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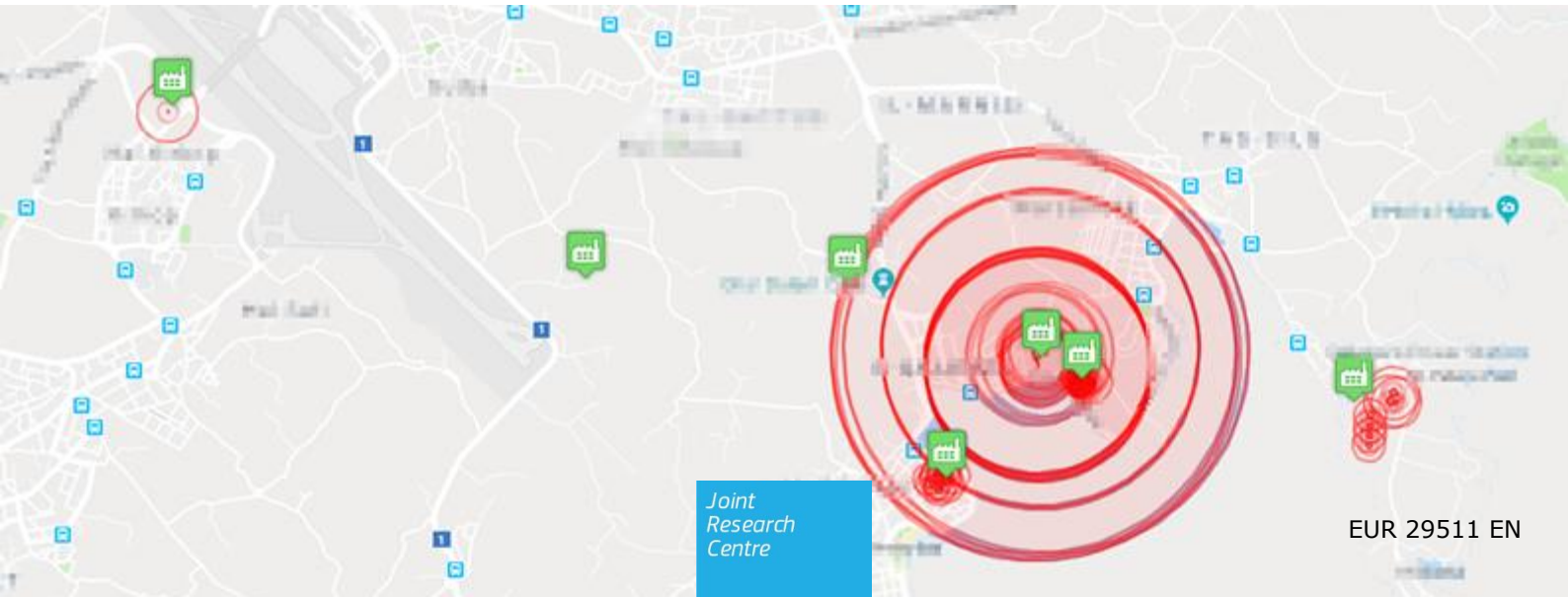
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Introduction to RAPID-N for Natech Risk Analysis and Mapping

A Beginner's Guide

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Abstract

The impact of natural hazards on industrial plants, pipelines, offshore platforms and other infrastructure that handles, stores or transports hazardous substances can cause fires, explosions, and toxic or radioactive releases. 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.

Successfully controlling Natech risk is usually a major challenge, which requires targeted prevention, preparedness and response. Systematic analysis of the Natech risk is a prerequisite for this purpose. Developed by the European Commission Joint Research Centre (JRC) in response to requests by competent authorities, the Rapid Natech Risk Analysis and Mapping System (RAPID-N) is an online software for the quick analysis and mapping of Natech accident risk both at local and regional levels. The system unites natural-hazard impact and damage assessment, Natech scenario development, and chemical accident consequence analysis capabilities under a single roof featuring an open, extensible, and collaborative architecture facilitating data entry, analysis and visualisation.

Since it became operational in 2012, the user base of RAPID-N has been growing, including more and more users from public authorities, research organisations, academia, and the private sector. According to feedback from the users, the system has been further developed in time to provide additional capabilities, such as a modern and mobile-friendly user interface, a more advanced analysis framework, and extended support for various natural hazards and industrial activities. Besides a comprehensive user manual, case-studies and hands-on training are also provided by the JRC to support the users.

As part of these support activities, this beginner's guide aims to deliver a comprehensive, yet easy-to-follow introduction to Natech risk analysis and mapping by using RAPID-N. The user interface, data estimation framework, and risk analysis methodology are explained in detail. Step-by-step tutorials are provided for various Natech risk analysis case-studies ranging from a simple single industrial plant scenario to a scenario involving multiple industrial plants and multiple plant equipment. The guide also includes updated information to the User Manual by describing features and capabilities added, updated, or deprecated since the publication of the manual.

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; Cruz and Krausmann, 2009; Girgin and Krausmann, 2016a). 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. Systematic analysis of the Natech risk a prerequisite for this purpose (Krausmann and Baranzini, 2012). RAPID-N is an online system for the analysis and mapping of accident risks at industrial plants due to natural-hazard impacts (Girgin and Krausmann, 2013a). It was developed by the European Commission Joint Research Centre (JRC) in 2010-2012 with initial support by the Scientific and Technological Research Council of Turkey (TUBITAK). The system has been operational since 2012 and it is publicly available at http://rapidn.jrc.ec.europa.eu. A comprehensive user guide is available, which is the precursor of this guide and describes the initial features of the system in detail (Girgin, 2012). At the beginning, RAPID-N was focused on the impacts of earthquakes on hazardous industrial plants (Girgin and Krausmann, 2012; Girgin and Krausmann, 2013b). In time it has been extended to also cover floods hazards (Girgin, 2016a; Girgin, 2017) and hazardous liquid transmission pipelines (Girgin and Krausmann, 2016b) for which prototype systems were developed.

1.1 Overview of RAPID-N

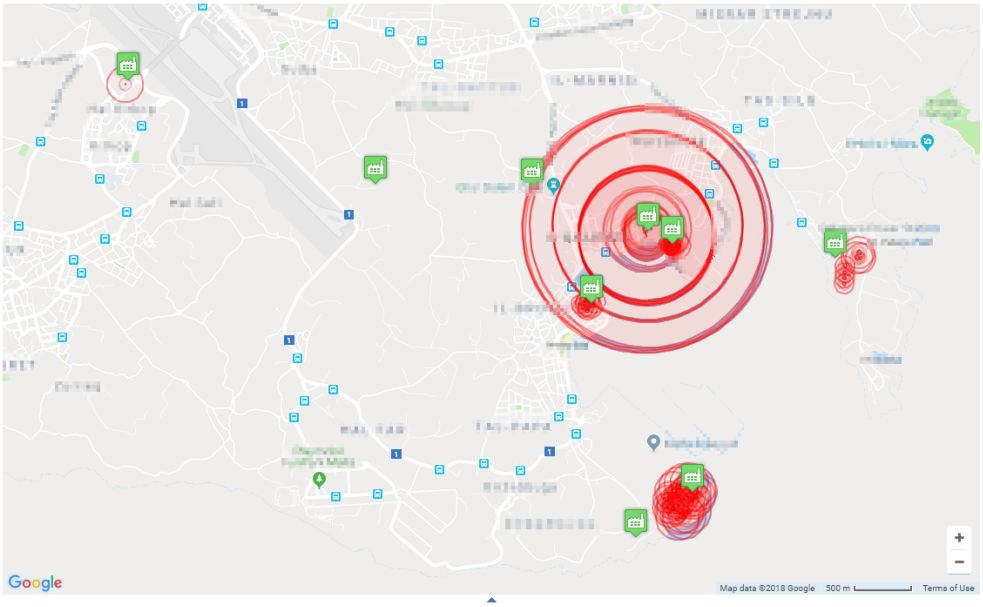
The primary aim of RAPID-N is rapid local (e.g. single plant) or regional (e.g. multiple plants distributed over a large geographic area) Natech risk analysis with minimum data requirements. Competent authorities can use RAPID-N for land-use or emergency planning by analysing the potential consequences of different Natech scenarios. RAPID-N can also support 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.

In order to analyse the Natech risk, RAPID-N first calculates natural-hazard severity parameters at the industrial installations either by using pre-calculated on-site hazard data, such as hazard maps, or by utilizing hazard-specific data estimation functions. Natural hazard impacts are evaluated separately for each industrial equipment, called plant units, 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, and finally 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 given in Figure 1.

RAPID-N does not contain any pre-defined, hard-coded models for the analysis. For each Natech scenario, a flowchart of the damage and consequence models required for risk analysis is created on-demand by using the individual model equations available in the system considering the available input data and the validity conditions of the equations. A starter set of model equations has already been implemented in RAPID-N, which is available to all users. However, the users can also define their own input data and equations to customize the calculations according to their needs. The data protection features of the system prevents user-specific modifications to affect other users, allowing the users to experiment with different analysis scenarios and methods. Therefore, RAPID-N can also be used as a test bed for scientific research and development purposes.

In order to preserve confidentiality, RAPID-N supports data access restrictions for critical information, such as industrial plant and risk analysis data.

Figure 1. Example Natech risk analysis report and map



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_p: 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(1.6998·10^{-6})
				DS3: P(2.5095·10^{-5})	Fire/Explosion Event: Pool Fire; $Q_{released}$: 4769.1 kg ❯	22.58 m, P(< 1·10^{-6})
				DS4: P(1.1644·10^{-6})	Fire/Explosion Event: Pool Fire; $Q_{released}$: 228918 kg ❯	92.69 m, P(< 1·10^{-6})
				DS5: P(< 1·10^{-6})	Fire/Explosion Event: Pool Fire; $Q_{released}$: 31850000 kg ❯	92.69 m, P(< 1·10^{-6})

Source: JRC, 2018

User registration is needed for data entry, and further authorisation is required for carrying out Natech risk analysis. All other data supporting the risk analysis process is publicly available. RAPID-N also 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.

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 in near real-time and collects information on recent events. Currently, the natural hazard database of RAPID-N contains information of about 22,000 earthquakes and 14,000 earthquake hazard maps. World-wide information on over 5,500 industrial plants (e.g. refineries, power plants) and 64,000 storage tanks collected from public sources is also available. However, they are not publicly accessible due to confidentiality constraints.

Recently, the user interface and risk analysis capabilities of RAPID-N were improved by re-designing and further developing its application and computation frameworks (Girgin, 2016b). The user interface was upgraded to a mobile-friendly, responsive interface. The computational modules were also upgraded to provide a more flexible data estimation and modelling framework facilitating further development and integration of RAPID-N with other related systems. Feasibility studies were performed in order to determine how RAPID-N can be integrated into existing natural hazard forecasting and early-warning systems to provide Natech-related information to support emergency management and response activities (Girgin et al., 2016; Girgin et al., 2017). Studies to integrate RAPID-N with advanced consequence modelling software, e.g. the Accident Damage Analysis Module (ADAM) of the JRC (Fabbri et al., 2017), are also on-going.

In order to support the competent authorities and other users, the JRC organises Natech risk assessment workshops, which include hands-on RAPID-N training. Reference local and regional risk analysis case-studies by using RAPID-N are also available (Girgin and Krausmann, 2013b; Girgin and Krausmann, 2017; Necci et al., 2017a; Necci et al., 2017b).

