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How to use RAPID-N

Methodology, models, technical information and tutorials

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Abstract

RAPID-N is a web-based system for analysing and mapping the risk of natural hazard impacts on industrial sites, also referred to as Natech risk. The system has been developed and is hosted by the European Commission Joint Research Centre (JRC) in response to stakeholder requests to support the systematic analysis of Natech risk. Since such multi-hazard risk analysis is very complex, comprehensive RAPID-N user guides were released in 2012 and 2018, describing the features of the system in detail and providing simple step-by-step guidance on how to use the system.

This document complements and expands on the existing user guides by providing detailed information on the consequence models implemented in RAPID-N. Moreover, it features supplementary tutorials that guide users through different Natech risk analysis case studies with increasing complexity. This guidance document also explains how to activate a new RAPID-N functionality that enables Natech consequence analysis using the calculation libraries of ADAM, a sophisticated consequence analysis system also developed by the JRC.

1 Introduction

The impact of natural hazards on industrial plants, pipelines, offshore platforms and other infrastructure that handles, stores or transports hazardous substances can cause secondary effects, such as fires, explosions, and toxic or radioactive releases (Showalter and Myers, 1994). These so-called Natech accidents are a recurring but often overlooked feature in many natural disasters and have often had significant human, environmental and economic impacts (Krausmann et al., 2017). Successfully controlling Natech risk is usually a major challenge, which requires targeted prevention, preparedness and response. The systematic analysis of Natech risk is a prerequisite for this purpose (Krausmann and Baranzini, 2012).

In order to support such analyses, the European Commission Joint Research Centre (JRC) has developed and maintains the RAPID-N system for the analysis and mapping of accident risks at industrial plants due to natural hazard impacts (Girgin and Krausmann, 2013a). RAPID-N is an online system that has been operational since 2012. It is publicly available at https://rapidn.jrc.ec.europa.eu.

RAPID-N is a unique tool that incorporates all functionalities needed for Natech risk analysis. Since such multi-hazard risk analysis is very complex and data intensive, RAPID-N is equipped for automatic data insertion. It features a property estimation framework that was designed to aid users and to help them carry out their risk analysis with the minimum amount of input required (Girgin and Necci, 2018). This feature is the main strength of the system and provides the flexibility needed to accommodate a wide range of different input data, related to both industrial installations and natural hazards. This process is based on a sophisticated set of equations and tables that allows to calculate (or estimate) all the missing information needed to run the analysis. While this constitutes a trade-off between data availability and accuracy, it provides an opportunity to carry out an analysis, even if with lower accuracy than had the user provided detailed data.

Comprehensive RAPID-N user guides were already released in 2012 and 2018, describing the features of the system in detail and providing simple cases and step-by-step guidance on how to use RAPID-N (Girgin, 2012; Girgin and Necci 2018). This guide for RAPID-N users is meant to complement and expand the existing RAPID-N manual and user guide, providing additional information on the technical background of the models used and further tutorials. This document guides RAPID-N users through different Natech risk analysis case studies with an increasing level of complexity. It includes simple cases with a few simple input parameters, to very detailed analyses with many input parameters for a customised risk analysis. In addition, the guide provides indications to users on how to interpret the RAPID-N risk analysis reports. Finally, the guide demonstrates how to activate a new RAPID-N functionality that allows Natech consequence analysis using the calculation libraries of ADAM, a sophisticated consequence analysis system also developed by the JRC.

2 RAPID-N

RAPID-N is an online, collaborative system for the analysis and mapping of accident risks at industrial plants due to natural hazard impacts developed by the JRC (Girgin and Krausmann, 2013a). The system has been operational since 2012 and is publicly available at https://rapidn.jrc.ec.europa.eu. The framework of the system has been implemented to accept any type of natural hazard. However, due to data availability RAPID-N is currently focused on the impacts of earthquakes on hazardous industrial plants (Girgin and Krausmann, 2012; 2013b). Extensions to also cover flood hazards as triggers (Girgin, 2016; 2017) and hazardous liquid transmission pipelines as targets (Girgin and Krausmann, 2016) were also explored. For both application areas prototype systems were developed and tested. These prototypes are, however, still under development.

The primary aim of RAPID-N is rapid local (e.g., single plant) or regional (e.g., multiple plants distributed over a large geographical area) Natech risk analysis with minimum data requirements. Competent authorities can use RAPID-N to support land-use or emergency planning by analysing the potential consequences of different Natech scenarios. RAPID-N can also assist natural disaster response activities by quickly identifying hazardous installations where Natech accidents might have occurred, so that first responders and the population in the vicinity of the plants can receive timely warning.

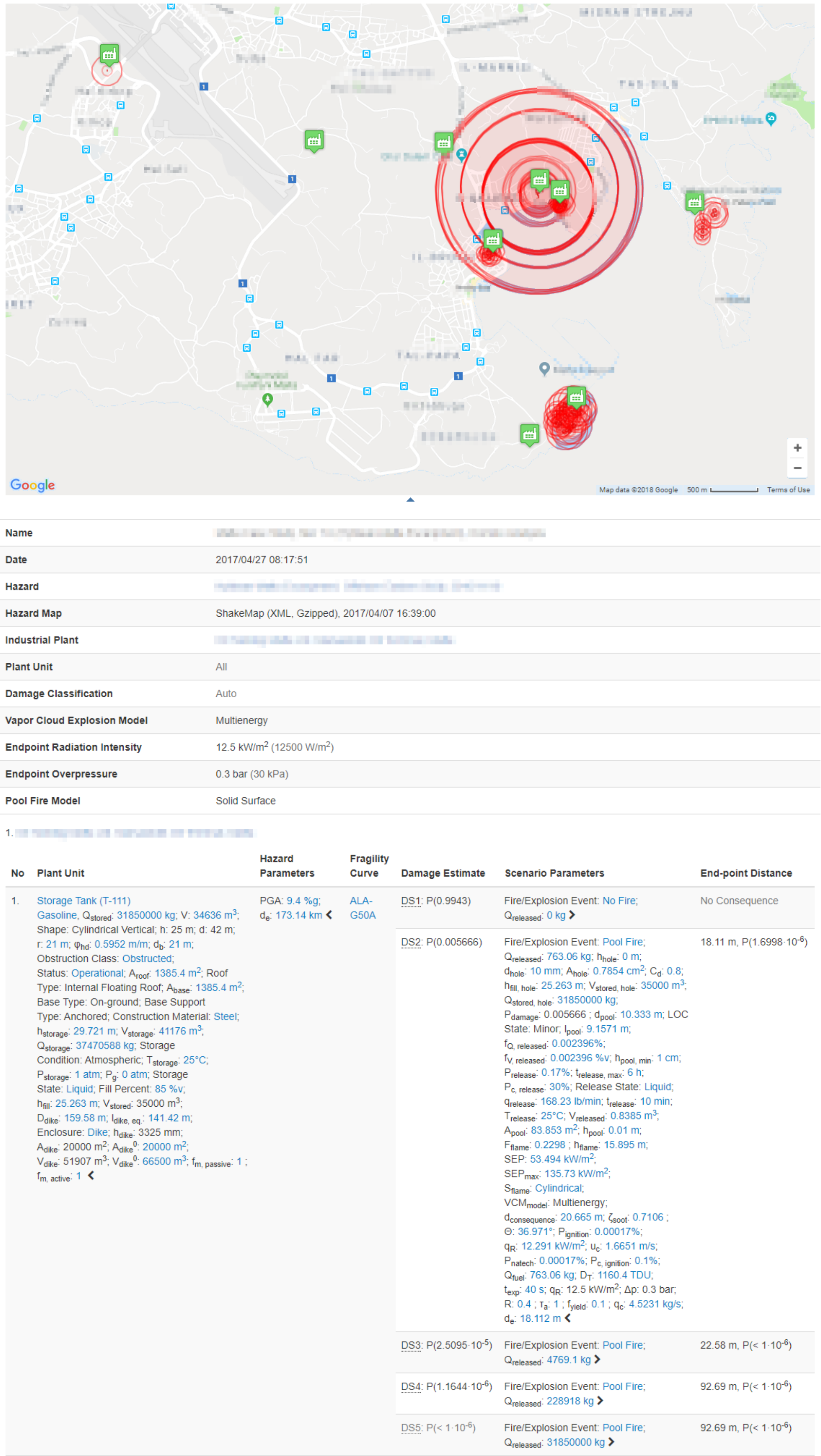
RAPID-N calculates natural hazard severity parameters at the industrial installations either by using pre-calculated on-site hazard data, such as shake maps and hazard maps, or by utilizing hazard-specific data estimation functions. Natural hazard impacts are evaluated separately for each industrial equipment, called plant unit, and the possible damage scenarios and corresponding occurrence probabilities are determined. For each damage scenario, case-specific Natech accident scenarios are generated by using appropriate risk states, which relate damage scenarios to consequence scenarios. The consequences are analysed by using the available consequence models (Girgin and Krausmann, 2013a). The results are presented as risk reports and interactive risk maps showing impact zones and their occurrence probabilities. An example Natech risk analysis report and risk map is presented in Figure 1.

RAPID-N does not contain any pre-defined, hard-coded models for the analysis. For each Natech scenario, a customised model for risk analysis is created by using the individual model equations available in the system, considering the available input data and the validity conditions of the equations. A standard set of model equations is available to all users. However, the users can also define their own input data and equations to customise the calculations according to their needs.

In order to preserve confidentiality, RAPID-N supports data access restrictions for critical information, such as industrial plant and risk analysis data. User registration is needed for data entry, and further authorisation is required for carrying out Natech risk analyses. RAPID-N features an open-model approach, in which all equations and methods needed for the analysis are fully documented and directly accessible from the analysis reports. Besides obtaining the values of the analysis parameters, the users can also easily follow how each parameter is calculated, access the associated algorithms, and view related bibliographic references (Girgin, 2012; Girgin and Necci, 2018).

In addition, RAPID-N has data extraction and importing capabilities which are used to keep track of recent natural hazard events (e.g., earthquakes) and to obtain and harmonize data automatically for Natech risk analysis. The system monitors online natural hazard data feeds from the U.S. Geological Survey (USGS) and the European-Mediterranean Seismological Centre (EMSC) in near real-time and collects information on recent events. Currently, the natural hazard database of RAPID-N contains information on more than 26,000 earthquakes and about 17,000 earthquake shake maps.

Figure 1. Example risk analysis performed with RAPID-N.



Name	[redacted]
Date	2017/04/27 08:17:51
Hazard	[redacted]
Hazard Map	ShakeMap (XML, Gzipped), 2017/04/07 16:39:00
Industrial Plant	[redacted]
Plant Unit	All
Damage Classification	Auto
Vapor Cloud Explosion Model	Multienergy
Endpoint Radiation Intensity	12.5 kW/m^2 (12500 W/m^2)
Endpoint Overpressure	0.3 bar (30 kPa)
Pool Fire Model	Solid Surface

1. [redacted]

No	**Plant Unit**	**Hazard Parameters**	**Fragility Curve**	**Damage Estimate**	**Scenario Parameters**	**End-point Distance**
1.	Storage Tank (T-111) Gasoline, Q_{stored}: 31850000 kg; V: 34636 m^3; Shape: Cylindrical Vertical; h: 25 m; d: 42 m; r: 21 m; φ_{hd}: 0.5952 m/m; d_b: 21 m; Obstruction Class: Obstructed; Status: Operational; A_{roof}: 1385.4 m^2; Roof Type: Internal Floating Roof; A_{base}: 1385.4 m^2; Base Type: On-ground; Base Support Type: Anchored; Construction Material: Steel; $h_{storage}$: 29.721 m; $V_{storage}$: 41176 m^3; $Q_{storage}$: 37470588 kg; Storage Condition: Atmospheric; $T_{storage}$: 25°C; $P_{storage}$: 1 atm; P_g: 0 atm; Storage State: Liquid; Fill Percent: 85 %v; h_{fill}: 25.263 m; V_{stored}: 35000 m^3; D_{dike}: 159.58 m; $l_{dike, eq.}$: 141.42 m; Enclosure: Dike; h_{dike}: 3325 mm; A_{dike}: 20000 m^2; $A_{dike}{}^0$: 20000 m^2; V_{dike}: 51907 m^3; $V_{dike}{}^0$: 66500 m^3; $f_{m, passive}$: 1 ; $f_{m, active}$: 1 ‹	PGA: 9.4 %g; d_e: 173.14 km ‹	ALA-G50A	DS1: P(0.9943)	Fire/Explosion Event: No Fire; $Q_{released}$: 0 kg ›	No Consequence
				DS2: P(0.005666)	Fire/Explosion Event: Pool Fire; $Q_{released}$: 763.06 kg; h_{hole}: 0 m; d_{hole}: 10 mm; A_{hole}: 0.7854 cm^2; C_d: 0.8; $h_{fill, hole}$: 25.263 m; $V_{stored, hole}$: 35000 m^3; $Q_{stored, hole}$: 31850000 kg; P_{damage}: 0.005666 ; d_{pool}: 10.333 m; LOC State: Minor; l_{pool}: 9.1571 m; $f_{Q, released}$: 0.002396%; $f_{V, released}$: 0.002396 %v; $h_{pool, min}$: 1 cm; $P_{release}$: 0.17%; $t_{release, max}$: 6 h; $P_{c, release}$: 30%; Release State: Liquid; $q_{release}$: 168.23 lb/min; $t_{release}$: 10 min; $T_{release}$: 25°C; $V_{released}$: 0.8385 m^3; A_{pool}: 83.853 m^2; h_{pool}: 0.01 m; F_{flame}: 0.2298 ; h_{flame}: 15.895 m; SEP: 53.494 kW/m^2; SEP_{max}: 135.73 kW/m^2; S_{flame}: Cylindrical; VCM_{model}: Multienergy; $d_{consequence}$: 20.665 m; ζ_{soot}: 0.7106 ; Θ: 36.971°; $P_{ignition}$: 0.00017%; q_R: 12.291 kW/m^2; u_c: 1.6651 m/s; P_{natech}: 0.00017%; $P_{c, ignition}$: 0.1%; Q_{fuel}: 763.06 kg; D_T: 1160.4 TDU; t_{exp}: 40 s; q_R: 12.5 kW/m^2; Δp: 0.3 bar; R: 0.4 ; τ_a: 1 ; f_{yield}: 0.1 ; q_c: 4.5231 kg/s; d_e: 18.112 m ‹	18.11 m, P($1.6998 \cdot 10^{-6}$)
				DS3: P($2.5095 \cdot 10^{-5}$)	Fire/Explosion Event: Pool Fire; $Q_{released}$: 4769.1 kg ›	22.58 m, P($< 1 \cdot 10^{-6}$)
				DS4: P($1.1644 \cdot 10^{-6}$)	Fire/Explosion Event: Pool Fire; $Q_{released}$: 228918 kg ›	92.69 m, P($< 1 \cdot 10^{-6}$)
				DS5: P($< 1 \cdot 10^{-6}$)	Fire/Explosion Event: Pool Fire; $Q_{released}$: 31850000 kg ›	92.69 m, P($< 1 \cdot 10^{-6}$)

3 Natech risk analysis

The existence of toxic, flammable, or explosive materials is one of the main hazards at industrial installations and creates a risk of a major accident. Accidents usually begin with the loss of containment of one or more such hazardous materials. The analysis of Natech scenarios aims to identify the severity and consequences of accidents which may affect the population, assets and the environment, and which are usually more severe as the amount of hazardous materials involved increases.

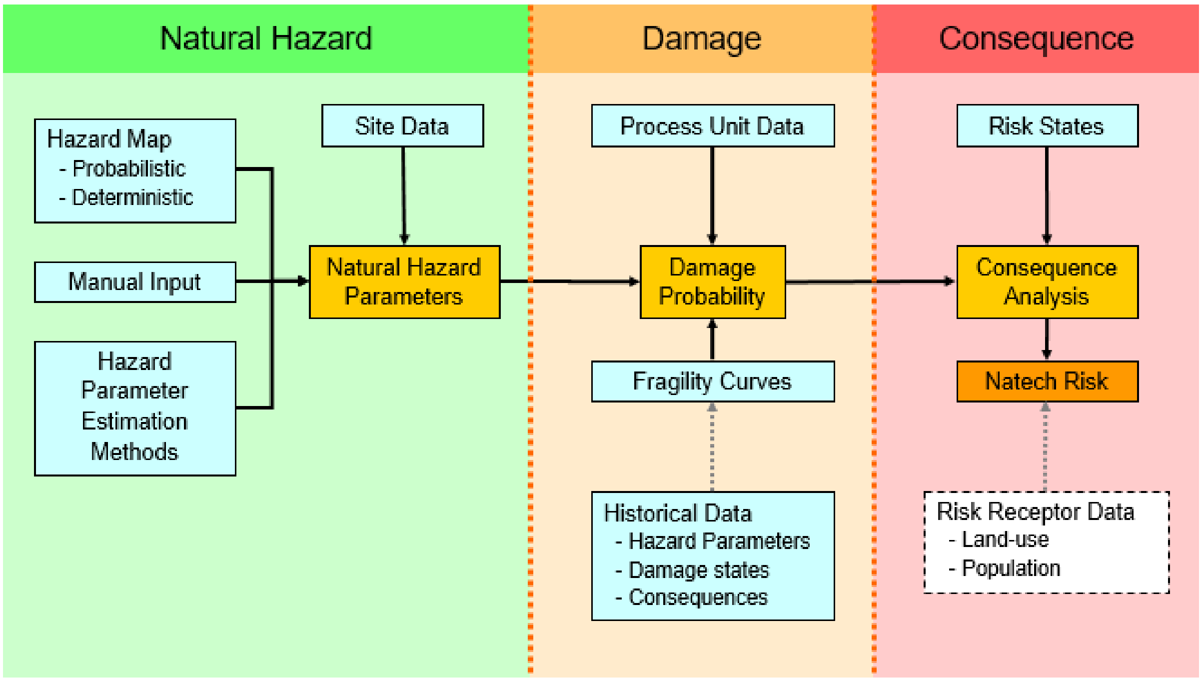
The analysis of Natech scenarios requires an assessment of:

- the exposed equipment containing hazardous material;
- the type and severity of natural hazard impact;
- the type of damage which results in loss of containment;
- the amount and release rate of hazardous material released from its containment;
- the type of hazard associated to the substance released;
- the physical effects of the accident scenarios;
- the vulnerability of people, the asset and of the environment.

3.1 Performing Natech risk analysis with RAPID-N

RAPID-N performs Natech risk analysis and mapping in several steps. First, plant units located in the natural hazard area are identified. Then, the **on-site hazard severity parameters** are calculated for each plant unit by using hazard maps, on-site hazard data, and hazard-specific data estimators. Based on the calculated data, possible **structural and functional damage scenarios** are determined and the associated **damage probabilities** are calculated by utilising damage functions and fragility curves. By using **risk state definitions**, which relate damage scenarios to consequence scenarios, probable Natech event scenarios are determined. Finally, the extent and severity of the Natech events are calculated by using case-specific **consequence models generated on-demand,** and the results are reported as **risk reports and risk maps**. Figure 2 shows the three components of the RAPID-N methodology. In the following sections the RAPID-N methodology is discussed in more detail.

Figure 2. Diagram outlining the Natech risk analysis methodology implemented in RAPID-N.



3.2 Natural hazard

For Natech risk analysis, all the industrial plant's installations and equipment that contain hazardous materials and which can potentially be exposed to natural hazards should be identified. RAPID-N incorporates a natural hazard module that allows the assessment of on-site natural hazard parameters. The module was designed to support a number of different natural hazards, but it has been fully developed for earthquakes only. A prototype application for floods also exists but is still in the experimental stage.

The implemented all-hazards approach requires the identification of the plant units for which the risk analysis should be performed. Users can choose to limit the analysis to a single industrial plant or a single industrial unit. Otherwise, all the plant units that are located within the impact zone of the natural hazard event (i.e., hazard boundary) are automatically selected by RAPID-N. For some natural hazards, such as earthquakes, the definition of the hazard boundary is quite fuzzy. If hazard boundary information is not available explicitly, the distance to the origin of the hazard is calculated for each plant unit available in the system and compared to the cut-off distance criteria (i.e., *Cut-off Distance* property) set by the system. RAPID-N allows users to define the cut-off distance for their assessment. For example, if the user sets the cut-off distance to 50 km, RAPID-N will analyse all plants and plant units that are within 50 km from the epicentre of the earthquake. For each identified plant unit, a set of on-site natural hazard parameters are assigned or calculated. For earthquakes, RAPID-N tracks online data feeds from USGS and EMSC to collect and provide to the user relevant information on recent events that can be used for the Natech risk analysis. Different methods are possible for assigning a new property to the set of on-site natural hazard parameters. In case multiple values are available for the same property, the order of preference is:

1. Manually entered on-site hazard data for risk analysis;
2. On-site hazard data available locally (i.e., for the industrial plant or unit);
3. Custom or default hazard map (the hazard parameters are extracted (i.e., interpolated) for each plant unit location);
4. Hazard-specific property estimators available in the data estimation framework are utilized to estimate on-site parameters by using the available data set.

3.2.1 Flood natural hazard prototype

In addition to the fully developed implementation for earthquakes, a prototype RAPID-N application for floods exists which takes into account two intensity parameters: water depth and velocity. The water depth and flow velocity are highly variable in space and in time. The input parameters should therefore reflect the spatial variability to provide more granularity and reliability of the final solution of the model. Not being able to capture this evolution, RAPID-N must use intensity parameters taken at a reference point during the flood. Alternatively, the maximum value reached by each intensity parameter can be used for the Natech risk analysis.

Unfortunately, the scarcity of available data and models currently prevents the proper use of RAPID-N's floods functionality. In contrast to earthquakes, the availability of flood hazard maps is either poor or their resolution is insufficient to be usable for Natech risk analysis. Similar to the implementation for earthquakes, an automated approach could be considered, where an external provider makes available water depth and velocity model outputs, such as EFAS – European Flood Awareness System (https://www.efas.eu/en). However, currently, EFAS does not provide water velocity as an output. Furthermore, the resolution of the other intensity parameters is very low (Fernandes et al., 2022).

RAPID-N currently accepts flood intensity parameters that are entered manually per industrial plant. This can be a limiting factor since plants can be very big with many installations and equipment distributed over a large area. This means that the flood intensity can vary significantly from one unit to the other. To overcome this issue, users should utilise multiple smaller industrial plant records that are subsets of the whole plant. Each industrial plant record should be chosen so that all units which the record comprises are subject to the same or similar flood severity. Note, though, that even if flood intensity parameters are provided to RAPID-N and some damage models are available (see Section 3.3.1), the system may not provide a proper analysis.

3.3 Natural hazard damage

Natural hazards can cause extensive damage to buildings, infrastructures and industrial equipment containing hazardous materials. The types of natural hazard damage are extremely diverse. The damage amplitude ranges from minor damage, such as small cracks, to complete collapse of a structure. Natural hazard damage analysis must take into account this diversity. Because the extent of damage is highly case-specific and varies significantly, a simplification is usually necessary to facilitate the analysis.

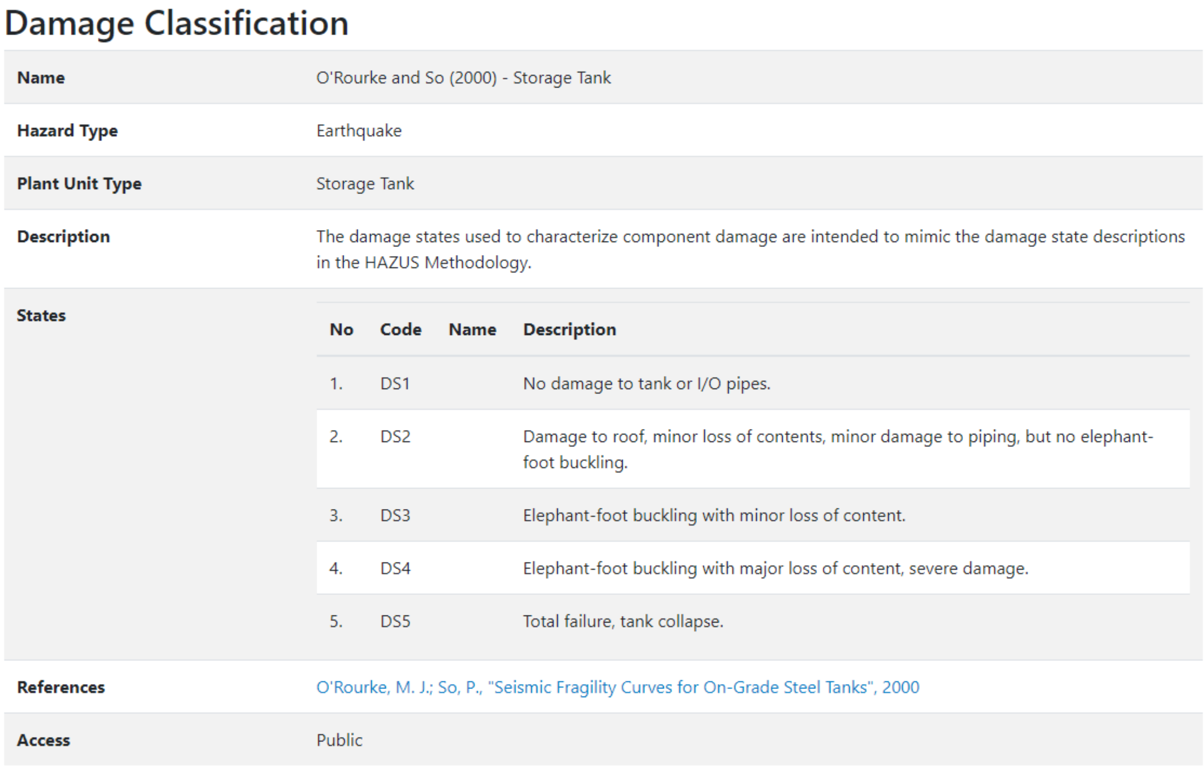
Generally, a **damage classification** is made by grouping similar damage scenarios into a set of classes of damage, ranging from no damage to complete damage gradually in several steps (FEMA, 1997). Damage classifications always have at least one class of damage. In RAPID-N, numerous damage classifications exist for earthquake-triggered damage and a very few additional classifications for other types of natural hazards. RAPID-N uses damage classes, called "**damage states**", which are a qualitative description of the equipment status after natural hazard impact used to define the extent of damage of an industrial unit (e.g., none, minor, moderate, major, catastrophic). An example RAPID-N "Damage classification" page is presented in Figure 3.

The other component of risk is likelihood. Damage to an industrial unit can be more or less likely depending on the type of unit and on the intensity of the natural hazard. Potential damage due to natural hazard to a plant unit is assessed by using on-site hazard parameters (assessed in the previous section), and a combination of damage states (that provide the extent of the damage) and "**fragility curves**" (functions that assess the likelihood of a damage state). Fragility curves are X-Y plots relating the intensity of one (or more) hazard parameter(s) (e.g., PGA) to the damage probability of a structure for a certain damage state (FEMA, 1997).

Together, damage states and fragility curves are frequently used to estimate natural hazard damage to engineered structures such as housing, bridges, or plant units. Typically, fragility curves related to plant units are prepared by statistical analysis of historical event data (e.g., O'Rourke and So, 2000). Fragility curves based on numerical analysis and modelling studies are also available (e.g., Berahman and Behnamfar, 2009). An example of fragility curves that RAPID-N assigned to a damage classification is presented in Figure 4. Every damage state and fragility curve relation is unique to a type of structure. Sometimes, damage states and fragility curves are only applicable to certain subsets of structures of the same type. For instance, specific fragility curves exist that apply only to storage tanks that are anchored and nearly full.

RAPID-N includes a database of damage states and fragility curves, which are accessible at the page "Damage Classifications" and "Fragility Curves", respectively. Each classification has its own associated fragility curves that tell how likely the each associated damage state is. Damage classifications and fragility curves are available for a number of different of types of industrial units. Some unit types feature multiple damage states and fragility relations. Different fragility curves have different validity conditions, which take into account parameters, such as building materials, shapes, and operative conditions. All these parameters are typically available in the data set of the industrial unit.

Figure 3. Example damage classification with five damage states used by RAPID-N.



