiation. Use separation distances, gas-tight divisions, and pressurized refuges (bridge/CCR). Treat PFP as life-safety shielding for escape routes and control spaces. Keep overboard scuppers normally closed; provide curbs/cofferdams to hold credible spill/runoff volumes until neutralized. Mark deck exclusion cones for vent/relief directions.

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			Flammability / Explosivity	Flame invisibility	Corrosivity	Refrigerated storage ~−33 °C) or ambient pressurized storage (≈10–18 bar)	Solubility in water	Density relative to air	Reactivity	Asphyxiation	Odour	Toxicity / Environmental impact
SF14	Emergency Response (includes muster, escape and rescue and environmental response)	Section 6.2 refers to availability of systems following loss of fuel containment. Section 17 covers drills and exercises.	Locations and arrangements to be based on consequence modelling and risk assessment results, so that muster stations, escape routes and LSA are available following a hazardous event. Emergency response plans, training and emergency plans to be based on the specific hazards.	Low radiant/sooty flame; small jet fires possible - UV/IR flame + ppm toxic detection auto-trigger isolation and exposure-cooling water mist (AFP). Emphasize isolate first; approach only with SCBA and after gas-free checks.	Materials selectivity / corrosion in wet NH_3 (Cu/Zn/galv attack; elastomer swell) - ER equipment (stretchers, tools, fittings) must be NH_3-compatible; avoid copper/brass. Provide alkali-resistant hoses and conductive, bonded recovery lines.	Low boiling point (−33 °C); JT cooling and icing - For rescue near refrigerated kit, carry cryo-PPE (face shield, cryo-gloves, splash apron). Keep ice-tolerant drains/gratings clear so responders do not lose egress. Shield structure and lines from cold impingement in ER layouts. Pressurized systems → high-momentum jets; rapid concentration rise - Hardwired ESD pushbuttons at skids and escape points; fast, fail-closed valves. Pre-assign no-go zones under vent/PRV cones; use remote CCTV for size-up; keep responders out of jet axes.	ER uses water curtains/scrubbers only as designed measures to deflect/dilute; all runoff goes to segregated neutralisation/holding (never bilge). Stage alkali-resistant decontamination stations; specify chemical-splash PPE.	Pre-plan plume cones and deck cordons; site windsocks. Mark escape routes above/cross-wind of low pockets; add dual-level extraction in response plans (high for warm gas, low near cold sources). Close HVAC intakes/dampers automatically on toxic alarm.	Do not use CO_2 for inerting in ER. Standardize dry N_2 for purges; interlock ER purging to safe vent/scrubber availability.	ER entries use SCBA and personal O_2 meters; lock out access during active purges; enforce permit-to-work with continuous gas checks.		Design ER around instrumented triggers, not smell ppm NH_3 alarms → muster + access lockouts. Provide pressurized refuges (bridge/CCR) and gas-tight routes to them. Issue portable NH_3 meters to teams; SCBA mandatory for entry to alarmed zones. Keep overboard scuppers normally closed in NH_3 zones; monitor pH/level on neutralisation tanks; pre-plan sampling points and reporting. If any discharge risk exists, deploy containment booms and notify per SOPEP-style procedures.
SF15	Personal Protective Equipment (PPE)				Specify butyl rubber or laminated-film gloves for liquid/NH_3 splash; EPDM acceptable for many NH_3 tasks; use nitrile only for brief contact with frequent change-out. Avoid natural rubber/PVC for prolonged exposure; document breakthrough times in the PPE matrix.	For refrigerated work or cold-line proximity: cryogenic face shield, insulated cryo-gloves (loose cuff, quick release), apron/splash sleeves, and non-absorbent outer layers that doff quickly if splashed. Add hard hats with face shields, cut-resistant liners under chemical gloves where sharp ice/metal is possible; hearing protection near relief/vent areas. Jet leaks & local high momentum; debris/ice exposure - Add hard hats with face shields, cut-resistant liners under chemical gloves where sharp ice/metal is possible; hearing protection near relief/vent areas.		Wear personal monitors at breathing zone; set muster/egress above and cross-wind of low pockets. Use hooded garments that shed condensate; do not kneel/crawl in cold-release zones.	Require chemical-splash goggles + full face shield, chemical suit, and liquid-tight boots for sampling/transfer. Place eyewash/showers within 10 s; route runoff to neutralisation/holding, not bilge.	Carry personal O_2 monitors during purge/suspect entries; SCBA mandatory if O_2 uncertain or low.	Tie access to detector status (no entry without healthy personal meter/SCBA where required); use beacons/horns so alarms penetrate PPE and noise.	Additional requirements for eye wash/shower facilities. Specific requirements for PPE and breathing apparatus (see Section 20 of Circ. 1687). Emergency response procedures need to cover spill of ammonia to sea. Base entry on instruments, not smell. Carry personal NH_3 meters; for alarmed/suspect spaces use SCBA (no half-masks). For controlled work below limits, allow full-face respirators with NH_3 cartridges only with continuous monitoring and normal O_2.