1.2 Structure of the Guide

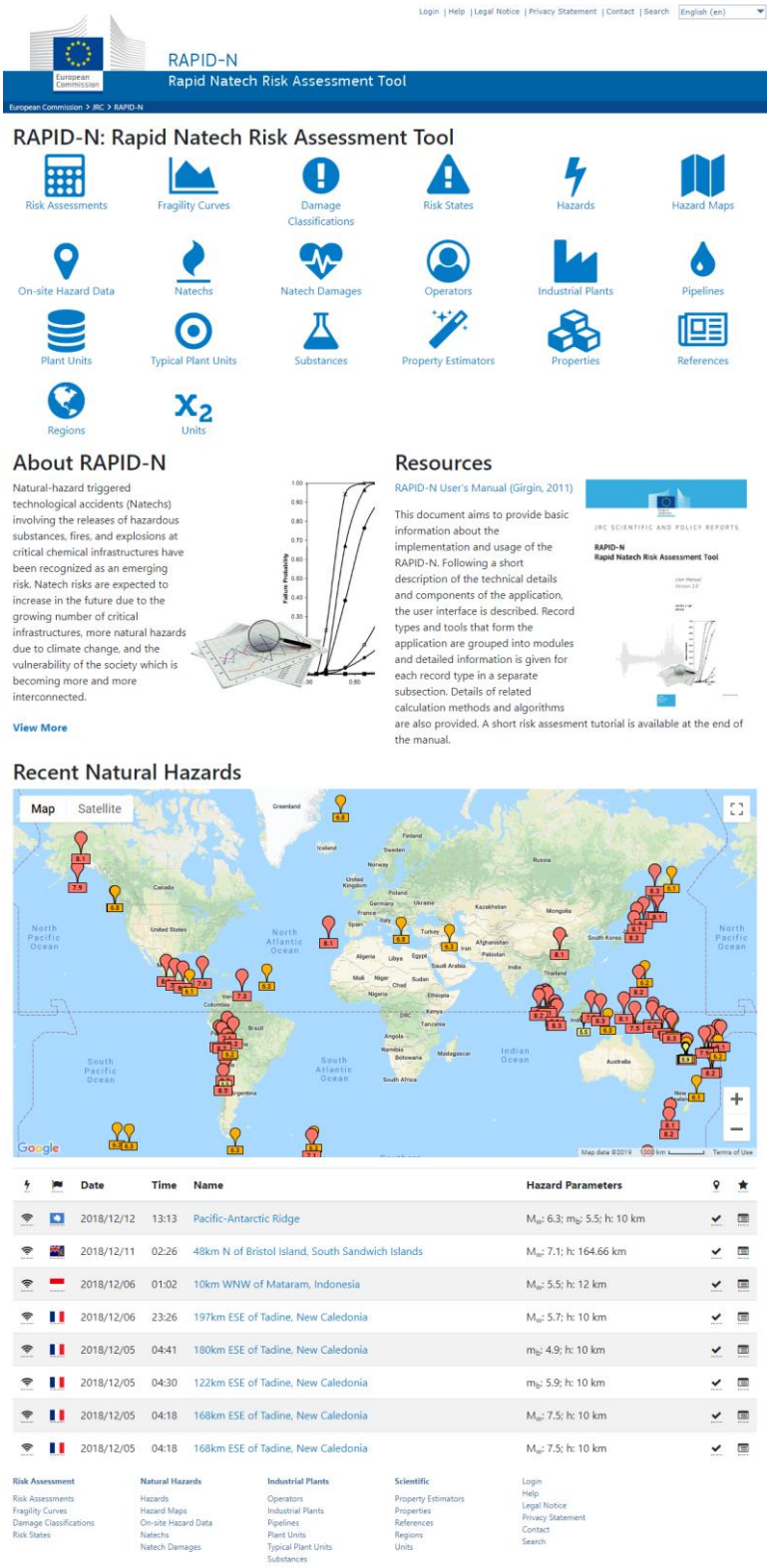
The guide is composed of five main sections. In the first section, the system and its user interface is explained. Data access rules, data query methods, and data entry features are described. In the second section, the data estimation framework of RAPID-N is described in detail. Besides properties and property estimators, which form the basis of the framework, the steps of the data estimation methodology are also defined. In the third section, the risk analysis framework of the system and its primary components, such as natural hazards, industrial plants, and risk analyses, are explained. Data entry options and also minimum data requirements are described. The steps of the Natech risk analysis methodology are indicated and information on customisation options of the analysis is provided. In the fourth section, the basics of the programming language that can be used by the users to develop their own data estimators are summarised. In the last section, step-by-step tutorials are provided for various Natech risk analysis case-studies ranging from a simple single plant scenario to a scenario involving multiple plants and multiple plant units. In addition to information on data entry and analysis steps that should be followed for each scenario, a short discussion on the risk analysis results are also provided to assist the users in the interpretation of the risk analysis reports and maps produced by the system.

The provided information and tutorials in this guide aim to facilitate the use of RAPID-N by a wide range of users world-wide and lessen the time necessary to perform Natech risk analysis by using the system. The guide also provides updated information to the User Manual (Girgin, 2012) by describing features and capabilities added, updated, or deprecated since the publication of the manual.

2 User Interface

RAPID-N features a mobile-friendly, responsive user interface which can be accessed at http://rapidn.jrc.ec.europa.eu by using any modern web browser supporting HTML 5 and JavaScript. The typical entry page of the system (i.e. home page) is illustrated in Figure 2.

Figure 2. Home page of RAPID-N



Source: JRC, 2018

The home page includes a standard menu at the top with quick access links to sign-in, help, contact, and search actions, as well as legal notice and privacy statement documents. This menu is permanent, i.e. displayed on all pages of the system.

The last item of the top menu is a drop-down list, from which the language of the system can be selected. RAPID-N supports multiple languages for the user interface elements, including menus and data entry forms. By changing the language, you can use the system in your preferred language. The default language is English.

Remark. Changing the language

Changing the language affects all user interface elements, but not the content, i.e. data stored in the records. Therefore, you can still see some information in the default language, although you set the language differently.

Remark. Default language

RAPID-N is a collaborative system, which aims to collect and share expert knowledge on Natech risk analysis. For this purpose, it is good practice to enter and share non-confidential data in the default language (i.e. English), so that it can be easily understood by a larger audience.

At the beginning of the home page a series of icons are available, each of which allows access to listing pages of different records provided by the system, such as risk analyses, hazards, industrial plants, plant units, and substances.

Below the icons, summary information about the system and the resources available for the users, such as the user manual, scientific articles, and case-study documents are shown.

Next to the information section, a map of recent natural hazard events is displayed on which the events are located by coloured markers in various sizes indicating their severities. A quantitative severity indicator (e.g. magnitude for earthquakes) is also provided for each event. An information window containing summary information about the event can be displayed by clicking on a marker. Clicking the "Details" link on the information window leads to the detailed information page of the event.

Hint. Recent natural hazards map

The map of recent natural hazards not only displays the most recent events, but also earlier but more severe events. For example, the map includes all earthquakes with a magnitude greater than M 8.0 and all earthquakes with a magnitude between M 7.0 and M 8.0 in the last 12 months. Therefore, it can be used to observe the overall distribution of the most important and most recent events.

The table below the map lists the most recent natural hazard events sorted in the decreasing order by the occurrence date. For each event, the table indicates the type of hazard, country of origin, occurrence date, name of the event, available hazard source data (e.g. focal depth, magnitude), and availability of hazard maps related to the event.

At the bottom of the page, a permanent quick access directory is available, which lists links to the listing pages of all records provided by the system and also the links available in the top menu. Similar to the top menu, the directory is displayed on all pages of the system.

Hint. Bottom directory

You can use the directory to quickly access different types of records without going back to the home or personal pages.

2.1 Record Types

The analysis framework of RAPID-N is based on data records, which are also called entities. Each record has a record type that defines the content (i.e. data fields) and role (i.e. how it is processed) of the record in the system. In fact, record types correspond to physical or theoretical definitions (e.g. natural hazards, industrial plants, hazardous substances, etc.) which play a role in Natech risk analysis, and records are data sets holding information on individual entities based on these definitions (e.g. Hurricane Harvey, Jamnagar Refinery, Gasoline, etc.). The system features record-type specific data entry forms which can be used to create or modify the associated records and information pages to visualise these records. Natech risk analysis is performed by using the records available in the system, which are either provided by the system itself or entered by the users.

The following record types are available in RAPID-N:

- *Properties* are used to define record-type specific characteristics and attributes of the records.
- *Property Estimators* are used to calculate values of properties by using scientific methods and readily available property data.
- Hazards are used to provide data on natural hazard events (i.e. scenarios).
- Hazard Maps are used to provide site-specific (i.e. on-site) natural hazard severity data for hazard events.
- *On-Site Hazard Data* are used to provide custom site-specific natural hazard severity data for industrial plants.
- Industrial Plants are used to provide information on hazardous industrial installations.
- *Pipelines* are used to provide information on hazardous pipeline systems.
- Plant Units are used to provide information on storage and processing units (i.e. equipment) located at industrial plants.
- Typical Plant Units are used to provide reference (i.e. representative) plant unit data for industrial plants, for which actual plant unit data is missing.
- Substances are used to provide information on hazardous substances.
- *Operators* are used to provide information on the operators of the industrial plants and pipelines.
- Damage Classifications are used to define qualitative damage states of the plant units that could occur due to natural hazard impacts.
- Fragility Curves are used to estimate the probability of various damage states based on on-site natural hazard severity data.
- Risk States are used to initiate consequence (e.g. fire, explosion, toxic release) scenarios that might be triggered by the damage scenarios.
- Risk Analyses are used to set-up the risk analysis process and store the results.
- *Natechs* are used to store information about historical Natech events.
- *Natech Damages* are used to provide information on historical Natech damage at industrial plants and plant units.
- References are used to provide bibliographic information on records.
- *Units* are used for unit conversion.

The record types which are covered in this guide are explained in detail in the Data Estimation Framework and Risk Analysis Framework sections. Please refer to the User Manual (Girgin, 2012) for the details of other record types.

2.2 User Access

You can sign-in to the system by clicking on the "Login" link in the top menu. Once you click the link, you will be forwarded to the European Commission's user authentication service known as "EU Login". If you already have an EU Login account, you can use your existing account to login to RAPID-N. Otherwise you can create an account by clicking the "Create an account" link on the EU Login page and following the instructions. Once you complete the sign-in process through EU Login, you will be redirected to RAPID-N.

Remark. EU Login

If you already signed in to EU Login before using RAPID-N, then EU Login will not display the login screen, but will directly redirect you to RAPID-N by using your active user account. If you have multiple EU Login accounts (i.e. work-related and personal) and want to use a specific one for RAPID-N, first make sure that you signed out from your EU Login accounts. Otherwise EU Login may redirect you to RAPID-N automatically as indicated above, without allowing you to change the account. You can use the "EU Logout" link on the top menu of RAPID-N to access the EU Login sign out page.

The first time you register to RAPID-N, the system will display a registration form when you are redirected back to the system. By filling in the form with your information, agreeing to the terms and conditions, and clicking the "Update" button, you can complete your registration. After the registration and also after all successive logins, your personal page will be displayed which shows your user information and icons for accessing record listing pages similar to the home page. You can modify your personal information at any time by clicking on the "Update" button, which leads to the user data entry form.

Remark. Personal information

Your name, surname, and e-mail address are provided automatically by EU Login. Therefore, if you need to modify this information you should use EU Login account settings. They cannot be changed in RAPID-N. Also your account password is controlled by EU Login and it should be changed though EU Login, if necessary.