Damage Classification

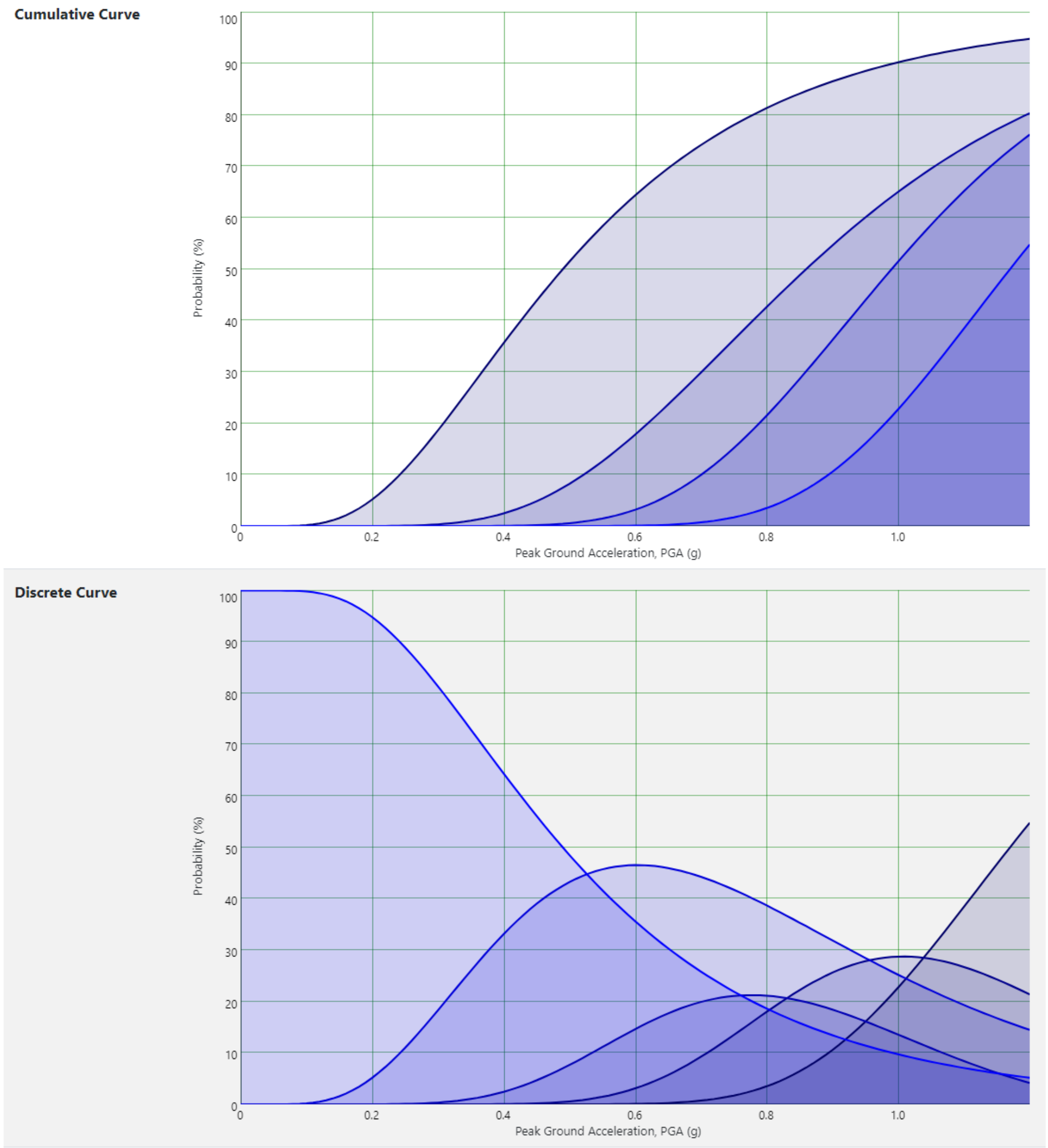
Name	O'Rourke and So (2000) - Storage Tank
Hazard Type	Earthquake
Plant Unit Type	Storage Tank
Description	The damage states used to characterize component damage are intended to mimic the damage state descriptions in the HAZUS Methodology.

States

No	Code	Name	Description
1.	DS1		No damage to tank or I/O pipes.
2.	DS2		Damage to roof, minor loss of contents, minor damage to piping, but no elephant-foot buckling.
3.	DS3		Elephant-foot buckling with minor loss of content.
4.	DS4		Elephant-foot buckling with major loss of content, severe damage.
5.	DS5		Total failure, tank collapse.

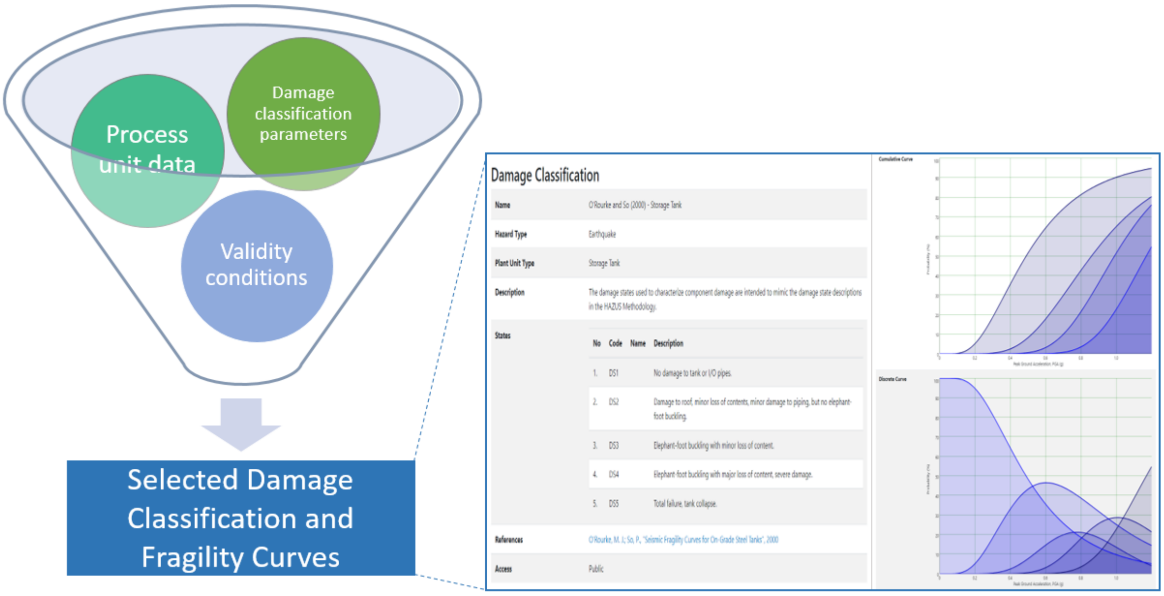
References	O'Rourke, M. J.; So, P., "Seismic Fragility Curves for On-Grade Steel Tanks", 2000
Access	Public

Figure 4. Example cumulative and discrete fragility curves in RAPID-N for earthquakes. Each curve represents a different damage state.



In every risk analysis performed by RAPID-N, a specific damage classification with its own fragility curves is chosen only when all the parameters listed in the validity conditions of the fragility curve are met. RAPID-N automatically selects the fragility curve that is the most suited for each unit, evaluating all the available parameters (Figure 5). When two or more classifications exist for which all the validity conditions are met, priority is given to the classification that is more specific to the unit (it has the highest number of parameters satisfied).

Figure 5. Selection process of the damage classification and associated fragility curves.



Damage Classification

Name	O'Rourke and So (2000) - Storage Tank
Hazard Type	Earthquake
Plant Unit Type	Storage Tank
Description	The damage states used to characterize component damage are intended to mimic the damage state descriptions in the HAZUS Methodology.

States

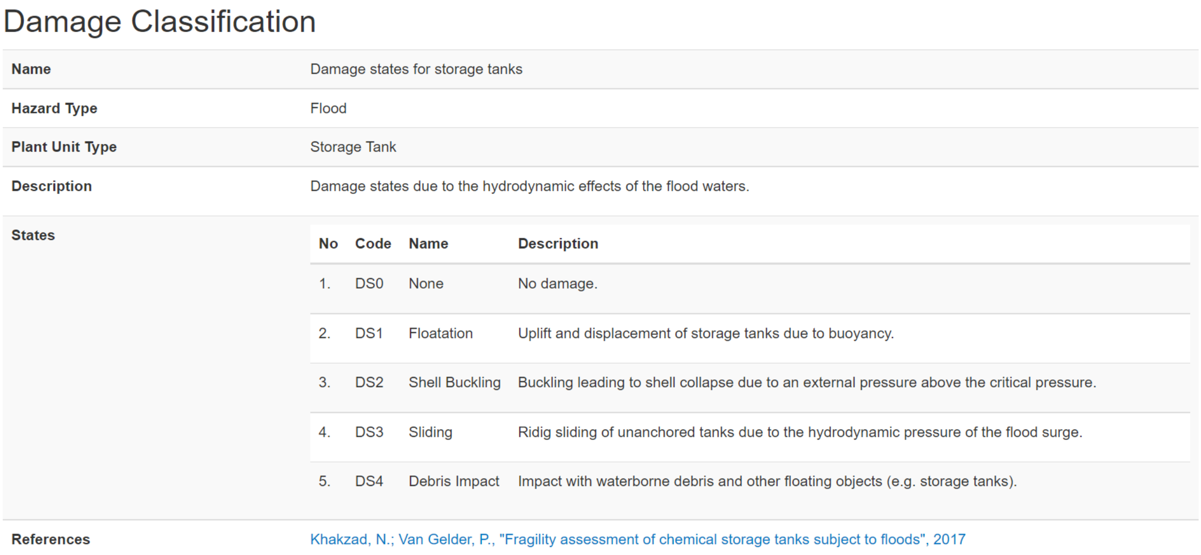
No	Code	Name	Description
1.	DS1		No damage to tank or I/O pipes.
2.	DS2		Damage to roof, minor loss of contents, minor damage to piping, but no elephant-foot buckling.
3.	DS3		Elephant-foot buckling with minor loss of content.
4.	DS4		Elephant-foot buckling with major loss of content, severe damage.
5.	DS5		Total failure, tank collapse.

References	O'Rourke, M. J.; So, P., "Seismic Fragility Curves for On-Grade Steel Tanks", 2000
Access	Public

3.3.1 Natural hazard damage for flood prototype

In contrast to assessing earthquake damage as discussed in the previous section, for floods many types of damage classification exist as the mechanisms by which damage is caused in industrial equipment may vary considerably and encompass a number of different phenomena, such as flotation, sliding, overturning, impact of floating debris, and buckling. Damage classifications must reflect this variety. An example of a proposed damage classification for floods that has been used in the prototype is shown in Figure 6. According to this classification, each damage state is associated to a different damage mode (e.g., uplifting vs. buckling vs. debris impact).

Figure 6. Example of damage classification used to describe flood damage in the RAPID-N flood prototype.



Damage Classification

Name	Damage states for storage tanks
Hazard Type	Flood
Plant Unit Type	Storage Tank
Description	Damage states due to the hydrodynamic effects of the flood waters.

States

No	Code	Name	Description
1.	DS0	None	No damage.
2.	DS1	Floatation	Uplift and displacement of storage tanks due to buoyancy.
3.	DS2	Shell Buckling	Buckling leading to shell collapse due to an external pressure above the critical pressure.
4.	DS3	Sliding	Ridig sliding of unanchored tanks due to the hydrodynamic pressure of the flood surge.
5.	DS4	Debris Impact	Impact with waterborne debris and other floating objects (e.g. storage tanks).

References	Khakzad, N.; Van Gelder, P., "Fragility assessment of chemical storage tanks subject to floods", 2017

Furthermore, the process of determining the damage probability due to flood events shows an additional complexity. The reason is that, unlike for earthquakes, damage states belonging to the same classification for flood-induced damage can be associated to different hazard intensity parameters (either flood depth, flood velocity, or both). For this reason, the RAPID-N approach that assigns a set of fragility curves to a damage classification using a single intensity parameter cannot apply. Instead, RAPID-N's scientific framework must be used to calculate the damage probability for each damage state separately, using different intensity parameters for each of them.

As highlighted in the scientific literature on the topic (e.g., Landucci et al. (2012), Khakzad and van Gelder (2017)), the extent of flood damage to a process unit, particularly to storage tanks, depends heavily on the unit's construction features and process parameters. Particularly the vessel shape, the unit content and overall weight influence most of the damage mechanisms associated to flooding (e.g., uplifting, toppling, sliding, and buckling). This complicates the assessment of natural hazard damage compared to RAPID-N's simple fragility curve approach to assess earthquake damage which uses only one ground motion intensity parameter. Also, fragility curves are functions of the intensity parameters of the natural hazard only and are unable to consider additional parameters that are specific to the unit. For this reason, the current RAPID-N framework is unable to address flood damage in a straightforward way. However, a prototype approach to flood damage which does not use fragility curves but exploits the system's property estimation framework has been implemented and tested. However, the functionality is still in an experimental stage.

This approach is based on the calculation of the resistance that each vessel offers against the floodwater's buoyancy and drag forces. Vessels that are filled with liquid or with gas liquefied under pressure offer a stronger resistance to the forces exerted by the flood than vessels that are empty or nearly empty or that have a lower shell thickness. For storage tanks, for instance, this behaviour is well known. In fact, one of the main recommendations for operators is to fill storage tanks with water prior to a flood to improve their resistance. For this reason, one of the key parameters that is calculated by the property estimation framework is the parameter *Critical Filling Degree* (CFD). This parameter indicates the minimum filling level that would allow the vessel to resist the forces exerted by the flood on the vessel. This parameter is then compared with the actual filling degree of the vessel, and failure occurs if the latter is lower than the CFD.

Some flood damage models, as well as a very few related risk states are available in RAPID-N for flood Natech risk analysis. However, the system is currently unable to correctly select a damage model as it expects a fragility curve for the analysis. For this reason, we discourage use of the floods functionality pending further work to address its current limitations.

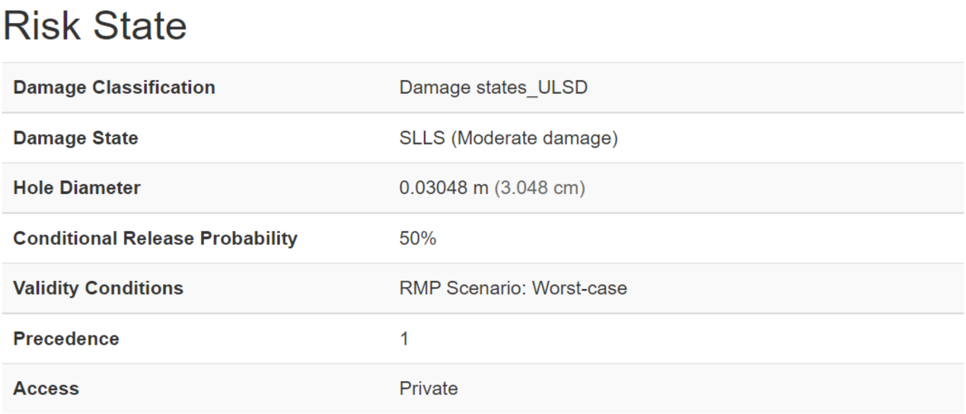
3.4 Risk analysis

3.4.1 Risk states

The consequences of industrial accidents due to natural hazard impact are driven by a number of different factors, the most important being the amount of hazardous material released, the rate at which it is released, the physical state of the substance, and the environmental conditions. In particular, determining the modality by which the substance is released into the open is a key component of assessing the accident's consequences. Earthquakes can affect the structural integrity of storage tanks in different ways, such as buckling or puncturing the vessel wall, and overturning the vessel. In addition to these, pipe connections can be affected, with very similar modalities. All these damage modes offer opportunities for the loss of primary containment of the equipment. When damage occurs, it can initiate a Natech accident.

For this purpose, damage scenarios, which are calculated by using on-site hazard parameters and damage functions, must be related to appropriate consequence scenarios. Similar to the simplification applied in describing damage scenarios by using damage states, possible consequence scenarios are also simplified to facilitate the analysis. A consequence scenario is defined by a set of parameters that establish the scenario for the models to calculate the consequences. In RAPID-N, a set of such parameters is called a **risk state**. In risk states, one or more scenario parameters, which are used during consequence analysis, are specified. These parameters may include **source-term parameters** (e.g., release rate, release duration, hole dimensions, pool area, evaporation rate), **analysis parameters** (e.g., type of accident scenario, conditional release probability), and **consequence parameters** (e.g., type of fire/explosion event, threshold concentration). Figure 7 reports an example of risk states used in RAPID-N.

Figure 7. Example risk state where the parameters: *Hole Diameter* and *Conditional Release Probability* have been associated to the damage state *SLSS (Moderate damage)* that belongs to damage classification *Damage states_ULSD*. The validity condition is that the *RMP_Scenario* is set to *Worst-Case*.



Risk State

Damage Classification	Damage states_ULSD
Damage State	SLLS (Moderate damage)
Hole Diameter	0.03048 m (3.048 cm)
Conditional Release Probability	50%
Validity Conditions	RMP Scenario: Worst-case
Precedence	1
Access	Private

3.4.1.1 Loss of containment scenarios

By far the most important function of a risk state is to define the Loss of Containment (LOC) scenarios that describe how the substance is released and define how the accident will proceed from there. The challenge for Natech accidents is how to assign the well-known conventional LOC scenario to a given damage state. There is no definitive guidance on how to undertake this task and for the moment this association relies on expert judgement (Necci and Krausmann, 2022).

Furthermore, there is a recognised knowledge gap in this regard, since the statistics of natural hazard damage used to build damage states do not cover LOCs and vice versa. In the past, simple one-to-one relations were used in the literature to relate damage states to release events, in which all damage states were associated to a unique type of release (Salzano et al., 2003; Fabbrocino et al., 2005). These early studies coined the term "risk state" to indicate the parameters that established the release scenarios associated to natural hazard damage.

Going one step further, RAPID-N supports conditional risk state definitions for each damage state. Conditional risk states allow different consequence scenarios to be defined for a single damage scenario, depending on plant unit properties (e.g., storage condition, construction material, volume), substance properties (e.g., type of substance, boiling point, vapour pressure), and damage properties (e.g., damage state). Using a different risk state for every damage state, RAPID-N is able to assign different parameters, including different LOC scenarios to each damage state. However, the same LOC may be assigned to two or more damage states.

3.4.1.1.1 Default LOC setup

RAPID-N comprises a standard set of simple LOC scenarios that are used for the analysis of the accident's consequences in the absence of user-defined risk states. Every LOC scenario is identified by a property named *LOC State* that sets a number of parameters (which correspond to RAPID-N properties). Table 1 reports the default LOC scenarios used by RAPID-N. The same result could be achieved by assigning *Hole Diameter*, *Release Duration*, *Released Volume Percent* and *Conditional Release Probability* as separate parameters in the risk states. For other risk states used by RAPID-N, the default release scenarios are assessed by setting the parameter *Released Volume Percent* only. Users are encouraged to use their own definitions of release scenarios using risk states.

Table 1. Default LOC states used by RAPID-N.

LOC State	LOC Type	Hole diameter	Release Duration	Released Volume Percent	Conditional Release probability
None	No release	-	-	0%	0%
Minor	Continuous release from a hole in the vessel	10 mm	10min	Calculated (or 1%)(1)	30%

Moderate	Continuous release from a hole in the vessel	25 mm	10 min	Calculated (or 5%)(1)	50%
Major	Continuous release from a hole in the vessel	100 mm	30 min	Calculated (or 20%)(1)	80%
Catastrophic	Instantaneous release	-	1 s	100%	100%

(1) The *Released Volume Percent* was the original standard property used by RAPID-N for the assessment of a LOC, instead of the property *Hole Diameter*. Now, a value is assigned to the property *Hole Diameter*, and *Released Volume Percent* is calculated accordingly. The standard values of this property (in brackets) are used only as a backup if the standard values of *Hole Diameter* cannot be set.

3.4.2 Consequence scenario modelling

Consequence scenarios are built on demand every time a user launches a risk analysis. The reason every risk analysis is different is the unique property estimator framework of RAPID-N that allows using the available models when needed, shifting from one model to the other on the basis of the available data. In RAPID-N only one accident scenario at a time is considered for every risk state. RAPID-N gives priority to the accident scenarios with the largest consequences that apply to the specific characteristics of the substance (e.g., toxic or flammable, liquid or gas) and the release dynamics (e.g., immediate or continuous release). RAPID-N also selects the model that is best suited for the case. However, users can select the type of accident (e.g., pool fire, vapour cloud explosion) and the available model they prefer (e.g., point source pool fire model or solid surface pool fire model), and RAPID-N will return an answer if the model applies to their specific case. The physical models for consequence analysis are discussed in detail in Chapter 4.

3.4.3 Assessment of the Natech probability

Risk analysis is by definition the evaluation of the likelihood of an unwanted event. This step is crucial for evaluating the risk and for prioritising investments for cost-effective Natech risk reduction. Natech probability analysis is composed of several steps. First, the likelihood of the release should be determined, then the likelihood of the Natech consequence scenarios can be analysed with the use of event trees or equivalent methods.

These methods allow the assessment of the probability of the many Natech consequence scenarios that can result from every critical event when the conditions change (e.g., hazardous material ignition/no ignition, safety barrier availability/unavailability). Equation 1 summarises the composition of the Natech probability of a specific Natech accident scenario for a given natural hazard scenario:

$$P_{\mathrm{Natech}} = P_{\mathrm{rel}} \cdot P_{\mathrm{sce}}(\mathrm{rel}) \tag{1}$$

where P_{Natech} is the probability of a specific Natech accident scenario, P_{rel} is the release probability and $P_{\mathrm{sce}}(\mathrm{rel})$ is the conditional probability of the Natech consequence scenario given the release. The release probability depends on the damage extent and on the probability that damage occurs at all. We observed from past accidents that damage does not always produce a release. However, scarce data is available to build consistent statistics of past accidents for all types of equipment. In general, more severe damage states have a higher likelihood to produce a release, while minor damage states have a lower one. To take account of this characteristic, the following relationship was implemented in RAPID-N:

$$P_{\mathrm{rel}} = P_{\mathrm{DS}} \cdot P_{\mathrm{rel}}(\mathrm{DS}) \tag{2}$$

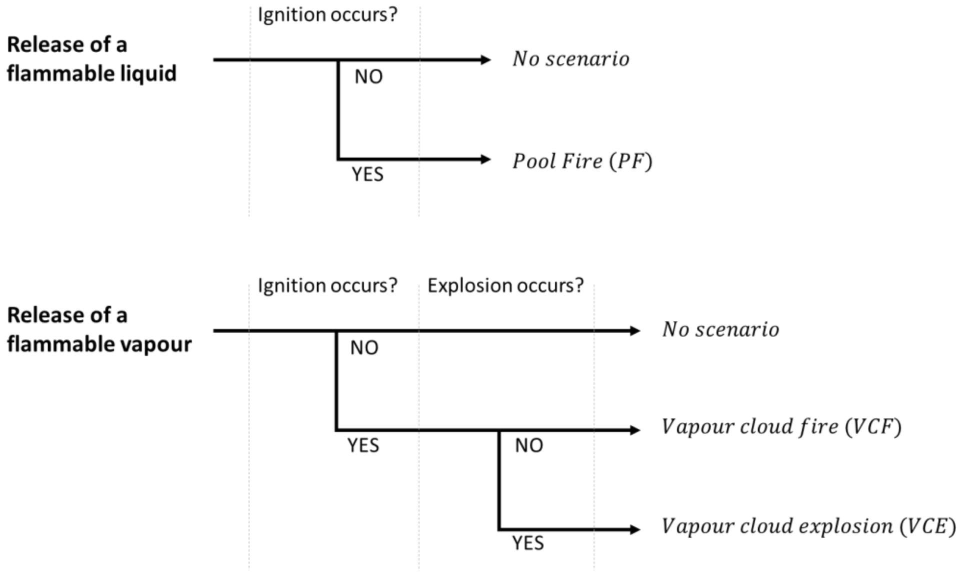
where P_{rel} is the release probability, P_{DS} is the probability of the selected damage state, and $P_{\mathrm{rel}}(\mathrm{DS})$ is the conditional release probability associated to the damage state. In most past analyses, $P_{\mathrm{rel}}(\mathrm{DS})$ was conservatively assumed as 1 regardless of the damage state (Antonioni et al., 2007) in the absence of more data to support quantification. The default values for $P_{\mathrm{rel}}(\mathrm{DS})$ used in RAPID-N are reported in the last column in Table 1.

The conditional consequence scenario probability, $P_{\mathrm{sce}}(\mathrm{rel})$, depends on the type of scenario that the system analyses. Equation 3 reports the expressions for the conditional probability of the most common types of consequence scenarios (toxic dispersion, pool fire (PF), vapour cloud fire (VCF), vapour cloud explosion (VCE). The scenario probability for flammable substances is calculated using the event tree method (see Figure 8).

$$\begin{cases} P_{\mathrm{sce}}(\mathrm{rel}) = 1 & \text{for toxic dispersion} \\ P_{\mathrm{sce}}(\mathrm{rel}) = P_{\mathrm{ign}} & \text{for PF} \\ P_{\mathrm{sce}}(\mathrm{rel}) = P_{\mathrm{ign}} \cdot \left(1 - P_{\mathrm{exp}}\right) & \text{for VCF} \\ P_{\mathrm{sce}}(\mathrm{rel}) = P_{\mathrm{ign}} \cdot P_{\mathrm{exp}} & \text{for VCE} \end{cases} \tag{3}$$

where P_{ign} is the conditional ignition probability and P_{exp} is the conditional explosion probability.

Figure 8. Event tree method used for the evaluation of the conditional consequence scenario probabilities for flammable substances.



4 Consequence analysis models in RAPID-N

4.1 U.S. EPA RMP Guidance for offsite consequence analysis

4.1.1 General description

The U.S. Environmental Protection Agency (EPA) issued regulations requiring facilities with large quantities of very hazardous chemicals to prepare and implement programmes to prevent the accidental release of those chemicals and to mitigate the consequences of any releases that do occur. In this framework, operators are required to conduct an offsite consequence analysis to provide information to the state, local, and federal governments and the public about the potential consequences of an accidental chemical release. The U.S. EPA RMP Guidance for Offsite Consequence Analysis methodology (EPA, 1999) offers a simplified procedure to evaluate offsite consequences. The associated RMP*Comp software tool developed by the National Oceanic and Atmospheric Administration (NOAA) and U.S. EPA performs the calculations described in the RMP guidance document.

The offsite consequence analysis consists of two possible approaches that assume two different types of consequence scenario: worst-case and so-called alternative scenarios. To simplify the analysis and ensure comparability, EPA has defined the "worst-case" scenario as the release of the largest quantity of a regulated substance from a single vessel or process line failure that results in the greatest distance to an endpoint. In broad terms, the distance to the endpoint is the distance a toxic vapour cloud, heat from a fire, or blast waves from an explosion will travel before dissipating to the point that serious injuries from short term exposures will no longer occur.

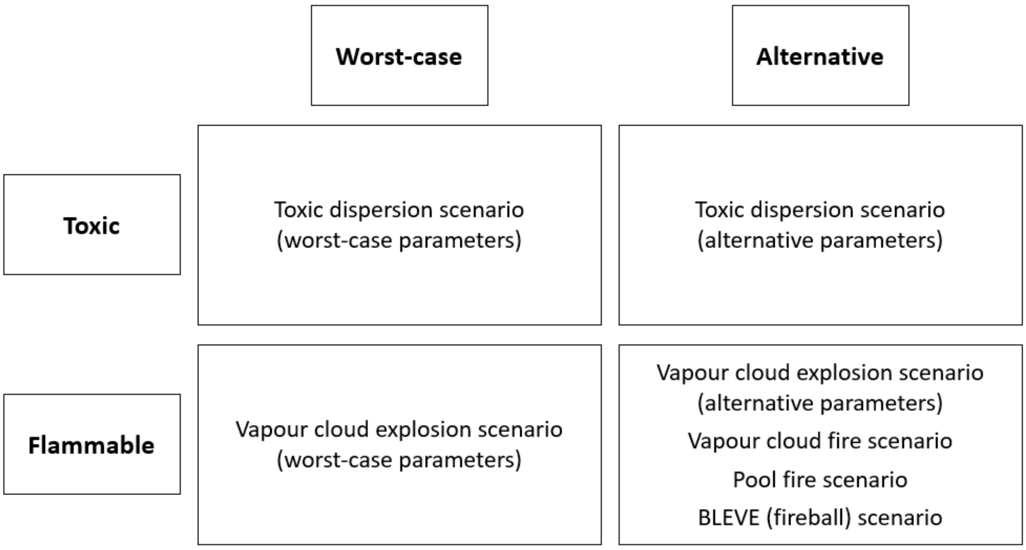
The consequence analysis methodology described in the RMP guidance (EPA, 1999) has been fully implemented in RAPID-N. The methodology uses simple equations to estimate release rates and reference tables to determine distances to the endpoint of concern. RAPID-N contains the reference tables in its database in the form of property estimators. Reference tables are used to assess the endpoint distances due to the dispersion of toxic substances, or fires and explosions of flammable materials. Results obtained using this method are expected to be conservative (i.e., they will generally, but not always, overestimate the distance to the endpoint).

4.1.2 RMP scenarios

The consequences of an accidental chemical release depend on several conditions at the time of the release. In particular, the type of hazardous substance, the conditions of the substance, at the site, of the environment around the site, and the meteorological conditions all play a key role. In the EPA RMP guidance, worst-case distances are based on modelling results that assume worst-case conditions. This combination of worst-case conditions occurs rarely and is unlikely to persist for long. Alternative scenario distances are based on modelling results that assume less conservative conditions. These assumptions represent conditions that are more likely to occur than the worst case. Both cases represent rough estimates of the potential consequence distances.

The worst-case scenario approach only supports toxic dispersion and vapour cloud explosion scenarios. Other scenarios (i.e., vapour cloud fire, pool fire, and boiling liquid expanding vapour explosion (BLEVE)) are considered alternative scenarios because their impact is by their very nature less than the worst case. Figure 9 shows the list of consequence scenarios that define the worst-case and the alternative scenarios for both toxic and flammable substances. Table 2 shows the main parameters that define the worst-case and the alternative scenarios.

Figure 9. Worst-case and alternative scenarios for toxic and flammable substances.



	Worst-case	Alternative
Toxic	Toxic dispersion scenario (worst-case parameters)	Toxic dispersion scenario (alternative parameters)
Flammable	Vapour cloud explosion scenario (worst-case parameters)	Vapour cloud explosion scenario (alternative parameters) Vapour cloud fire scenario Pool fire scenario BLEVE (fireball) scenario

Table 2. Parameters that define the worst-case and the alternative RMP scenarios.