	Collision Protection	Generally covered by Section 5.3 and 6.4 and various requirements for different areas.	Because ammonia releases after collision are toxicity-led, can form dense cold plumes, turn water into caustic runoff, and flash violently, collision protection must combine inboard/double-hull placement, crashworthy supports and guards, immediate isolation at the tank, protected routing, high-mast venting, and segregated neutralisation—all interlocked to impact-driven ESD and HVAC closure—so a breach is contained, directed, and kept away from people and critical structure long enough for safe isolation and response.									

Table 3: Hydrogen

Safety Function (see main report for definitions)		**Principle References in IGF Code**	**Property**										
			Low Energy Density	**Flammability / Explosivity**	**Embrittlement**	**Low Temp at LH2 Cryogenic storage**	**Asphyxiation**	**Expansion ratio $LH_2 \rightarrow CH_2$ ~1:700**	**Colourless / Odourless**	**Density relative to air (buoyancy)**	**Diffusivity**	**Flame Invisibility**	**High Laminar Velocity (propensity for DDT)**
SF1	Layout and arrangement (inc. structure, layout)	Generally covered by Sections 5 and 6	Additional storage space required - needs to be reflected in layout	Use dispersion and consequence modelling to inform layout., including avoidance of congestion.						Use dispersion and consequence modelling to inform layout.			Use dispersion and **suitable** consequence modelling to inform layout, including avoidance of congestion.
SF2	Fuel containment (inc. material compatibility of storage tanks, piping, leak detection etc.)	Generally covered by Sections 5, 6 (fuel containment), 7 (materials/piping), 8 (bunkering), 9 (fuel supply), 10 (propulsion). Section 16 covers manufacture, workmanship and testing.	Hydrogen's low volumetric energy density forces larger/more numerous tanks and longer pipe runs, which raises leak likelihood and system complexity.	Wide flammability range and tiny ignition energy properties force earlier intervention, wider protected zones, faster detection/ventilation, and more aggressive automatic shutdown than conventional fuels	Hydrogen embrittlement threatens containment integrity by turning small flaws into fast-growing cracks under stress. Material properties and manufacture (inc. welding)/testing of fuel-containing equipment need to reflect specific properties of hydrogen.	LH_2 storage calls for vacuum-insulated double barriers, disciplined BOG/relief control, cryogenic-qualified materials, dual-level gas detection with high-capacity ventilation, and tightly interlocked operations—so cold leaks are contained, vapour is routed and dispersed safely, and the system stays crack-tolerant under extreme temperatures.				Hydrogen is far lighter than air, fuel-containment should be engineered to drive any leak upward and out fast, and to keep it away from people and intakes. Buoyancy shapes containment toward upward leak paths, high-point monitoring, and vertical venting, with added low-level coverage for cryogenic scenarios.	Material properties and manufacture (inc. welding)/testing of fuel-containing equipment need to reflect specific properties of hydrogen. Hydrogen's high diffusivity pushes containment toward welded, double-barrier, low-permeation designs with aggressive leak testing, robust ventilation, and dense detection—treating permeation and micro-leaks as normal design loads rather than rare anomalies.	Hydrogen's near-invisible flame pushes containment safety toward automatic, instrumented detection and remote action—UV/IR flame + gas detection driving ESD, controlled venting/ignition at masts, spacing, and automatic cooling	This calls for need to prevent flashback and rapid flame acceleration—with flame arresters, fast isolation, robust vent/relief design, smooth/short flow paths, disciplined inerting/purging, and rapid detection-to-ESD—so flames cannot propagate or pressurize equipment faster than your protections can act.