2.3 Data Access

Many records available in RAPID-N, such as hazards, hazard maps, substances, properties, property estimators, and references are publicly available. Hence, it is not necessary to sign-in to the system to access such information. However, signing-in allows you to create your own records. In addition, depending on the access restrictions, some records and functionalities are only available to certain registered users. Therefore, signing in is highly recommended to be able to use all available features of the system.

RAPID-N has a three-level access control for most of the record types, which includes private, restricted, and public states. Private records are only accessible by the users who created these records, i.e. the owners. This is the default state while creating new records.

Remark. Private records

The private access level provides confidentiality for records with critical information such as risk analyses and plant units which can be protected by using this state.

Owners can set the state of their records individually as restricted. In this state, a record is also accessible by other registered users. However, it can only be modified or deleted by its owner. Therefore, the other users have only read-only access. Finally, a record which is in the restricted state can be made publicly available by the administrators by setting its state as public. Such records are available to all users, including the ones who did not sign in, i.e. visitors. Similar to the restricted state, public records can only be deleted by their owners. However, they can only be modified by the administrators if necessary. Therefore, this state indicates that the record is complete and in its final form.

Remark. Restricted records

The restricted state is an intermediate state which aims to indicate that the information provided in the record (e.g. bibliographic reference, property estimator) might be useful for the user community of RAPID-N and also the public. Registered users are able to access the record immediately once its state is set as restricted, whereas for public access records, peer-review by the administrators (i.e. setting the state as public) is necessary. This allows publicly available information to be validated and quality controlled.

In addition to the data access states, which affect how data is accessed, created and modified, the system also requires authorisation for the creation of selected record types. Risk analysis, property, and property estimator records require this additional authorisation step due to their critical role in the system. Authorisation is granted by the administrators based on the provided personal information (e.g. job title, institution) once a user is registered to the system. Authorisation is permanent, i.e. does not need to be renewed unless it is cancelled by the administrators.

Remark. Authorisation

Because authorisation is not an automated process, there can be a short delay between being registered to the system and being authorised for performing risk analyses and creating properties and property estimators. Users receive an email from the administrators once authorisation has been granted.

2.4 Data Query and Listing

By clicking on the icons on the home and personal pages, or by using the links available in the bottom directory of each page, you can access the listing pages of the related record types. Although each listing page displays information on different record types, they have a common interface which is composed of filters, action buttons, a navigation bar, and a records table. An example listing page is given in Figure 3.

Figure 3. Example records listing page

Units

- Code - | - Name - | - None - | - SI Prefix - | List | Create

75 records found. 1 2 » | 10 | Name

No	Code	Symbol	Name	Factor	Unit	SI	Spacing	Position
1.	A	A	ampere	-	-	-	✔	✔	1#
2.	Ao	Å	ångström	Ω	$1 \cdot 10^{-10}$	m	-	✔	1#
3.	atm	atm	atmosphere	Ω	101325	Pa	-	✔	1#
4.	bar	bar	bar	Ω	1000000	dyn/cm^2	✔	✔	1#
5.	B	barrel	barrel	Ω	42	gal	-	✔	1#
6.	Bq	-	becquerel	Ω	1	1/s	✔	✔	1#
7.	BTU	BTU	British Thermal Unit	Ω	1055.1	J	✔	✔	1#
8.	cal	cal	calorie	Ω	4.184	J	✔	✔	1#
9.	cd	cd	candera	-	-	-	-	✔	1#
10.	C	-	coulomb	Ω	1	A/s	✔	✔	1#

Source: JRC, 2018

By default, the listing pages list all records available in the system, which are accessible by the active user. As indicated before in the data access section, visitors and different registered users may see different sets of records due to access restrictions. Specific records can be searched by using the available filters. Multiple filters can be entered at the same time. The system applies the logical *AND* operator to combine the filters; hence, entering multiple filters results in a more restricted query, usually yielding a lower number of matching records.

In order to perform the query, the "List" button located at the end of the filters should be clicked. Pressing the "Enter" key on the keyboard while typing on a textual filter also automatically triggers the query action. Depending on user rights, a "Create" button might also be displayed next to the "List" button, which leads to the data entry form of the related record type.

The system features 4 types of filters: textual, drop-down list, date, and existence.

Textual filters allow free-text search by using keywords, which can be further customized by using special characters and keyword groups. By default, keywords entered in the textual filters are searched as a whole in the related data fields of the records. For example, performing a search by entering the keyword `degree` into the "Name" filter on the "Units" listing page will return 4 matching records, which are "degree", "degree Celsius", "degree Fahrenheit", and "degree Rankine". However, the same query with the keyword `deg` will return no results, as there are no units in the database which include "deg" as a whole in the name field.

In order to extend the search to partial words, the asterisk (`*`) character can be utilized at the beginning and/or at the end of the keyword. The asterisk is regarded as a placeholder for zero or more characters, and therefore indicates "starting with", "ending with", or "including" criteria, if located at the beginning, at the end, or at both sides of a keyword, respectively. For example, a query with `deg*` will return the initial 4 matching records, as all records including the word "degree" also contain a word starting with "deg".

Multiple keywords separated by one or more space characters are combined with the logical *OR* operator. Therefore, a query with `deg* percent` keywords will return 8 records, which include 4 additional records containing the word "percent": "percent", "percent by volume", "percent by weight", and "percent standard gravity".

Keyword groups that are composed of multiple keywords can be entered in quotation marks to prevent evaluation as multiple keywords. For example, the query with `deg* cel*` will return 4 degree records matched by the `deg*` keyword, as the second keyword `cel*` does not match additional units. But, the same query with the `"deg* cel*"` keyword group will return only one record which is "degree Celsius", as "degree" matches the `deg*` keyword and "Celsius" matches the `cel*` keyword of the keyword group.

Remark. Order of the keywords

The order of the keywords in a keyword group is important and affects how the keywords are searched. For example, `"deg* cel*"` and `"cel* deg*"` are not identical.

In order to exclude a keyword or keyword group, the minus (`-`) character can be utilized at the beginning of the keyword or keyword group. For example, `deg* -cel*` will return 3 records, i.e. all 4 degree records, except "degree Celsius" because "Celsius" matches the `cel*` keyword which is excluded.

By entering multiple keywords or keyword groups and utilizing special characters, advanced queries can be performed easily by using the textual filters.

Remark. Textual filters

Textual filters are case insensitive, i.e. lower case and upper case characters are considered to be identical, unless the related data field of the record is case sensitive. For example, the `degree` and `DEGREE` keywords return the same results. The only exceptions (i.e. case-sensitive filters) are the filters related to the "Code" data fields of the "Unit" and "Property" records, as these data fields are case-sensitive.

Drop-down filters match the records which have the same value in the related data field as the value selected in the drop-down filter. Usually drop-down filters correspond to the drop-down list input elements of the records and include the options presented by these input elements. There are also two additional special options available, which are *Any* and *None*. The records having a value (i.e. any value) set or having no value set for the specified data field can be queried by using the Any and None options, respectively.

Similarly, existence filters check whether or not any value exists in the related data field.

Date filters match the records with the specified date value in the related date field. See the Date Input section for more details on the date fields.

The records matching the filters, if any, are listed on the listing pages in a tabular format. Each row in the table corresponds to a separate record. Because some queries may match a very large number of records, the results are tabulated through pagination, i.e. each time a limited number of records are tabulated based on the active page number and the number of rows per page (Figure 3).

Above the results table, a navigation bar is provided which includes tools to navigate through the results and modify how the results are listed. The first item on the navigation bar is an indicator, which displays the total number of records in the results set. Next to the indicator, a pagination element is provided which shows the active page and allows navigation through the other result pages.

Hint. Rows per page

The default number of rows per page is 25, which can be changed by the "Rows Per Page" drop-down list next to the pagination element. Setting a new number of rows per page does not reset the current starting row number. For example, if the current starting row is 26, then 50 rows starting from the 26th row are displayed if rows per page is changed from 25 to 50.

Normally, results are tabulated as sorted by the default sorting column of the results table, which depends on the record type. The sorting column can be changed by using the "Sort By" drop-down list. The direction of sorting (i.e. ascending or descending) can be specified by clicking the "Sort Direction" button, which toggles the sorting direction between the ascending and descending orders. The active sorting column is indicated by a triangle next to the column name, which points up or down for ascending or descending order, respectively.

Hint. Local sorting

The sorting settings affect not only the results visible on the active page, but also on all other pages, i.e. all results matching the query are sorted accordingly. By clicking the table column labels, you can also sort the results in the current page locally. Similar to the normal sorting, the sorted column is indicated with a triangle. Successive clicks on the same label change the sort direction. Local sorting is not permanent, i.e. the sorting column and direction will reset to the defaults specified in the sorting settings if the active page is changed or refreshed.

2.5 Data Entry

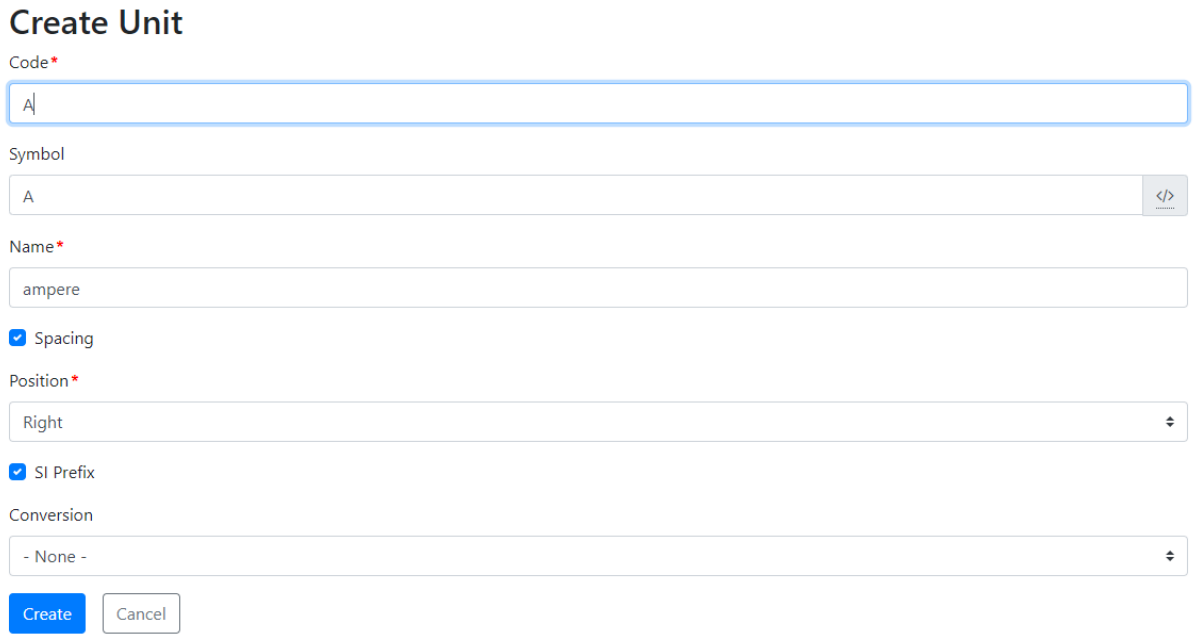
Data entry to the system is done through interactive data forms. You can access the record-specific data entry forms by clicking the "Create" button displayed on the record listing pages. Create buttons are also displayed for specific record types on the information pages of the related records. For example, the industrial plant information page displays a "Create" button for the "Risk Analysis" record type, which leads to the risk analysis data entry form and sets the plant data field automatically.

Remark. Display of the "Create" buttons

"Create" buttons are only displayed if the user has the right to create an associated record. Most of the time being a registered users is enough to create records, but additional limitations exist for certain record types as indicated in the Data Access section.

