Table 4 — Minimum periodic hydrogen fuelling station inspection and test checklist

No.	Content/Requirement	Requirement value	Reference to ISO 19880-1 (clause)	Pass/ Fail	Link to other standards/ Remarks
	Work permit (to assess risk and safety measures required)		5.3.5.2, 15.5		Per local authority (grinding/ welding)
	Good housekeeping				
	Maintenance log up to date				
	— sensor calibration				
	— leakage test				
	— PRD within calibration date				
	— Hose within date				
	Dispensed hydrogen quality test report	ISO 14687, Grade D	12.6, 9		ISO 14687 and ISO 19880-8
	Dispensing system fuelling protocol	Per applicable standard	12.5.3 (1) 8.2		SAE J2601
	Dispensing system fuelling limit test	Per applicable standard	12.5.3 (2) 8.2		SAE J2601
	Vehicle to dispenser communications	Per applicable standard	12.5.3 (3) 8.2		SAE J 2799 and SAE J 2601
	Verify emergency and safety functions	100 %	5.3, 12.5, 14.8		
	Verify emergency communications according to the risk assessment.	100 %	13.8		Test communications with emergency responders

15.2 Maintenance and testing frequency of gas detection

The gas detection system shall be maintained in accordance with the service requirements of the manufacturer. The service frequency shall be once per year as a minimum, or more often if so specified by the manufacturer.

Maintenance shall be performed by trained persons.

The following periodic maintenance actions shall be performed as a minimum:

— each gas detector shall be calibrated with a certified gas mixture;

— the entire system shall be checked for the desired settings;

— an overall function test shall be performed including the associated actions (see 11.2);

— an operation test shall be performed.

Special attention shall be given to detectors that are in an environment where pollution is influencing the operation, or detectors that are exposed to substances which reduce the lifetime of the detector.

All maintenance operations shall be recorded in a fuelling station log.

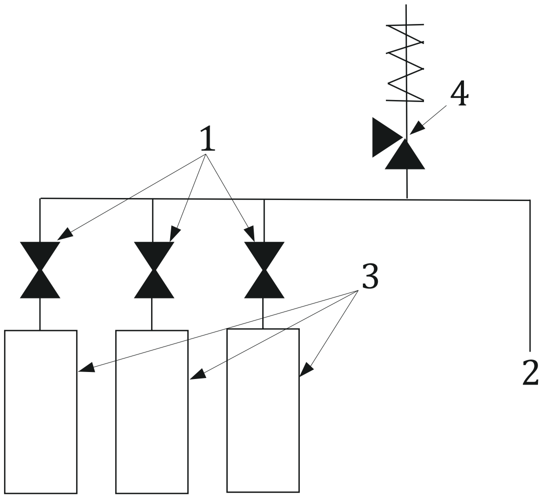
15.3 Maintenance and inspection frequency of filters

Filters for particulates and other possible fuel contaminants and operating debris (e.g. seal, gasket, desiccant materials) shall be inspected and replaced at a regular interval, according to the manufacturer's specifications. The pressure drop across dispensing system filters shall not exceed that required by the fuelling protocol, see 8.3.2.

15.4 Maintenance of pressure relief devices

Pressure safety equipment shall be inspected and either repaired or replaced at a regular interval, according to the manufacturer's specifications.

During maintenance, isolation of pressure relieving safety accessories from the equipment which it is designed to protect should only be permitted if the source of pressure, which could lead to an unsafe condition, is simultaneously isolated from the equipment with the pressure relief device. A typical arrangement is shown in Figure 3.



Key

1 isolating valves

2 pressure source

3 pressure vessel(s)

4 safety valve(s)

NOTE This figure is reproduced from EN 764-7: 2002.

Figure 3 — Illustration of one method of simultaneous isolation

Prior to isolation the continued need to protect against external sources of overpressure such as solar radiation and fire should be addressed.