SF3	Spill containment and drainage	Sections 5.9, 5.10, 6.4, 6.5, 8.3, 8.5, 15.3, 15.4		Wide flammability + tiny ignition energy: even small pockets in drains/ducts can ignite; flames may be hard to see.		LH_2 instant freezing/embrittlement of common materials; icing can block drains; air/oxygen condensation on cold surfaces can create LOx-enriched fire hazards. Huge expansion ($LH_2 \rightarrow GH_2$ ~1:700): small liquid pools flash into large gas clouds.				Hydrogen rises fast, but very cold vapour from LH_2 can be temporarily heavier than air and pool in low spots.	Hydrogen rises fast, but very cold vapour from LH_2 can be temporarily heavier than air and pool in low spots.		High burning velocity raises flashback risk through vented paths.
SF4	Purging / Inerting	Sections 6.3, 6.4, 6.5, 8.5, 10.4, 13 Section 18.4 covers inerting and purging operations.		Even trace O_2 or H_2 pockets are risky. Interlocked purge sequences with proof-of-purge (O_2 analyser + H_2 detector), two thresholds (enable/abort), and automatic ESD if verification fails		Choose the right inerting gas based on storage state (cryogenic liquid or compressed gas). Air ingress condenses/oxygen enriches; N_2 can freeze/plug; thermal shock during transitions. Use helium for cold purges/cooldown-warmup	N_2/He displace oxygen. O_2 monitoring in purge areas, interlocked access control, alarm beacons, and clear exhaust routing.	Tiny liquid remnants can create big gas volumes during warmup. Stage warmups with controlled venting to masts, rate-limit purges, and size reliefs for transients.		Gas stratifies high; purge paths matter. For enclosures, bottom-in / top-out displacement purges; verify sweep of high points (no pockets). For piping/equipment, choose displacement vs dilution method and confirm volume changes.	Small leaks and back-diffusion can re-form flammable mixes after a purge. Use all-welded construction where possible, double-block-and-bleed on purge tie-ins.		Any ignition can travel fast up a line. Flame arresters, check valves, choke orifices, and purge outlet routing to elevated vent masts—never to drains or enclosed headers.

Safety Function (see main report for definitions)		Principle References in IGF Code	Property										
			Low Energy Density	Flammability / Explosivity	Embrittlement	Low Temp at LH2 Cryogenic storage	Asphyxiation	Expansion ratio LH_2 → CH_2 ~1:700	Colourless / Odourless	Density relative to air (buoyancy)	Diffusivity	Flame Invisibility	High Laminar Velocity (propensity for DDT)
SF5	Gas/vapour detection	Sections 15.3, 15.7, 15.8 and 15.11		Small leaks can ignite easily. Gas detectors to be suitable for hydrogen detection and reflect LFL/LEL. Dense gas-detector coverage with low setpoints (early warn/ESD), strict hazardous-area zoning, Ex-rated equipment, bonding/grounding, hot-work controls, rapid automatic isolation (ESD).		Initially denser-than-air until warmed; huge expansion on warmup. Dual-level detection (low & high), cross-ventilation at deck level near spill areas, controlled warm-up and venting to masts, keep drains open/unenclosed (no water seals).			Human senses are poor detectors. Fixed H_2 detection in tank rooms, valve boxes, annuli, ducts, bunkering stations; portable meters for crews; periodic proof-testing and calibration.	CH_2 rises and accumulates at high points. Open-deck layouts, no overhead pockets, high-level extraction, ceiling-mounted detectors, intakes kept above/away from release points; vent masts discharging upward.	CFD-based dispersion modelling to validate detection. Sensor performance benchmarks to reflect both CH2 and LH2. Hydrogen escapes through micro-gaps and elastomers. All-welded construction where possible, metal gaskets, bellows-sealed valves, double-wall/monitored piping, helium leak testing, treat permeation as a continuous load in ventilation/detection.	Flame is hard to see, low radiant heat → Fires may be missed initially. UV/IR flame detection at vent tips and release points, automatic deluge/mist for exposure protection, alarms and access interlocks (do not rely on human sight).	Fast flame spread/flashback in lines and congested spaces. Flame arresters (deflagration/detonation rated as needed), non-return valves, choke orifices, short/smooth flow paths, disciplined purging/inerting before interventions, quick-acting shutoff valves.