	Worst-case scenario	**Alternative scenario**
Toxic endpoint thresholds	Defined substance by substance.	Defined substance by substance.
Endpoint thresholds for flammable substances	Overpressure 1 psi for vapour cloud explosion.	Overpressure 1 psi for vapour cloud explosion; Radiant heat 5 kW/m^2 for 40 seconds (or equivalent dose) for fires; Lower Flammability Limit for vapour cloud fire.
Wind speed/Stability	Wind speed 1.5 m/s and "stable" (class F) atmospheric conditions.	Wind speed 3 m/s and "neutral" (class D) atmospheric conditions.
Ambient temperature/Humidity	T= 25°C and 50% relative humidity.	T= 25°C and 50% relative humidity.
Height of release	Ground-level release, height = 0 m.	Ground-level release, height = 0 m.
Surface roughness	Urban (obstructed terrain) or rural (flat terrain), as appropriate.	Urban (obstructed terrain) or rural (flat terrain), as appropriate.
Dense or neutrally buoyant gases	Determined automatically for each substance according to the gas density.	Determined automatically for each substance according to the gas density.
Temperature of the released substance	For liquids, use the highest daily maximum temperature, for gas liquefied under refrigeration use boiling temperature.	Process or ambient temperature, as appropriate for the scenario.

4.1.2.1 RMP scenarios in RAPID-N

RAPID-N has implemented both the worst-case and the alternative RMP scenarios. Combinations of parameters from both scenarios are also possible. Normally, worst-case and alternative scenarios would be applied to different releases. However, in RAPID-N the releases are defined by damage states and risk states (see Sections 3.3 and 3.4.1), and the worst-case and alternative scenarios would be applied to the same releases. **As a general rule, worst-case parameters are used wherever possible. If some accident types are available only for the alternative scenarios (e.g., pool fire or vapour cloud fire), the alternative parameters are chosen instead.**

4.1.3 RMP releases

A release is determined by the amount and release rate of the hazardous substance for which containment was lost during an accident. There are two release types according to the RMP methodology:

1. **Worst-case releases**, which consider the release of the entire inventory of the unit in relatively short time (10 minutes);
2. **Alternative releases**, which assume that the substance is released from a hole in a vessel or pipe. In this case, the release rate depends on different factors: hole size, unit pressure, and the properties of the substance which the users decide. Also, the release duration is a parameter that the users may change.

For both release types, 4 generic release cases are defined (see also Table 3):

- Gaseous releases: The released substance is a gas stored under pressure, which expands in a jet upon release. The release state is gas.
- Liquefied gases: The released substance is a gas stored as a liquid under pressure. The release state can be liquid, gaseous or a mix of the two phases. The released liquid flashes almost immediately and forms an equivalent amount of vapour.
- Gases liquefied by refrigeration: The released substance is a gas stored as a liquid at low temperature. The release state is liquid. A pool forms of liquid that boils at ambient temperature.
- Liquid releases: The released substance is a liquid. A pool forms of liquid that evaporates at ambient temperature.

Table 3. Types of release scenarios covered by the RMP guide.

Release case	Type of release	Release amount	Release duration	Outcome
Gas release	Worst-case	Entire inventory released	10 minutes	Plume
	Alternative	Release from a hole in a vessel or pipe	User defined	Plume or puff
Gas liquefied	Worst-case	Entire inventory released	10 minutes	Plume
	Alternative	Release from a hole in a vessel or pipe	User defined	Plume or puff
Gas liquefied refrigerated	Worst-case	Entire inventory released	Immediate	Pool spread
	Alternative	Release from a hole in a vessel or pipe	User defined	Pool spread
Liquid release	Worst-case	Entire inventory released	Immediate	Pool spread
	Alternative	Release from a hole in a vessel or pipe	User defined	Pool spread
Pool evaporation or boiling	Worst-case	Entire inventory released	Pool evaporation time (10 minutes if boiling)	Plume
	Alternative	Release from a hole in a vessel or pipe	Pool evaporation time (10 minutes if boiling)	Plume

In RAPID-N, the release scenarios are not taken from the RMP methodology but instead use the risk state definitions (Section 3.4.1). However, RMP worst-case and alternative release scenarios are used for setting other parameters in RAPID-N.

4.1.4 RMP toxic dispersion modelling

The RMP guidance provides reference tables for the assessment of the worst-case distances for the dispersion of toxic vapours in air. Tables relate the endpoint distance to the release rate and the endpoint concentration (the concentration below which no permanent injury is expected) for the selected substance. RMP endpoint concentrations are provided for every substance in the guide. RMP chooses the endpoint concentrations as follows in order of precedence:

1. The **Emergency Response Planning Guideline 2 (ERPG-2[1])** developed by the American Industrial Hygiene Association is used whenever available,
2. The **Level of Concern (LOC)** concentration derived for extremely hazardous substances is used when the ERPG-2 is not available. LOC is derived as **one-tenth of the Immediately Dangerous to Life and Health (IDLH[2])** concentration, developed by the National Institute of Occupational Safety and Health (NIOSH).

Every table in the RMP guidance document represents a specific set of conditions that characterise the dispersion scenario. The parameters and conditions that affect the dispersion, including the associated RAPID-N properties, are reported in Table 4. There are a total of 16 combinations of the described parameters and as many reference tables for the dispersion of toxic substances. Additional tables are provided for releases of the most common and abundant toxic substances, namely chlorine, ammonia, and sulphur dioxide.

Table 4. The parameters that influence the toxic dispersion endpoint distances and associated RAPID-N properties.

Parameter name	RAPID-N property	Parameter description	Condition name	Condition description
Gas / vapour density	*RMP Plume Type*	Represents the relative density of the gas	Neutrally buoyant	Gas density is similar to air density
			Dense gas	Gas is denser than air
Topography	*Topography*	Represents the surface roughness	Urban	The terrain is obstructed with obstacles (e.g., buildings)
			Rural	The terrain is flat with no obstacles (e.g., crop fields)
Release duration	*Gaseous Release Duration*	Estimate the duration of the release	10-minute release	The release lasts 10 minutes or less
			60-minute release	The release lasts for more than 10 minutes
Atmospheric conditions	*RMP Scenario*	Atmospheric stability class and wind speed used in the scenario	Worst-case	F (stable) Atmospheric Stability and Wind Speed 1.5 m/s
			Alternative	D (neutral) Atmospheric Stability and Wind Speed 3.0 m/s

4.1.4.1 RMP toxic dispersion modelling in RAPID-N

RAPID-N has implemented property estimators that include all the tables in the RMP guide and it uses them to determine the endpoint distance of toxic dispersion scenarios. RAPID-N automatically selects the dispersion tables that are the most appropriate for the input scenario parameters entered by the user. Then it uses the release rate and the RMP endpoint concentration to read the value of the matching endpoint distance from the table.

RAPID-N incorporates the RMP endpoint concentrations for all regulated toxic substances in its substance database. If users are interested in concentrations that are different from the default concentration, they can change the parameter *RMP Toxic Endpoint*. The value of the *RMP Toxic Endpoint* is expressed in mg/L.

The default endpoint concentrations cannot be directly changed for the special substances that have their own tables (i.e., ammonia, chlorine and sulphur dioxide). For changing the RMP endpoint concentration of any of these substances, users can use a generic version of the same substance (i.e., Ammonia-generic, Sulphur

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[1] ERPG-2 is defined as the maximum airborne concentration below which it is believed that nearly all individuals could be exposed for up to 1 hour without experiencing or developing irreversible or other serious health effects or symptoms that could impair an individual's ability to take protective actions.

[2] IDLH (pre-1994) concentrations were defined in the NIOSH Pocket Guide to Chemical Hazards as representing the maximum concentration from which one could escape within 30 minutes without a respirator and without experiencing any escape-impairing or irreversible health effects.

Dioxide-generic and Chlorine-generic). These “generic” substances have the same properties as the original substances but lack the unique identifiers that trigger the activation of the substance-specific tables. For generic substances, generic tables are used instead of the specific tables, allowing the use of any RMP endpoint concentration. However, it should be noted that generic tables are less accurate than the substance-specific tables.

Note: Although RAPID-N allows users to enter any type of atmospheric stability and wind speed, the only two possible atmospheric conditions that can be modelled by RAPID-N using the RMP methodology are “worst-case” (Stability F, Wind Speed 1.5 m/s) and “alternative” (Stability D, Wind Speed 3.0 m/s). Different combinations of stability and wind speed are not accepted by the system when running RMP scenarios. Users are encouraged to set the RAPID-N property *RMP Scenario* instead of the atmospheric parameters *Atmospheric Stability* and *Wind Speed*. The *RMP Scenario* default setting is worst case but can be changed to alternative. If RAPID-N is not running RMP scenarios (e.g., if the ADAM module is activated), different conditions can be specified (see Sections 5.6 and 6.1.2).

4.1.5 RMP vapour cloud explosion modelling

Vapour cloud explosions are generally considered unlikely events. A number of conditions are necessary for a vapour cloud explosion to occur:

- Massive and rapid release of flammable materials;
- Turbulent conditions that allow the flammable substance to mix with air (either by turbulent release, or by a congested environment in the area of the release, or both);
- High reactivity of the flammable substance.

When the explosion occurs, a blast spreads from the ignition point in every direction. Targets on its way experience a rapid pressure build-up and decline known as pressure wave or blast wave which is characterised by the peak overpressure. Explosions can be divided into two main categories: near surface blasts (hemispherical model) and free air blasts (spherical model).

Vapour cloud explosions are addressed in the RMP methodology with a method based on the TNT-equivalent model where the amount of flammable material that explodes is converted into an equivalent amount of trinitrotoluene (TNT) using a near-surface model (EPA, 1999). TNT is the reference explosive for which the relationship between the distance travelled by the blast wave, the peak overpressure, and the mass of explosive is well known. A typical relationship is that between the scaled peak overpressure (ratio of the peak overpressure and the ambient pressure) and the scaled distance (ratio of the explosion radius and the cubic root of the explosive mass – see Equation 4).

The RMP endpoint distances are calculated on the basis of a **reference peak overpressure of 1 psi**. The RMP guide provides a simple equation (Equation 4 – left-hand part) to determine the endpoint distances to 1 psi peak overpressure as a function of the heat of combustion of the substance, the quantity of the substance in the cloud, and the portion of the cloud that actually participates in the explosion, or the yield factor. In the right-hand part, Equation 4 utilises a reference value of the scaled distance ($\overline{D} = 17$) for a peak overpressure of 1 psi (EPA, 1999, Eq. C-1):

$$D = \overline{D} \cdot \sqrt[3]{W_{\mathrm{TNT}}} = 17 \cdot \sqrt[3]{\gamma \, W_{\mathrm{f}} \frac{H_{\mathrm{cf}}}{H_{\mathrm{cTNT}}}} \qquad (4)$$

where D is the endpoint distance in metres, $\overline{D}$ is the scaled distance, W_{TNT} is the equivalent mass of TNT, γ is the yield factor, W_{f} is the mass of the flammable substance in the cloud in kg, H_{cf} and H_{cTNT} are the heat of combustion of the flammable substance and of TNT, respectively. In RMP, vapour cloud explosions can be worst-case or alternative scenarios.

Worst case

In the worst-case scenario, assumptions are made that, although unlikely, lead to the worst possible consequences:

- The total amount of flammable substance released forms a flammable cloud;
- The entirety of cloud is within flammability limits;

- The cloud detonates;
- The yield factor, γ, is 10%.

For the worst-case scenario, the guide also provides a table where the endpoint distances (calculated by means of the TNT-equivalent model) are reported as a function of the explosive mass in the cloud for every substance listed in the guide.

Alternative

The alternative scenario makes assumptions that are more likely to occur in case of an accident:

- Only a portion of the flammable substance released forms a flammable cloud;
- The entirety of cloud is within flammability limits;
- The cloud deflagrates;
- The yield factor, γ, is 3%.

The alternative scenario has an additional step that calculates the portion of the released material that would generate a flammable cloud. Many hazardous substances generate two phases upon release: a vapour phase that forms the flammable cloud and a liquid phase that drops on the ground. The RMP guide provides a simple relationship which uses the “Flash fraction factor” (FFF) which is unique for every substance. Equation 5 shows the relationship used to calculate the flammable mass in the vapour cloud:

$$\mathrm{QF} = \min(\mathrm{QS} \cdot \mathrm{FFF} \cdot 2, \mathrm{QS}) \tag{5}$$

where QF is the quantity flashed into vapour plus aerosol, QS is the overall flammable mass released, 2 is a corrective factor to account for spray and aerosol. The guide provides FFFs for all the flammable substances. However, it also provides a simple equation to estimate the FFF for substances not directly covered by the guide.

4.1.5.1 RMP vapour cloud explosion modelling in RAPID-N

RAPID-N has implemented a simple equation to determine the endpoint distance as a function of the explosive mass in the cloud. Furthermore, RAPID-N incorporates an equation to estimate the amount of explosive substance in the cloud for alternative scenarios. RAPID-N uses a property estimator to calculate the FFF for all other flammable substances not covered by the RMP guide.

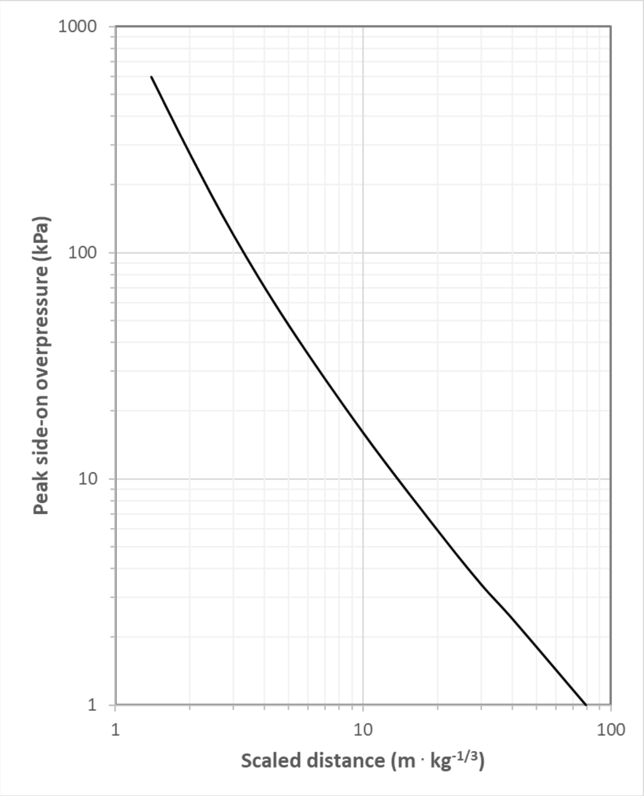
Furthermore, RAPID-N has implemented a new estimator (Equation 6) that allows the assessment of the endpoint distance for **any value of the peak overpressure**, other than the standard peak overpressure of 1 psi, which is the only value for which the RMP guide could provide endpoint distances. Distance is obtained by multiplication of the cubic root of the TNT-equivalent mass and the scaled distance. Scaled distance for values other than 1 psi is calculated using an interpolation formula, calibrated with data that relate the peak overpressure and the scaled distance obtained from TNO’s Yellow Book (van den Bosch and Weterings, 2005, Figure 5.6). Figure 10 shows the relationship between the scaled distance and the peak overpressure for a surface blast of TNT used as a basis for Equation 6.

$$D = \bar{D} \cdot \sqrt[3]{W_{\mathrm{TNT}}} = \left(a + \frac{b}{\left(1 + \left(\frac{\Delta P_s}{c}\right)^d\right)} \right) \cdot \sqrt[3]{\gamma\, W_{\mathrm{f}} \frac{H_{\mathrm{cf}}}{H_{\mathrm{cTNT}}}} \tag{6}$$

where D is the endpoint distance (in m), $\bar{D}$ is the scaled distance, W_{TNT} is the equivalent mass of TNT, γ is the yield factor, W_{f} is the mass of the flammable substance in the cloud (in kg), H_{cf} and H_{cTNT} are the heat of combustion of the flammable substance and of TNT, respectively, $a = 1.347$, $b = 9.122 \cdot 10^7$, $c = 2.607 \cdot 10^{-8}$, $d = 0.8006$ are fitting coefficients, and ΔP_s is the peak overpressure (in kPa).

If users are interested in values that are different from the standard 1 psi overpressure, they can change the property *Endpoint Overpressure* in the “Create Risk Assessment” or “Update Risk Assessment” pages.

Figure 10. Relationship between the scaled distance and the peak side-on overpressure for a surface burst of TNT.



Data source: TNO Yellow Book (van den Bosch and Weterings, 2005); original data from Marshall (1976)

4.1.5.2 Multi-energy vapour cloud explosion model in RAPID-N

Furthermore, RAPID-N includes an adaptation of the Multi-energy model for the calculation of the endpoint distances of vapour cloud explosion scenarios. This model assumes that rapid combustion of a vapour cloud generates a blast only in those parts of a quiescent vapour cloud which are sufficiently obstructed and/or partially confined, in accordance with past accident observations. Contrary to the TNT-blast models, in which the contributing energy is based on the total energy content of the cloud, the Multi-energy approach takes into account the total combustion energy of those parts of the cloud that are located in obstructed and/or partly confined areas. The remaining parts of the flammable vapour-air mixture in the cloud burn out slowly, without significant contribution to the blast. This idea is called the Multi-energy concept and underlies the method of blast modelling. The other main difference with the TNT-equivalency model is that the equivalency is based on the energy developed by burning a finite volume of fuel and air mixture, and not on the mass of the fuel. The Multi-energy apporach also allows the assessment of endpoint distances for clouds that are unconfined or partially confined. RAPID-N includes models for the assessment of the endpoint distances for both confined and unconfined clouds.

If the cloud is unconfined, the steps to calculate the explosion endpoint distances in RAPID-N are:

1. Calculate the volume of the vapour cloud, using a uniform stoichiometric concentration for the vapour cloud;
2. Calculate the energy that is produced by burning the fuel in the whole cloud;
3. Calculate the scaled distance for the target overpressure for unconfined vapour clouds;
4. Calculate the distance to the endpoint.

If the cloud is at least partially confined, the steps to calculate the explosion endpoint distances in RAPID-N are:

1. Calculate the volume of the vapour cloud, using a uniform stoichiometric concentration for the vapour cloud;
2. Calculate the volume within the vapour cloud that is in an obstructed area;

3. Calculate the energy that is produced by burning the fuel in the obstructed area;
4. Calculate the scaled distance for the target overpressure for confined vapour clouds;
5. Calculate the distance to the endpoint.

The Multi-energy model requires input from an experienced user who is able to estimate the free volume in the obstructed region of the cloud. The associated RAPID-N estimator is the *Obstructed Region Free Volume*, and RAPID-N cannot calculate it automatically. If the user sets the value *"Obstructed"* for the RAPID-N property *Obstruction Class*, then the entirety of the vapour cloud volume (and mass) is considered to lie in an obstructed area.

4.1.6 RMP vapour cloud fire modelling

Vapour cloud fires (Flash fires) can result from the ignition of a cloud of flammable substance dispersed in air. Such a fire represents a severe heat hazard to anyone in the area of the cloud. The aim of vapour cloud fire modelling is to identify this area by calculating the distance reached by the flammable vapour with a concentration in air equal to or greater than the lower flammability limit (LFL) of the substance. The distance to the LFL represents the maximum distance at which radiant heat effects of a vapour cloud fire might have serious consequences. The RMP guide provides four tables for the dispersion of flammable vapours in air. These tables relate the endpoint distance to the release rate and the endpoint concentration (the LFL) for the selected substance. **The RMP vapour cloud fire scenario is an alternative scenario**.

Table 5 lists the parameters that generate four unique combinations that represent the conditions of the four different RMP tables.

Table 5. Parameters that influence the vapour cloud fire endpoint distances.

Parameter name	Parameter description	Condition name	Condition description
Gas/vapour density	Represents the relative density of the gas	Neutrally buoyant	Gas density is similar to air density.
		Dense	Gas is denser than air.
Topography	Represents the surface roughness	Urban	The terrain is obstructed with obstacles (e.g., buildings).
		Rural	The terrain is flat with no obstacles (e.g., crop fields).

Because all vapour cloud fires are alternative scenarios, the following conditions apply to all such scenarios:

- The atmospheric conditions considered are for the "alternative" scenario: Neutral (D) stability and wind speed 3.0 m/s.
- The flammable vapour releases are all assumed to be long-lasting events (60-min release).

4.1.6.1 RMP vapour cloud fire modelling in RAPID-N

In RAPID-N, vapour cloud fire scenarios are never chosen automatically by the system. Users can manually select vapour cloud fire scenario in the "Create Risk Assessment" page of RAPID-N by adding the property *Fire/Explosion Event* as a risk assessment parameter and selecting the option *Vapour Cloud Fire* (see Section 5.4 for more information on manual data input).

RAPID-N has implemented property estimators that include all the tables of the RMP guide and it uses them to determine the distance to LFL for vapour cloud fire scenarios. **RAPID-N includes the RMP endpoint concentrations (LFLs) for all regulated flammable substances** in its substance database. If users are interested in concentrations that are different from the default concentration, they can change the parameter *LFL*.

Note: Since vapour cloud fire is an alternative scenario, the only possible atmospheric conditions that can be modelled by RAPID-N using the RMP methodology for vapour cloud fires is "Alternative" (Stability D, Wind Speed 3.0 m/s). Choosing other values will not impact the results obtained via this method but will give the false impression that the results belong to different meteorological conditions than those of the alternative scenario. When not using RMP scenarios but the ADAM Mode, different conditions can be specified (see Sections 5.6 and

6.1.2). When using RMP models, users are encouraged to set the RAPID-N property *RMP Scenario* instead of the properties of the atmospheric parameters: *Atmospheric Stability* and *Wind Speed*. *RMP Scenario*'s default setting is "Alternative" for vapour cloud fire scenarios.

4.1.7 RMP pool fire modelling

Pool fires are "alternative" scenarios for flammable liquids and gases liquefied by refrigeration. In this scenario, the pool formed by the spill of a flammable liquid ignites and a fire starts on top of the liquid layer. The fire burns those who are engulfed by the flames and radiates heat in every direction. In general, the larger the pool the larger is the endpoint distance. RMP assumes the pool fire endpoint distance as the **distance at which the radiant heat is equal to 5 kW/m²**. The endpoint distance *D* is calculated, using Equation 7, as a product of the square root of the pool area *A* and a "Pool fire factor" (PFF), which takes into account the physical properties of the burning substances and the target heat radiation for the endpoint distance:

$$D = \mathrm{PFF} \cdot \sqrt{A} \tag{7}$$

The RMP guide calculates the PFF for all regulated substances and provides a method for estimating the PFF for substances that are not covered by the guide (EPA, 1999). Equation 7 is derived from the point source pool fire model presented in the TNO Yellow Book (van den Bosch and Weterings, 2005). The point source model assumes that all the energy is radiated from a single point that is hovering above the pool centre. In its technical background, the RMP guide also provides a more complete description of the point source model. From the model the guide derives simplified equations that calculate the endpoint distance, for both boiling and non-boiling liquids, using the physical properties of the substance, instead of the PFF (EPA, 1999 - Appendix D). The simplified relationships assume conservative values for the pool fire parameters. In particular, the heat of combustion radiated is assumed equal to 0.4 for all substances and the atmospheric transmissivity is assumed equal to 1. Equation 8 shows the equation for non-boiling liquids.

$$D = H_c \cdot \sqrt{0.4 \frac{\left(\frac{0.0010\,A}{H_v + C_p(T_b - T_a)}\right)}{4\pi q}} \tag{8}$$

where *D* is the endpoint distance (in m), *A* is the area of the pool (in m^2), H_c is the heat of combustion of the substance (in J/kg), H_v is the heat of vaporisation of the substance (in J/kg), C_p is the heat capacity of the substance (in J/kg K), T_b is the boiling temperature of the substances, T_a is the ambient temperature, and q is the target heat radiation (for RMP it is 5000 W/m^2).

4.1.7.1 RMP pool fire modelling in RAPID-N

RAPID-N has implemented property estimators that calculate the distance to the endpoint for pool fire scenarios using both Equation 7 (preferred, valid for all regulated substances found in the RMP guide) and Equation 8 (valid for other substances that do not have a pool fire factor, e.g., gasoline, diesel fuel no. 2, or custom substances specified by RAPID-N users). RAPID-N includes pool fire factors for all regulated substances and it provides an estimator that allows the calculation of PFF for all other substances. Furthermore, RAPID-N has implemented additional models that allow the assessment of the endpoint distance for different values of the target heat radiation, other than the standard heat radiation of 5000 W/m^2, which is the only value for which the RMP guide could provide endpoint distances.

4.1.7.2 TNO point source pool fire model in RAPID-N

RAPID-N has implemented the models that are described in the RMP guide for both boiling and non-boiling flammable liquids. The point source model implemented in RAPID-N also allows the assessment of the endpoint distance for any reference value of the heat radiation. Also, the parameters *Radiative Factor of the Heat of Combustion* and *Atmospheric Transmissivity* become parameters that users may change although the default values set by RAPID-N are the same that the RMP guide suggests (the default *Radiative Factor of the Heat of Combustion* is 0.4 and the default *Atmospheric Transmissivity* is 1).

4.1.7.3 TNO solid surface pool fire model in RAPID-N

This model was added to provide more realistic results for pool fires. The point source model is accurate as long as the pool size is small, but it becomes too conservative when the pool size increases. The reason is that large pool fires generate high quantities of soot that shields part of the energy radiated by the pool. For this reason, a new estimator was added that exploits the solid surface model presented in the TNO Yellow book (van den Bosch and Weterings, 2005). In the solid surface model, the geometry of the pool fire matters. Pool fires are assumed as cylinders with a circular base and a height, which can be tilted by the action of the wind. The heat radiated from the fire is equally distributed on the fire surface and takes into account the presence of soot.

A key parameter is the "view factor" that indicates the portion of the fire surface that is in the line of sight with a potential target at a given distance. It is obtained from the solid angle at which the target sees the flame. In principle, view factors exist for tilted cylinders viewed from any cardinal direction. However, the solid surface model implemented in RAPID-N assumes that wind tilts the cylinder toward the target. This is the most conservative assumption which returns the largest values of the endpoint distance. With the air transmissivity, heat radiative factor (corrected by the presence of soot), and view factor, the amount of heat that is received by a target at a given distance from a fire can be calculated.

The solid surface model utilises complex non-linear equations to calculate the view factor that cannot be easily reversed to obtain the endpoint distance for a given target heat radiation, like the RMP guide did for the point source model. Instead we built an estimator that utilises a numerical method (i.e., Newton's method) to calculate the endpoint distance. Using this estimator, endpoint distances for any values of the target heat radiation can be calculated. The full details of the calculations are available directly in RAPID-N at the property estimator *Distance to endpoint thermal dose for pool fire (TNO Solid Surface Model)*.

4.1.7.4 INERIS pool fire model in RAPID-N

INERIS conducted a study that analysed the existing models for pool fires and proposed a simplified model to assess the endpoint distance of pool fires for French industrial sites that fall under the Seveso directive. The study concluded that for very large pools, the pool size was the main parameter that determined the distance at which a fire was capable of causing damage, while parameters like wind or the type of substance were almost irrelevant for the endpoint distance for low and intermediate values of the heat flux (INERIS, 2006). The study elaborated the safety distances that were already established in a French rule[3]. In the study, three target values of the thermal radiation flow, which correspond to as many levels of damage to the exposed population, were used to assess the damage areas: 3 kW/m^2, 5 kW/m^2, and 8 kW/m^2. In addition to the two correlations provided by the rule for the 3 kW/m^2 and 5 kW/m^2 damage levels, a third correlation was proposed for the 8 kW/m^2 level (new threshold introduced by another French rule[4]). Three correlations were presented, one for every value of the target heat radiation (Equation 9). The correlations apply to large pool fires and are a function of only one parameter known as *Equivalent Pool Length* (the square root of the pool area).

$$r = aK^{0.85}\left(1 - bK^{0.85}\right) \tag{9}$$

where r is the endpoint distance (calculated from the pool centre), K is the equivalent pool length (length of a square with the same area as the area of the pool), a and b are two coefficients (see Table 6). The correlations are valid for pool fires with the equivalent pool length of 300 m or smaller.

Table 6. Coefficients for different valued of heat flux that are used in Equation 9.

Target heat flux	a	b
3 kW/m^2	2.8	2.2×10^{-3}
5 kW/m^2	3.8	3.1×10^{-3}
8 kW/m^2	2.25	1.8×10^{-3}

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[3] Circulaire du 09/11/89 relative aux ICPE (dépôt ancien de liquide inflammable, Rubrique 253), https://aida.ineris.fr/reglementation/circulaire-091189-relatice-icpe-depot-ancien-liquide-inflammable-rubrique-253

[4] Arrêté du 22 octobre 2004 relatif aux valeurs de référence de seuils d'effets des phénomènes accidentels des installations classes, https://www.legifrance.gouv.fr/jorf/id/JORFTEXT000000238461

4.1.8 RMP BLEVE modelling

Boiling Liquid Expanding Vapour Explosions (BLEVEs) are special types of explosions that involve gases liquefied under pressure. When the flammable substance is released into the air, the sudden flashing of a portion of the substance generates a cloud of vapour and aerosol. When ignited, the cloud expands and rises in a fireball that releases a large amount of energy in a very short amount of time. The fire burns those who are engulfed by the flames and radiates heat in every direction. In the RMP methodology, BLEVEs are alternative scenarios for flammable gases liquefied under pressure. RMP assumes the BLEVE endpoint distance as the **distance at which the target receives a dose equivalent to a radiant heat of 5 kW/m² for a duration of 40 s**. The equivalent thermal dose is 3,420 $(\mathrm{kW/m^2})^{4/3}\mathrm{s}$. The RMP guide provides a table with the endpoint distances (and the duration) of fireball events for all regulated substances as a function of the quantity of material that is involved. In its technical background, the RMP guide also provides a relationship to calculate the endpoint distance, using the physical properties of the substance (EPA, 1999 - Appendix D). Equation 10 represents the standard and can be used for regulated and non-regulated substances alike:

$$D = \sqrt{\frac{2.2\ \tau_a\ R\ H_c\ m_f^{0.67}}{4\ \pi\ \left[\frac{3420000}{t}\right]^{\frac{3}{4}}}} \tag{10}$$

where *D* is the endpoint distance (in m), τ_a is the atmospheric transmissivity (assumed to be 1), *R* is the radiative factor of heat of combustion (assumed to be 0.4), H_c is the heat of combustion of the substance (in J/kg), m_f is the mass of fuel in the fireball (in kg), and *t* is the fireball duration (in s).