The data entry forms include mobile-friendly and responsive input elements, such as text fields, drop-down lists, and check boxes, which are common to web-based applications. There are also some enhanced input elements, such as fuzzy number fields, wiki editors, calendars, and input lists. The data entry forms also include data entry maps that allow entry of geographical information, such as coordinates and physical boundaries, the details of which are given in the Mapping section. The forms are dynamic, i.e. some of the input elements are shown or hidden according to the values of others. Input elements that must not be left empty (i.e. which are mandatory) are indicated by an asterisk (*) in their labels. Textual input elements are generally restricted to the entry of specific types of data, such as numbers, dates, or coordinates. Usually, such elements are indicated with special icons appended to the input elements. An example data entry form illustrating different input elements is shown in Figure 4.

Figure 4. Example data entry form

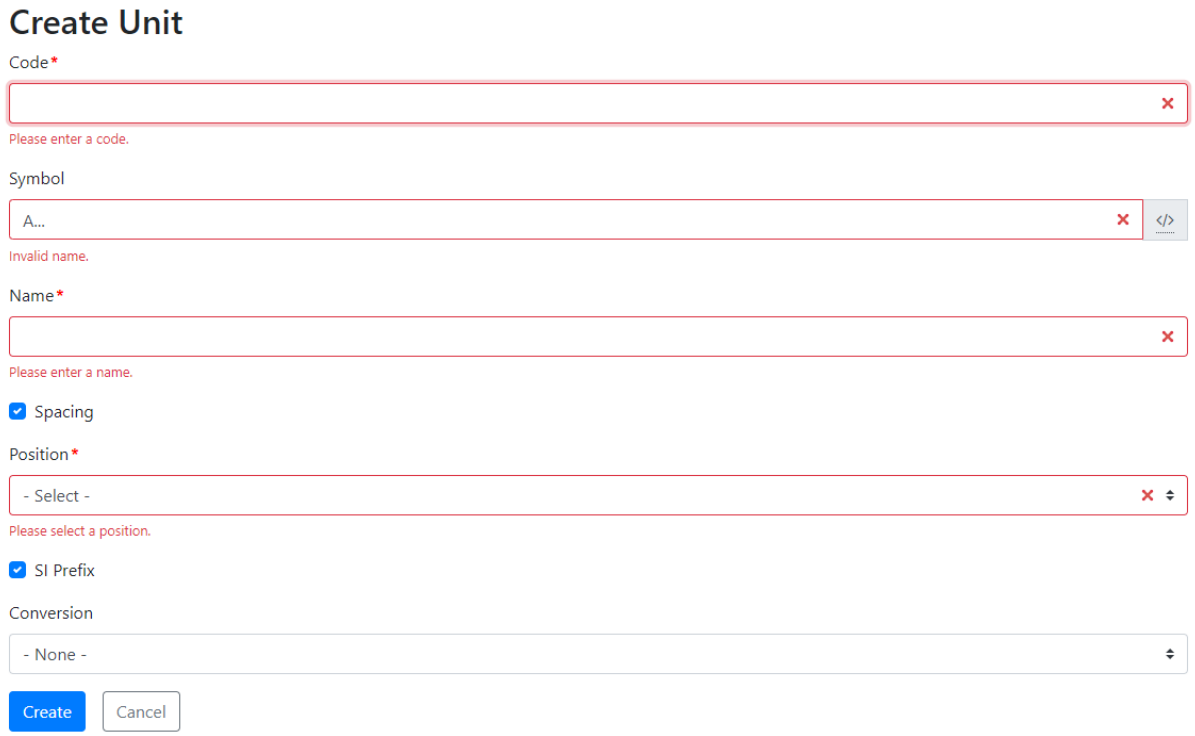


Source: JRC, 2018

Form data is validated on the client-side before submission of the data to the server for processing. If empty or invalid input data are found, the related input elements are highlighted and error messages are displayed to indicate the identified errors (Figure 5). Form submission is not possible until all invalid inputs are corrected. After the submission,

form data is also validated on the server to prevent unauthorized actions and to perform additional validation which is not possible on the client-side. If all data is found to be valid, it is processed and the associated action is performed (e.g. the record is created, the analysis is performed, etc.). Otherwise, the form is re-displayed with the entered data, and invalid input elements are indicated for correction as illustrated in Figure 5.

Figure 5. Example data entry form with invalid input data



Source: JRC, 2018

Input elements which are either specific to RAPID-N or have some additional features not commonly found are as follows:

2.5.1 Date Input

Date input provides a calendar window from which you can choose the date easily. In order to display the calendar window, click the "Calendar" icon next to the input element. By default, the date format (i.e. YYYY/MM/DD, DD/MM/YYYY, MM/DD/YYYY) which is used to enter and visualize the dates depends on the active language of the system. You can customize the date format by setting its value in your personal information.

Remark. Default time zone

Dates should be in entered in the Coordinated Universal Time (UTC) to prevent possible confusion among the records due to location-specific time zones.

2.5.2 Wiki Input

Wiki input allows multi-line formatted text input, which features headings, emphasized text, subscript and superscript, ordered and unordered lists, and hyperlinks. These features can be utilized in the text by using a simple mark language with special tags. An example wiki content illustrating available tags with corresponding formatted output is given in Figure 6.

Figure 6. Example wiki content with corresponding formatted output

```
== Heading ==

This is a paragraph.

This is another paragraph.

Example '''emphasized''' text.

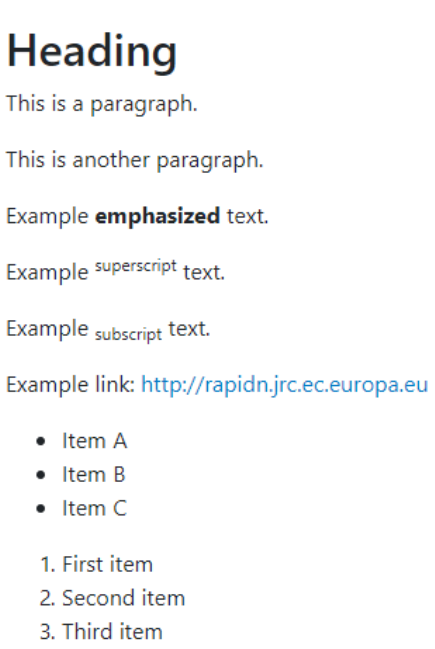
Example ^^superscript^^ text.

Example ^_subscript_^ text.

Example link: [http://rapidn.jrc.ec.europa.eu]

* Item A
* Item B
* Item C

# First item
# Second item
# Third item
```



Source: JRC, 2018

2.5.3 Combo Box Input

Combo box input is a combination of a text input and a drop-down list, which allows the selection of existing values instead of re-typing manually. By clicking the button next to the input element, text input or drop-down list modes can be toggled.

Remark. Combo boxes

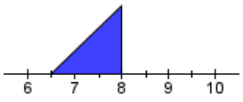
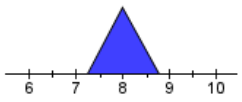
Because they allow standardisation of data values, the use of existing values through the drop-down list is good practice for combo box inputs.

2.5.4 Fuzzy Number Input

Input data available for the analysis is not always well-defined and can include some uncertainties. For example, substances often have different values for the same properties (e.g. heat of combustion) based on the characteristics and limitations of the analysis methods used to measure the values. Therefore, sometimes data may be available not as exact numbers, but as range or boundary values such as 2.0 – 2.2, $< 10^{-3}$, > 0.8, etc. In order to prevent loss of valuable information by enforcing the users to convert such values to their point-value approximates for the data entry, the system allows fuzzy numbers to be entered for numerical data. Signed and unsigned integer, decimal and scientific fuzzy numbers are supported.

In order to simplify the calculations, five different fuzzy number types are defined in the system, which describe *less than*, *greater than*, *in between*, *about* and *exact* value conditions that are encountered frequently. Trapezoidal fuzzy numbers with constant slopes are used to represent fuzzy values (Buckley, 2006). A trapezoidal fuzzy number is defined by four numbers $a \leq b \leq c \leq d$, where the base of the trapezoid is the interval $[a, d]$ and its core is the interval $[b, c]$. A value of 20% is selected as the default fuzziness amount, which results in a 20% slope for one-sided conditions (i.e. less than and greater than) and a 10% slope at sides for the two-sided condition (i.e. about). Examples of supported fuzzy numbers and their corresponding four-number presentation and point-value approximations are given in Table 1.

Table 1. Supported fuzzy number types

Type	Example	Definition	Point-value
Less than	< 8 	[6.4, 8.0, 8.0, 8.0]	7.467
Greater than	> 8 	[8.0, 8.0, 8.8, 9.6]	8.533
Between	7 – 9 	[7.0, 7.0, 9.0, 9.0]	8.0
About	~8 	[7.2, 8.0, 8.0, 8.8]	8.0
Exact	8 	[8.0, 8.0, 8.0, 8.0]	8.0

Source: Girgin, 2012

Remark. Handling of fuzzy numbers

By default, fuzzy numbers are automatically converted to their point-value approximations for the calculations. The system also has the capability to use fuzzy arithmetic instead of ordinary arithmetic for the calculations, whenever necessary. In this case, the results are presented by using the five fuzzy number types supported by the system, if possible. For example, if the result is [5, 5, 6, 6], it is shown as 5 – 6.

Besides the quantitative uncertainty that can be specified by the fuzzy number types, fuzzy numbers also support a qualitative uncertainty indicator. By appending a question mark (`?`) at the end of the fuzzy number, you can indicate that there is a further uncertainty (i.e. doubt) on the specified value. For example, `10?` indicates that the value might be 10, or `10 - 20?` indicates that the value might be between 10 and 20.

Remark. Use of fuzzy numbers

Because fuzzy numbers allow uncertainty in the data to be specified explicitly, they allow a better representation of the state of the data quality. Therefore, it is good practice to utilize fuzzy numbers if input data is not well-defined and if it can be represented by the supported fuzzy number types (i.e. less than, greater than, between, about, and exact).

2.5.5 Unit Input

Most of the numerical data utilized by the system require that the unit of the data to be specified. For this purpose, the system features unit input elements which allow composite units to be entered by using a simple format that is composed of base unit codes, separators, and exponentials. The base units supported by the system and corresponding unit codes can be accessed through the "Units" listing page, which is available at http://rapidn.jrc.ec.europa.eu/unit/list.

Codes of the base units that support metric (i.e. SI) prefixes can be combined with standard SI prefix codes to obtain multiple or fractional units. For example, gram denoted by `g` can be prefixed with `k` to obtain kilogram (`kg`, 1000 gram), or with `m` to obtain milligram (`mg`, 10^{-3} gram). A list of SI prefix codes and the corresponding scaling factors is given in Table 2.

Table 2. List of SI prefixes

Prefix	Symbol	Factor	Code
yotta	Y	10^{24}	Y
zetta	Z	10^{21}	Z
exa	E	10^{18}	E
peta	P	10^{15}	P
tera	T	10^{12}	T
giga	G	10^{9}	G
mega	M	10^{6}	M
kilo	k	10^{3}	k
hecto	h	10^{2}	h
deca	da	10^{1}	da

Prefix	Symbol	Factor	Code
deci	d	10^{-1}	d
centi	c	10^{-2}	c
milli	m	10^{-3}	m
micro	µ	10^{-6}	u
nano	n	10^{-9}	N
pico	p	10^{-12}	P
femto	f	10^{-15}	F
atto	a	10^{-18}	A
zepto	z	10^{-21}	Z
yocto	y	10^{-24}	y

Source: Girgin, 2012

Remark. Case-sensitivity of unit codes

Unit codes and SI prefixes are case-sensitive, i.e. they should be specified exactly as they are defined. For example, `bar` is a valid unit code, whereas `BAR` or `Bar` are not valid.