SF6	Fire detection	Sections 11.7, 15.9, 15.11		Fires can start from small releases; prevention depends on catching leaks early. Use of suitable fire detection for hydrogen. CFD based validation of detectors. Pair flame detection with dense, low-threshold gas detection to catch pre-ignition releases (warn ≈0.4% vol H_2, trip ≈1% vol) and auto-boost ventilation. Treat gas + flame as a combined detection system.		Ice/frost can obscure optics; cold plumes may refract sensors. Provide heated/hooded detector heads, keep optics clear of frosting zones, and verify performance during cold operations (precool, bunkering, warm-up)				Flame/gas location depends on temperature and time since release. Place flame and gas sensors high (ceilings, mast tips, overhead recesses) and add low-level gas detectors near LH_2 spill areas/transfer skids. Ensure detector fields of view are not blocked; design in high-level extraction.	Flame/gas location depends on temperature and time since release. Place flame and gas sensors high (ceilings, mast tips, overhead recesses) and add low-level gas detectors near LH_2 spill areas/transfer skids. Ensure detector fields of view are not blocked; design in high-level extraction.	Use of suitable fire detection for hydrogen fires. H_2 flames can be hard (or impossible) to see, with weak IR output compared to hydrocarbons. Use UV or UV/IR flame detectors certified for hydrogen; avoid IR-only. Place at vent masts, PRV tips, bunkering stations, valve boxes, tank rooms, and along likely jet paths. Add CCTV with UV/IR overlay where people work. Do not rely on human sight or thermal feeling.	Jet fires form/propagate fast. Flames establish quickly and can move/upstream if fuel continues. Favour fast-response detectors and short voting delays. Tie flame detection directly to ESD (isolate fuel, purge) and automatic deluge/mist for exposure protection on adjacent equipment.

Safety Function (see main report for definitions)		Principle References in IGF Code	Property										
			Low Energy Density	Flammability / Explosivity	Embrittlement	Low Temp at LH2 Cryogenic storage	Asphyxiation	Expansion ratio $LH_2 \rightarrow CH_2$ ~1:700	Colourless / Odourless	Density relative to air (buoyancy)	Diffusivity	Flame Invisibility	High Laminar Velocity (propensity for DDT)
SF7	Ignition Source Control (inc. hazardous area classification and Ex-rating of equipment etc.)	Section 12		Area classification and associated methodology must reflect properties of hydrogen, including reinforcement of ignition source control measures (portable equipment, smoking etc.). Small releases can ignite from weak sources. Static sparks can be ignition competent. Bonding/grounding of transfer skids, hoses, pipe spools, and vent stacks; use conductive hoses/liners. Limit gas velocities during purging/bunkering to manage charge generation; maintain humidity where applicable. Anti-static flooring and clothing policies in classified areas; no plastic PPE/tools that accumulate charge. Hot equipment or rubbing contacts can ignite. Enforce temperature-class limits on equipment surfaces within zones; shield/insulate hot parts. Specify non-sparking fan designs, certified Ex motors/starters, and alignment/condition monitoring to prevent frictional heating. Tall vent masts and open decks are exposed to lightning and remote ignition.						Gas migrates into recesses and enclosures. Enforce pressurisation/purge (Ex p) for control cabinets in hazardous areas; monitor purge pressure with trips. Ignition sources above leaks (CH_2) or near deck (fresh LH_2 vapour) are critical. Zone high points (ceilings, catwalk undersides) for GH_2; add near-deck zoning around LH_2 transfer/spill areas. Keep air intakes, HVAC, lighting, and motors outside plume extents or Ex-rated where encroachment is possible.		Personnel may not see a nearby ignition source consequence. UV/IR flame detection and low-threshold gas detection drive automatic isolation and ignition-source cut-off. Hard access interlocks (beacons/horns) to keep people/tools out of energised zones during alarms.	Once ignited, flames can travel upstream. Fit flame arresters, non-return valves, and choke orifices at vents and purge/bunkering lines. Interlock fuel isolation (ESD) to close fast-acting valves on gas or flame detection.