4.1.8.1 RMP BLEVE modelling in RAPID-N

In RAPID-N, BLEVE scenarios are never chosen automatically by the system. Users can manually select BLEVE scenario in the “Create Risk Assessment” page of RAPID-N by adding the property *Fire/Explosion Event* as a risk assessment parameter and selecting the option *BLEVE* (see Section 5.4 for more information on manual data input). RAPID-N incorporates a set of property estimators for BLEVE scenarios that are based on Equations 10 and 11 for the calculation of the endpoint distance. RMP regulated substances all feature a heat of combustion. Users can change the damage criteria by setting a value of the property *Thermal Dose* different from the standard value of 3,420 $(\mathrm{kW/m^2})^{4/3}\mathrm{s}$.

4.2 ADAM

ADAM is a consequence analysis tool also developed by the JRC to assess the physical effects and associated damage of an industrial accident resulting from an unintended release of a hazardous substance (Fabbri et al., 2017). Given an accident scenario, ADAM can model the physical effects occurring during the accident and calculate their impact on the exposed population. The software addresses three groups of accidents: atmospheric dispersion of toxic substances, fires, and explosions. Due to the tool’s high level of sophistication and accuracy, the results obtained with ADAM can support the design of effective safety barriers, the organization of internal and external emergency plans, and the definition of land use around an industrial facility.

ADAM requires knowledge of the type and amount of substance contained in the facility, its physical and storage conditions, the type and mode of rupture (release scenario), the accident duration, the environment around the accident, and the weather conditions. This data composes the set of input parameters that define the consequence scenario and which ADAM utilises. The hazardous substance plays an important role in the accident. Each substance is characterised by specific thermodynamic, fluid mechanic and transport properties, which can significantly influence the extent of the physical effects and toxicological properties that affect the vulnerability of people to the substance. ADAM keeps a substance database with both physical and toxicological properties of hundreds of hazardous substances.

ADAM is composed of three modules, each addressing a different physical problem. Each module provides input to the next. The module *Source Term* (Module 1) determines the hazardous material amount involved in the accident and its evolution with time. The main output of this module consists of the following information: 1) release flow rate and overall amount of the substance, 2) thermodynamic properties of the release, 3) thermodynamic properties of the vessel’s content, 4) jet flow characteristics, 5) rainout calculation, 6) pool evaporation. The module *Physical Effects* (Module 2) contains models for several types of fires, explosions and airborne toxic dispersion. Module 2 determines the footprint of the accident on a map and the maximum distance reached by the accident's physical effects. Module *Vulnerability* (Module 3) determines the level of harm caused by the accident's physical effects (thermal radiation, blast overpressure, or toxic dose) on the exposed population (Fabbri et al., 2018, 2020; Fabbri and Wood, 2019).

ADAM's Modules 1 and 2 have been implemented in RAPID-N and allow a more advanced assessment of the physical effects of Natech accidents. RAPID-N users can now choose ADAM as an alternative to the fast but less detailed RMP methodology for consequence analysis, thereby providing more options to customise the risk analysis and improving the accuracy of the RAPID-N outputs. Use of the ADAM calculation libraries in RAPID-N is described in Section 5.6.

5 Tutorials

In order to demonstrate the data entry and analysis steps that should be followed to perform Natech risk analysis in RAPID-N, several tutorials are provided in this section. The tutorials start with data entry for the basic records required for the risk analysis (e.g., natural hazard event, industrial plants) and are followed by risk analyses ranging from an analysis involving a single plant to an analysis involving multiple plants and plant units. Some steps which are identical in the tutorials are described in detail in the first tutorial explaining the step, but they are also usually repeated in the subsequent tutorials so that each tutorial can be used standalone. Still, it is suggested to follow the tutorials in the given order.

A similar set of tutorials was presented in a previous technical user guide (Girgin and Necci, 2018). There have been important updates since the last document was released, most notably the introduction of the ADAM Module for consequence analysis and an export functionality. For this reason, the tutorials have been updated in this document. This document also includes some additional steps not covered in the previous user guide, such as data entry and use of on-site hazard data.

Nevertheless, the tutorials in this chapter should be used together with the information provided in Girgin and Necci (2018), and in the following sections the interested user is referred frequently to Girgin and Necci (2018) where more detailed information on the different aspects of using RAPID-N can be found.

5.1 Creating natural hazard data

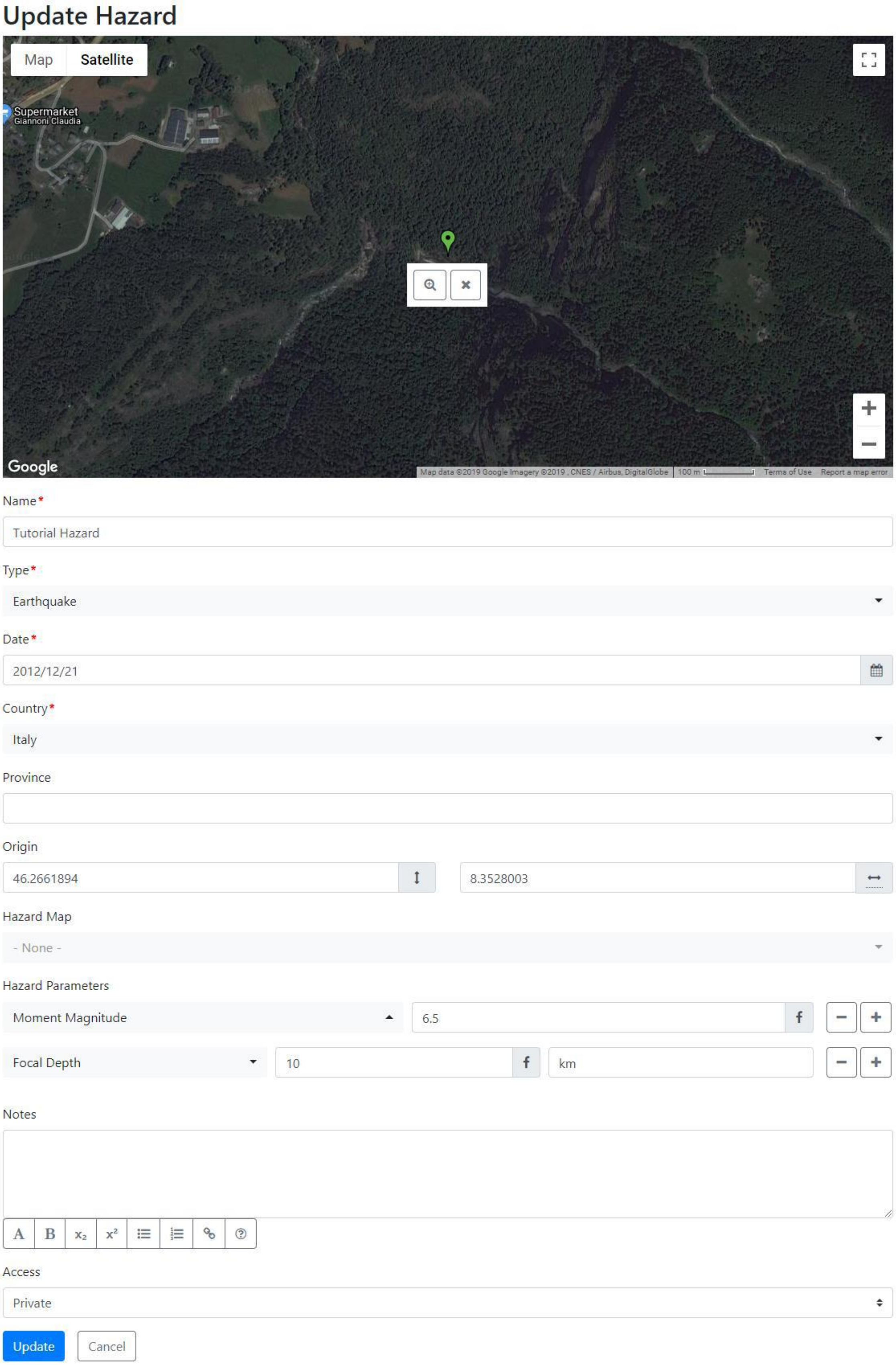
RAPID-N provides a large database of past earthquakes, which is publicly available for Natech risk analysis. However, frequently it is also necessary to define case-specific natural hazard scenarios, which are not limited to historical events and earthquakes. This tutorial demonstrates how a natural hazard event scenario can be entered in the system. The described hazard event is used for the risk analysis tutorials which are provided in the following sections.

The “Hazards” listing page, which is accessible through RAPID-N’s home or personal pages, or from the bottom directory available at each RAPID-N page, lists the available natural hazard records in the system. By clicking on the "Create" button on the listing page you can access the “Create Hazard” page, which displays the natural hazard data entry form.

Remark. Create button
Because only registered users are allowed to create new records, the "Create" button is only available if you sign in to the system. See *User Access and Data Access* sections in Girgin and Necci (2018) for more details.

The natural hazard data entry form is composed of a map from which the geographic location and spatial extent of the natural hazard event can be set, and a series of input elements through which natural hazard event data can be entered. Detailed information on hazard records is given in the *Hazards* section in Girgin and Necci (2018). An example data entry form is shown in Figure 11, which includes the data that will be entered throughout the tutorial. At the end of the tutorial your data entry form should be in a similar state; therefore, you can use the figure to check and validate your data entry steps. Required input is marked with a red asterisk.

Figure 11. Natural hazard data entry form with tutorial data.



Update Hazard

Name*
Tutorial Hazard

Type*
Earthquake

Date*
2012/12/21

Country*
Italy

Province

Origin
46.2661894
8.3528003

Hazard Map
- None -

Hazard Parameters
Moment Magnitude 6.5
Focal Depth 10 km

Notes

Access
Private

For creating natural hazard data, follow these steps:

1. Specify the name of the natural hazard event in the *Name* text input field. For this tutorial, we will use "Tutorial Hazard". If you want you can also indicate another name. Type the name in the input field.
2. Select the type of the natural hazard (e.g., earthquake, flood, landslide, etc.) by using the *Type* drop-down list. Select the "Earthquake" option.
3. Enter the date of the event in the *Date* input field. You can either type the date or choose it from the calendar window by clicking on the "Calendar" icon located at the end of the input field. Select today as the date.

Remark. Time zone
The date should be in the Coordinated Universal Time (UTC). See the *Unit Input* section in Girgin and Necci (2018) for more details on the date inputs.

4. Specify the country of origin by choosing a country from the *Country* drop-down list. Select "Italy".
5. In addition to the country, the province of the origin can also be indicated by using the *Province* text input field. Because it is not mandatory, leave it empty.
6. You can indicate the coordinates of the origin of the natural hazard event in the *Coordinates* input field. You can manually enter the coordinates or select a point on the map, which is located at the top of the data entry form. If you click on a location on the map, a point will be displayed and its coordinates will be automatically entered in the *Coordinates* input field. You can change the coordinates manually by entering new latitude and longitude values, or by dragging and dropping the point on the map to another location. See the *Mapping* section in Girgin and Necci (2018) for a detailed description on how to edit features on the map. For this tutorial, enter 46.2661894 as latitude and 8.3528003 as longitude manually.

Remark. Coordinate format
In addition to the decimal degrees format (e.g., 45.5084), you can also enter the coordinates manually in degrees decimal minutes (e.g., 45 30.504) or degrees minutes seconds (e.g., 45 30 30.24) formats. See the *Data Entry Maps* section for more details.

7. From the *Hazard Map* drop-down list, you can specify the default hazard map of the event, which is by default utilised by the system for the calculation of on-site hazard parameters as indicated in the *Hazards* section in Girgin and Necci (2018). The drop-down list only displays the hazard maps available in the system that are linked to the natural hazard event. Because the natural hazard event does not exist yet (i.e., it has not yet been created), there are no hazard maps available; hence, the list is empty. Select "Default".
8. By using the *Hazard Parameters* input, you can enter the parameters describing the source characteristics of the natural hazard event. Initially, the "No hazard parameters" message will be displayed with an "Add" button indicated by a “plus” icon. By clicking on the "Add" button you can add a new parameter data row to the hazard parameters list. According to the hazard type selected in the *Type* drop-down list, the related properties available in the system will be listed in the *Property* drop-down list of the row. Once you choose a property, additional input elements will be displayed in the same row for entry of the parameter value. You can specify the value and other related information (e.g., measurement unit) of the parameter by using these input elements. By clicking the "Remove" button indicated by a “minus” icon you can remove the parameter data row from the list, or by clicking the "Add" button again you can add a new parameter data row. See the *Properties Input* section in Girgin and Necci (2018) for details of property data entry.

   For this tutorial, you will add two hazard parameters:

   (a) For the first parameter, click on the "Add" button and select the "Moment Magnitude" property from the list which will be displayed in a new row. Once you select the property, a numerical value input box, which supports fuzzy numbers, will be displayed in the same row. Enter 6.5 as the value.

   (b) For the second parameter, click on the "Add" button displayed on the *Moment Magnitude* row. A new row will be added to the list. Select the "Focal Depth" property in the new row. Once you select the property, besides a numerical value entry input similar to the first parameter, a unit input box will also be displayed because focal depth is a numerical property with a reference unit of kilometre. Enter 10 as the value and km as the unit.

Hint. Search box
You can use the inline search box of the *Property* drop-down list to filter the available properties and select the property that you want quickly.

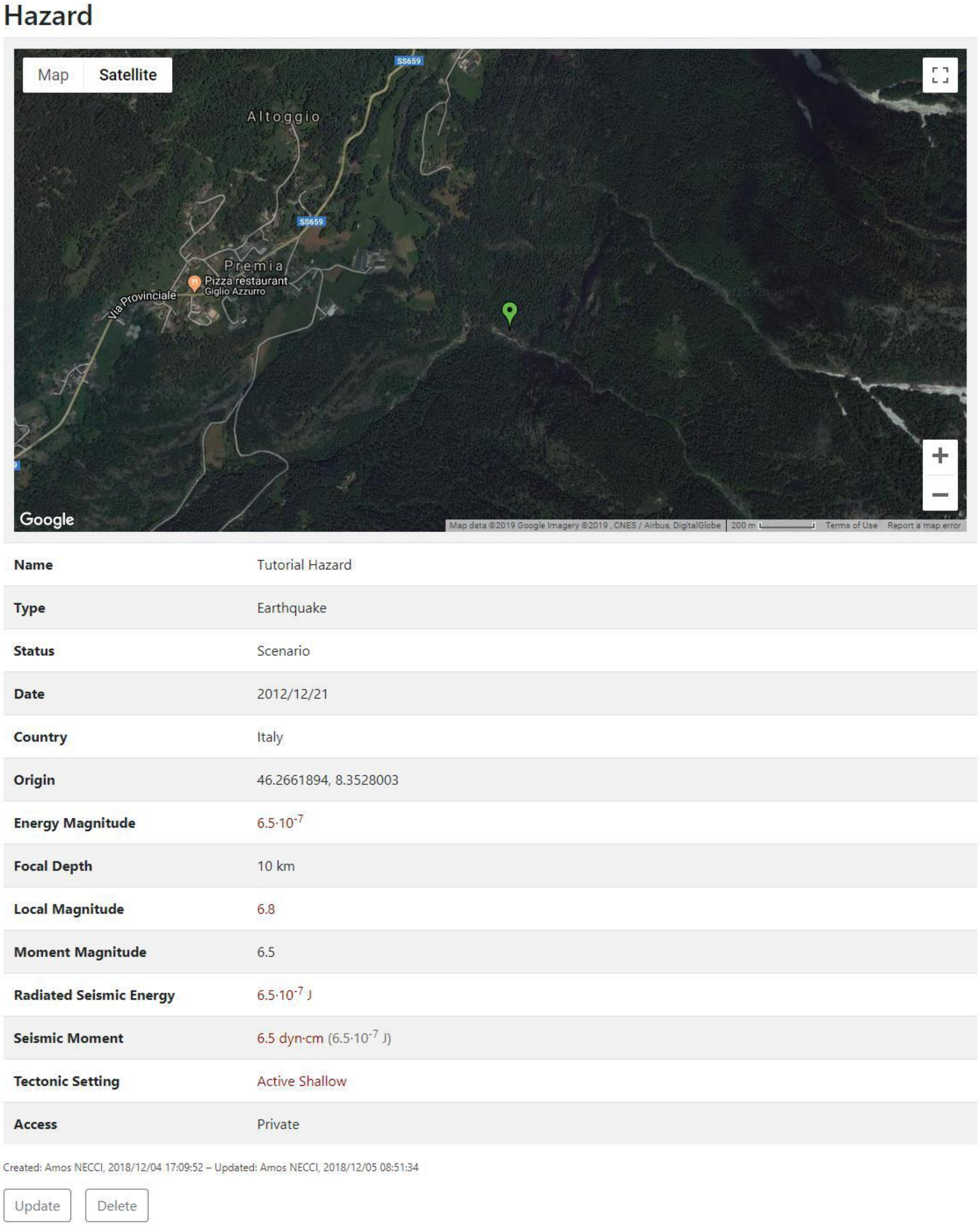
Remark. Available properties
A full listing of the properties with their data types and related reference units is available at the “Properties” listing page.

9. You can specify notes or remarks about the natural hazard event by using the *Notes* wiki input field. For this tutorial, leave it empty.
10. Specify the access level of the natural hazard record by selecting a state from the *Access* drop-down list. Select "Private", which makes the record accessible only to you. See the *Data Access* section in Girgin and Necci (2018) for a detailed description of the available access levels and the access control mechanism of the system.

After all the input data has been entered, click on the "Create" button to complete data entry and save the natural hazard record in the system. The “Create Hazard” page will be closed and replaced with the “Hazard” page, which will display the record information and provide access to associated actions, such as updating or deleting of the record, or creating related records such as hazard maps, on-site hazard data, and risk assessments. The page should be similar to the one shown in Figure 12.

Besides the data that you entered, you will also see additional data related to the event that is estimated by RAPID-N automatically by using its data estimation framework. The estimated data is shown together with the user-defined data but is highlighted in red (Figure 12). By hovering the mouse pointer over the estimated value you can see how the data was estimated (i.e., which property estimator was used). Also, by clicking on the value you can access the “Property Estimator” information page of the associated estimator which provides detailed data on the estimation method. See the *Data Estimation Framework* section in Girgin and Necci (2018) for more details on the data estimation capabilities of RAPID-N.

Figure 12. Natural hazard information page of the tutorial natural hazard event.



Hazard

Name	Tutorial Hazard
Type	Earthquake
Status	Scenario
Date	2012/12/21
Country	Italy
Origin	46.2661894, 8.3528003
Energy Magnitude	$6.5 \cdot 10^{-7}$
Focal Depth	10 km
Local Magnitude	6.8
Moment Magnitude	6.5
Radiated Seismic Energy	$6.5 \cdot 10^{-7}$ J
Seismic Moment	6.5 dyn·cm ($6.5 \cdot 10^{-7}$ J)
Tectonic Setting	Active Shallow
Access	Private

Created: Amos NECCI, 2018/12/04 17:09:52 – Updated: Amos NECCI, 2018/12/05 08:51:34

5.2 Creating industrial plant and plant unit data

RAPID-N requires data on the hazardous installations to assess the Natech risk. This includes information related to the hazardous materials on site and the plant units. Thus, it is necessary to define case-specific industrial plants. This tutorial demonstrates how to create an industrial plant record and how to add the information on plant units located at the plant. The described industrial plant and plant units are used for the risk analysis tutorials provided in the following sections.

5.2.1 Industrial plant

The “Industrial Plants” listing page, which is accessible through RAPID-N’s home or personal pages, or from the bottom directory at each page, lists the available industrial plant records in the system. By clicking on the "Create" button on the listing page, you can access the “Create Industrial Plant” page which displays the industrial plant data entry form.

The industrial plant data entry form is composed of a map, from which you can set the geographic location and draw the boundaries of the plant, and a series of input elements through which you can enter industrial plant data. Detailed information of industrial plant records is given in the *Industrial Plants* section in Girgin and Necci (2018). An example industrial plant data entry form is presented in Figure 13, which includes the data that will be entered throughout the tutorial. At the end of the tutorial, your data entry form should look similar; therefore, you can use the figure to check and validate your data entry steps.

For the tutorial, follow these steps:

1. Specify the name of the industrial plant in the *Name* text input field. For this tutorial, we will use "Tutorial Plant A". If you want, you can indicate another name. Type the name in the input field.
2. The operator of the plant can be selected by pressing the "Select" button in the *Operator* input field and selecting an operator from the “Operators” listing page which will be opened. Because it is not mandatory, leave it empty.
3. Specify the country of the plant by choosing a country from the *Country* drop-down list. Select "Italy".
4. The province of the plant can be indicated by using the *Province* text input field. Because it is not mandatory, leave it empty.
5. The city of the plant can be indicated by using the *City* text input field. Type the city name "Ispra".
6. The address can also be indicated by using the *Address* text input field. Because it is not mandatory, leave it empty.
7. You can indicate the coordinates of the industrial plant in the *Coordinates* input field. You can manually enter the coordinates or select a point on the map, which is located at the top of the data entry form. For this tutorial, enter 45.8095019 as latitude and 8.6319478 as longitude. The map at the top of the page will automatically zoom in on the industrial plant area. A white point and a toolbar will be displayed on the map at the specified location.

   You can use the map toolbar to delineate the industrial plant boundaries. Click on the "Create Geometry" button indicated by a rectangle icon to generate a polygon on the map. Drag and drop the polygon edges to change the polygon shape, so that it resembles the polygon in Figure 13. See the *Mapping* section in Girgin and Necci (2018) for a detailed description on how to edit features on the map.
8. By using the *Properties* input, you can enter the parameters describing the characteristics of the industrial plant. Initially, the "No plant properties" message will be displayed with an "Add" button indicated by a “plus” icon. By clicking on the "Add" button you can add a new parameter data row to the properties list. Once you choose a property, additional input elements will be displayed in the same row for the entry of the parameter value. You can specify the value and other related information (e.g., measurement unit) of the parameter by using these input elements. By clicking the "Remove" button, indicated by a “minus” icon, you can remove the parameter from the list, or by clicking the "Add" button again you can add a new parameter. See the *Properties Input* section in Girgin and Necci (2018) for the details of property data entry.

   For this tutorial, you will add one property:

   Click on the "Add" button and select the "Year of Construction" property from the list. Once you select the property, a numerical value input box will be displayed. Enter 2000 as the value.

Hint. Search box
You can use the inline search box of the *Property* drop-down list to filter the available properties and select the property that you want quickly.

Remark. List of properties
A full listing of the properties with their data types and related reference units is available at the Properties listing page.

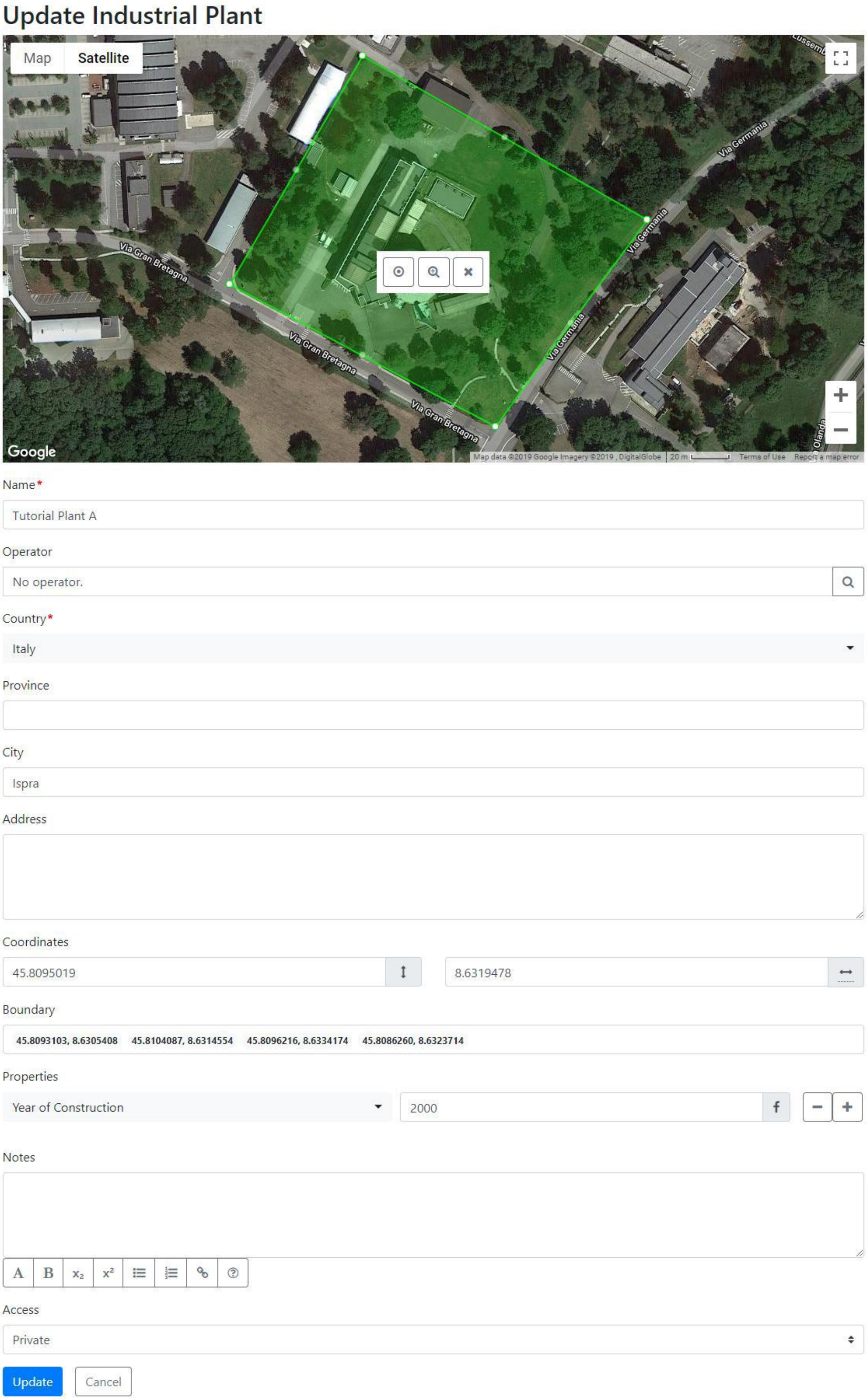
9. You can specify some notes or remarks about the industrial plant by using the *Notes* wiki input field. See the *Wiki Input* section in Girgin and Necci (2018) for more details on wiki inputs. For this tutorial, leave it empty.

After all the input data has been entered, click on the "Create" button to complete data entry and save the industrial plant record in the system. The “Create Industrial Plant” page will be closed and replaced with the “Industrial Plant” page, which will display the record information and provide access to associated actions, such as updating or deleting of the record, or creating related records (i.e., plant units, on-site hazard data, Natechs and risk analyses). The page should look similar to the one shown in Figure 14.

Besides the data that you entered, you will also see additional data related to the event that is estimated automatically by RAPID-N by using the data estimation framework. The estimated data is shown together with the user-defined data, but highlighted in red (Figure 14). By hovering the mouse pointer over the estimated value you can see how the data was estimated (i.e., which property estimator was used). Also, by clicking on the value, you can access to the “Property Estimator” information page of the related estimator which provides detailed data on the estimation method. See the *Data Estimation Framework* section in Girgin and Necci (2018) for more details on the data estimation capabilities of the system. The map shows the industrial plant location and boundaries in a vivid green, while pre-existing plant units already in the RAPID-N database are depicted in red. At this point, you should not be able to see any red polygons at the plant.

Remark. Other industrial plants
Other industrial plants already existing in the RAPID-N database that are either public or created by your user account may be present in the same area shown by the map. They are also reported, as well as their boundaries, in a paler shade of green compared to the current industrial plant.

Figure 13. Industrial plant data entry form with tutorial data.



Update Industrial Plant

Name*

Tutorial Plant A

Operator

No operator.