In order to specify composite units, the dot (`.`) and slash (`/`) characters can be used to indicate multiplication and division, respectively. The exponentials of the units constituting the composite unit can be indicated by integer numbers following each unit. The minus sign (`-`) before a number indicates a negative exponent. For example, `kg.m/s2` denotes kilogram meter per second square, which is newton (`N`). It is also identical to `kg.m.s-2`.

Remark. Automated unit conversion

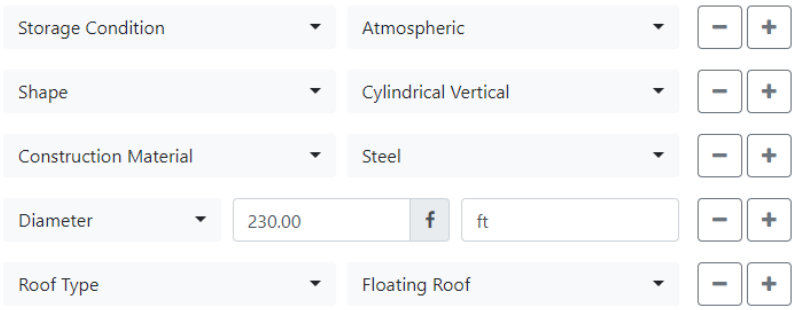
The system has an automated unit conversion capability. Therefore, numerical data with a specific unit can be entered not only by using the specified unit, but also with all compatible units. For example, a value with the unit of meter (`m`) can be entered in kilometre (`km`), feet (`ft`), inch (`in`), etc. The system uses the user-defined (i.e. entered) unit for the visualisation, but converts the value into the reference unit for the analysis. For example, if the reference unit is meter, `10 in` is considered as `3.048 m` for the calculations. Therefore, manual conversion of units is not necessary for the data entry.

2.5.6 Properties Input

The analysis performed by RAPID-N strongly depends on the characteristics of the related entities. Natural hazard parameters, physical conditions of the plant units, chemical properties of the substances, etc. are necessary for the analysis and their values significantly affect the results. Although the system has data estimation capabilities to complete missing data, a minimum set of input data is still necessary. For this purpose, the system provides properties input element.

A properties input element with example data is given in Figure 7.

Figure 7. Example properties input



Source: JRC, 2018

Properties input allows multiple property data to be entered. Each property data includes the related property and its value together with additional information, such as measurement unit. Each property can be selected from a drop-down list which lists the properties that are available (i.e. exists and accessible) in the system that are related to the record type as grouped by property types.

Hint. Search box

If the number of properties available for a record type is more than 20, the drop-down list also displays an inline search box which can be used to filter the properties for quick selection. If a keyword is entered in the search box, only the properties matching the keyword anywhere in their names, including as part of the words, are displayed. For example, the `vol` keyword matches "Volume", "Released Volume", etc.

The input elements presented for the property value depend on the type of the selected property. For tabular properties, the system uses drop-down list elements from which a selection can be made. Similar to the property drop-down lists, property value drop-down lists also feature search boxes if the number of options is high. For numerical properties, property values can be specified as ordinary or fuzzy numbers in integer, decimal, or scientific notation. See the Fuzzy Number Input section for details of the fuzzy numbers. For selected numerical properties the input can be limited to integers only. Similarly, depending on the nature of the property, possible numerical values might be limited to a certain range of values (e.g. positive numbers, numbers between 0 – 100, etc.). Numerical property data inputs may also require the unit of measurement to be specified, which should be compatible with the reference unit of the related property. The details of the properties, including the supported data types and validity constraints, are described in the Properties section.

For each entered property data, the system automatically checks the consistency between the record type, property, and the property data, including context of the property, correctness of the data type, correctness of the value, presence and compatibility of the measurement unit information, and concordance of the entered properties with each other based on the validity conditions of the properties. For example, the diameter property is not valid if the shape is set as rectangular or the roof type property is only valid for cylindrical vertical tanks under atmospheric storage conditions. Problems identified during the validation are indicated for each property data separately, so that they can be corrected by the user.

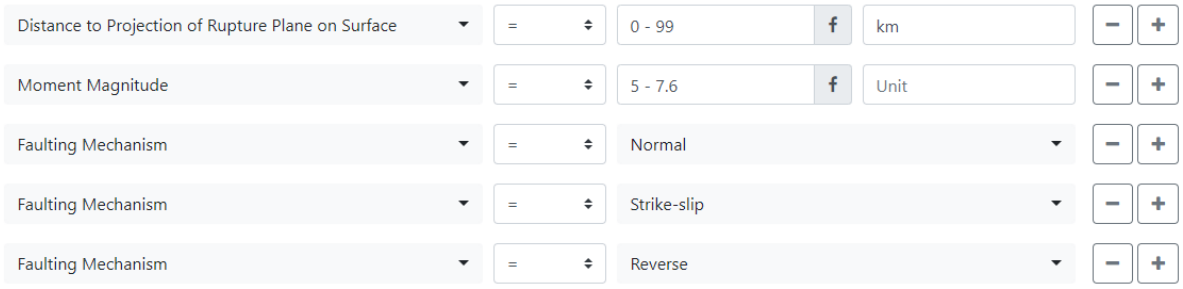
Remark. Data estimation

The system has data estimation capabilities to estimate missing property data by using other readily available data sources (e.g. maps) or by utilizing its data estimation framework, which calculates property data by using property-specific estimation functions. Details of the data estimation capabilities are given in the Data Estimation Framework section.

2.5.7 Conditions Input

Some data utilized by RAPID-N is only valid (i.e. can only be utilized) if certain conditions are met. For example, the diameter of a plant unit can only be defined if the unit has a circular cross section. Similarly, a damage function, which can be used to estimate a damage parameter, can be suitable only for specific natural hazard conditions. In order to indicate such specific conditions, the system features conditions input elements. A conditions input element with example condition data is given in Figure 8.

Figure 8. Example conditions input



Source: JRC, 2018

Conditions input allows multiple conditions to be specified. For each condition, the condition property, condition type, and conditional value (if required) should be specified. Condition properties can be selected from the properties available in the system that are related to the record type for which data is entered. The condition type can be selected from a drop-down list. The system supports three condition types, which are *equal to* (=), *not equal to* (≠), and *does not exist* (∅). The does not exist condition is valid if the related property value is not available. It can be used to set validity in case of unavailability of other property data. Equal to and not equal to condition types test whether the available property value is the same as the value indicated in the condition (i.e. conditional value). For tabular condition properties, the conditional value can be selected from the drop-down list of options provided by the system. For other condition properties, the value should be entered manually. If the property has a reference unit, the unit of the conditional value should also be indicated and it has to be compatible with the reference unit.

Remark. Validity of no data

Because they need property data to test the validity, equal to and not equal to conditions are not valid if property data is not available (i.e. is missing).

Numerical conditions can be entered by using the fuzzy number notation, but in this case they are regarded as range expressions instead of fuzzy numbers. Example range expressions and their meanings are illustrated in Table 3.

Table 3. Range expressions for numerical conditions

Expression	Description	Definition
< 8	Less than 8	$x < 8$
> 8	Greater than 8	$x > 8$
7 - 9	Between 7 and 9	$7 \leq x < 8$
8	Exactly 8	$x = 8$

Source: Girgin, 2012

Multiple conditions can be specified for a single condition property, which are evaluated with logical *OR* operators (e.g. Modified Mercalli Intensity, MMI = 5 or = 6 or = 7). Thus, the validity of a single condition is enough to make the estimator valid for a specific condition property. Conditions of different condition properties are evaluated with logical *AND* operators (e.g. MMI = 5 and Peak Ground Acceleration, PGA ≥ 0.2 g). Therefore, the validity of all condition properties is necessary to make a conditions list valid.

Conditions are visualized by the system as a comma-separated list of conditions grouped by condition properties. Example conditions data view is given in Figure 9.

Figure 9. Example condition data view



Source: JRC, 2018

2.6 Mapping

RAPID-N features a mapping system with built-in GIS analysis capabilities for the entry, visualisation, and analysis of geographical information. The location and boundaries of natural hazards, industrial plants, and plant units can be easily mapped by using the interactive map available at the data entry pages. For industrial plants and plant units, a special mapping tool is also provided, which facilitates entry of multiple records and delineation of their boundaries. RAPID-N uses Google Maps API for editing geographical features (i.e. points, polygons, polylines, and circles) and displaying then on the maps.

2.6.1 Editing Features

The basic feature editing functionality provided by the system is identical for the mapping tool and the maps provided in the data entry pages (i.e. data entry maps). The mapping tool includes a full screen map which covers the whole page, whereas by default the data entry maps are limited in size which can be extended, if necessary. A typical map in editing mode is shown in Figure 10.

Figure 10. Example map in editing mode



Source: JRC, 2018

Hint. Full screen map editing

For data entry maps, you can toggle to the full screen map view mode by clicking on the "Full Screen" button located on the top left corner of the map. While in this mode, clicking the button again or pressing the "Esc" key on the keyboard will bring you back to the data entry form with a normal size map.

In order to delineate a feature, first zoom in to the location of the related entity (e.g. industrial plant) in the map. You can use the zoom in and zoom out buttons located on the bottom left corner of the map to change the zoom level (Figure 10). Alternatively you can also use the scroll wheel of your mouse for zooming.

Remark. Use of the "Ctrl" key

For data entry forms, you may need to press the "Ctrl" key on the keyboard while turning the scroll wheel to enable zooming, otherwise it may scroll the page instead. A "Use ctrl + wheel to zoom the map" message is displayed on the map whenever this is necessary.

You can pan the map by clicking a location on the map and dragging it to another location.