15.5 Hot work

Maintenance operations requiring the generation of an ignition source within the restriction distances while the installation is in operation or pressurized with hydrogen should only be performed in case of service necessity and the atmosphere in the work area should be continuously analysed using a portable, transportable or, if applicable, fixed, hydrogen detector. Welding and grinding should be done with the utmost care. Hydrogen pipes and equipment should be protected from welding and grinding sparks by suitable protection devices such as welding/fire blankets. Such maintenance operations should be covered by a risk assessment, with specific attention to explosion and fire risks, in which all the measures necessary for ensuring safety are pre-defined.

15.6 Modifications to the hydrogen fuelling station and associated equipment

All modifications shall be assessed for impact on process safety and follow a management of change process.

Annex A
(informative)

Safety methodologies and risk assessment

A.1 General

The requirements for permitting (as applicable) and/or the justification for the safe design of a hydrogen fuelling station differ from country to country. In some countries/regions, specific hydrogen fuelling station regulations, codes or guidance documents exist, typically detailing prescriptive requirements or recommendations to be followed in the design, installation or operation of a fuelling station. A non-comprehensive list of examples is included in A.2.

Alternatively, the justification for the safe design of a station can utilise the process of risk assessment. A.3 to A.6 provide guidance on quantitative or semi-quantitative risk assessment for hydrogen fuelling stations in the specific context of informing site specific considerations to be taken.

A.2 Regional specific permitting guidance

A.2.1 Example of existing guidance

The following are regional specific permitting guides giving guidance on safety for hydrogen fuelling stations, typically using prescriptive methods:

1) Californian GO-Biz Hydrogen Permitting Station Guidebook:

   http://business.ca.gov/Programs/Permits/HydrogenStationPermitting.aspx

2) NOW Approval Guidelines for Hydrogen Refuelling Stations:

   http://www.h2-genehmigung.de/Index/Index?lang=1

3) NREL: Regulations, Codes, and Standards (RCS) Template for California Hydrogen Dispensing Stations

   http://www.hydrogen.energy.gov/permitting/stations_related.cfm

A.2.2 Example safety distances from each country/region

ISO maintenance portal URN (https://standards.iso.org/iso/19880/-1/ed-1/en) includes a table of examples of safety distances collected by ISO/TC 197, through country representative members during the preparation of ISO/TS 19880-1, which conveys a status of country specific safety distances at that the time of publication of the ISO/TS 19880-1 (2016). It demonstrates the wide range of results that can be found for similar equipment in similar environments around the world.

This table was not an inclusive list of values internationally and is not meant to be a recommendation for these applications.

A.3 Methodology for semi-quantitative and quantitative risk assessment for assessing hydrogen installation safety

A.3.1 General

It may be possible to use quantitative risk assessment (QRA) and/or semi-quantitative (e.g., consequence-only) analysis instead of prescriptive requirements to allow the hydrogen fuelling station to use alternative methods which are of an equivalent, or higher, level of safety to the prescriptive requirements. Using QRA may allow (for instance using mitigation measures) for shorter safety distances and/or simplified station layout.

If QRA is used, this subclause provides recommendations for performing that analysis. This analysis focuses on hazards involved with the release and ignition of hydrogen mixtures and related physical effects. This does not cover non-hydrogen hazards associated with the fuelling station, see 5.5.

Developing an approach to protect against harm should consider the following factors:

— nature of the hazards (e.g., thermal, pressure, potential for asphyxiation, etc.);

— behaviour of hydrogen under the design and operating conditions;

— equipment design and operating conditions;

— installation design and location, including protection measures;

— targets (e.g., person, property, equipment) which are being protected from effects of potential hazards.

A semi-quantitative risk assessment provides an intermediary level between the textual evaluations of qualitative risk assessment and the numerical evaluation of quantitative risk assessment, by evaluating risks with a score. Semi-quantitative risk assessment provides a structured way to rank risks according to their probability, severity, or both (criticality), and for ranking risk reduction actions for their effectiveness. This is achieved through a predefined scoring system that allows one to map a perceived risk into a category, where there is a logical and explicit hierarchy between categories. Semi-quantitative risk assessment is generally used where one is attempting to optimize the allocation of available resources to minimise the impact of a group of risks.

It helps achieve this in two ways:

— first, the risks can be placed onto a sort of map so that the most important risks can be separated from the less important;

— second, by comparing the total score for one or a series of risks before and after any proposed risk reduction measures, one can get a feel for how relatively effective the mitigation strategies are and whether they merit their costs.