Country*

Italy

Province

City

Ispra

Address

Coordinates

45.8095019 8.6319478

Boundary

45.8093103, 8.6305408 45.8104087, 8.6314554 45.8096216, 8.6334174 45.8086260, 8.6323714

Properties

Year of Construction 2000

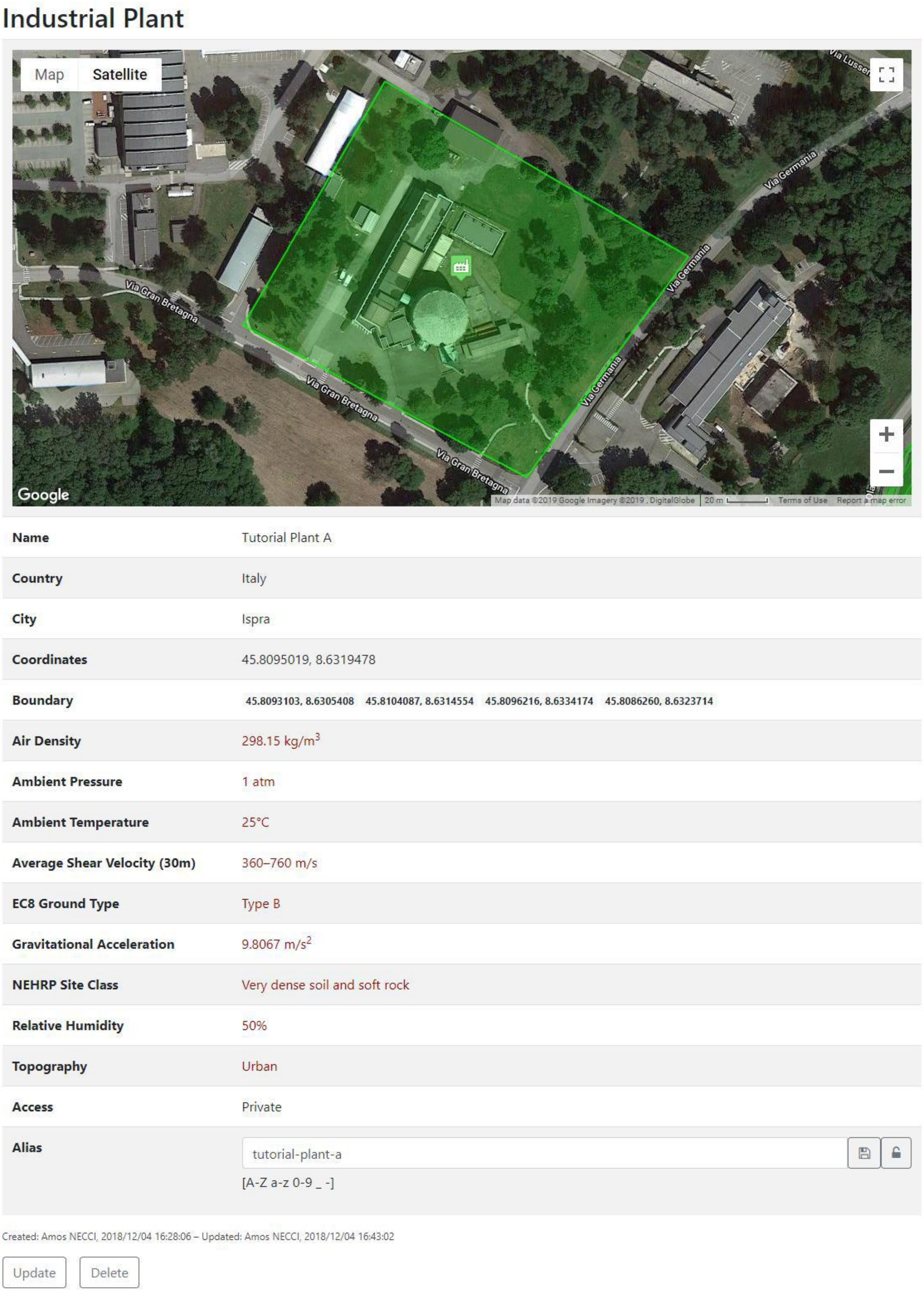
Notes

Access

Private

Update Cancel

Figure 14. Industrial plant information page.



Industrial Plant

Name	Tutorial Plant A
Country	Italy
City	Ispra
Coordinates	45.8095019, 8.6319478
Boundary	45.8093103, 8.6305408 45.8104087, 8.6314554 45.8096216, 8.6334174 45.8086260, 8.6323714
Air Density	298.15 kg/m^3
Ambient Pressure	1 atm
Ambient Temperature	25°C
Average Shear Velocity (30m)	360–760 m/s
EC8 Ground Type	Type B
Gravitational Acceleration	9.8067 m/s^2
NEHRP Site Class	Very dense soil and soft rock
Relative Humidity	50%
Topography	Urban
Access	Private
Alias	tutorial-plant-a [A-Z a-z 0-9 _ -]

Created: Amos NECCI, 2018/12/04 16:28:06 – Updated: Amos NECCI, 2018/12/04 16:43:02

Update Delete

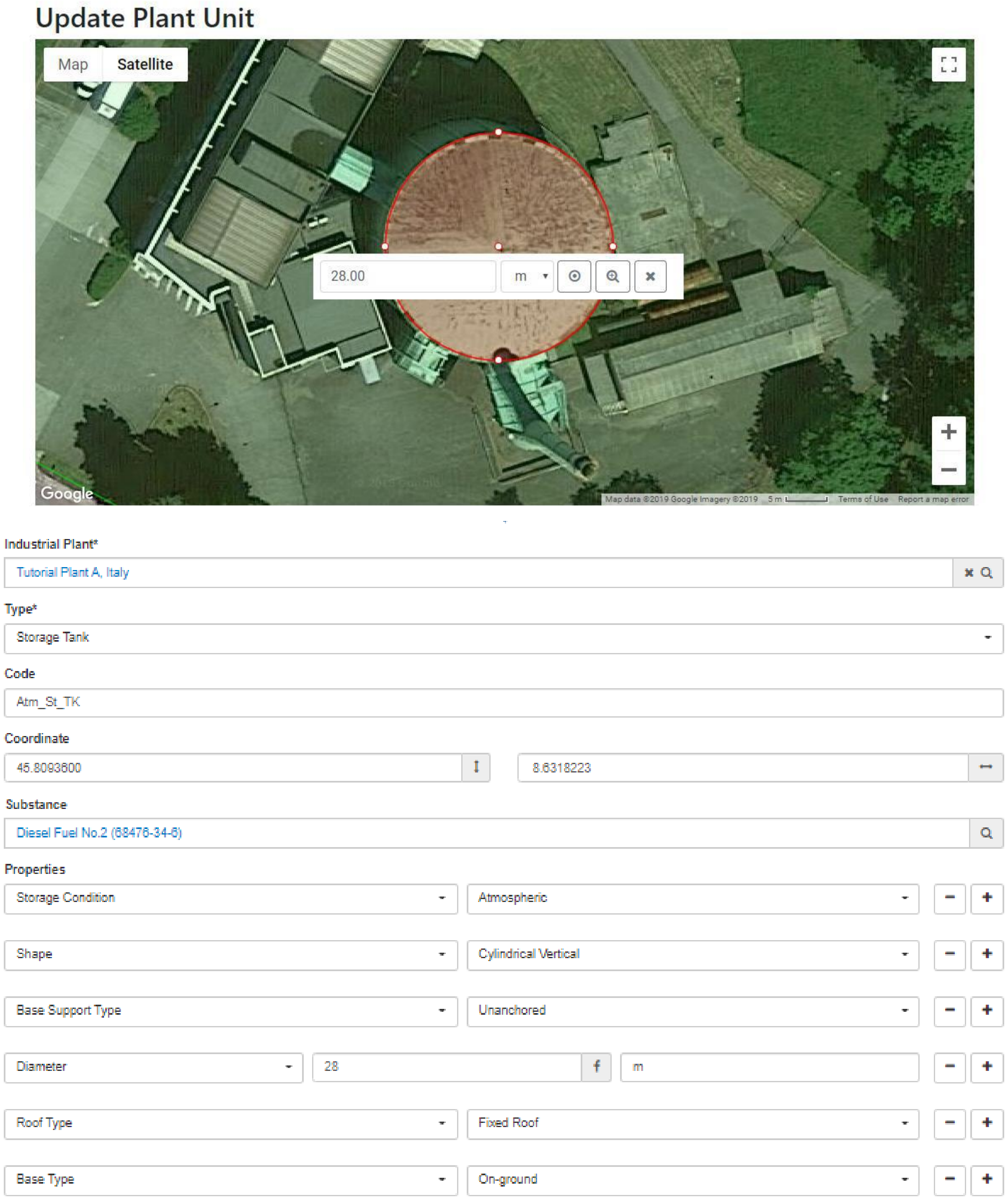
5.2.2 Plant units

You can add plant units to the current industrial plant record directly from the “Industrial Plant” page. Initially, the "No plant units" message will be displayed under the *Plant Units* section on the page. By clicking on the

"Create" button under the *Plant Units* section, you can access the "Create Plant Unit" page, which displays the plant unit data entry form.

The plant unit data entry form is composed of a map, from which you can view the associated industrial plant boundaries and draw the shape of the plant unit, and a series of input elements through which you can enter plant unit data. Detailed information on plant unit records is given in the *Plant Units* section in Girgin and Necci (2018). An example plant unit data entry form is shown in Figure 15, which includes the data that will be entered throughout the tutorial for one of the plant units. At the end of the tutorial your data entry form should look similar; therefore, you can use the figure to check and validate your data entry steps.

Figure 15. Plant unit data entry form with tutorial data.



Update Plant Unit

Industrial Plant*: Tutorial Plant A, Italy

Type*: Storage Tank

Code: Atm_St_TK

Coordinate: 45.8093800 | 8.6318223

Substance: Diesel Fuel No.2 (68476-34-6)

Properties

Storage Condition	Atmospheric
Shape	Cylindrical Vertical
Base Support Type	Unanchored
Diameter	28 m
Roof Type	Fixed Roof
Base Type	On-ground

For this tutorial, you will add two plant units: one atmospheric storage tank containing diesel fuel and one stack.

For the data entry of the first unit, follow these steps:

1. Select the type of the plant unit (e.g., storage tank, reactor, pump, etc.) by using the *Type* drop-down list. Select the "Storage Tank" option.
2. Specify a code for the plant unit in the *Code* text input field. For this tutorial, we will use "Atm_St_TK". If you want, you can indicate another code. Type the code in the input field.
3. On the map located at the top of the page, click on the centre of the big tank within the facility boundaries to set the plant unit coordinates. A white point and a toolbar will be displayed on the map at the clicked location. The *Coordinate* text input fields will be automatically filled. See the *Mapping* section in Girgin and Necci (2018) for a detailed description on how to edit features on the map.
4. The substance can be indicated by pressing the "Select" button in the *Substance* input field to open the "Substances" listing page. Search the substance by using the provided filters as described in the *Data Query and Listing* section in Girgin and Necci (2018) and select "Diesel Fuel No.2" from the substance list. You can use `Diesel` as the keyword to find it quickly.
5. By using the *Properties* input, you can enter the parameters describing the characteristics of the plant unit. Initially, the "No plant unit properties" message will be displayed with an "Add" button indicated by a "plus" icon. By clicking on the "Add" button you can add a new parameter data row to the properties list. According to the plant unit type selected in the *Type* drop-down list, the related properties available in the system will be listed in the row. Once you choose a property, additional input elements will be displayed in the same row for the entry of the parameter value. You can specify the value and other related information (e.g. measurement unit) of the parameter by using these input elements. By clicking the "Remove" button, indicated by a "minus" icon, you can remove the parameter from the list, or by clicking the "Add" button again you can add a new parameter. See the *Properties Input* section in Girgin and Necci (2018) for the details of property data entry.

   For this unit, you will add six properties:

   (a) Click on the "Add" button and select the "Shape" property from the list. Once you select the property, a drop-down input box will be displayed. Select the option "Cylindrical Vertical".

   (b) Click on the "Add" button and select the "Base Support Type" property from the list. Once you select the property, a drop-down input box will be displayed. Select the option "Unanchored".

   (c) Click on the "Add" button and select the "Roof Type" property from the list. Once you select the property, a drop-down input box will be displayed. Select the option "Fixed Roof".

   (d) Click on the "Add" button and select the "Base Type" property from the list. Once you select the property, a drop-down input box will be displayed. Select the option "On-ground".

   (e) Click on the "Add" button and select the "Storage Condition" property from the list. Once you select the property, a drop-down input box will be displayed. Select the option "Atmospheric".

   (f) Click on the "Add" button and select the "Diameter" property from the list. Once you select the property, a numerical value input box (which supports fuzzy numbers) and a unit input box will be displayed. Enter "28" as the value and "m" as the unit. A circle is automatically drawn on the map around the unit coordinate, matching the given diameter.

Remark. Mandatory properties

This is the **minimum number of properties needed** to describe a plant unit of this type. You can add many more properties in this manner, for instance, the height of the tank, the internal pressure, the filling percentage, etc. The more properties are provided, the more realistic are the results. If users do not enter any additional properties, all properties needed to complete the set of data of the unit will be estimated by the system and they will appear in red in the "Plant Unit" data page.

Hint. Search box

You can use the inline search box of the *Property* drop-down list to filter the available properties and select the property that you want quickly.

Remark. List of properties
A full listing of the properties with their data types and related reference units is available at the "Properties" listing page.

6. You can use the map toolbar on the map to modify the plant unit shape and ensure a perfect fit with the satellite image. You can drag and drop at any point inside the circle to move it. You can also drag and drop the points displayed on the circle to change its size (i.e., diameter). See the *Mapping* section in Girgin and Necci (2018) for a detailed description on how to edit features on the map.
7. You can specify some notes or remarks about the plant unit by using the *Notes* wiki input field. For this tutorial, leave it empty.

After all the input data has been entered, click on the "Create" button to complete data entry and save the plant unit record in the system. The "Create Plant Unit" page will be closed and replaced with the "Industrial Plant" page displayed initially. A table listing the plant units of the plant is now available in the *Plant Units* section on that page. Currently, the table contains only one record row, which describes the plant unit you just created.

For the data entry of the second unit, follow these steps:

1. Select the type of the plant unit (e.g., storage tank, reactor, pump, etc.) by using the *Type* drop-down list. Select the "Stack" option.
2. Specify a code for the plant unit in the *Code* text input field. For this tutorial, we will use "Stk". If you want, you can indicate another name. Type the name in the input field.
3. Click at the base of the chimney within the facility boundaries to set the plant unit coordinates. A white point and a toolbar will be displayed on the map at the coordinate location. The *Coordinate* text input fields will be automatically filled.
4. The substance can be indicated by pressing the "Select" button in the *Substance* input field, to open the "Substances" listing page. Since the stack is not supposed to contain any hazardous material, leave it empty.
5. By using the *Properties* input, you can enter the parameters describing the characteristics of the plant unit as you did for the first plant unit before.

   For this unit, you will add two properties:

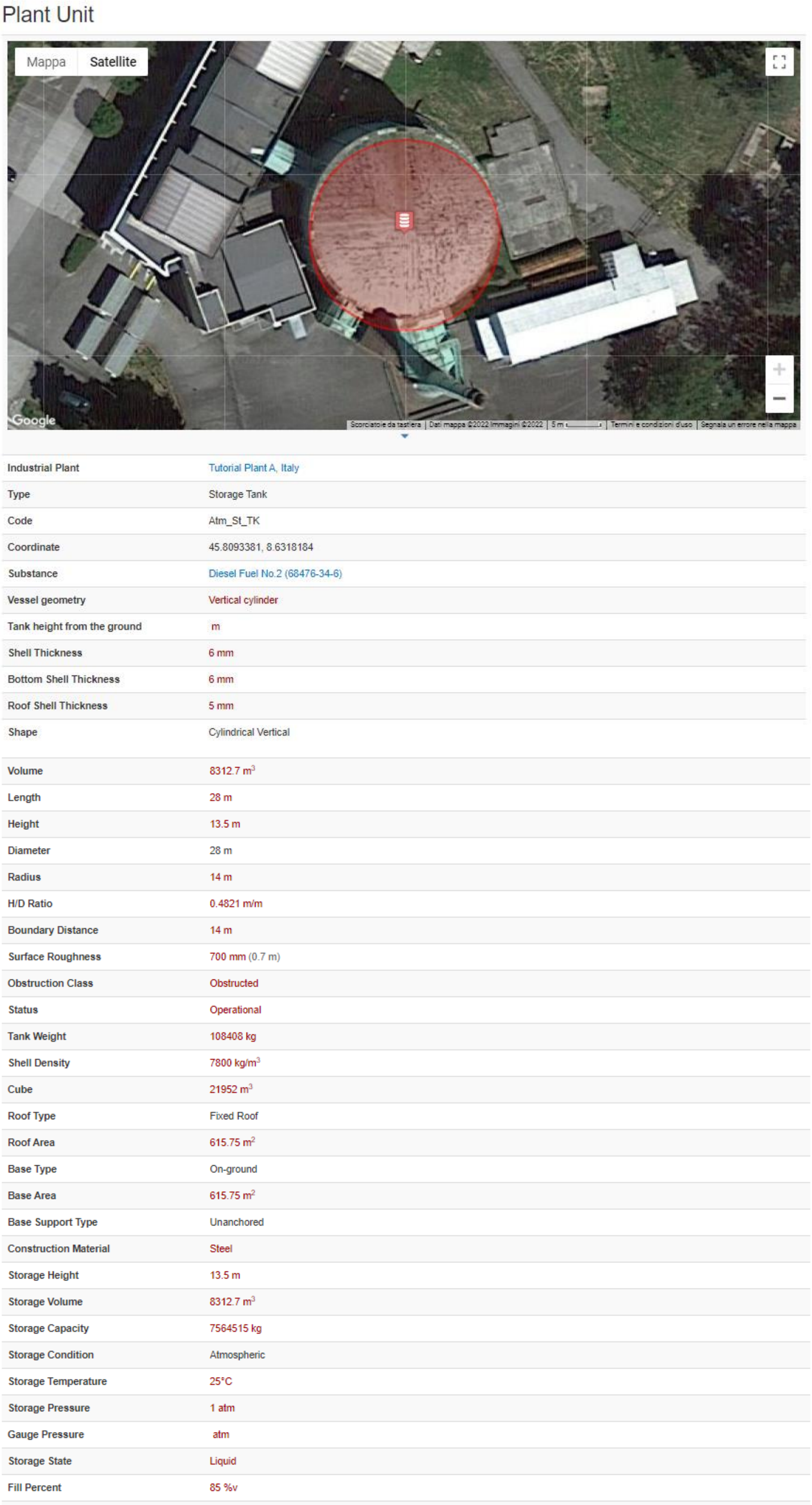
   (a) Click on the "Add" button and select the "Shape" property from the list. Once you select the property, a drop-down input box will be displayed. Select the option "Cylindrical Vertical".

   (b) Click on the "Add" button and select the "Diameter" property from the list. Once you select the property, a numerical value input box (which supports fuzzy numbers) and a unit input will be displayed. Enter "5" as the value and "m" as the unit. A circle is automatically drawn around the unit coordinate, matching the given diameter.
6. You can use the map toolbar on the map to modify the plant unit shape and ensure a perfect fit with the satellite image as you did for the first plant unit.
7. You can specify some notes or remarks about the plant unit by using the *Notes* wiki input field. For this tutorial, leave it empty.

After all the input data has been entered, click on the "Create" button to complete data entry and save the plant unit record in the system. The "Create Plant Unit" page will be closed and replaced with the "Industrial Plant" page displayed initially. The plant units table now contains two record rows, which describe the plant units you created in the tutorial.

If you click on one of the two plant units listed, the system will open the "Plant Unit" page (Figure 16), which will display the record information and provide access to associated actions, such as updating or deleting of the record, or creating related records. In this page, you may notice that the properties that you have entered are marked in black. Besides the data that you entered you will also see additional data related to the selected plant unit. These records are marked in red and are estimated by RAPID-N automatically by using the data estimation framework. The estimated data is shown together with the user-defined data. By hovering the mouse pointer over the estimated value you can see how the data was estimated (i.e., which property estimator was used). Also, by clicking on the value, you can access to the "Property Estimator" information page of the related estimator which provides detailed data on the estimation method. The map shows the plant unit location and shape in red.

Figure 16. Plant unit data page.



Plant Unit

Industrial Plant	Tutorial Plant A, Italy
Type	Storage Tank
Code	Atm_St_TK
Coordinate	45.8093381, 8.6318184
Substance	Diesel Fuel No.2 (68476-34-6)
Vessel geometry	Vertical cylinder
Tank height from the ground	m
Shell Thickness	6 mm
Bottom Shell Thickness	6 mm
Roof Shell Thickness	5 mm
Shape	Cylindrical Vertical
Volume	8312.7 m^3
Length	28 m
Height	13.5 m
Diameter	28 m
Radius	14 m
H/D Ratio	0.4821 m/m
Boundary Distance	14 m
Surface Roughness	700 mm (0.7 m)
Obstruction Class	Obstructed
Status	Operational
Tank Weight	108408 kg
Shell Density	7800 kg/m^3
Cube	21952 m^3
Roof Type	Fixed Roof
Roof Area	615.75 m^2
Base Type	On-ground
Base Area	615.75 m^2
Base Support Type	Unanchored
Construction Material	Steel
Storage Height	13.5 m
Storage Volume	8312.7 m^3
Storage Capacity	7564515 kg
Storage Condition	Atmospheric
Storage Temperature	25°C
Storage Pressure	1 atm
Gauge Pressure	atm
Storage State	Liquid
Fill Percent	85 %v

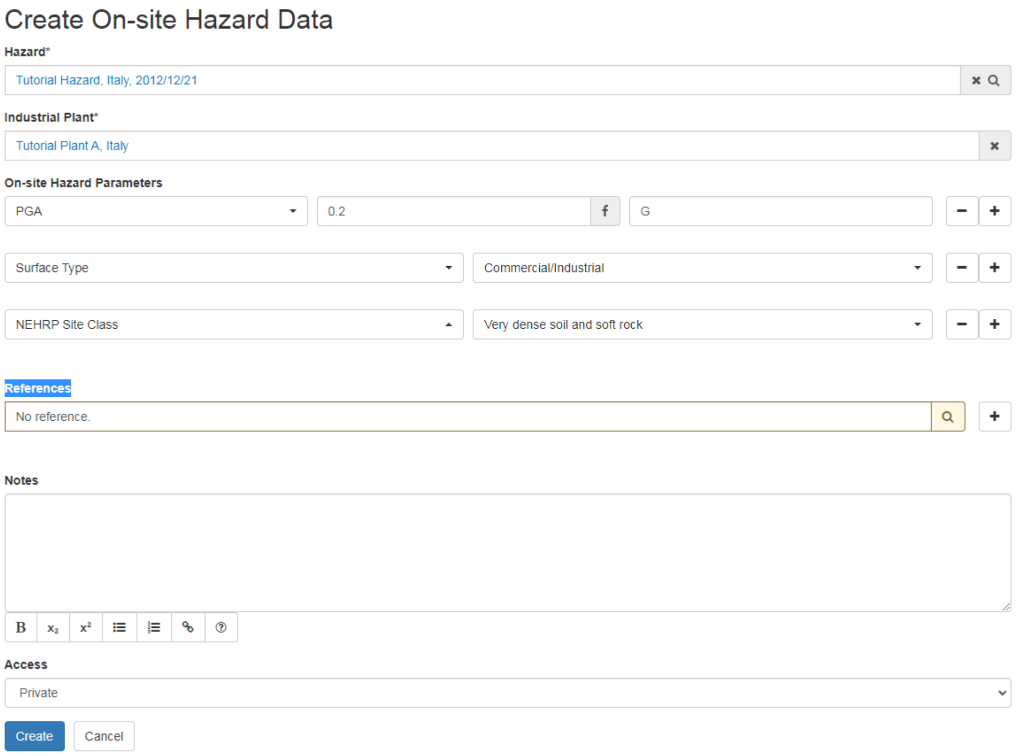
5.2.3 On-site hazard data (optional)

Every plant can have several on-site hazard data records, each one for a different natural hazard that affects the site. On-site hazard data are used to assign a set of specific properties that concern the natural hazards for the plant site. The properties can be intensity parameters of the natural hazard (e.g., *Peak Ground Acceleration*, *Spectral Acceleration*) or other properties that assist in the calculation of the intensity parameters (e.g., *Ground Layer Depth*). **The values assigned to properties using on-site hazard data will replace the existing values assigned to all the plant units belonging to the current plant record via the natural hazard record (either using estimators or hazard maps).**

You can add on-site hazard data to the current industrial plant record directly from the “Industrial Plant” page. Initially, the "No on-site hazard data" message will be displayed under the *On-site Hazard Data* section on the page. By clicking on the "Create" button under the *On-site Hazard Data* section, you can access the “Create On-site Hazard Data” page, which displays the on-site hazard data entry form (Figure 17). For this tutorial, you will add on-site hazard parameters to the current plant record for one reference natural hazard. For the data entry of the on-site hazard parameters, follow these steps:

1. Select a hazard record which will be used to define the natural hazard event to which the current on-site hazard parameter will apply. Click on the "Select" button in the hazard input to open the “Hazards” listing page. Search for the hazard record named "Tutorial Hazard" (see Section 5.1) and once the search results are displayed, select it from the listing table by clicking on its name.
2. Click on the "Add" button in the *On-site Hazard Parameters* section. Select the property "Peak Ground Acceleration" from the drop-down list. Type "0.2" in the value field and "G" in the unit field.
3. Click on the "Add" button in the *On-site Hazard Parameters* section. Select the property "Surface Type" from the drop-down list. Select “Commercial/Industrial” from the drop-down menu.
4. Click on the "Add" button in the *On-site Hazard Parameters* section. Select the property "NEHRP Site Class" from the drop-down list. Select “Very dense soil and soft rock” from the drop-down menu.
5. You can add an existing reference or add a new one (“Select” or “Add” buttons in the Reference input) to specify data sources or add comments using the *Notes* wiki input field. For this tutorial, leave both empty.
6. Click on the "Create" button to save the on-site hazard data record and perform the analysis.

Figure 17. On-site hazard data creation page.



Create On-site Hazard Data

Hazard*

Tutorial Hazard, Italy, 2012/12/21

Industrial Plant*

Tutorial Plant A, Italy

On-site Hazard Parameters

PGA | 0.2 | G

Surface Type | Commercial/Industrial

NEHRP Site Class | Very dense soil and soft rock

References

No reference.

Notes

Access

Private

5.3 Single plant Natech risk analysis with default parameters

A risk analysis involving a single plant can be a useful tool for plant operators and engineering companies to identify Natech hazards and quantify Natech risks. It can also be useful for public authorities that want to investigate the Natech risks of a hazardous site in their territory.

In this tutorial, the users will learn the basics of Natech risk analysis by using RAPID-N and following a step-by-step guided procedure. The resources needed for this exercise are composed of a natural hazard record named "Tutorial Hazard" and an industrial plant record named "Tutorial Plant A". Sections 5.1 (Creating natural hazard data) and 5.2 (Creating industrial plant and plant unit data) provide detailed instructions on how to create these records.

5.3.1 Data entry

For the data entry and analysis, follow these steps:

1. From the RAPID-N home or personal pages, click on the "Risk Analyses" icon to access the “Risk Analyses” listing page.
2. Click on the "Create" button in the toolbar to open the “Create Risk Analysis” page.
3. Choose a name for your risk analysis case study and type it in the name input field. For this tutorial, use the name "Tutorial Risk Analysis 1".
4. You must select a hazard record, which will be used to define the triggering natural hazard event. Click on the "Select" button in the hazard input to open the “Hazards” listing page. Search for the hazard record named "Tutorial Hazard" and once the search results are displayed, select it from the listing table by clicking on its name. The hazard record you selected is the tutorial hazard record that you created previously, which is a scenario earthquake with a moment magnitude of 6.5 and focal depth of 10 km, having an epicentre that is approximately 60 km away from the case-study plant.
5. You can choose one of the hazard maps related to the hazard, which will provide pre-calculated on-site hazard parameters for the analysis. If left as "Default", RAPID-N will use the default hazard map specified in the hazard record. Leave it as "Default".

Remark. Estimation of on-site hazard parameters
If no default hazard map is specified in the natural hazard record or the *Enable Hazard Maps* risk analysis property is set as disabled, the system will use other methods (i.e., on-site hazard data records or data estimation by using property estimators) to calculate the on-site hazard parameters.

Remark. Use of a hazard map
Use of a hazard map does not limit the calculation of on-site parameters to the parameters that are available in the hazard map. RAPID-N uses the available parameters to estimate additional ones by utilising the data estimation framework.

6. You can choose a specific industrial plant for the analysis or let RAPID-N identify and consider all the plants located in the natural hazard area based on the specified cut-off radius. For this tutorial, you must select a case-study plant. Click on the "Select" button in industrial plant input to open the "Industrial Plants" listing page. Search for the industrial plant named "Tutorial Plant A" and select it from the list by clicking its name.
7. At this point, by clicking the names of the hazard and industrial plant you can access associated information pages, which provide detailed information on the hazard and industrial plant, respectively.
8. By using the *Plant Unit* drop-down list, you can choose whether the analysis should consider all plant units located at the plan or whether it should focus only on a specified single plant unit. For this tutorial, select All.
9. You can specify custom on-site hazard parameters which should be considered for the analysis by entering them manually in the *On-Site Hazard Parameters* section. For this tutorial, do not add any on-site hazard parameters.