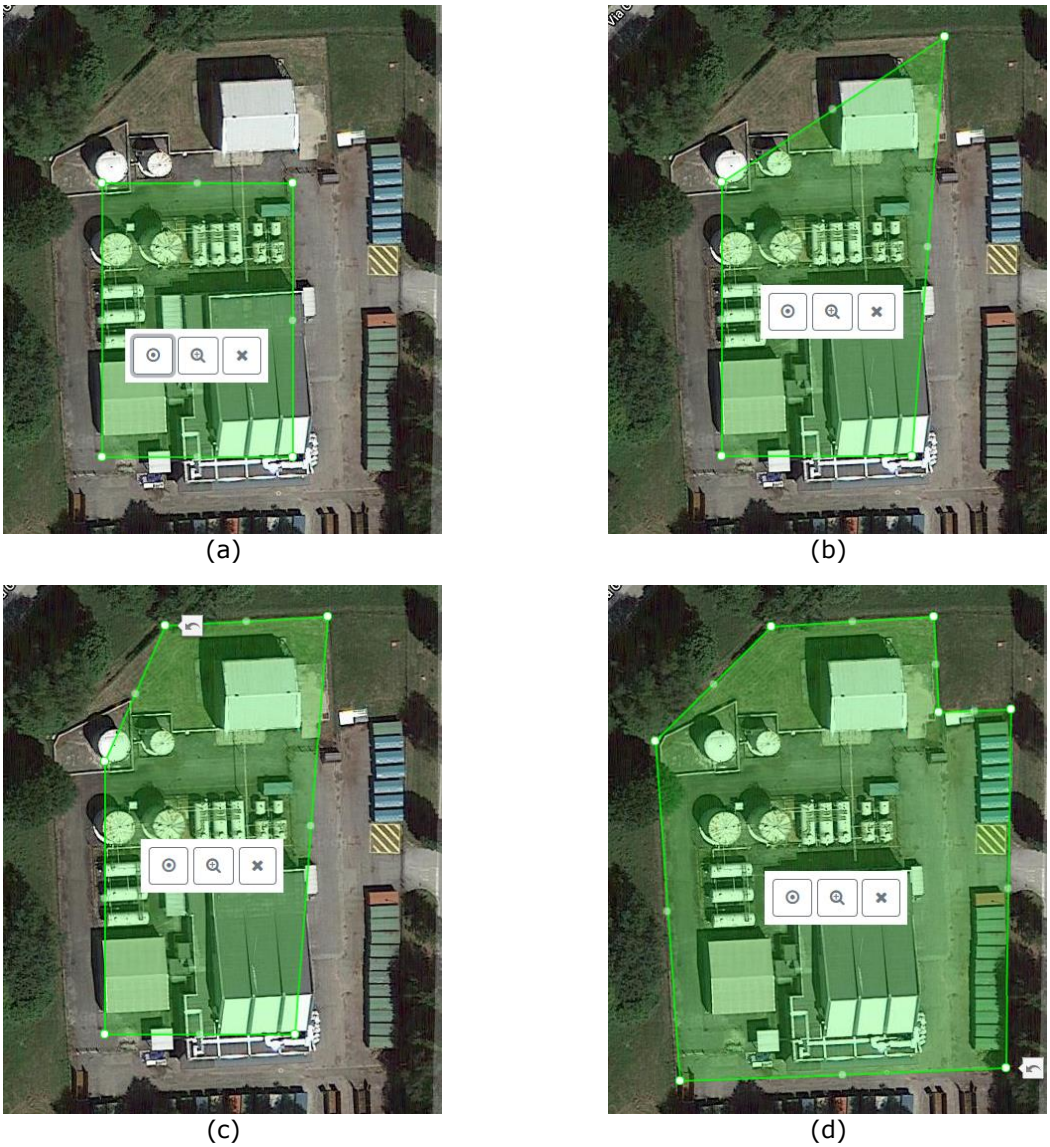
By default, the map displays a high-resolution satellite image overlaid with labels, e.g. street and place names. You can change the map type by using the "Map" and "Satellite" buttons on the top right corner of the map (Figure 10). In the satellite mode the labels, and in the map mode the terrain can be toggled on and off by clicking the related checkboxes, which are displayed when you click on the associated map type button.

Clicking a location on the map initializes the editing process. The system automatically focuses on the spot and displays a white point and a toolbar on the map (Figure 11.a). You can easily change the location of the point by dragging and dropping it to somewhere else. The point can be brought back to the previous location by clicking the "Undo" button that will be displayed beside the point. The point can be removed completely by clicking the right-most "Remove" button on the map toolbar and confirming the removal by clicking "Ok" on the displayed modal dialog. Once the point is deleted, it cannot be undone, but a new point can be created by clicking the same location on the map.

For point features, the white point indicates the feature itself. For other feature types (i.e. polygon, polyline, circle) it is only the initial state, which indicates the origin of the feature without any geometry data. By clicking the "Create Geometry" button on the map toolbar indicated by a rectangle icon, the point can be converted into a feature with initial geometry data (i.e. boundary). By default, the system creates a medium sized rectangle, line, or circle for polygon, polyline, and circle features, respectively.

The initial rectangle boundary for polygon features has 4 "real" vertices on each corner marked by white points, and 4 "virtual" vertices located at the mid-points of the lines connecting the real vertices (i.e. boundary lines). The shape of the boundary can be modified by moving the vertices, i.e. dragging and dropping them to other locations (Figure 11.b). Moving a real vertex deforms the boundary without changing the number of boundary lines. Therefore, the number of vertices is not affected. On the other hand, moving a virtual vertex converts it into a real vertex. Subsequently, the original line that the virtual vertex belongs to is divided into two line segments, for which two additional virtual vertices are created (Figure 11.c). A real vertex can be removed from the polygon by right-clicking on the vertex. Once the vertex is removed, two line segments connecting the vertex to the neighbouring real vertices are also removed and a new line is created to connect the neighbour vertices to each other (Figure 11.b). By performing successive real and virtual vertex modifications, the shape of the boundary can be easily modified to match the physical boundaries of the related entity (e.g. industrial plant) (Figure 11.d). Each vertex move can be undone by clicking the "Undo" button displayed next to the vertex after the move. It is also possible to move the whole polygon by dragging and dropping it to a new location.

Figure 11. Polygon editing



(a) (b) (c) (d)

Source: JRC, 2018

Remark. Undo editing

Undo support for vertex moves is limited to a single step, i.e. only the last modification can be undone. Relocation of a polygon as a whole (i.e. polygon drag-and-drop) cannot be undone. Similarly, removed vertices can also not be undone. Therefore, you should create a new vertex at the same location if you want to revert to the previous shape.

For circular features, the map toolbar includes a diameter input tool, which can be used to set the diameter of the circle manually in meters or feet. Changing the unit, automatically resizes the circle while keeping its centre fixed. The size (i.e. diameter) of the circle can also be modified on the map by moving the point markers located on the circle boundary similar to the vertices of a polygon. Different from the polygons, the number of points is fixed for circles and limited to 4 for each cardinal direction. One-step undo is available for each modification. A feature can be removed completely by clicking the "Remove" button on the map toolbar and confirming the removal. Alternatively, by clicking the "Remove Geometry" button indicated by a dotted circle on the toolbar, the feature can be converted into a single point located at the geometric centre of the feature. Clicking the "Zoom" button on the map toolbar will pan the map to the centre of the feature and set the zoom level, so that the whole feature is visible on the map with the highest zoom level possible.

2.6.2 Data Entry Maps

Data entry maps available at the data entry pages are linked to the input elements of the associated data entry forms. Whenever you create or modify a feature on the map, the values of the related input elements are updated automatically.

For example, once you create a point on the map, its coordinates (i.e. latitude and longitude) will be displayed in the coordinates input of the data entry form and they will be updated whenever you change the location of the point. Similarly, modifying the boundaries of a polygon updates the boundaries input. Because changing the boundaries also usually affects the geometric centre of the feature (i.e. origin), coordinates input will also be updated automatically.

Hint. Country drop-down list

Besides geometric input elements, the country drop-down list is also linked to the map. Whenever you choose a country, the map automatically pans and focuses on the geographic boundaries of the selected country. You can use this feature to facilitate location finding.

The links to the input elements are operational not only from the map to the inputs, but also vice versa. So, if you enter or update the coordinates manually in the input field, the origin of the feature on the map will be updated to reflect the new coordinates.

Hint. Manual input of coordinates

You can use the automated link between the input elements and the map to locate an entity (e.g. industrial plant), for which coordinate data is available in advance.

Remark. Invalid coordinates

Entering an invalid latitude or longitude in the coordinate input will remove the point on the map and subsequently clear the manually entered coordinate data, as it is linked to the map.

By default, the coordinates in the data entry form are displayed in decimal degrees (e.g. 45.5084). But if you want, you can change it into degrees decimal minutes (e.g. 45 30.504) or degrees minutes seconds (e.g. 45 30 30.24) by changing the coordinate format setting in your personal page.

Remark. Coordinate format

Coordinate format setting only affects how the coordinates are displayed, but not how they should be entered. Coordinate inputs can "smartly" detect the format that you use for data entry and convert them into decimal degrees automatically for storage. Therefore, you can use any of the three formats to enter coordinates, without performing a manual conversion. This is especially useful if the coordinate data is originally not available in the standard decimal degrees format.

Remark. Reference coordinate system

Although the system supports multiple coordinate formats, currently it does not support user-defined coordinate systems and map projections. The coordinates should be in the World Geodetic System (WGS 84, EPSG:4326), which is the reference coordinate system used by the Global Positioning System (GPS).

Although the location of the feature can be modified manually for features with a geometry (i.e. polygon, polyline, and circle), their boundaries cannot be modified, because the boundary input is currently read-only.

In addition to coordinates and boundary inputs, the circle feature also updates the values of the "Diameter" and "Radius" properties, if they exist in the properties list of the entity. If the circle already exists on the map when you add these properties for the first time, their values are automatically entered by the system and modified subsequently whenever the circle is modified. Similarly, manually modifying the value of the "Diameter" or "Radius" property automatically updates the circle on the map, including the diameter input on the mapping toolbar. Because they are linked, changing the diameter also changes radius, and vice versa.

Hint. Diameter units

The units of the diameter input tool and the diameter and radius properties are independent of each other. Hence, they can be set differently (e.g. `ft` for diameter input tool, `m` for diameter or radius property). The system automatically performs unit conversion and updates the values accordingly.

The system decides the type of feature (i.e. polygon or circle) based on the "Shape" property. By default, the feature type is set to polygon. Once a "Shape" property is added to the list of properties and its value is set to one of the following values, the circle editing mode is activated:

- Cylindrical Dished Vertical
- Cylindrical Hemispheroidal
- Cylindrical Vertical
- Spherical
- Spheroidal

Removing the "Shape" property or changing its value to something different than the values indicated above, disables circle editing mode and removes the circle on the map, if it exists. Similarly, activating circle editing mode removes the existing polygon feature.

2.6.3 Mapping Tool

In addition to the data entry maps provided at the data entry pages, RAPID-N also features a mapping tool specifically designed to map a large number of plants and plant units easily and quickly. Besides facilitating delineation of the boundaries of plants and plant units, the tool also allows entry of basic information about the associated records, which can be further elaborated later through the related data entry forms.

The mapping tool can be accessed by clicking on the "Mapping Tool" icon on the home and personal pages, or by following the link available in the bottom directory displayed at each page. For quick access to the tool, you can also use the following URL address: http://rapidn.jrc.ec.europa.eu/mapping_tool.

The mapping tool provides a map that is similar to the data entry maps, but covers the whole page area. Zoom in/out buttons located at the bottom right corner, and the map type selection buttons located at the top left are identical and function as explained in the Editing Features section. The Full screen button located at the top right corner also exists and can be used to make the map even larger by covering the full screen.

Different from the data entry maps, the mapping tool also provides a toolbar with several tool buttons and a search box, which is located at the top left corner of the map. The toolbar includes the following items (from left to right):

Plant Unit Button activates the plant unit editing mode, which allows you to create new plant units.

Plant Button activates the industrial plant editing mode, which allows you to create new plants.

Auto-pan Button toggles the automatic map pan mode, which helps you to enter data easily by panning the map automatically so that the active feature is located at the centre of the map. By default, it is disabled.

Search Box allows quick zooming to a specific area by entering an address. If you enter a place name (e.g. city, town, industrial plant, etc.) in the search input and press the "Enter" key, the system automatically queries and zooms to the boundaries of the specified location. By using the standard zoom in/out functionality you can focus on the exact location you are interested in.

Remark. Location search box

If the search query returns information on multiple locations, the first location is displayed on the map. In order to obtain a single result, you can enter additional keywords, such as the country or province name, which further restricts the query. If no results are returned, the existing map location will be kept.

Close Button closes the mapping tool and returns to the personal page.

Once you focus on an area in the mapping tool, either by using the search functionality or by using the standard zoom in/out – pan features, the system automatically loads the existing plants and plant units that are located in the map area, which are accessible. Each plant and plant unit is indicated by a separate map icon (i.e. marker) and the associated boundaries are also mapped on the map. By clicking on a marker, you can select the related feature (i.e. plant or plant unit) and open its data window.

Hint. Auto-pan

If auto-pan is enabled, the map will automatically pan to the marker location and the data window will be opened at the centre of the page.

If you do not have editing access to the selected feature, the data window will only display information about the related record, such as its name for industrial plants, or type and shape for the plant units. By clicking on the "Details" link provided at the data window heading, you can access the information page of the record, from which you can obtain more detailed information.