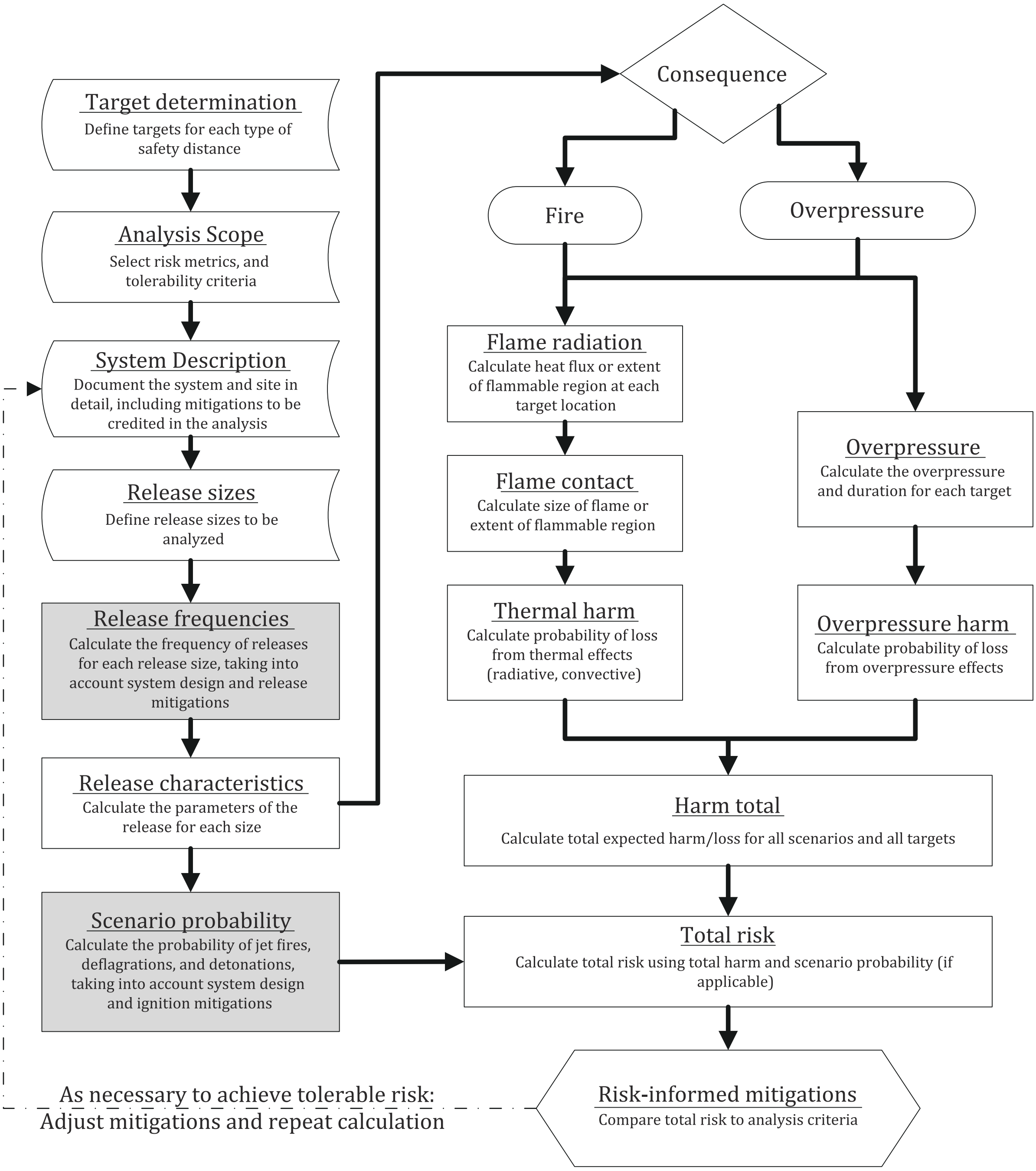
For performing a semi-quantitative risk assessment, a full mathematical model is not always needed. It could sometimes offer the advantage of being able to evaluate a larger number of different kind of risk issues in a limited time. Nonetheless, all forms of risk assessment require the greatest possible collection and evaluation of data available on the risk issue.