Safety Function (see main report for definitions)		Principle References in IGF Code	Property										
			Low Energy Density	Flammability / Explosivity	Embrittlement	Low Temp at LH2 Cryogenic storage	Asphyxiation	Expansion ratio LH_2 → CH_2 ~1:700	Colourless / Odourless	Density relative to air (buoyancy)	Diffusivity	Flame Invisibility	High Laminar Velocity (propensity for DDT)
SF8	Pressure Relief	Section 6.7, 6.9, 10.5		Additional requirements for pressure relief to prevent ignition. Relief discharges can ignite from weak sources; once ignited, flames can be near-invisible. Treat vent tips as hazardous zones; use Ex-rated nearby equipment, bonding/grounding of stacks. High-velocity gas jets can generate charge; vent masts are tall strike points. Bond/ground vent stacks, provide lightning protection, maintain conductive continuity across spools and supports. PRVs and vents for BOG emergency release.		Cold discharge causes icing and oxygen condensation near outlets; materials can embrittle. Use cryogenic-rated materials for PRVs, seats, stems, and stacks; drip/ice shields, heated/insulated sections where needed.		Small LH_2 heat-inleak or spills create large gas volumes and rapid tank pressure rise. Size PRVs/burst disks/BOG systems for credible heat-inleak and upset cases; provide elevated vent masts with unobstructed discharge.		Reliefs produce long, fast plumes that travel and ignite easily. Keep vent lines short, straight, and smooth to limit pressure drop/acceleration	Relief devices may see more frequent low-rate duty (seating wear, weep). Choose metal seats/soft goods compatible with H_2; specify tightness class; schedule functional testing and inspection/overhaul intervals accordingly.		Ignited discharge can drive flames back toward equipment if geometry allows. Place non-return devices, choke orifices, and detonation/deflagration arresters where appropriate

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SF9	Ventilation (HVAC)	Section 13		Even small concentrations are hazardous. Use dense, fast gas detection interlocked to ventilation boost (warn) and ESD + shutdown of non-Ex HVAC (trip). Keep fans/controls Ex-rated where required and located outside hazardous volumes when feasible (ducted extraction from the hazard). Duct interiors should not become ignition sources; fires may be unseen. Use conductive, bonded/grounded metallic ducts, non-sparking (AMCA spark-resistant) fans, and UV/IR flame + gas detection at exhaust points/vent masts with automatic response.		Fresh plumes can pool low before warming; cold surfaces can frost/ice. Provide dual-level detection and the ability to extract both low and high, at least in spill/transfer areas. Heat/insulate vulnerable intakes and keep air inlets upwind/aloft from cryogenic sources.				Location of ventilation to be based on dispersion model and to ensure removal from gas pockets at top of confined spaces.	CH_2 rises and accumulates at high points; small leaks spread quickly. Make dilution ventilation a primary barrier with high-level extraction and low-level make-up air to sweep ceilings/overhead recesses. Eliminate pockets. Verify with calcs/CFD that credible leaks stay <25% LFL at sensors. Treat small, persistent sources as normal design loads. This calls for continuous ventilation (not just emergency) to dilute background emissions; monitor trends on detectors to catch slow drift upward. Cross-contamination risk --> Gas can migrate via shared HVAC. No recirculation from hazardous spaces; dedicated, once-through systems with pressure cascades (hazardous spaces kept negative to safe areas). Fit automatic dampers to isolate zones on alarm.		
SF10	Process Control and Monitoring	Section 15		Generally, parameters and executive actions for process control need to reflect process and fuel properties. Low alarm thresholds and tight permissives (no fuel enable unless H_2 < warn and O_2 < target where inerted). Fast scan rates, short alarm delays. Continuity checks on bonding/grounding; velocity/flow supervision during purges/transfers. Charge control via flow limits and automatic bonding verification permissive before transfer.	Condition monitoring at high-stress/low-temp points (supports, nozzles, welds) via strain/temperature logging and inspection intervals. Operating envelope protection (interlocks on min metal temp/max ΔT, max cycles) and lifetime counters for pressure/thermal cycles.	Continuous temperature, pressure, boil-off rate, and vacuum-annulus monitoring with rate-of-change alarms. Interlocked BOG compressors/consumers, relief status monitoring (position/seat leakage), controlled cooldown/warm-up ramps, and vacuum loss trips with predefined response.				Dual-level sensing (high and low) where LH_2 is present; airflow confirmation at both elevations. Zoned ventilation control (high-point extraction, optional low-level pull near transfer areas)	Treat small leaks as continuous loads; trend H_2 readings for slow creep. Background ventilation control with auto-boost on deviation; annulus/valve-box monitoring; tight bypass management for any detector out of service.	UV or UV/IR flame detection plus fixed H_2 gas detection; automatic proof-testing capability. Use two-tier alarms (warn ≈0.4% vol, trip ≈1% vol), voting tailored for fast actuation (e.g., 1ooN warn, 2ooN trip), and automatic ignition-source cut-off.	Fast detection-to-action timing. High-speed shutoff valves, flame arrester health status in CMMS, and verified purge flows (flow switches/FTs) before enabling fuel.