If you have editing access to the selected feature, then the editing mode will be activated. In this case the data window includes input elements, through which you can set or modify certain properties of the selected record as illustrated in Figure 12. The system also enables the editing mode for the selected feature, so you can modify the feature (e.g. move, resize, reshape) as described in detail in the Editing Features section.

The input elements displayed in the data window depend on the type of the selected record. For industrial plants, only the name input is available. For plant units, you can select the type (e.g. storage tank, reactor), shape (e.g. cylindrical, spherical), storage condition (e.g. atmospheric, pressurized), base type (e.g. on-ground, above ground), and roof type (e.g. fixed roof, floating roof). For both record types it is also possible to enter notes.

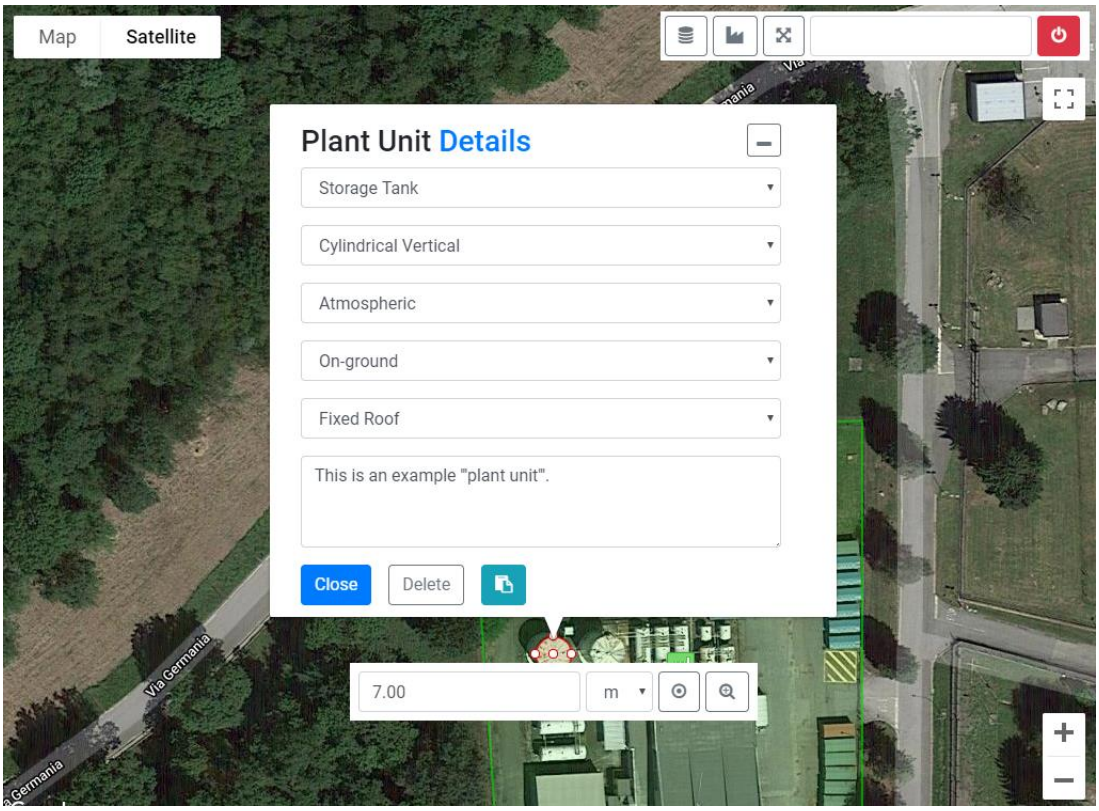
The feature type of the plants is a polygon. For plant units, the system automatically selects the feature type based on the "Shape" property similar to the case of the data entry forms. See the Data Entry Maps section for the list of shapes that enable circle editing mode.

In order to finish editing and save the changes, you should click on the "Close" button.

Remark. Automated linking of plants and plant units

While saving a plant unit record, the system checks if the associated feature (i.e. polygon or circle) is located inside a boundary polygon of a plant and if such a plant is found, the plant unit and the plant are automatically linked to each other (i.e. plant of the plant unit is set as the identified plant). This facilitates data entry by getting rid of the need to manually indicate the relation between plant and plant units.

Figure 12. Data window in editing mode



Source: JRC, 2018

The editing mode also allows you to delete the record if you are allowed to delete it. In order to delete the record click on the "Delete" button and confirm it through the modal dialog which will be displayed.

Remark. Deleting a record

Delete action is irreversible, i.e. can not be undone.

The "Set Default" button indicated by a copy-paste icon located at the bottom of the data window allows you to set the data of the selected record, including the feature data (i.e. diameter, boundary), as a template for the new records that will be created.

In order to create a new record, you should first activate either the plant or plant unit editing mode by clicking the associated buttons on the map toolbar located at the top right corner. Once an editing mode is activated, clicking on a location on the map will create a new editable feature and display its associated data window, through which you can set the record data. If the default data is set previously, the new record will initially contain all the properties (e.g. name, type, shape, etc.) as defined by the default data and the feature will also be initialized according to the default feature, i.e. its boundaries or diameter will be identical to the default feature.

Hint. Quick copy-paste with default data

By setting a record data as the default data, you can easily create clones (i.e. identical copies) of the record on the map. This is especially useful for large industrial plants (e.g. refineries), which include many identical plant units (e.g. storage tanks).

You can close the mapping to by clicking on the "Close" button on the map toolbar.

3 Data Estimation Framework

RAPID-N features an innovative data estimation framework to minimize the data required for the data entry and also to calculate the data which is required for the analysis but has not been or cannot be provided (i.e. entered) by the users.

The framework is based on Properties and Property Estimators, which are described in detail in the following sections. The steps followed for the data estimation are also explained in the Data Estimation Methodology section. Besides data estimation purposes, the framework is also utilized by the system to generate case-specific damage and consequence models on-demand to perform the calculations necessary for the risk analysis. Therefore, it forms the backbone of the system.

3.1 Properties

Although they describe different characteristics and attributes, the properties of entities can be defined in a similar manner. Independent of the entity type (e.g. substance, plant unit, etc.), each property has a value defined by a number, a string of characters, or a set of pre-defined options. Generally, units are used to define the scales of numerical values. Some properties may be conditionally valid. For example, the diameter of a plant unit can only be defined if it has a spherical or cylindrical shape. Similar conditions also apply for natural hazard, industrial plant, and substance properties. Considering this similarity, RAPID-N uses a common framework to define properties of different entities, i.e. records. Property records are used for this purpose.

Remark. Authorisation

Authorisation is required to create new properties.

An example property data entry form is given in Figure 13. The type of the property determines the context of the property, i.e. to which record types it is related. It can be selected from the list of property types available in the system. Each property has a name and two types of short identifiers: code and symbol. The property code is used to represent the property in the property estimation functions. The codes should be unique. They are also case-sensitive. For example, the codes `d` and `D` are not identical and refer to different properties. Symbols, which support subscript, superscript or italic formatting, are used to represent properties in shorthand notation for display in information pages and record tables.

Remark. Property codes

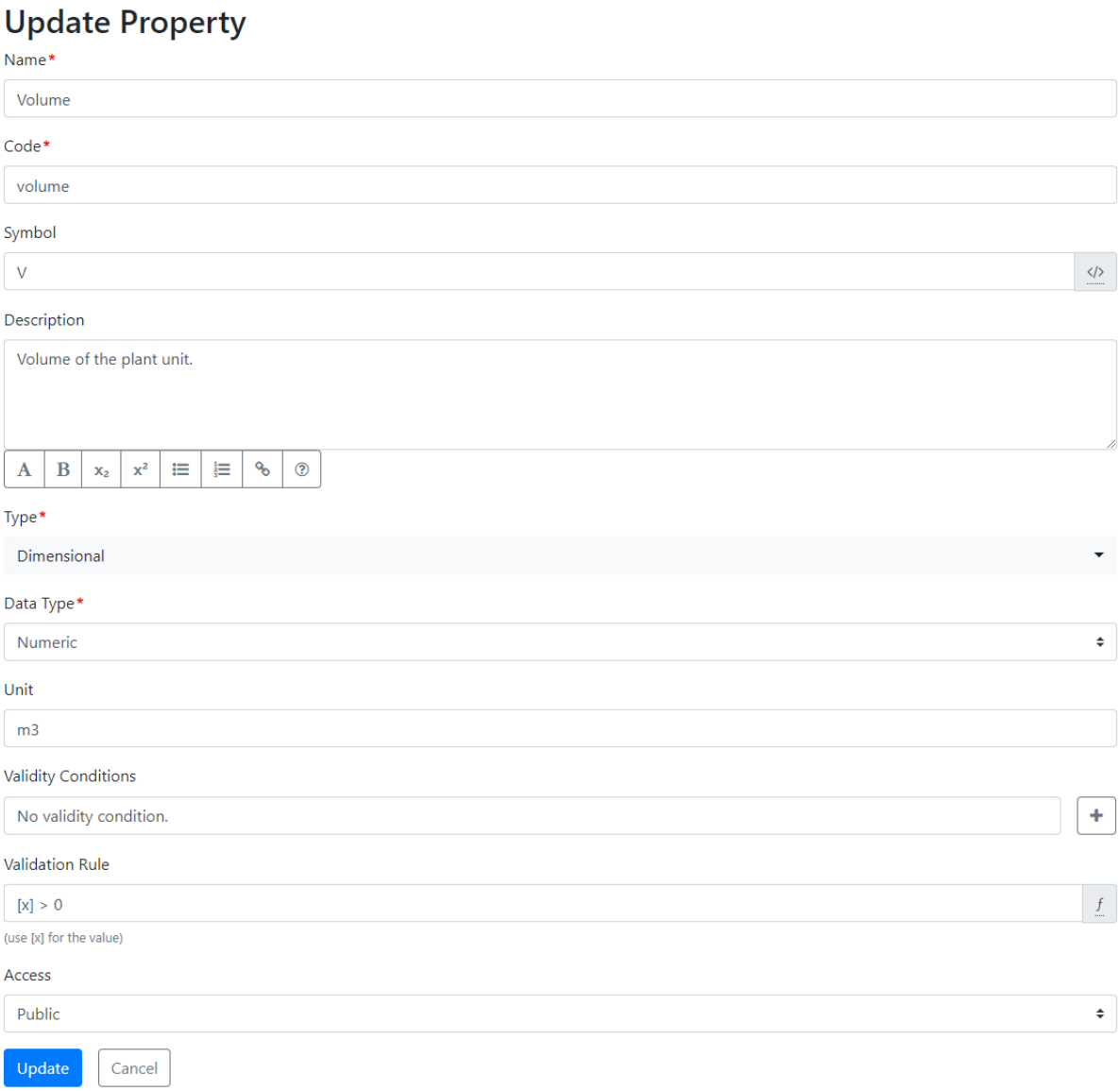
In order to facilitate recognition of the properties and to increase the readability of the estimation functions that utilize the property codes to denote property values, use of shorthand and abbreviated unit codes should be avoided. It is better practice to use `diameter` as the code of the diameter property, instead of only `d`, as `d` is not self explanatory and can be easily confused with properties like density or depth.

The data type defines the nature of the property values. Currently, four different data types are supported by the system, which are *integer*, *numeric*, *string* and *tabular*.

The integer data type allows only integer values to be entered, whereas the numeric data type supports decimal and scientific values, as well. If necessary, fuzzy numbers can be entered for both numerical data types. They also allow the unit of the property to be specified. The system treats the unit defined in the property as the reference unit, but also allows the user to enter values in all possible compatible units. See Unit Input section for more details on the units.