A.3.2 Summary of methodology

Risk assessment provides a framework to establish a common understanding of the system safety level based on robust science and engineering models. The process enables transparent, evidence-based safety decisions. The QRA approach uses a combination of probabilistic and deterministic models to evaluate potential consequences on the targets identified in the previous section. Risk is characterized by a set of hazard exposure scenarios, the causes associated with each scenario, the undesirable consequences associated with the scenario, and uncertainty about these elements (this uncertainty is generally expressed by probability). In consequence-only modelling, the probability term is ignored, but the remainder of the analysis follows the same methodology.

The process for risk-informing mitigations includes the following steps, as displayed in Figure A.1:

- Target determination– Define the targets being protected, and as necessary, the hazard sources.
- Table A.2 provides many examples of targets.
- Analysis scoping – Select appropriate risk type for each target and establish tolerability criteria (e.g., acceptable/unacceptable risk level) for each target.
- System description – Document the system and installation being analysed, including mitigations to be credited in the analysis and which events they mitigate (see 5.1).
- Cause analysis – Identify and model the hazard scenarios and quantify the probability of each scenario in the model for each source and target.
- Consequence analysis – Identify the physical effects for each scenario, and quantify the impact of those effects on the targets.
- Risk assessment – Integrate the cause and consequence models into an assessment of the total risk; Perform sensitivity studies and changing modelling assumptions to identify appropriate combination of mitigation elements to maintain risk level within the tolerability region.
- Risk-informed mitigations – Increase or reduce mitigations to achieve risk level within tolerability region (including consideration of uncertainty).



NOTE 1 Grey shading denotes an analysis step that is used only in full-QRA approach.

NOTE 2 Concave rectangle denotes an analysis step.

NOTE 3 Rectangle denotes a calculation step.

NOTE 4 Diamond denotes branching.

Figure A.1 — Example of a risk-informed approach to safety distances

A.3.3 Analysis scoping

A.3.3.1 Target determination

Each characterisation of safety distance in Table A.1 affects one or more classes of target. Table A.3 provides many examples of targets for each type of safety distance. It is presupposed that types of safety distance are defined according to national requirements/guidance, with appropriate targets and hazards sources defined for each type of safety distance. Table A.2 provides examples of sources for the different types of safety distance.

A.3.3.2 Hazards

A.3.3.2.1 General

The primary hazards related to the use of hydrogen are the release and subsequent ignition of hydrogen. The two main hazards are thermal effects (e.g. conduction or radiation from hydrogen flames or post flame gases) and blast effects (overpressure and impulse) from deflagrations and detonations. Both of these hazards should be modelled for all sources and all targets.

A.3.3.2.2 Hazard distance

Hazard distance is a distance from the (source of) hazard to a determined (by physical or numerical modelling, or by a regulation) physical effect value (normally, thermal or pressure) that may lead to a harm condition (ranging from "no harm" to "max harm") to people, equipment, or environment.

The calculation of hazard distances is deterministic based on a predetermined scenario (for example, a leak flow rate considered as most likely scenario or in some cases the worst-case scenario). Which means that hazard distances do not consider the probability of a hazardous event occurring. Hence, the direct use of hazard distances may lead to restriction of activities over large areas.

Thus, for practical applications, hazard distances should be used as an input to risk informed safety distances that employ both deterministic and/or probabilistic components of the QRA methodology. The probabilistic method should not underplay or underestimate the potential hazards, but take into account most scenarios, including those with a low probability of a hazardous event occurring as well as available means of protection, detection, and isolation to generate safety distances corresponding to an acceptable risk level.

A.3.3.3 Risk and harm criteria and tolerability limit selection

Risk and harm criteria are established through close interactions with stakeholders, which may include detailed surveys of existing risk benchmarks. A best practice is to ensure that risk from hydrogen fuelling should be equal to or less than the risk posed by similar activities, which could include gasoline fuelling, occupational accidents, general accident rates within the population, etc.