Safety Function (see main report for definitions)		Principle References in IGF Code	Property										
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SF11	Emergency Shutdown	Sections 5.4, 5.6, 8.5, 9.4, 10.3, 10.4, 10.5, 14.3, 15 Shutdown via SSL described in Sections 8.5.7 and 18.		Generally, parameters and executive actions for ESD need to reflect fuel properties. Process system should be subject to HAZOP. Small leaks can become ignitable very quickly. Two-tier logic (Warn → ESD-1, Trip → ESD-2). On ESD-1: boost ventilation, inhibit starts, de-energise non-Ex loads in zones. On ESD-2: isolate fuel (close fast-acting valves), purge defined volumes, shut non-essential power, and stop transfer/compression. Ignition sources can be created during ESD actions. Bonding/grounding checks as permissives, intake/mast isolation on storm/strike alarms, and no-spark device selection for actuators within zones.		Small heat-inleak or residual liquid can drive rapid pressure rise and cold hazards. Interlocks for BOG management (start consumers/compressors or blow to vent), vacuum-loss trips on double-wall tanks/lines, helium purge permissives for cold transitions, and rate-limited warm-up/cool-down.				Hazardous gas can appear in different elevations. Voting from high-level and low-level gas detectors (in LH_2 areas) to trigger the right ESD tier; auto-close HVAC dampers and shut intakes that intersect dispersion envelopes.	Hazardous gas can appear in different elevations. Integrate dispersion alarms with ESD logic. Voting from high-level and low-level gas detectors (in LH_2 areas) to trigger the right ESD tier; auto-close HVAC dampers and shut intakes that intersect dispersion envelopes.	Humans may not perceive the event. Generally, parameters and executive actions on ESD need to reflect fuel properties. Process system should be subject to HAZOP. Combine UV/IR flame and H_2 gas detection in the cause-and-effect; automated actions (isolation/ventilation/ignition cut-off) without waiting for operator confirmation; access interlocks (beacons/horns, door mag-locks) in alarmed zones.	Once ignited, flames can travel upstream fast. Close-in, fast shutoff valves (fail-closed, spring-return), non-return valves, and automatic blowdown to elevated vent masts where appropriate; inhibit any sequences that could draw flame back (e.g., reverse flows).

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SF12	Active Fire Protection	Sections 11.4 to 11.6		Active fire protection should be suitable for hydrogen fires Training for firefighting needs to reflect specific properties of hydrogen Treat fuel shutoff as the primary "extinguishing agent." Configure AFP to cool and shield while ESD isolates and purges. Avoid "knocking down" a stable vent-tip flame unless the fuel can be stopped—otherwise you create an unignited cloud hazard Water mist/deluge for exposure protection and structure cooling; dry chemical may help at small, localised flames only with confirmed isolation (re-ignition likely). CO_2/inert gas flooding is generally not effective for open areas and poses asphyxiation risk—use only in small, tight enclosures with interlocks, gas-tightness, and O_2 monitoring. Foam has no role for hydrogen (non-pool fuel).		Do not apply water directly to LH_2 pools (accelerates boil-off, icing, and spread). Use AFP to protect exposures and create water curtains only for separation—not onto the cryogen. Keep heated/hooded nozzles and clearances so icing does not disable sprays. Consider O_2 monitoring where LOx enrichment may occur.			Favor flame + gas detection over smoke detection for actuation. Use beacons/horns and access interlocks so crew do not walk into an invisible flame while AFP operates.	Aim cooling sprays and mist curtains to protect up-high exposures (GH_2) and provide low-level mist curtains near LH_2 transfer/spill areas to reduce heat flux to decks and equipment while gas detection/ventilation manage dispersion.		Flame detectors must work on hydrogen's UV/IR flame spectrum. Prioritize water mist/deluge for exposure protection and structural cooling (not "seeing" the flame). Provide CCTV/UV-IR overlays at vent masts and bunkering skids.	Size fixed water mist/deluge rings and remote fire monitors to deliver rapid, uniform cooling to adjacent equipment, cable trays, and structure. Keep short actuation delays and interlock with fast fuel isolation (ESD)—extinguishment without isolation risks re-ignition.