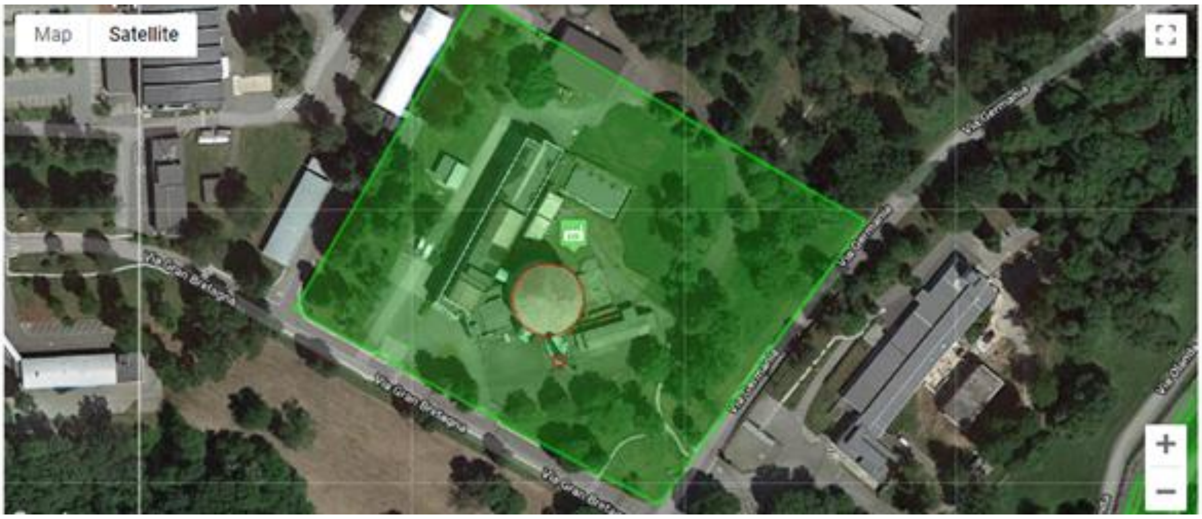
10. You can specify *Risk Analysis Parameter* which allows you to customise the risk analysis calculations. For this tutorial, our aim is to perform a simple risk analysis. Therefore, we will let RAPID-N use the default parameters by not entering any custom parameters. Leave the *Risk Analysis Parameters* input empty.
11. Click on the "Create" button to save the risk analysis record and perform the analysis.

RAPID-N will collect all necessary data, estimate missing ones, and assess natural hazard impact, possible Natech scenarios, and related consequences for the plant units located at the specified industrial plant. At the end of the analysis, an analysis report and a risk map will be displayed.

5.3.2 Results of the risk analysis

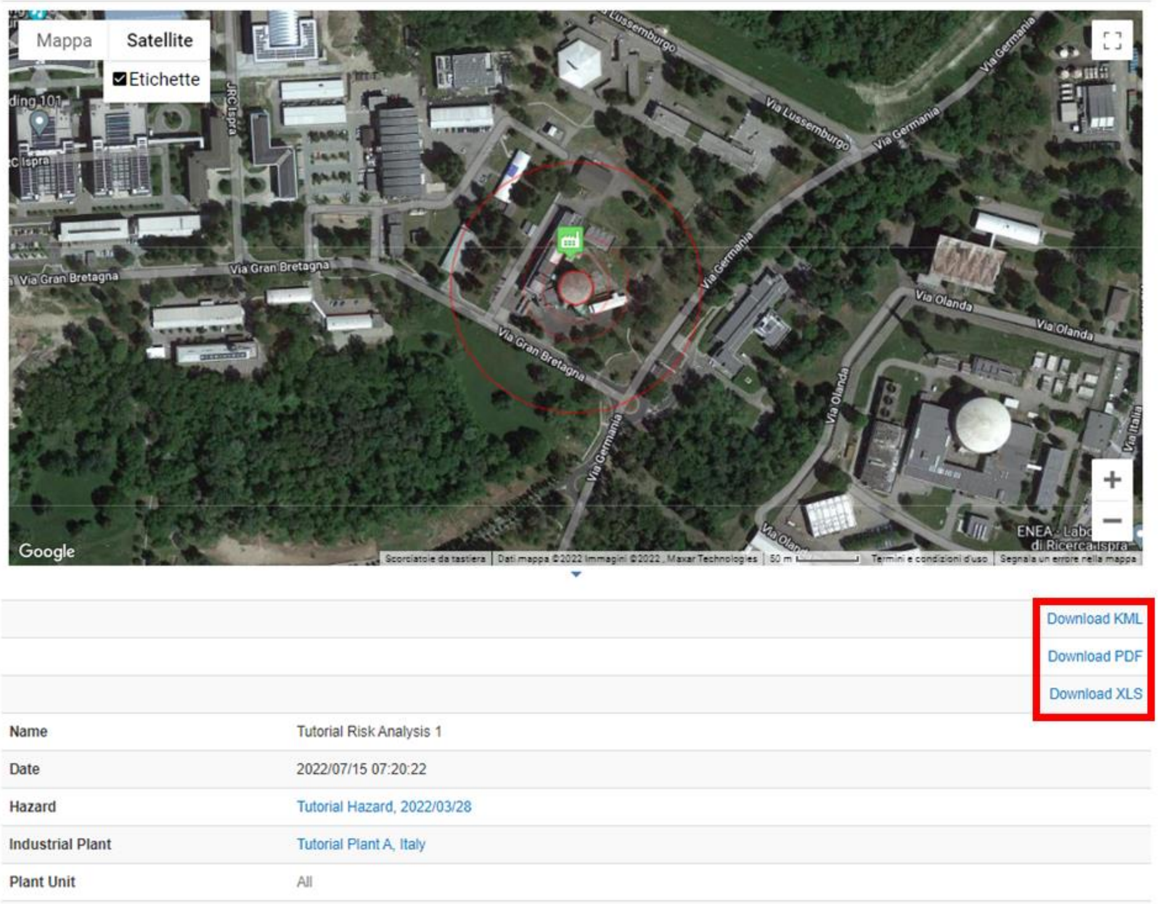
The Tutorial Plant is a very simple plant. It is composed of only two units: an unanchored atmospheric storage tank and a stack identified as "Atm_St_TK" and "Stk" respectively. If you did not select any on-site hazard parameters for the creation of the plant and plant unit data (see section 5.2.3), the resulting map will resemble Figure 18.

Figure 18. Tutorial plant and plant units.



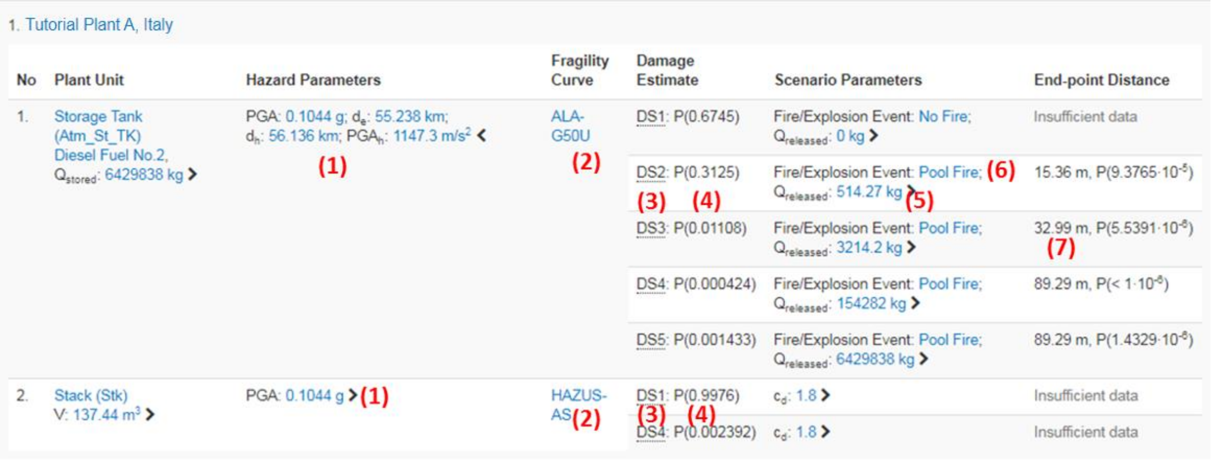
The risk analysis map and summary is given in Figure 19, whereas Figure 20 shows the associated analysis report. Endpoint distances are represented as circles around each damaged unit.

Figure 19. Risk analysis map.



Name	Tutorial Risk Analysis 1
Date	2022/07/15 07:20:22
Hazard	Tutorial Hazard, 2022/03/28
Industrial Plant	Tutorial Plant A, Italy
Plant Unit	All

Figure 20. Risk analysis results report.



1. Tutorial Plant A, Italy

No	Plant Unit	Hazard Parameters	Fragility Curve	Damage Estimate	Scenario Parameters	End-point Distance
1.	Storage Tank (Atm_St_TK) Diesel Fuel No.2, Q_{stored}: 6429838 kg >	PGA: 0.1044 g; d_e: 55.238 km; d_h: 56.136 km; PGA_h: 1147.3 m/s² < (1)	ALA-G50U (2)	DS1: P(0.6745)	Fire/Explosion Event: No Fire; $Q_{released}$: 0 kg >	Insufficient data
				DS2: P(0.3125) (3) (4)	Fire/Explosion Event: Pool Fire; (6) $Q_{released}$: 514.27 kg > (5)	15.36 m, P($9.3765 \cdot 10^{-5}$)
				DS3: P(0.01108)	Fire/Explosion Event: Pool Fire; $Q_{released}$: 3214.2 kg >	32.99 m, P($5.5391 \cdot 10^{-6}$) (7)
				DS4: P(0.000424)	Fire/Explosion Event: Pool Fire; $Q_{released}$: 154282 kg >	89.29 m, P(< $1 \cdot 10^{-6}$)
				DS5: P(0.001433)	Fire/Explosion Event: Pool Fire; $Q_{released}$: 6429838 kg >	89.29 m, P($1.4329 \cdot 10^{-6}$)
2.	Stack (Stk) V: 137.44 m³ >	PGA: 0.1044 g > (1)	HAZUS-AS (2)	DS1: P(0.9976) (3) (4)	c_d: 1.8 >	Insufficient data
				DS4: P(0.002392)	c_d: 1.8 >	Insufficient data

Hazard impact/exposure

RAPID-N calculated the earthquake intensity parameters at the plant, more specifically at the location of the two units. The calculated intensity is expressed as peak ground acceleration (PGA), and it is equal to 0.1044 g for both units (indicated under (1) in Figure 20). The intensity is the same for both units, because they are located next to each other. For units scattered around a large facility, or many facilities, the results might be different.

Note that this result is obtained using RAPID-N property estimators. If the user has followed the optional tutorial in Section 5.2.3 and set a peak ground acceleration value using on-site hazard data, this will be used instead. In that case, the value of the peak ground acceleration shown in the report would be 0.2 g. This will affect the damage and Natech probabilities as well, which would be different from the values shown in Figure 20 and the following text.

Damage assessment

RAPID-N chose a fragility curve for each unit (see (2) in Figure 20) and calculated the probable damage. The atmospheric storage tank has 5 damage states (DS1: None, DS2: Minor, DS3: Moderate, DS4: Extensive, and DS5: Complete), while the stack has only 2 (DS1: None, and DS4: Extensive) (indicated by (3) in Figure 20).

Damage probability

Based on the fragility curves, for the atmospheric storage tank the probability of damage is 31% for DS2, about 1.1% for DS3 and much lower for DS4 and DS5 (see (4) in Figure 20). The probability of damage to the stack is very small (0.2%).

One may conclude that for this hazard scenario minor damage to the tank is likely, moderate damage is unlikely and extensive or complete damage are extremely rare. Extensive damage to the stack is also improbable.

Consequences

The severity of the consequences can be directly related to the level of physical damage, i.e., to the damage state. The higher the damage, the higher the amount of hazardous substance released. In this case, the amount of fuel (diesel) released varies between 500 kg for minor damage to more than six thousand tons in case of complete damage (see (5) in Figure 20). As the fuels and chemicals are often valuable products, their accidental loss is not only a safety concern but also an immediate cost to the business.

The storage tank shows consequences of the "Pool Fire" type, as it contains a liquid fuel that may ignite if released (indicated by (6) in Figure 20). In case the fuel spill ignites, the resulting fire can affect humans as far as 15.4 m away in case of minor tank damage and as far as 89 m away in case of complete damage (see (7) in Figure 20). Damage classes DS4 (Extensive) and DS5 (Complete) result in the same end-point distance, as the size of the fire is supposed to be limited by a containment dike. The values of the endpoint distances would indeed be different should we remove the containment dikes. Natech probabilities are also shown next to the endpoint distances. In this scenario, Natech probabilities have taken into account the occurrence of release and ignition after the damage and are therefore much lower than the damage probabilities. See Section 3.4.3 for more details on how Natech probabilities are calculated.

The stack does not contain any hazardous material. Thus, in case of damage it does not have any direct consequence aside from the repair/rebuilding costs. **The absence of hazardous materials means that RAPID-N cannot perform the Natech risk analysis which is indicated in the risk analysis results as "Insufficient Data" (Figure 20).** Nevertheless, in this case RAPID-N conducts the earthquake damage analysis for the respective equipment which can already provide useful information for prevention purposes. Also, there were past cases which involved secondary damage to plant units due to impact of debris from collapsed stacks (Girgin, 2011). Hence, such non-hazardous units might be included into domino scenarios, especially if the damage probability is high.

5.3.3 Export functionality

The risk analysis results obtained by RAPID-N can be downloaded via a dedicated export functionality (indicated by the red box at the right hand side of Figure 19). The two outcomes of the risk analysis, the map and the analysis report, are downloaded separately.

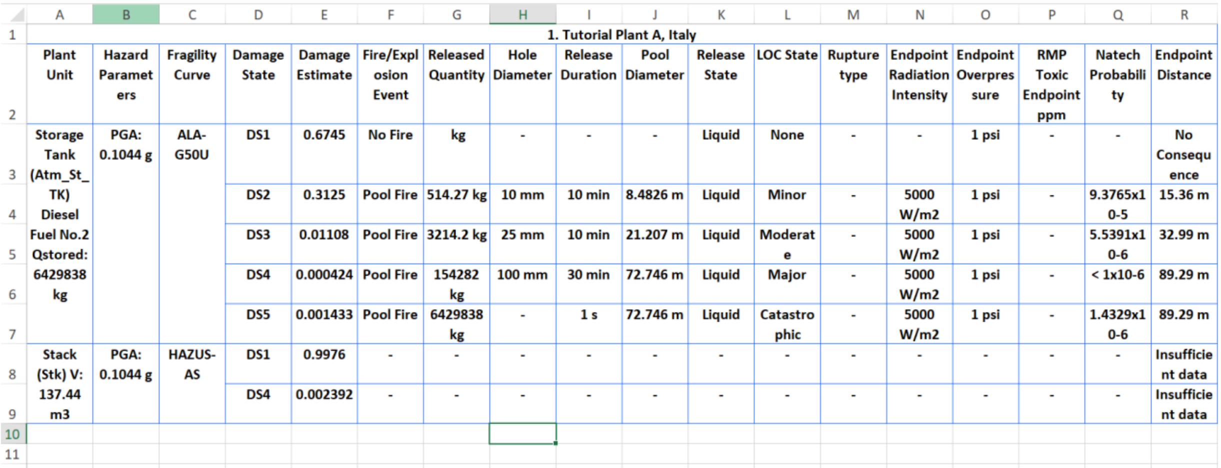
Click on the button "Download KML" to download a KML file with the shapes that define the maximum extent of the accident consequences (endpoint distances).

Click on the button "Download PDF" to download a PDF file with a summary of the risk analysis report with the most important properties.

Click on the button "Download XLS" to download an Excel file with a summary of the risk analysis report with the most important properties.

Figure 21 shows the Excel file exported for this risk analysis.

Figure 21. Exported risk analysis summary.



1. Tutorial Plant A, Italy

Plant Unit	Hazard Parameters	Fragility Curve	Damage State	Damage Estimate	Fire/Explosion Event	Released Quantity	Hole Diameter	Release Duration	Pool Diameter	Release State	LOC State	Rupture type	Endpoint Radiation Intensity	Endpoint Overpressure	RMP Toxic Endpoint ppm	Natech Probability	Endpoint Distance
Storage Tank (Atm_St_TK) Diesel Fuel No.2 Qstored: 6429838 kg	PGA: 0.1044 g	ALA-G50U	DS1	0.6745	No Fire	kg	-	-	-	Liquid	None	-	-	1 psi	-	-	No Consequence
			DS2	0.3125	Pool Fire	514.27 kg	10 mm	10 min	8.4826 m	Liquid	Minor	-	5000 W/m2	1 psi	-	9.3765x10-5	15.36 m
			DS3	0.01108	Pool Fire	3214.2 kg	25 mm	10 min	21.207 m	Liquid	Moderate	-	5000 W/m2	1 psi	-	5.5391x10-6	32.99 m
			DS4	0.000424	Pool Fire	154282 kg	100 mm	30 min	72.746 m	Liquid	Major	-	5000 W/m2	1 psi	-	< 1x10-6	89.29 m
			DS5	0.001433	Pool Fire	6429838 kg	-	1 s	72.746 m	Liquid	Catastrophic	-	5000 W/m2	1 psi	-	1.4329x10-6	89.29 m
Stack (Stk) V: 137.44 m3	PGA: 0.1044 g	HAZUS-AS	DS1	0.9976	-	-	-	-	-	-	-	-	-	-	-	-	Insufficient data
			DS4	0.002392	-	-	-	-	-	-	-	-	-	-	-	-	Insufficient data

5.4 Single plant Natech risk analysis with custom parameters

In the previous tutorial, on-site hazard intensity parameters were estimated automatically by RAPID-N by using available property estimators (i.e., ground motion prediction equations - GMPE in case of earthquakes). However, these parameters can also be specified manually for the analysis. This tutorial will demonstrate how to customise hazard-related data. In this tutorial we will set up a risk analysis case study with the following features:

- A custom peak ground acceleration value of 0.15 g that affects all plant units. This is yet another method to set up natural hazard parameters for this risk analysis.
- A custom value of 12.5 kW/m^2 assigned to the heat radiation intensity from a fire to define the threshold level for the endpoint distance caused by fires. This value, for which fatalities are assumed within minutes of exposure and which is indicative of the threshold for domino effects, will replace the standard value of 5 kW/m^2 that is used as default by RAPID-N for risk analysis.
- A custom value of 0.3 bar assigned to the blast peak overpressure to define the threshold level for the endpoint distance caused by explosions. This value will replace the standard value of 1 psi (0.069 bar) that is used as default for risk analysis.
- A custom model selected to estimate the heat radiation from pool fires: the TNO solid surface model. This model will be used instead of the EPA RMP correlation (TNO point source model).

The input needed for this exercise is composed of a natural hazard record named "Tutorial Hazard" and an industrial plant record named "Tutorial Plant B”. Section 5.1 provides instructions on how to create the natural hazard. "Tutorial Plant B” is a public record in RAPID-N that every user is free to use for training purposes.

5.4.1 Data entry

Steps 1-8 are similar to the tutorial of Section 5.3, which can be used to complement the information provided in this section.

1. From the RAPID-N home or personal pages click on the "Risk Analyses" icon to access the “Risk Analyses” page.
2. Click on the "Create" button to open the “Create Risk Analysis” page.
3. Choose a name for your risk analysis and type it in the name input field. For this tutorial, use the name "Tutorial Risk Analysis 2".
4. Select the natural hazard scenario by clicking on "Select" in the hazard input to open the “Hazards” listing page and click on the hazard name on the hazards listing table after performing a search for "Tutorial Hazard".
5. You can choose a hazard map from the *Hazard Map* drop-down list or let RAPID-N utilise the default hazard map of the hazard record, if it is available. Select "Default".
6. You can choose a particular industrial plant for the analysis or let RAPID-N identify and consider all the plants located in the natural hazard impact area. Select the industrial plant named "Tutorial Plant B" by clicking on the "Select" button, performing a search by name, and clicking the name of the plant in the table listing the search results.
7. You can customise on-site hazard parameters by manually entering various hazard parameters. For this tutorial, click on the "Add" button in *On-site Hazard Parameters* input. Select the property "Peak Ground Acceleration" from the drop-down list. Type "0.15" in the value field and "G" in the unit field.
8. Click on the "Add" button in *Risk Assessment Parameters* input. Select the property "Endpoint Radiation Intensity" from the drop-down list. Type "12.5" in the value field and "kW/m2" in the unit field.
9. Click on the "Add" button in *Risk Assessment Parameters* input. Select the property "Endpoint Overpressure" from the drop-down list. Type "0.3" in the value field and "bar" in the unit field.
10. Click on the "Add" button in *Risk Assessment Parameters* input. Select the property "Pool Fire Model" from the drop-down list. Select “Solid Surface” from the drop-down menu.
11. Click on the "Create" button to save the risk analysis record and perform the analysis.

5.4.2 Results

Tutorial Plant B is a more complex plant compared to Tutorial Plant A. It is divided in four areas as shown in Figure 22.

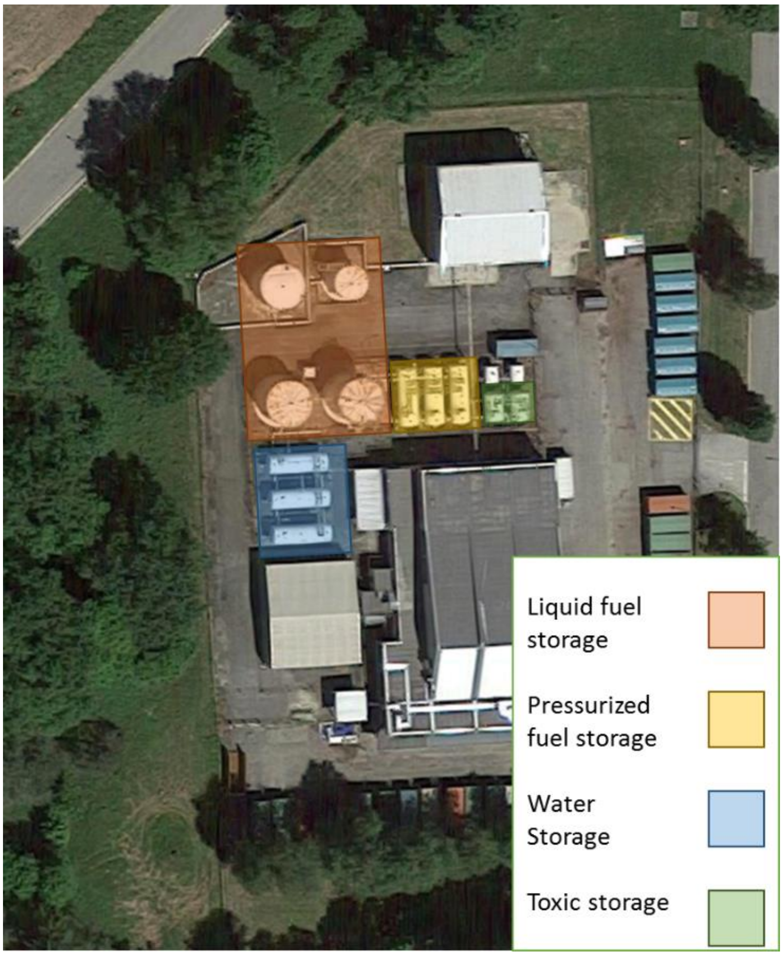
The *liquid fuel storage area* includes four cylindrical vertical atmospheric storage tanks containing flammable liquids. Two of the storage tanks contain gasoline and are anchored, while the other two contain diesel and are unanchored. For each tank pair, one of the storage tanks is filled to 45% of its capacity, while the other is filled to 85% of its capacity.

The *water storage area* contains three horizontal cylindrical tanks with water at atmospheric pressure, one of which is on the ground and the other two are on a support above ground.

The *pressurized fuel storage area* contains three horizontal cylindrical tanks with flammable gases liquefied under pressure. Two tanks contain propane, one of which is on the ground and the other is on a support. The third tank contains butane and is on a support.

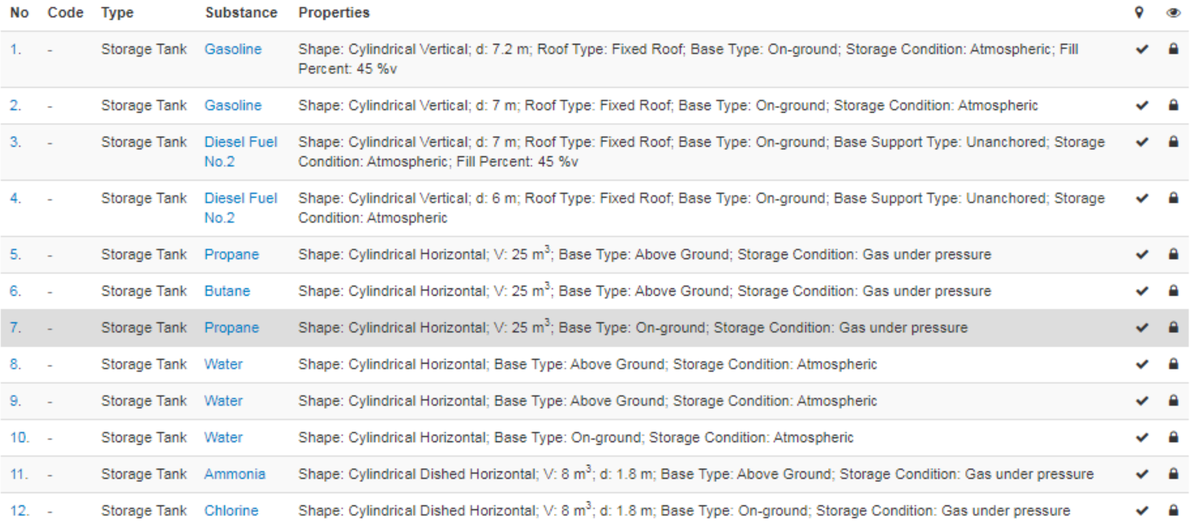
The *toxic storage area* contains two horizontal cylindrical tanks with toxic gases liquefied under pressure. One tank contains ammonia and is on a support above ground, the other tank contains chlorine and is on the ground.

Figure 22. Tutorial plant units.



A summary of the plant units and their description is provided in Figure 23.

Figure 23. Details of tutorial plant units.



No	Code	Type	Substance	Properties	📍	👁
1.	-	Storage Tank	Gasoline	Shape: Cylindrical Vertical; d: 7.2 m; Roof Type: Fixed Roof; Base Type: On-ground; Storage Condition: Atmospheric; Fill Percent: 45 %v	✓	🔒
2.	-	Storage Tank	Gasoline	Shape: Cylindrical Vertical; d: 7 m; Roof Type: Fixed Roof; Base Type: On-ground; Storage Condition: Atmospheric	✓	🔒
3.	-	Storage Tank	Diesel Fuel No.2	Shape: Cylindrical Vertical; d: 7 m; Roof Type: Fixed Roof; Base Type: On-ground; Base Support Type: Unanchored; Storage Condition: Atmospheric; Fill Percent: 45 %v	✓	🔒
4.	-	Storage Tank	Diesel Fuel No.2	Shape: Cylindrical Vertical; d: 6 m; Roof Type: Fixed Roof; Base Type: On-ground; Base Support Type: Unanchored; Storage Condition: Atmospheric	✓	🔒
5.	-	Storage Tank	Propane	Shape: Cylindrical Horizontal; V: 25 m^3; Base Type: Above Ground; Storage Condition: Gas under pressure	✓	🔒
6.	-	Storage Tank	Butane	Shape: Cylindrical Horizontal; V: 25 m^3; Base Type: Above Ground; Storage Condition: Gas under pressure	✓	🔒
7.	-	Storage Tank	Propane	Shape: Cylindrical Horizontal; V: 25 m^3; Base Type: On-ground; Storage Condition: Gas under pressure	✓	🔒
8.	-	Storage Tank	Water	Shape: Cylindrical Horizontal; Base Type: Above Ground; Storage Condition: Atmospheric	✓	🔒
9.	-	Storage Tank	Water	Shape: Cylindrical Horizontal; Base Type: Above Ground; Storage Condition: Atmospheric	✓	🔒
10.	-	Storage Tank	Water	Shape: Cylindrical Horizontal; Base Type: On-ground; Storage Condition: Atmospheric	✓	🔒
11.	-	Storage Tank	Ammonia	Shape: Cylindrical Dished Horizontal; V: 8 m^3; d: 1.8 m; Base Type: Above Ground; Storage Condition: Gas under pressure	✓	🔒
12.	-	Storage Tank	Chlorine	Shape: Cylindrical Dished Horizontal; V: 8 m^3; d: 1.8 m; Base Type: On-ground; Storage Condition: Gas under pressure	✓	🔒

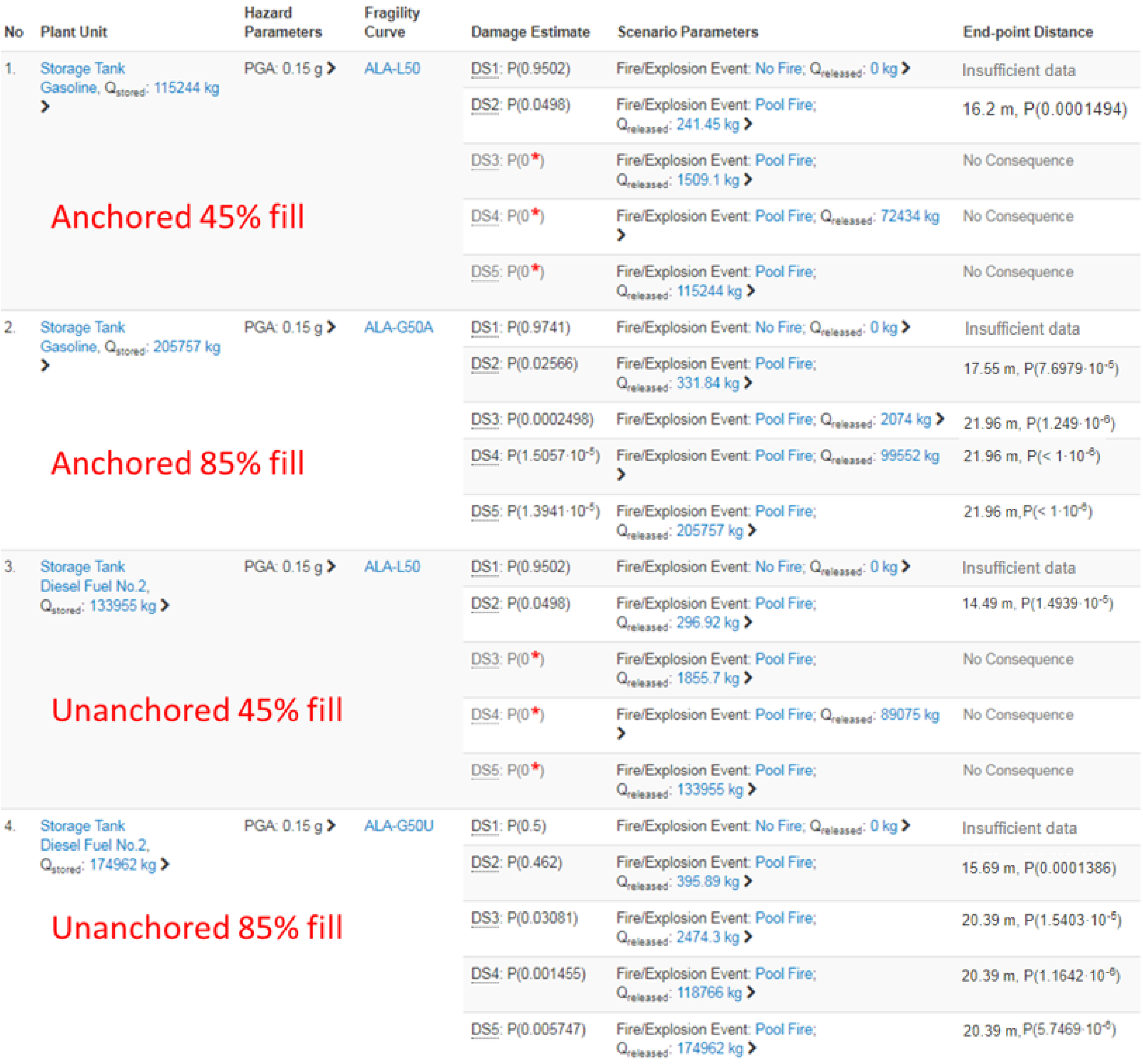
For each unit, a similar report as described in the previous tutorial (Figure 20) is shown in the results page. However, the results are different due to different physical, operational, and hazardous characteristics of the units. Since the impact areas are significantly different, in the following some specific risk analysis results will be commented for each area separately.