For personnel risk, including workers and/or members of the general public, four widely used fatality risk criteria are:

— FAR (fatal accident rate) – the number of fatalities per 100 million exposed hours;

— AIR (average individual risk) or individual risk per annum - the individual risk averaged over the population which is exposed to risk from the facility;

— PLL (potential loss of life) – the average number of fatalities (per system-year);

— F-N curves representing the expected frequency at which N or more people will be exposed to a fatal hazard (cumulative distribution function). Such curves may be used to express societal risk criteria.

Other criteria may be used, such as:

— average number of hydrogen releases per system-year;

— average number of jet fires per system-year;

— average number of deflagrations/detonations per system-year.

Consequence-based harm or damage criteria may be used, such as:

— heat flux level;

— thermal dose;

— flame temperature;

— flame length;

— peak overpressure;

— gas concentration;

— fluid temperature.

Acceptance criteria should be specified. These may be specified in terms of single values, acceptance bounds or distributions, use of ALARP (as low as reasonably practicable), option comparison, etc.

Due to the complexity and uncertainties involved in predicting performance in engineered systems, there will always be a level of subjectivity attached to any risk assessment result. This uncertainty should be considered when selecting risk and harm criteria and tolerability limits.

A.3.3.4 System description

The analysis should contain documentation of the installation and operational environments (as-built and as-operated). Documentation should contain sufficient detail to allow replication by an independent expert.

The documentation should define and identify the system, and components, their functions, and their relationships and interfaces. Block diagrams, P&IDs, and other figures should be included to facilitate understanding of the boundaries of the system, components of the system, and functions of each component in each operational environment. Installation characteristics should be described, including expected use conditions and layout diagrams. Expected operating parameters/states of hydrogen in the system should be documented.

The scope of work should capture and define the work activities and intended applications. If multiple operational environments are contained in one analysis, the work activities should be defined for each operational environment.

A.3.3.5 Cause analysis

A.3.3.5.1 General

The goal of cause analysis is to provide insight into the causes of hazardous exposures and the likelihood of those causes. This involves creating models that describe the scenarios that occur after a release of hydrogen, and quantifying these models using probability information.

A.3.3.5.2 Exposure scenarios

At a minimum, exposure scenarios should contain the following elements:

— Release of hydrogen. Release sizes that are to be modelled should be defined based on national requirements or guidance.

— Occurrence of ignition. At a minimum, ignition should be sub-divided into immediate and delayed ignition.

— Jet fires, deflagrations/detonations.

Root causes of releases should be identified qualitatively. Use of root cause information in quantification is optional. Root causes should include:

— leaks from individual components, including separation of a component or unintended operation;

— shutdown failures;

— accidents, including collisions and drive-offs;

— human errors.

Scenario and root cause models may also include:

— leak detection systems;

— system isolation;

— more detailed bifurcations of "ignition".

For QRA, exposure scenario fault expressions may be documented graphically, e.g. in Event Trees or Event Sequences Diagrams, or fault expressions can be manually specified. Root causes may be given as a list, or documented graphically, e.g. in Fault Trees, or through fault expressions.

A.3.3.5.3 Data for scenario quantification

Data used should be of sufficient quality to support decision making. Sources of data should be documented in the analysis.

Analysts should use published, hydrogen-specific data if it is available.

Non-published, hydrogen-specific data, such as proprietary company-specific data, may be used. If such data are used, it is presupposed that the data are documented and made available to the regulatory body or designated reviewer if requested. The designated reviewer should give extra scrutiny on inputs that lower probabilities below commonly used data sources.

In lieu of hydrogen-specific data, commonly accepted, published data sources (for example; OREDA, ESReDA, AiCHE API 521 or Sandia Laboratories H2 data) from similar industries and applications should be used.

A.3.3.6 Consequence analysis

A.3.3.6.1 General

This involves determining the physical effects of the scenarios, as well as the target response to those physical effects.

A.3.3.6.2 Physical effects of the accidents

The physical effects of hydrogen fires which should be modelled for a target are 1) thermal effects and 2) pressure effects. The primary physical effects relevant to ignited hydrogen releases are fire effects (for example; impinging flames, high temperature, heat flux) and explosions.