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			Low Energy Density	Flammability / Explosivity	Embrittlement	Low Temp at LH2 Cryogenic storage	Asphyxiation	Expansion ratio $LH_2 \rightarrow CH_2$ ~1:700	Colourless / Odourless	Density relative to air (buoyancy)	Diffusivity	Flame Invisibility	High Laminar Velocity (propensity for DDT)
SF13	Passive Fire and Explosion Protection	Section 11.3		Passive fire and explosion protection requirements to be based on consequence modelling and risk assessment. Favor layout and segregation: cofferdams, fire divisions, and standoff distances that keep equipment and escapes outside credible flame/explosion envelopes. Use non-combustible materials and cable/passive firestops to prevent fire spread through penetrations. Provide bonding/grounding and lightning protection on tall metallic structures (vent masts/blast walls) so passive features do not become ignition sites during a release.		Use cryogenic-rated insulation and cold shields, secondary containment/drip trays that do not confine vapour, and materials with toughness at cryogenic temps. Keep organics away from cold zones to avoid LOx-enriched fire risks; design decks/scuppers so ice does not block passive relief paths.				Shape enclosures and shelters to prevent gas pockets (no overhead traps) and add high-level passive openings to relieve gas build-up aloft; near cryogenic operations, ensure deck-level openings/shields so cold plumes do not accumulate in recesses.	Treat background releases as a design load: open architecture, permanently ventilated valve boxes with passive high-level outlets, and double barriers/secondary enclosures that fail safe to atmosphere.	Size structural fire protection (intumescent/insulation, fireproofing of supports, cable trays, and penetrations) by calculated jet-fire/heat-flux rather than visual cues. Provide thermal shields between hazard sources and critical structure.	Include PFP and barrier design loads on bulkheads for jet fires. Verification of PFP material performance under hydrogen jet flame temperatures (>2,000 °C). Minimize congestion and confinement (short valve boxes, smooth internals, open structures). Where confinement is unavoidable, provide low-mass explosion relief (vents/panels/rupture membranes) with directed, unobstructed discharge away from people and intakes; avoid long tortuous vent ducts that boost overpressure.
SF14	Emergency Response (includes muster, escape and rescue and environmental response)	Section 6.2 refers to availability of systems following loss of fuel containment. Section 17 covers drills and exercises.	Locations and arrangements to be based on consequence modelling and risk assessment results, so that muster stations, escape routes and LSA are available following a hazardous event. Emergency response plans, training and emergency plans to be based on the specific hazard.										
SF15	Personal Protective Equipment (PPE)			Antistatic garments, conductive footwear, and bonding/grounding straps for personnel during transfer/bunkering. No plastic combs, tapes, or non-conductive tools that can hold charge. Intrinsically safe (Ex) portable electronics only.		Cryogenic gloves (loose cuff for quick release), full face shield over safety goggles, cryogenic apron and splash-covering outerwear, long pants over the boot tops (not tucked in). No water onto LH_2 spills; keep organic fabrics away from LOx-frosted areas; de-ice passively—do not pry or splash.	SCBA for entries into suspect or alarmed spaces; no cartridge respirators. O_2 monitor on the entrant and the attendant; enforce entry permits and continuous gas checks.		Personal clip-on H_2 detectors (and O_2 monitors when inerting is possible) assigned per person in classified areas; mandatory bump-test policy before use. Helmet-mounted lights are not a substitute for detection.		Ensure no tight cuffs/seals that can trap cold liquid	PPEs used should be flame resistant and suitable for hot-surface exposure.	
	Collision Protection	Generally covered by Section 5.3 and 6.4 and various requirements for different areas.	Because hydrogen forms ignitable clouds easily, rises fast (but LH_2 can start heavy), expands ~700× on warm-up, and can jet violently from high-pressure storage with an invisible flame, collision protection must combine inboard/double-hull placement, crashworthy guards, immediate isolation at the source, high-mast venting, pocket-free open geometry, dual-elevation detection in LH_2 areas, and bonded H_2-compatible hardware—so any breach is contained, directed aloft, and isolated quickly, keeping people, intakes, and ignition sources out of harm's way.										