Figure 24 reports the analysis result summary for the atmospheric liquid fuel storage area. It is important to note that RAPID-N selected different fragility curves for each storage tank depending on their filling level and their support type (i.e., anchored or unanchored). For the two tanks with a filling level of 45%, RAPID-N selected the same fragility curve which means that their damage and Natech probabilities will be identical. This fragility curve was selected because the system does not at the moment include fragility curves for <50% filling level that would distinguish between anchored or unanchored tanks. However, for the two other tanks with filling levels at 85%, RAPID-N selected different fragility curves, one for anchored tanks and the other for unanchored tanks. **In case no damage occurs, RAPID-N indicates this outcome as “Insufficient Data” (damage state is “None”) and as “No Consequence” if the probability of the damage state is lower than a minimum threshold to be considered (10^{-6})**.

Figure 25 reports the summary of the results for the pressurized fuel storage area. Similar to the atmospheric liquid fuel storage tanks, RAPID-N selected different fragility curves for the pressurized storage tanks depending on whether they are on the ground or on supports. For the two tanks on a support (above ground) RAPID-N selected the same fragility curve which means that their damage and Natech probabilities will be identical. However, for the third tank on the ground, RAPID-N was not able to assign any fitting fragility curve (dashed red circle) in Figure 25 and could therefore not assess the damage. This is due to limited knowledge available about earthquake impact on on-ground pressurized tanks in the scientific and technical literature. By providing custom fragility damage functions or fragility curves, the users can also analyse this kind of unit with RAPID-N. The Natech scenario is a Vapour Cloud Explosion, which may be harmful to humans and to structures up to several hundred meters away.

Figure 26 shows the analysis summary for the water storage area. For the two tanks on a support (above ground) RAPID-N selected the same fragility curve, resulting in identical damage levels and Natech probabilities. However, the third tank is on the ground, and fragility curves are available for on-ground atmospheric storage tanks. Therefore, RAPID-N selected the corresponding fragility curve. **In this case, "Insufficient Data" is reported as result considering that water is not a hazardous material and RAPID-N cannot calculate the consequences of the damage.**

Figure 24. Results of the analysis for atmospheric storage tanks.

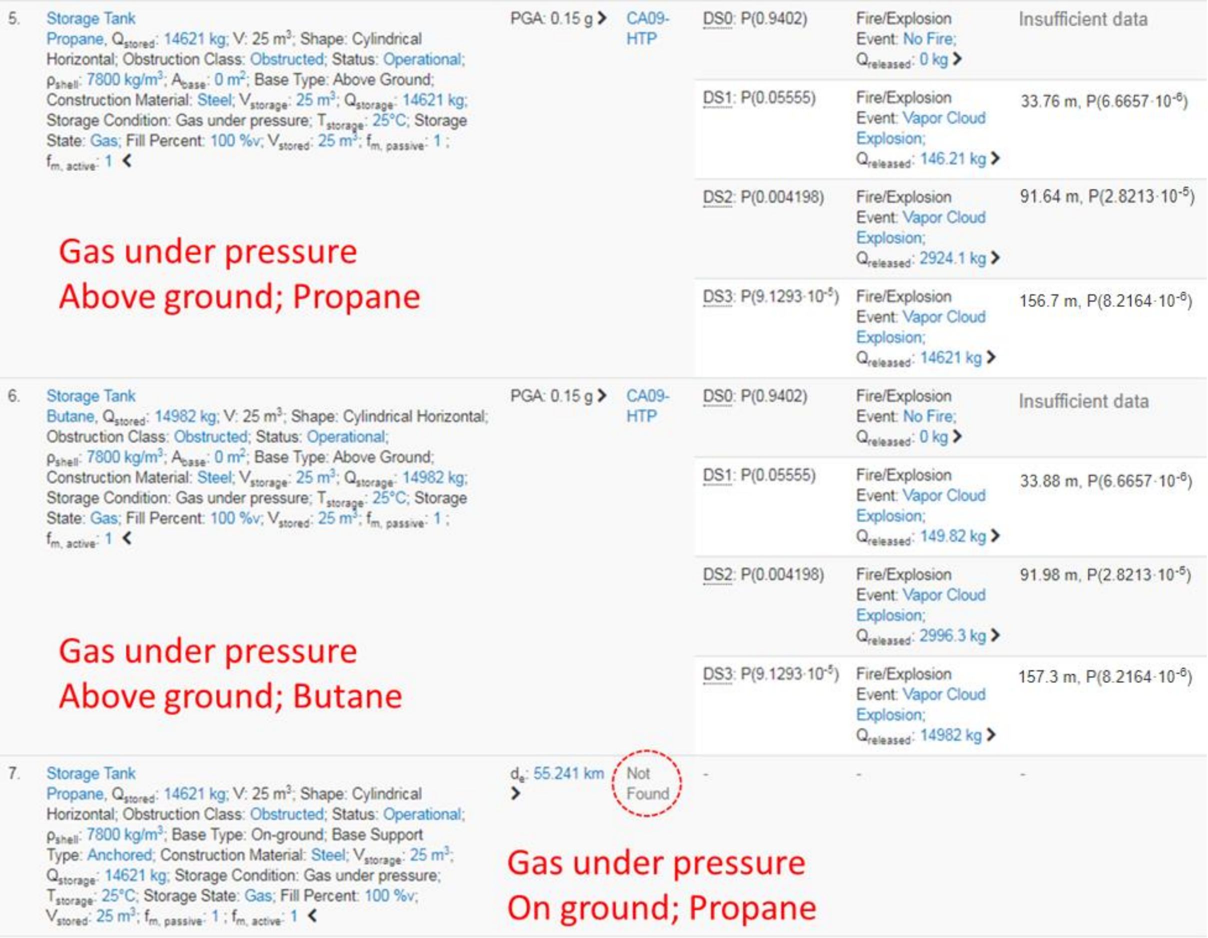


No	Plant Unit	Hazard Parameters	Fragility Curve	Damage Estimate	Scenario Parameters	End-point Distance
1.	Storage Tank Gasoline, Q_{stored}: 115244 kg Anchored 45% fill	PGA: 0.15 g	ALA-L50	DS1: P(0.9502)	Fire/Explosion Event: No Fire; $Q_{released}$: 0 kg	Insufficient data
				DS2: P(0.0498)	Fire/Explosion Event: Pool Fire; $Q_{released}$: 241.45 kg	16.2 m, P(0.0001494)
				DS3: P(0*)	Fire/Explosion Event: Pool Fire; $Q_{released}$: 1509.1 kg	No Consequence
				DS4: P(0*)	Fire/Explosion Event: Pool Fire; $Q_{released}$: 72434 kg	No Consequence
				DS5: P(0*)	Fire/Explosion Event: Pool Fire; $Q_{released}$: 115244 kg	No Consequence
2.	Storage Tank Gasoline, Q_{stored}: 205757 kg Anchored 85% fill	PGA: 0.15 g	ALA-G50A	DS1: P(0.9741)	Fire/Explosion Event: No Fire; $Q_{released}$: 0 kg	Insufficient data
				DS2: P(0.02566)	Fire/Explosion Event: Pool Fire; $Q_{released}$: 331.84 kg	17.55 m, P($7.6979 \cdot 10^{-5}$)
				DS3: P(0.0002498)	Fire/Explosion Event: Pool Fire; $Q_{released}$: 2074 kg	21.96 m, P($1.249 \cdot 10^{-6}$)
				DS4: P($1.5057 \cdot 10^{-5}$)	Fire/Explosion Event: Pool Fire; $Q_{released}$: 99552 kg	21.96 m, P($< 1 \cdot 10^{-6}$)
				DS5: P($1.3941 \cdot 10^{-5}$)	Fire/Explosion Event: Pool Fire; $Q_{released}$: 205757 kg	21.96 m, P($< 1 \cdot 10^{-6}$)
3.	Storage Tank Diesel Fuel No.2, Q_{stored}: 133955 kg Unanchored 45% fill	PGA: 0.15 g	ALA-L50	DS1: P(0.9502)	Fire/Explosion Event: No Fire; $Q_{released}$: 0 kg	Insufficient data
				DS2: P(0.0498)	Fire/Explosion Event: Pool Fire; $Q_{released}$: 296.92 kg	14.49 m, P($1.4939 \cdot 10^{-5}$)
				DS3: P(0*)	Fire/Explosion Event: Pool Fire; $Q_{released}$: 1855.7 kg	No Consequence
				DS4: P(0*)	Fire/Explosion Event: Pool Fire; $Q_{released}$: 89075 kg	No Consequence
				DS5: P(0*)	Fire/Explosion Event: Pool Fire; $Q_{released}$: 133955 kg	No Consequence
4.	Storage Tank Diesel Fuel No.2, Q_{stored}: 174962 kg Unanchored 85% fill	PGA: 0.15 g	ALA-G50U	DS1: P(0.5)	Fire/Explosion Event: No Fire; $Q_{released}$: 0 kg	Insufficient data
				DS2: P(0.462)	Fire/Explosion Event: Pool Fire; $Q_{released}$: 395.89 kg	15.69 m, P(0.0001386)
				DS3: P(0.03081)	Fire/Explosion Event: Pool Fire; $Q_{released}$: 2474.3 kg	20.39 m, P($1.5403 \cdot 10^{-5}$)
				DS4: P(0.001455)	Fire/Explosion Event: Pool Fire; $Q_{released}$: 118766 kg	20.39 m, P($1.1642 \cdot 10^{-6}$)
				DS5: P(0.005747)	Fire/Explosion Event: Pool Fire; $Q_{released}$: 174962 kg	20.39 m, P($5.7469 \cdot 10^{-6}$)

Figure 27 shows the result summary for the toxic storage area. For the ammonia tank on a support (above ground) RAPID-N successfully found and selected one fragility curve, while for the other tank containing chlorine that is on the ground, RAPID-N was not able to find any fragility curve and could therefore not assess the damage. In that case the Natech scenario is not calculated. The release of toxic material to the environment is dangerous because of the inherent danger posed by the dispersion of toxic vapours in the air. This scenario is very serious and in case of DS3 (extensive damage), the endpoint distance is of the order of tens of kilometres.

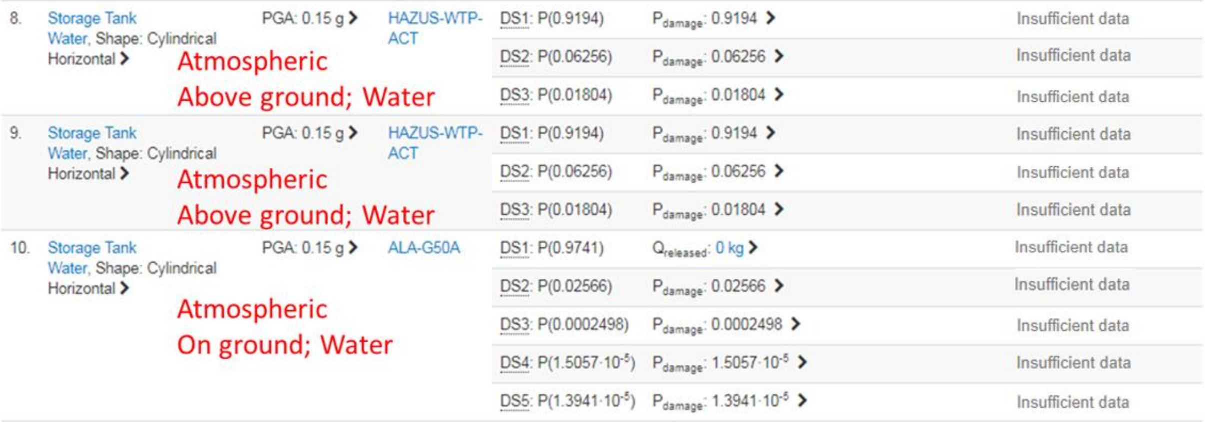
Figure 28 displays the risk analysis results on a map. Endpoint distances are represented as circles around each unit. **Fire and explosion scenarios have red circles, while toxic dispersion scenarios have orange circles**. The circle denoting the impact of the most severe toxic dispersion scenario modelled (see Figure 27 – DS3) is not visible on the map as its radius is almost 21 km.

Figure 25. Results of the risk analysis for pressurised storage tanks.



5.	Storage Tank Propane, Q_{stored}: 14621 kg; V: 25 m^3; Shape: Cylindrical Horizontal; Obstruction Class: Obstructed; Status: Operational; ρ_{shell}: 7800 kg/m^3; A_{base}: 0 m^2; Base Type: Above Ground; Construction Material: Steel; $V_{storage}$: 25 m^3; $Q_{storage}$: 14621 kg; Storage Condition: Gas under pressure; $T_{storage}$: 25°C; Storage State: Gas; Fill Percent: 100 %v; V_{stored}: 25 m^3; $f_{m,\ passive}$: 1 ; $f_{m,\ active}$: 1 <	PGA: 0.15 g >	CA09-HTP	DS0: P(0.9402)	Fire/Explosion Event: No Fire; $Q_{released}$: 0 kg >	Insufficient data
				DS1: P(0.05555)	Fire/Explosion Event: Vapor Cloud Explosion; $Q_{released}$: 146.21 kg >	33.76 m, P(6.6657·10^{-6})
				DS2: P(0.004198)	Fire/Explosion Event: Vapor Cloud Explosion; $Q_{released}$: 2924.1 kg >	91.64 m, P(2.8213·10^{-5})
				DS3: P(9.1293·10^{-5})	Fire/Explosion Event: Vapor Cloud Explosion; $Q_{released}$: 14621 kg >	156.7 m, P(8.2164·10^{-6})
6.	Storage Tank Butane, Q_{stored}: 14982 kg; V: 25 m^3; Shape: Cylindrical Horizontal; Obstruction Class: Obstructed; Status: Operational; ρ_{shell}: 7800 kg/m^3; A_{base}: 0 m^2; Base Type: Above Ground; Construction Material: Steel; $V_{storage}$: 25 m^3; $Q_{storage}$: 14982 kg; Storage Condition: Gas under pressure; $T_{storage}$: 25°C; Storage State: Gas; Fill Percent: 100 %v; V_{stored}: 25 m^3; $f_{m,\ passive}$: 1 ; $f_{m,\ active}$: 1 <	PGA: 0.15 g >	CA09-HTP	DS0: P(0.9402)	Fire/Explosion Event: No Fire; $Q_{released}$: 0 kg >	Insufficient data
				DS1: P(0.05555)	Fire/Explosion Event: Vapor Cloud Explosion; $Q_{released}$: 149.82 kg >	33.88 m, P(6.6657·10^{-6})
				DS2: P(0.004198)	Fire/Explosion Event: Vapor Cloud Explosion; $Q_{released}$: 2996.3 kg >	91.98 m, P(2.8213·10^{-5})
				DS3: P(9.1293·10^{-5})	Fire/Explosion Event: Vapor Cloud Explosion; $Q_{released}$: 14982 kg >	157.3 m, P(8.2164·10^{-6})
7.	Storage Tank Propane, Q_{stored}: 14621 kg; V: 25 m^3; Shape: Cylindrical Horizontal; Obstruction Class: Obstructed; Status: Operational; ρ_{shell}: 7800 kg/m^3; Base Type: On-ground; Base Support Type: Anchored; Construction Material: Steel; $V_{storage}$: 25 m^3; $Q_{storage}$: 14621 kg; Storage Condition: Gas under pressure; $T_{storage}$: 25°C; Storage State: Gas; Fill Percent: 100 %v; V_{stored}: 25 m^3; $f_{m,\ passive}$: 1 ; $f_{m,\ active}$: 1 <	d_e: 55.241 km >	Not Found	-	-	-

Figure 26. Risk analysis results for water storage area.

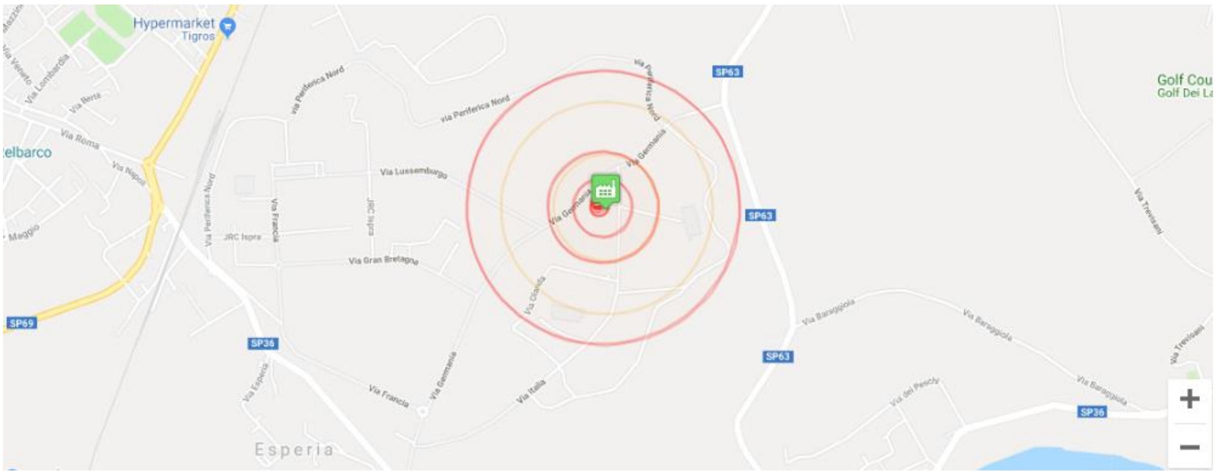


8.	Storage Tank Water, Shape: Cylindrical Horizontal >	PGA: 0.15 g >	HAZUS-WTP-ACT	DS1: P(0.9194)	P_{damage}: 0.9194 >	Insufficient data
				DS2: P(0.06256)	P_{damage}: 0.06256 >	Insufficient data
				DS3: P(0.01804)	P_{damage}: 0.01804 >	Insufficient data
9.	Storage Tank Water, Shape: Cylindrical Horizontal >	PGA: 0.15 g >	HAZUS-WTP-ACT	DS1: P(0.9194)	P_{damage}: 0.9194 >	Insufficient data
				DS2: P(0.06256)	P_{damage}: 0.06256 >	Insufficient data
				DS3: P(0.01804)	P_{damage}: 0.01804 >	Insufficient data
10.	Storage Tank Water, Shape: Cylindrical Horizontal >	PGA: 0.15 g >	ALA-G50A	DS1: P(0.9741)	$Q_{released}$: 0 kg >	Insufficient data
				DS2: P(0.02566)	P_{damage}: 0.02566 >	Insufficient data
				DS3: P(0.0002498)	P_{damage}: 0.0002498 >	Insufficient data
				DS4: P(1.5057·10^{-5})	P_{damage}: 1.5057·10^{-5} >	Insufficient data
				DS5: P(1.3941·10^{-5})	P_{damage}: 1.3941·10^{-5} >	Insufficient data

Figure 27. Risk analysis results for the toxic area.

11.	Storage Tank Ammonia, Q_{stored}: 5469.4 kg; V: 8 m^3; Shape: Cylindrical Dished Horizontal; d: 1.8 m; r: 0.9 m; Obstruction Class: Obstructed; Status: Operational; ρ_{shell}: 7800 kg/m^3; A_{base}: 0 m^2; Base Type: Above Ground; Construction Material: Steel; $V_{storage}$: 8 m^3; $Q_{storage}$: 5469.4 kg; Storage Condition: Gas under pressure; $T_{storage}$: 25°C; Storage State: Gas; Fill Percent: 100 %v; V_{stored}: 8 m^3; $f_{m, passive}$: 1 ; $f_{m, active}$: 1 ❮ Gas under pressure Above ground; Ammonia	PGA: 0.15 g ❯	CA09-HTP	DS0: P(0.9402)	$Q_{released}$: 0 kg ❯	Insufficient data
				DS1: P(0.05555)	$Q_{released}$: 54.694 kg; P_{damage}: 0.05555 ; LOC State: Minor; $f_{Q, released}$: 1%; $f_{V, released}$: 1 %v; $P_{release}$: 1.6664%; $t_{gas, max}$: 6 h; $t_{release, max}$: 6 h; $P_{c, release}$: 30%; Release State: Gas; $q_{release}$: 5.4694 kg/min; $t_{release}$: 10 min; $T_{release}$: 25°C; $V_{released}$: 0.08 m^3; $h_{release}$: 0 m; q_{gas}: 5.4694 kg/min; $q_{gas, reduced}$: 5.4694 kg/min; t_{gas}: 10 min; PT: Bouyant; S_{flame}: Cylindrical; ζ_{soot}: 0.8 ; $t_{ignition}$: 10 min; P_{natech}: 1.6664%; RT_{RMP}: Table 10; Q_{fuel}: 54.694 kg; d_e: 0.1 mile ❮	160.9 m, P(0.01666)
				DS2: P(0.004198)	$Q_{released}$: 1093.9 kg; P_{damage}: 0.004198 ; LOC State: Major; $f_{Q, released}$: 20%; $f_{V, released}$: 20 %v; $P_{release}$: 0.3359%; $t_{gas, max}$: 6 h; $t_{release, max}$: 6 h; $P_{c, release}$: 80%; Release State: Gas; $q_{release}$: 36.463 kg/min; $t_{release}$: 30 min; $T_{release}$: 25°C; $V_{released}$: 1.6 m^3; $h_{release}$: 0 m; q_{gas}: 36.463 kg/min; $q_{gas, reduced}$: 36.463 kg/min; t_{gas}: 30 min; PT: Bouyant; S_{flame}: Cylindrical; ζ_{soot}: 0.8 ; $t_{ignition}$: 10 min; P_{natech}: 0.3359%; RT_{RMP}: Table 10; Q_{fuel}: 364.63 kg; d_e: 0.2 mile ❮	321.9 m, P(0.003359)
				DS3: P($9.1293 \cdot 10^{-5}$)	$Q_{released}$: 5469.4 kg; P_{damage}: $9.1293 \cdot 10^{-5}$; LOC State: Catastrophic; $f_{Q, released}$: 100%; $f_{V, released}$: 100 %v; $P_{release}$: 0.009129%; $t_{gas, max}$: 6 h; $t_{release, max}$: 6 h; $P_{c, release}$: 100%; Release State: Gas; $q_{release}$: 328163 kg/min; $t_{release}$: 1 s; $T_{release}$: 25°C; $V_{released}$: 8 m^3; $h_{release}$: 0 m; q_{gas}: 328163 kg/min; $q_{gas, reduced}$: 328163 kg/min; t_{gas}: 0.01667 min; PT: Bouyant; S_{flame}: Cylindrical; ζ_{soot}: 0.8 ; $t_{ignition}$: 10 min; P_{natech}: 0.009129%; RT_{RMP}: Table 10; Q_{fuel}: 5469.4 kg; d_e: 13 mile ❮	20.921 km, P($9.1293 \cdot 10^{-5}$)
12.	Storage Tank Chlorine, Q_{stored}: 12527 kg; V: 8 m^3; Shape: Cylindrical Dished Horizontal; d: 1.8 m; r: 0.9 m; Obstruction Class: Obstructed; Status: Operational; ρ_{shell}: 7800 kg/m^3; Base Type: On-ground; Base Support Type: Anchored; Construction Material: Steel; $V_{storage}$: 8 m^3; $Q_{storage}$: 12527 kg; Storage Condition: Gas under pressure; $T_{storage}$: 25°C; Storage State: Gas; Fill Percent: 100 %v; V_{stored}: 8 m^3; $f_{m, passive}$: 1 ; $f_{m, active}$: 1 ❮	d_e: 55.247 km ❯	Not Found	-	Gas under pressure On ground; Chlorine	-

Figure 28. Risk analysis map.



5.5 Multiple plant Natech risk analysis

A risk analysis study for a hazard scenario involving multiple industrial plants simultaneously can be useful for public authorities who want to investigate the Natech risks in an area under their jurisdiction that could include several industrial plants with hazardous substances. This is an easy and straightforward task with RAPID-N.

The resources needed for this exercise are composed of a natural hazard record named "Tutorial Hazard" and two industrial plant records named "Tutorial Plant A” and "Tutorial Plant B”. Section 5.1 provides instructions on how to create the record "Tutorial Hazard" and Section 5.2 on how to create the record "Tutorial Plant A”. "Tutorial Plant B” is a public record in RAPID-N that every user is free to use for training purposes.

5.5.1 Data entry

1. From RAPID-N’s home or personal pages click on the "Risk Analyses" icon to open the “Risk Analyses” listing page.
2. Press on the "Create" button to open the “Create Risk Analysis” page.
3. Choose a name for your risk analysis case study and type it in the *Name* input field. For this tutorial, use the name "Tutorial Risk Analysis 3".
4. You must select a hazard record for the analysis. Click on the "Select" button to open the “Hazards” listing page. Search for the hazard case named "Tutorial Hazard" and select it from the list by clicking on its name.
5. You can choose a hazard map from the *Hazard Map* drop-down list or let RAPID-N utilise the default hazard map of the hazard record, if it is available. Select "Default".
6. You can choose a particular industrial plant for the analysis or let RAPID-N consider all the plants located in the natural hazard impact area, e.g., within a specific cut-off distance. For this tutorial, do not select a specific industrial plant but let RAPID-N select the plants within the default cut-off distance which is 200 km.
7. You can specify on-site hazard parameters manually to modify the hazard intensity. Any hazard parameter indicated manually will be applied to all plant units regardless of their location and characteristics. For this tutorial, do not set any hazard parameters.
8. You can specify risk analysis parameters which allow you to customise the risk analysis calculations. For this tutorial, do not set any risk analysis parameters.
9. Press on the "Create" button to save the risk analysis record and perform the analysis.