NOTE Debris effects (e.g., from over-pressurization of hydrogen vessel) are not required to be modelled.

Modelling of these required physical effects requires modelling several physical processes: release, jet flames, and deflagrations and detonations.

The physical models used should be validated for use in on hydrogen within the parameter ranges expected in the fuelling installation or specific equipment.

A.3.3.6.3 Hydrogen release characteristics

The first step in characterizing consequences is to characterize the release of hydrogen and the extent of the flammable envelope. Thermodynamic parameters of releases from high-pressure hydrogen systems can be estimated using notional nozzle models. The selected model should be validated for use in high-pressure hydrogen systems within the parameter ranges expected in the fuelling installation or specific equipment. The selected model should be specified in the analysis documentation.

A.3.3.6.4 Ignition sources

The source of ignition for an installation or the process itself should be examined. A non-comprehensive list of examples is as follows:

— lightning;

— static electricity (including clothing);

— mechanical sparks (for example; moving parts, tools not suitable for explosive atmospheres);

— naked flames;

— hot surfaces (for example; overheating by adiabatic compression);

— electrical components and installations (for example; electric sparks);

— exposed live cables.

A.3.3.6.5 Jet flame behaviour

Releases from high-pressure hydrogen systems that are ignited immediately produce momentum driven jet flames. A validated hydrogen model should be used to predict the characteristics of a jet flame necessary to meet the goals of the analysis. The selected characteristic(s) should be specified in the analysis documentation. Characteristics relevant to the goals of the analysis may include flame length, flame width, or heat flux. The position at which these characteristics are calculated should be specified in the analysis.

A.3.3.6.6 Deflagration and detonation behaviour

Releases from hydrogen systems which are not immediately ignited may accumulate and result in a flash fires or explosions.

Thermal and overpressure effects created from hydrogen deflagration or detonation can vary significantly based on the scenario.

The least significant is a flash fire when the cloud is ignited in its extremity (regions below 10 % of hydrogen). Flash fires result in thermal effects with very small overpressure.

When the cloud is important and ignition near the central stoichiometric region, the overpressure effects (and associated impulse) produced could be more important.

The turbulence in the hydrogen release, and/or the presence of objects, and/or release in a confined space can potentially result in an increase of the overpressure generated.

Blast effects may be modelled using validated software code based on computational fluids dynamics (CFD), empirical or phenomenological methods.

NOTE An example can be found in NORSOK Z013, Annex G.

A.3.3.7 Harm models

A harm or damage model or criteria is used to translate the physical effects into the harm to a person, a component, or structure. This should be done through use of either a model or criteria, including single criteria, deterministic models, probability models, probit functions. The selected criteria or model may come from reference to establish scientific information or national standard. The selected model or criteria should be specified in the analysis documentation.

A.3.3.8 Risk calculation

Some forms of risk assessment calculate risk for multiple individual scenarios and some use one calculation of risk for multiple scenarios.

When the total risk for the system is required, this should be calculated by combining the results of the scenario (cause) analysis and the consequence analysis into the total.

Risk is expressed as follows:

$$R = \sum_n (f_\mathrm{n} * c_n)$$

where

R is summed risk over all n selected scenarios;

f_n is the frequency of scenario n;

c_n is the consequence for scenario n.

Risk may be calculated separately for each type of consequence (e.g., harm, loss).

In all cases, a combination of risk analysis and consequence-only analysis may be used. For example, a regulatory body can ask for a consequence-only analysis for additional specific scenarios and can ask for a total risk analysis to include additional scenarios.

A.3.3.9 Risk-informed mitigations

The estimated risk level should be compared to the risk acceptance criteria.

If the estimated risk level is above the acceptance criteria, the analyst should implement additional mitigations or increase safety distances to reduce the risk level, and re-run the analysis.

If the estimated risk level is below the acceptance criteria, the mitigations or safety distance may be reduced.

Analysts should consider and discuss appropriate methods to account for uncertainty when comparing to risk criteria. This should be addressed through use of conservative risk criteria, or sensitivity analysis or methods to propagate uncertainties.