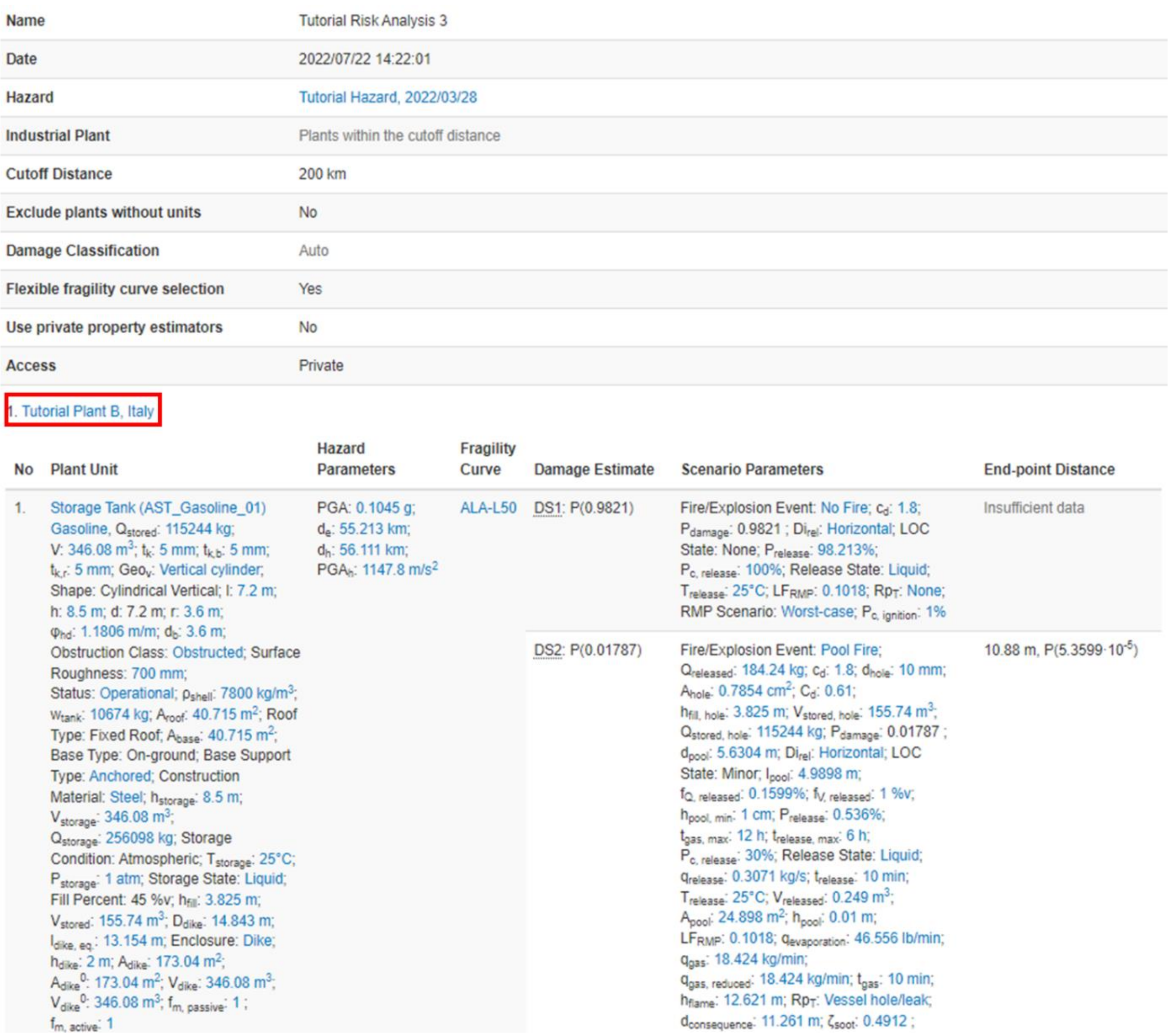
5.5.2 Results

RAPID-N identified the industrial plants within the cut-off distance (Tutorial Plant A and B), carried out the risk analysis using the tutorial hazard, and displayed the analysis results on a map. This tutorial assumes that you have followed all previous tutorials and done nothing else with the system before. In this case, only Tutorial Plant A and Tutorial Plant B will be displayed. However, if you have created other industrial plants in this area before using this tutorial, be aware that they will be included in the results, as well. Figure 29 shows a zoomed view of the area with the plants and their calculated Natech risk at local level (note the large worst-case toxic dispersion scenario circle in orange in the left image, and the smaller fire/explosion scenario circles in red in the right image). It is important to highlight that **there are areas in which the risk due to different plants can overlap**.

In addition, results for all plants (Tutorial Plant A and Tutorial Plant B) will be listed in the analysis results table. Results for one plant are shown in Figure 30 as an example (Tutorial Plant B). The results for the other plant would follow in the table. Each plant name is shown just before the list of results (Figure 30).

Figure 29. Risk analysis map showing both plants and all scenario endpoint distances.

Figure 30. Risk analysis results.



Name	Tutorial Risk Analysis 3
Date	2022/07/22 14:22:01
Hazard	Tutorial Hazard, 2022/03/28
Industrial Plant	Plants within the cutoff distance
Cutoff Distance	200 km
Exclude plants without units	No
Damage Classification	Auto
Flexible fragility curve selection	Yes
Use private property estimators	No
Access	Private

1. Tutorial Plant B, Italy

No	Plant Unit	Hazard Parameters	Fragility Curve	Damage Estimate	Scenario Parameters	End-point Distance
1.	Storage Tank (AST_Gasoline_01) Gasoline, Q_{stored}: 115244 kg; V: 346.08 m^3; t_k: 5 mm; $t_{k,b}$: 5 mm; $t_{k,r}$: 5 mm; Geo_v: Vertical cylinder; Shape: Cylindrical Vertical; l: 7.2 m; h: 8.5 m; d: 7.2 m; r: 3.6 m; φ_{hd}: 1.1806 m/m; d_b: 3.6 m; Obstruction Class: Obstructed; Surface Roughness: 700 mm; Status: Operational; ρ_{shell}: 7800 kg/m^3; w_{tank}: 10674 kg; A_{roof}: 40.715 m^2; Roof Type: Fixed Roof; A_{base}: 40.715 m^2; Base Type: On-ground; Base Support Type: Anchored; Construction Material: Steel; $h_{storage}$: 8.5 m; $V_{storage}$: 346.08 m^3; $Q_{storage}$: 256098 kg; Storage Condition: Atmospheric; $T_{storage}$: 25°C; $P_{storage}$: 1 atm; Storage State: Liquid; Fill Percent: 45 %v; h_{fill}: 3.825 m; V_{stored}: 155.74 m^3; D_{dike}: 14.843 m; $l_{dike, eq}$: 13.154 m; Enclosure: Dike; h_{dike}: 2 m; A_{dike}: 173.04 m^2; A_{dike}^0: 173.04 m^2; V_{dike}: 346.08 m^3; V_{dike}^0: 346.08 m^3; $f_{m, passive}$: 1 ; $f_{m, active}$: 1	PGA: 0.1045 g; d_e: 55.213 km; d_h: 56.111 km; PGA_h: 1147.8 m/s^2	ALA-L50	DS1: P(0.9821)	Fire/Explosion Event: No Fire; c_d: 1.8; P_{damage}: 0.9821 ; Di_{rel}: Horizontal; LOC State: None; $P_{release}$: 98.213%; $P_{c, release}$: 100%; Release State: Liquid; $T_{release}$: 25°C; LF_{RMP}: 0.1018; Rp_T: None; RMP Scenario: Worst-case; $P_{c, ignition}$: 1%	Insufficient data
				DS2: P(0.01787)	Fire/Explosion Event: Pool Fire; $Q_{released}$: 184.24 kg; c_d: 1.8; d_{hole}: 10 mm; A_{hole}: 0.7854 cm^2; C_d: 0.61; $h_{fill, hole}$: 3.825 m; $V_{stored, hole}$: 155.74 m^3; $Q_{stored, hole}$: 115244 kg; P_{damage}: 0.01787 ; d_{pool}: 5.6304 m; Di_{rel}: Horizontal; LOC State: Minor; l_{pool}: 4.9898 m; $f_{Q, released}$: 0.1599%; $f_{V, released}$: 1 %v; $h_{pool, min}$: 1 cm; $P_{release}$: 0.536%; $t_{gas, max}$: 12 h; $t_{release, max}$: 6 h; $P_{c, release}$: 30%; Release State: Liquid; $q_{release}$: 0.3071 kg/s; $t_{release}$: 10 min; $T_{release}$: 25°C; $V_{released}$: 0.249 m^3; A_{pool}: 24.898 m^2; h_{pool}: 0.01 m; LF_{RMP}: 0.1018; $q_{evaporation}$: 46.556 lb/min; q_{gas}: 18.424 kg/min; $q_{gas, reduced}$: 18.424 kg/min; t_{gas}: 10 min; h_{flame}: 12.621 m; Rp_T: Vessel hole/leak; $d_{consequence}$: 11.261 m; ζ_{soot}: 0.4912 ;	10.88 m, P($5.3599 \cdot 10^{-5}$)

5.6 Using ADAM calculation libraries

As described in Section 4.2, RAPID-N includes the option to run the calculation libraries of the JRC consequence analysis tool ADAM. The calculation libraries can be activated by the users on demand, while creating or modifying any risk analysis record.

In the “Create Risk Assessment” entry form page, users should add “ADAM mode” under *Risk Assessment Parameters* and set it to “On” (Figure 31).

The input needed for this exercise is composed of a natural hazard record named "Tutorial Hazard" and an industrial plant record named "Tutorial Plant A”. Sections 5.1 and 5.2 provide detailed instructions on how to create these records.

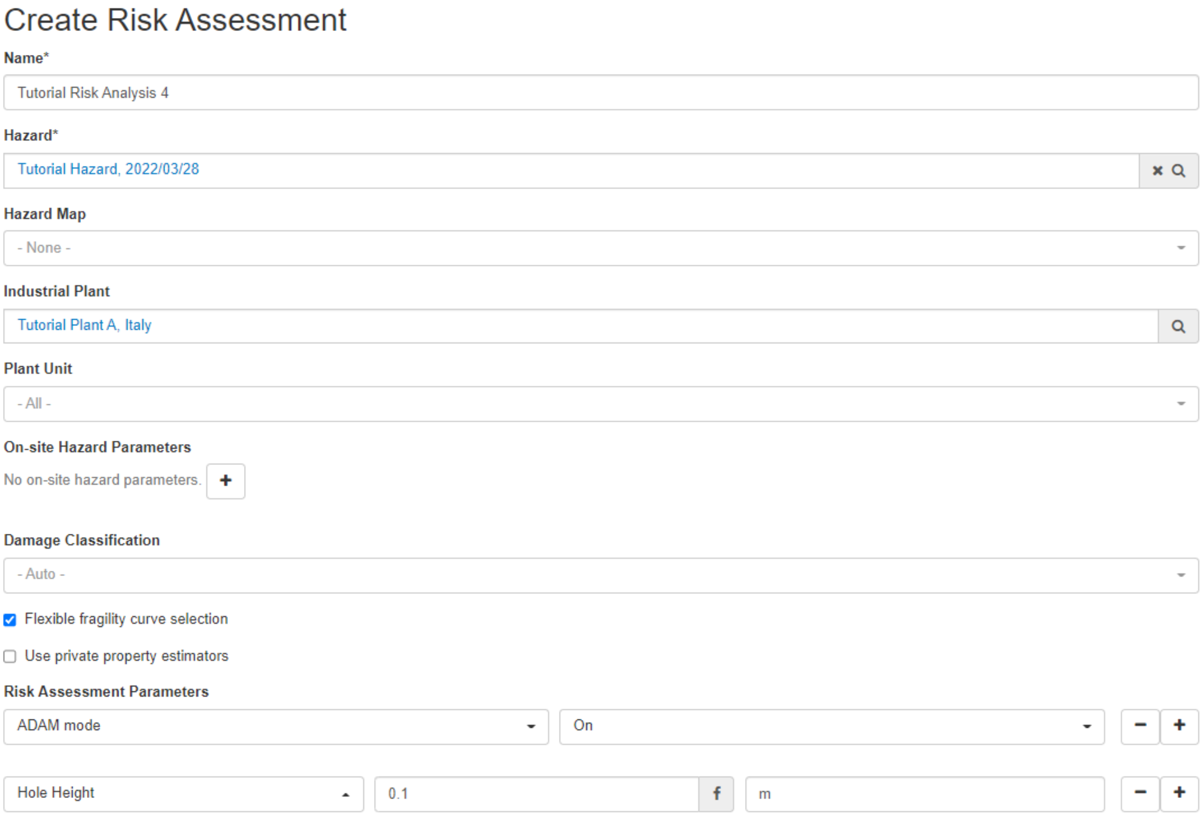
5.6.1 Data entry

1. From the RAPID-N home or personal pages click on the "Risk Analyses" icon to open the “Risk Analyses” listing page.
2. Press on the "Create" button to open the “Create Risk Analysis” page.
3. Choose a name for your risk analysis case study and type it in the name input field. For this tutorial, use the name "Tutorial Risk Analysis 4".
4. Select a hazard record for the analysis. Click on the "Select" button to open the “Hazards” listing page. Search for the hazard case named "Tutorial Hazard" and select it from the list by clicking on its name.
5. You can choose a hazard map from the *Hazard Map* drop-down list or let RAPID-N utilise the default hazard map of the hazard record, if it is available. Select "Default".
6. You can choose a specific industrial plant for the analysis or let RAPID-N identify and consider all the plants located in the natural hazard area. For this tutorial, you must select a case-study plant. Click on the "Select" button in industrial plant input to open the “Industrial Plants” listing page. Search for the industrial plant named "Tutorial Plant A" and select it from the list by clicking its name.
7. You can specify on-site hazard parameters manually to modify the natural hazard intensity. Any hazard parameter indicated manually will be applied to all plant units regardless of their location and characteristics. For this tutorial, do not set any on-site hazard parameters.
8. Click on the "Add" button in *Risk Assessment Parameters* input. Select the property "Hole height" from the drop-down list. Type "0.1" in the value field and "m" in the unit field.
9. You can specify additional risk analysis parameters, which allow you to customise the risk analysis calculations. For this tutorial, add “ADAM Mode” in *Risk Assessment Parameters* input and set it to “On”.
10. Press on the "Create" button to save the risk analysis record and perform the analysis.

Remark. Warning: Timeout when using ADAM Mode

The advanced consequence analysis methodology of ADAM requires more computing power than the standard RMP methodology used by RAPID-N which translates into a longer time for calculations. Large projects would easily overwhelm our servers. RAPID-N has therefore a timeout that interrupts the risk analysis calculations after a while. This prevents prolonged denial of service when many risk analyses are performed at the same time. Large or even medium-sized projects will easily reach the timeout and the risk analyses may be interrupted before obtaining any results. For this reason, we recommend that the ADAM mode is used only for small projects with 10 plant units or less.

Figure 31. Activating the ADAM module in RAPID-N.



Create Risk Assessment

Name*

Tutorial Risk Analysis 4

Hazard*

Tutorial Hazard, 2022/03/28

Hazard Map

- None -

Industrial Plant

Tutorial Plant A, Italy

Plant Unit

- All -

On-site Hazard Parameters

No on-site hazard parameters.

Damage Classification

- Auto -

☑ Flexible fragility curve selection

☐ Use private property estimators

Risk Assessment Parameters

ADAM mode: On

Hole Height: 0.1 m

6 RAPID-N Properties used for consequence analysis

In this section, the most important properties used for consequence analysis are described in detail.

6.1.1 Substance, container and operative conditions

Unless otherwise stated, the following properties can be manually entered on the “Plant Unit” page. Under certain conditions, some of the properties below can be estimated automatically by RAPID-N.

Vessel Geometry

This property indicates the vessel type based on the vessel geometry. Available vessel geometries are: Spherical, Cylindrical horizontal, and Cylindrical vertical.

This property must be provided by the user.

Diameter

This property indicates the diameter of the vessel.

This property must be provided by the user.

Height

This property indicates the height of the vessel.

This property must be provided by the user.

Length

This property indicates the length of the vessel.

This property must be provided by the user.

Volume

This property indicates the volume of the vessel.

For cylindrical vessels, if *Diameter* and either *Length* or *Height* are available, RAPID-N calculates *Volume*. For Spherical vessels, if *Diameter* is available, RAPID-N calculates *Volume*.

Tank Height from Ground

This property indicates the distance (height) of the vessel from the ground. This property was added to RAPID-N to allow calculations with the ADAM Mode and has no influence on the analyses made without the ADAM Mode.

For on-ground vessels, the default *Tank Height from Ground* is 0 m. For above ground vessels, the default *Tank Height from Ground* is 1 m.

Storage Condition

This property indicates the type of storage condition inside the container. Different storage conditions result in different scenario types. The available storage conditions are: Atmospheric, Pressure, Gas under pressure, Gas liquefied under pressure, Refrigerated atmospheric, Refrigerated pressure.

Although some property estimators for this property exist, they are valid only in a few cases. Therefore, it is recommended that this property is provided by the user.

Storage Temperature

Temperature at which the substance is stored inside the container.

This property must be provided by the user. If users do not enter a value, *Storage Temperature* is set equal to the *Ambient Temperature*.

Storage Pressure

Storage pressure represents the pressure inside the plant unit. This parameter affects the release rate - and ultimately the amount of substance released – during accidents.

This property must be provided by the users. If users do not enter a value, *Storage Pressure* is set equal to the substance vapour pressure (provided that the substance has the property *Vapour Pressure*) if the *Storage Condition* is Gas liquefied under pressure, or equal to the *Ambient Pressure* if the *Storage Condition* is Atmospheric. If the *Storage condition* is of any other type, this property must be provided by the user.

Gauge Pressure

Gauge pressure is the difference between the pressure inside the container and the atmospheric pressure outside the vessel. This parameter affects the release rate - and ultimately the amount of substance released – during accidents.

This property must be provided by the users. If users do not enter a value, *Gauge Pressure* is set equal to 0 if *Storage Condition* is Atmospheric, or to the value of the *Storage Pressure* minus the *Ambient Pressure* (when these properties are available).

Fill percent

Fill percent indicates the portion of the vessel which is filled with a liquid, or that is occupied by a liquid phase.

The default value of *Fill percent* is 85%. In case the substance is a gas and does not have a liquid phase, *Fill percent* is set to 100%.

If *Volume* and either *Stored Quantity* or *Stored Volume* are available, RAPID-N automatically calculates *Fill percent*.

Stored Quantity

Stored Quantity indicates the amount of hazardous substance contained inside the vessel.

If *Stored Volume* is available, RAPID-N calculates the stored quantity automatically.

Stored Volume

Stored Volume indicates the volume of the vessel which is filled with a liquid, or that is occupied by a liquid phase. In case the substance is a gas and does not have a liquid phase, *Stored Volume* is equal to the volume of the vessel.

If *Stored Quantity* is available, or if *Volume* and *Fill percent* are available, RAPID-N calculates the *Stored Volume*.

SubstanceID_ADAM

This code identifies every substance in ADAM. This property was added to RAPID-N to allow calculations using the ADAM Mode. It has no influence on the analyses made without the ADAM Mode.

This property is associated to every substance; it must NOT be entered or changed by the users.

Dike Area

This property indicates the area of the secondary containment bund around the container (if present). This area limits the size of pools formed after releases of liquid hazardous materials.

This property must be provided by the user. If users do not enter a value, RAPID-N calculates the *Dike Area*, considering a *Volume* equal to the volume of the tank and a depth of 2m.

6.1.2 Meteorological and environmental conditions

Unless otherwise stated, the properties below can be manually entered either on the “Industrial Plant” page or the “Risk Assessment”[1] page.

Ambient Temperature

Ambient Temperature is the temperature of air at the industrial site. *Ambient Temperature* influences several scenarios, in particular pool evaporation scenarios and atmospheric dispersion scenarios.

Default *Ambient Temperature* is set by an estimator at 25 °C.

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[1] Users should be aware that the chosen value of the property assigned on the "Risk Assessment" page will apply to all units and all scenarios in the Risk Assessment. A better way for users to assign a value to their property is to create their own estimators.

Wind Speed

Indicates the average wind speed representative of the industrial site and its surroundings. The value reported by this property indicates the wind speed at 10 m height from the ground. Wind speed influences several scenarios, in particular fire scenarios and atmospheric dispersion scenarios.

If RAPID-N is running RMP scenarios, the default *Wind Speed* is 1,5 m/s for the RMP worst-case scenario, and 3 m/s for the RMP alternative scenario. If RAPID-N is not running RMP scenarios but uses the ADAM Mode, the default *Wind Speed* is 2 m/s for stable atmospheric stability and 5 m/s for neutral atmospheric stability.

Relative Humidity

Relative humidity is the ratio of the partial pressure of water vapour in the air at the industrial site to the equilibrium vapour pressure of water at the *Ambient Temperature*. *Relative Humidity* affects the transmission of heat radiation from fires in air.

The default *Relative Humidity* is set to 50%.

Atmospheric Stability

Atmospheric stability depends on the temperature difference of air at different heights that generates a temperature gradient. While some gradients determine a stable atmosphere, others generate an unstable atmosphere. The RMP methodology and ADAM both use Pasquill classes to indicate the atmospheric stability which affects atmospheric dispersion scenarios.

Atmospheric Stability class F is automatically associated with worst-case scenarios, while class D is associated with the alternative scenario.

Solar Radiation

Indicates the value of the solar radiation at the site. This parameter influences the rate at which pools evaporate. Solar radiation values are tabulated for different situations including night and day times, sky coverage and fog. For this reason, *Solar Radiation* is associated with *Atmospheric Stability*.

RAPID-N calculates *Solar Radiation* if *Wind Speed* and *Atmospheric Stability* are available.

6.1.3 Release scenarios

Unless otherwise stated, the following properties can be manually introduced in RAPID-N on the "Risk Assessment"[2] page.

ADAM Source Term

This property allows the selection of the hypotheses for the dispersion source term. It helps to choose the release rate for accidents with a long duration. Users can select either of the following options: a) the maximum release rate, b) the average release rate, or c) a time varying release rate. This property was added to RAPID-N to allow calculations with the ADAM Mode. It has no influence on the analyses made without the ADAM Mode.

The default *ADAM Source Term* is average release rate.

Rupture Type

Rupture Type indicates the rupture type and the extent of damage suffered by the unit (e.g., Catastrophic rupture, Vessel hole/leak).

This property is associated by RAPID-N to every scenario automatically. Property estimators govern the relationship between the damage state and the *Rupture Type*.

LOC State

LOC State indicates the release type and the main condition of the release: No release, Minor release, Moderate release, Major release, catastrophic release.

---

[2] Users should be aware that the chosen value of the property assigned on the "Risk Assessment" page will apply to all units and all scenarios in the Risk Assessment. A better way for users to assign a value to their property is to create their own estimators.

This property is associated by RAPID-N to every scenario automatically. Property estimators govern the relationship between the damage state and the *LOC State*.

Hole Height from Vessel Bottom

This property indicates the distance (height) of the rupture hole from the vessel's bottom. This property was added to RAPID-N to allow calculations with the ADAM Mode. It has no influence on the analyses made without the ADAM Mode.

The default value is 0 m.

Hole Diameter

This property indicates the diameter of the hole from which the substance is released. In the assessment the release hole is always assumed circular. Rather than being the actual diameter of the rupture, this value indicates an equivalent reference size.

Hole Diameter is set automatically by the system via property estimators.

Pipe Diameter

This property is used for releases from pipes. It indicates the main diameter of the pipe connection. This property was added to RAPID-N to allow calculations with the ADAM Mode. It has no influence on the analyses made without the ADAM Mode.

Pipe Length at Rupture

This property indicates the length of the pipe between the container and the point of rupture. It was added to RAPID-N to allow calculations with the ADAM Mode. It has no influence on the analyses made without the ADAM Mode.

Release Duration

Indicates the duration of the release event and thus of the duration of the accident. This value is also used to determine the average concentration of toxic substance to which the population is exposed for the duration of the accident.

6.1.3.1 Pools

Unless otherwise stated, the properties below can be manually entered either on the "Industrial Plant" page or the "Risk Assessment"[3] page.

Ground Temperature

Ground Temperature is the temperature of the soil at the industrial site. Ground Temperature influences release models, in particular the pool evaporation models. This property was added to RAPID-N to allow calculations with the ADAM Mode and has no influence on the analyses made without the ADAM Mode.

The default *Ground Temperature* is set by an estimator at 285 K.

Ground Thermal Conductivity

Ground Thermal Conductivity is the thermal conductivity of the soil at the industrial site. *Ground Thermal Conductivity* influences release models, in particular the pool evaporation models. This property was added to RAPID-N to allow calculations with the ADAM Mode and has no influence on the analyses made without the ADAM Mode.

The default *Ground Thermal Conductivity* is set by an estimator at $2.5 \cdot 10^{-7}$ W/m K.

Ground Thermal Diffusivity

Ground Thermal Diffusivity is the thermal diffusivity of the soil at the industrial site. *Ground Thermal Diffusivity* influences release models, in particular the pool evaporation models. This property was added to RAPID-N to allow calculations with the ADAM Mode and has no influence on the analyses made without the ADAM Mode.

---

[3] Users should be aware that the chosen value of the property assigned on the "Risk Assessment" page will apply to all units and all scenarios in the Risk Assessment. A better way for users to assign a value to their property is to create their own estimators.

The default *Ground Thermal Conductivity* is set by an estimator at 0.207 m^2/s.

Near-release Roughness

Near-release Roughness is the average roughness of the soil at the industrial site. *Near-release Roughness* influences release models, in particular the pool evaporation models. This property was added to RAPID-N to allow calculations with the ADAM Mode and has no influence on the analyses made without the ADAM Mode.

The default *Near-release Roughness* is set by an estimator at 1 cm.

6.1.4 Consequence

The properties below can be manually entered on the "Risk Assessment"[4] page

Fire/Explosion Event

Fire/Explosion Event indicates the type of accident scenario that involves flammable substances. This property allows a multiple choice between a selection of options. The available choices are: Pool Fire, Jet Fire, Fireball, Vapor Cloud Fire, Vapor Cloud Explosion, and No Fire.

Based on the substances property and the process conditions, the property estimators choose the value that is the most appropriate for the *Fire/Explosion event*.

Target Height

It indicates the relative height of the exposed population with respect of the industrial site. It is useful to consider the morphology of the site. It is also useful if either the exposed people or the source of the accident are located on different floors. This property was added to RAPID-N to allow calculations with the ADAM Mode. It has no influence on the analyses made without the ADAM Mode.

The default *Target Height* is 0 m.

6.1.4.1 Atmospheric dispersion

Surface Roughness

This property denotes the average height of obstacles near the release that affect airborne dispersion of hazardous vapours. This property was added to RAPID-N to allow calculations with the ADAM Mode and has no influence on the analyses made without the ADAM Mode.

The default *Surface Roughness* is 700 mm. It can also be manually entered in the "Risk assessment"[4] page.

RMP Toxic Endpoint ppm

This property sets the target threshold for the toxic concentration. The chosen level of concentration determines the endpoint distance for all toxic dispersion scenarios. This value changes for each substance.

This property is available for every toxic substance in the RAPID-N database or it can be derived from other toxicological properties (e.g., IDLH, ERPG, etc.). It can be manually entered in the "Substances" page.

6.1.4.2 Fires

Unless otherwise stated, the properties below can be manually entered on the "Risk Assessment"[4] page.

Endpoint Radiation Intensity

This property sets the target threshold for the radiation intensity. The chosen level of heat radiation determines the endpoint distance for all fire scenarios. The default *Endpoint Radiation Intensity* value is 5 kW/m^2 (equivalent to irreversible damage to people upon 40 s of direct exposure).

Pool Fire Model

This property allows the users to select the pool fire model they prefer for the analysis. The choices are: Point source, Solid surface and RMP pool fire model. This property is not used when the ADAM Mode is active.

---

[4] Users should be aware that the chosen value of the property assigned on the "Risk Assessment" page will apply to all units and all scenarios in the Risk Assessment. A better way for users to assign a value to their property is to create their own estimators.

The default *Pool Fire Model* used in RAPID-N is the RMP pool fire model.

ADAM Pool fire model

This property allows users to select the specific pool fire model for the analysis with ADAM. Currently, this property offers the TNO solid surface model as the only option and it is therefore always selected for calculations with ADAM. In the future, other models may become available (e.g., Shokri model and Mudan model). This property was added to RAPID-N to allow calculations with the ADAM Mode and has no influence on the analyses made without the ADAM Mode.

The default *ADAM Pool fire model* is the TNO solid surface model.

6.1.4.3 Explosions

Unless otherwise stated, the properties below can be manually entered on the "Risk Assessment"[5] page.

Endpoint Overpressure

This property sets the target threshold for the explosion overpressure. The chosen level of overpressure determines the endpoint distance for all explosion scenarios.

The default *Endpoint Overpressure* is 1 psi (equivalent to irreversible damage to people).

ADAM Explosion Model

ADAM Explosion Model allows users to select the specific explosion model that is used for the analysis with ADAM. However, this property offers the Baker–Strehlow–Tang model as the only option, and it is always selected when the calculations are made. In the future, other models may become available (e.g., TNT equivalent). This property was added to RAPID-N to allow calculations with the ADAM Mode and has no influence on the analyses made without the ADAM Mode.

The default *ADAM Explosion Model* is the Baker-Strehlow-Tang model.

Baker–Strehlow–Tang Reactivity Index

The *Baker–Strehlow–Tang Reactivity Index* allows users to select the reactivity that is used for the analysis with ADAM. The available choices are: High reactivity, Medium reactivity, Low reactivity, and Reactivity from substance. This property was added to RAPID-N to allow calculations with the ADAM Mode and has no influence on the analyses made without the ADAM Mode.

This property has the option Reactivity from Substance set as a default.

Baker–Strehlow–Tang Obstacle Density Index

Describes the density of obstacles in the area of the vapour cloud explosion. The choices available are High, Medium and Low. This property was added to RAPID-N to allow calculations with the ADAM Mode and has no influence on the analyses made without the ADAM Mode.

This property has the option Medium set as a default.

Baker–Strehlow–Tang Ground Burst

This property applies a correction to the explosion when the explosion is in the air and when the explosion is on the ground. The choices are Ground Burst and Mid-air Burst. This property was added to RAPID-N to allow calculations with the ADAM Mode and has no influence on the analyses made without the ADAM Mode.

This property has the option Ground Burst set as a default.

Baker–Strehlow–Tang Flame Expansion Index

It represents the dimensions the explosion can exploit to expand. The available choices are: 2D, 2.5D, and 3D. This property was added to RAPID-N to allow calculations with the ADAM Mode and has no influence on the analyses made without the ADAM Mode.

This property has the option 2.5D set as a default.

---

[5] Users should be aware that the chosen value of the property assigned on the "Risk Assessment" page will apply to all units and all scenarios in the Risk Assessment. A better way for users to assign a value to their property is to create their own estimators.

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