The string data type allows character strings to be entered as property values. For strings, Unicode characters are supported which allow a wide range of specialized (e.g. mathematical) and language specific characters to be entered by the users.

Figure 13. Example property data entry form



Source: JRC, 2018

Hint. List of Unicode characters

You can refer to the "List of Unicode characters" page of Wikipedia for a listing of the Unicode characters by category.

The tabular data type restricts the property value to certain options specified explicitly. The allowed options must be entered in the options list. For each option, a unique code and name should be entered. A description of the option can also be specified. An example tabular property record view is given in Figure 14.

Remark. Option descriptions

Although option descriptions are not utilized for data entry and visualisation, they provide valuable information about the meaning of the options. Therefore, it is good practice to provide descriptions, although they are not mandatory.

Figure 14. Example tabular property record view

Property

Name	Roof Type
Code	roof-type
Type	Structural
Data Type	Tabular

Options

No	Code	Name	Description
1.	R	Fixed Roof	Fixed roof tanks are meant for liquids with very high flash points (e.g. fuel oil, water, bitumen). Cone roofs, dome roofs and umbrella roofs are usual. Dome roof tanks are meant for tanks having slightly higher storage pressure than that of atmosphere (e.g. slop oil).
2.	F	Floating Roof	Floating roof tanks do not have a fixed roof (i.e. it is open in the top) and has a floating roof which travels up and down along with the liquid level. Medium flash point liquids (e.g. naphtha, kerosene, diesel, crude oil) are stored in these tanks.
3.	I	Internal Floating Roof	Interal floating roof tanks are used for liquids with low flash points (e.g. ATF, MS, gasoline, ethanol). They are cone roof tanks with a floating roof inside which traps the vapor from low flash point fuels.
5.	O	Open Roof	Open roof tanks do not have any roof covering the roof top.

Sort By	Name
Validity Conditions	Shape: Cylindrical Vertical
Access	Public

Source: JRC, 2018

For tabular properties, the system uses drop-down list inputs to facilitate data entry. The options are listed in the drop-down list according to the sorting criteria. If sorting is set as name or code, the options are listed as sorted by the sorting criteria in ascending order. If the list order is selected, they are listed according to their order in the options list.

Hint. Search box

For tabular properties including more than 20 options, the system provides an inline search box, which can be used to filter the options for quick selection. If a keyword is entered in the search box, only the properties matching the keyword anywhere in their names, including as part of the words, are displayed

If the property is only valid under certain conditions, validity conditions can be defined by using the related properties based on property type. For example, the *diameter* property can be enabled (i.e. set valid) only for plant units having a circular cross section in any direction based on the *shape* property. See Conditions Input section for more information on the validity conditions and how to enter them.

Additionally, a validation rule can be specified to limit property data entry to certain values. Validation rules are similar to the single-line functions described in the Estimation Functions section, in which an x character in square blankets (`[x]`) denotes the entered value. The validation rule is evaluated for each entered value of the property, and the value is considered as valid only if the evaluation result is equal to `TRUE`. A common use is the "value greater than zero" rule (i.e. `[x] > 0`) to allow only unsigned (i.e. positive) values for numerical properties. See the Estimation Functions section for details on the single-line functions.

Remark. Standard value

For numerical properties, the value of the property in the reference unit is used to substitute the value parameter in the validation rule (i.e. `[x]`).

The system features property input elements for entering values of different properties (i.e. property data) for each record, e.g. natural hazard, industrial plant, plant unit, etc. See Properties Input section for the details of these input elements.

Available property data is displayed on the information pages of the associated records in a tabular format that is identical to the basic record data, i.e. data entered by using other input elements. Each property is indicated by its name, and the corresponding value is displayed as formatted according to the data type of the property. For numerical properties, if the unit of a property value is different from the reference unit of the property, its value in the reference unit is also displayed in parenthesis next to the original value. An example property data view is given in Figure 15.

Figure 15. Example property data view

Ambient Pressure	1 atm
Ambient Temperature	25°C
Gravitational Acceleration	9.8067 m/s^2
NACE Code	Manufacture of refined petroleum products
NEHRP Site Class	Very dense soil and soft rock
Relative Humidity	50%
Topography	Urban

Source: JRC, 2018

3.2 Property Estimators

RAPID-N utilizes user-defined property data as input to calculations needed for the analysis. However, such data may be incomplete in some cases, and in fact it is quite common to have a lack of information especially on industrial entities (e.g. plants and plant units). In order to make the analysis possible with minimum data input, the system features a data estimation framework to calculate missing data by using scientific estimation methods. The data estimation methodology is generic and independent of the record type and nature of the property (i.e. the same procedure is used to estimate property data for different record types).

Property estimators are utilized by the system for three main purposes:

1. *To perform calculations necessary for the analysis.* The system does not contain any pre-defined, hard-coded models for the analysis. For each Natech scenario, a flowchart of the damage and consequence models required for risk analysis is created on demand by using the property estimators available in the system and all computation is performed by using the these estimators.
2. *To calculate missing property data by using the available property data*. For example, the volume of a plant unit can be calculated geometrically from its dimensions if they are available. This reduces the amount of data to be entered by the user, as it eliminates the need to enter data which can be computed by using readily available information.

3. *To provide case-specific default values of the properties*. For example, a property estimator can be defined to provide a default value for the topography based on the location. This usage is similar to making assumptions in calculations and allows the risk analysis procedure to be completed even with limited data by sacrificing some accuracy.

Use of the property estimators increases the flexibility of the analysis capabilities of RAPID-N as such estimators can do many calculations that would normally have to be hard-coded into the system. For example, RAPID-N does not include any built-in functions for the calculation of plant unit volumes. All volume-related calculations are done by using property estimators. Therefore, if a new plant unit type with a specific shape is added to the system, there is no need to update the source code. Only a new property estimator should be added to support the plant unit, which can be done very easily through the data entry interface.

Remark. Authorisation

Authorisation is required to create new property estimators.

An example property estimator data entry form is given in Figure 16. For each property estimator, the property to be estimated should be selected from the list of properties. The type of the estimator can be selected either as a value or as a function estimator. For value estimators, the estimated value can be selected from the list of allowed values for tabular properties or entered as strings or numbers (including fuzzy numbers) for string and numerical properties, respectively. For function estimators, the estimation function should be entered which can be a simple single-line function or a complex function involving conditions, loops, or internal function calls. Estimation functions can utilize values of other properties, which allows calculation of property values based on other property data. The value returned by the estimation function should be compatible with the data type of the estimated property. See the Estimation Functions section for more information on the estimation functions.

Remark. Use of fuzzy numbers

Although fuzzy numbers are supported both as value estimators and also as the return values of the function estimators, it is good practice to use exact numbers wherever possible, since the fuzzy numbers increase the uncertainty of the calculations.

For properties having a reference unit, the unit of the value estimated by the estimator should be indicated. The specified unit should be compatible with the reference unit of the property.

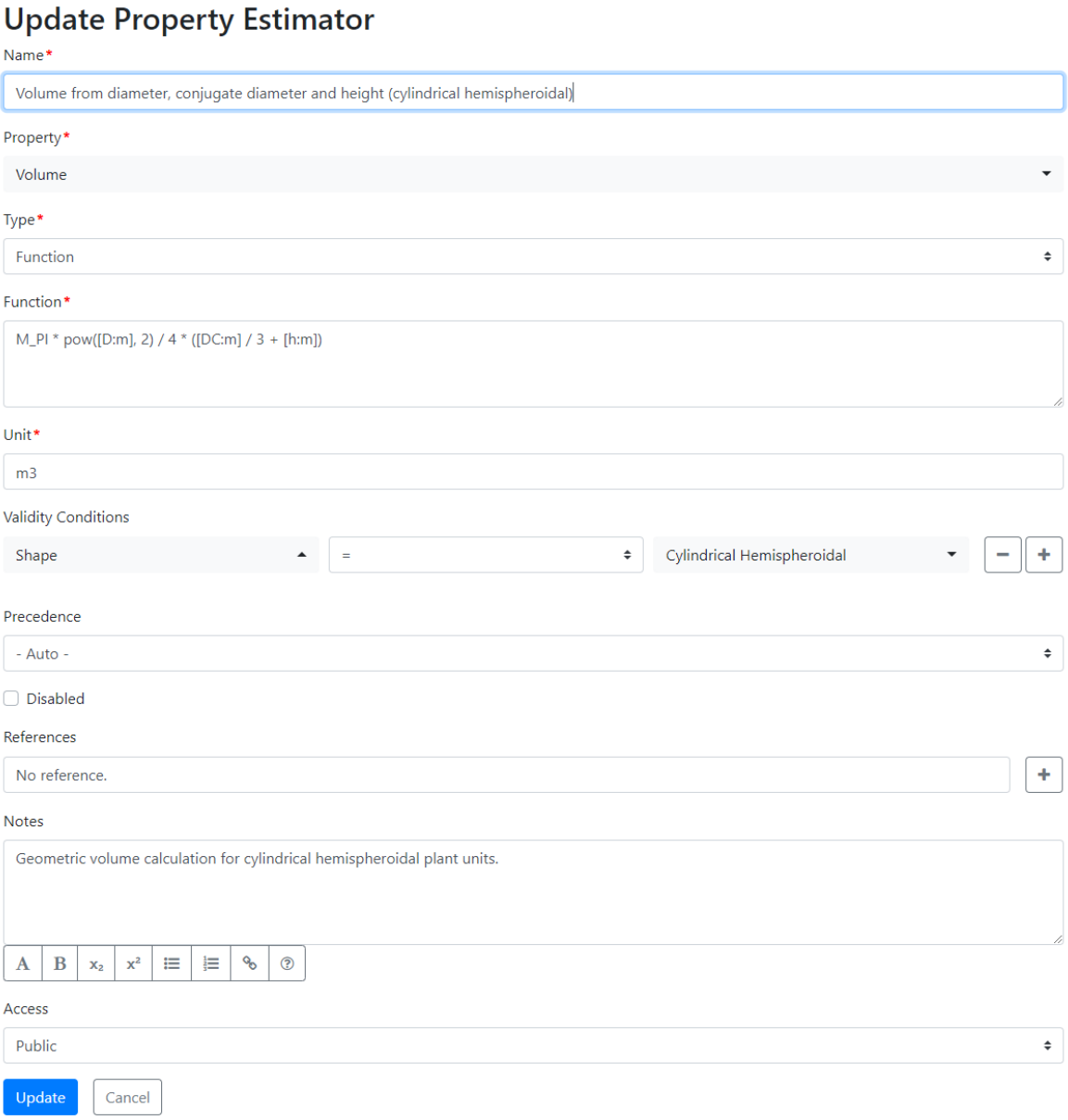
If required, the precedence of the property estimator over the other property estimators of the same property can be specified. The precedence is used while comparing the estimated values of different estimators during the estimation process. See Data Estimation Methodology section for more details.

If available, bibliographic references of the property estimator can also be indicated.

Remark. Bibliographic references

In order for a property estimator to be made publicly available, it should be peer-reviewed for scientific adequacy and validated by comparing some case-study results with reference data based on measurements or original computations. Both peer-review and validation tasks require reference documents, which can be consulted whenever necessary. Therefore it is good practice to provide at least one bibliographic reference, which provides enough information about the rationale, scope and structure of the estimation method.

Figure 16. Example property estimator data entry form



Source: JRC, 2018

Hint. Entering notes

You can use the notes field of the property estimator to provide additional information on the estimation method. For example, you can indicate the page number of the reference that describes the estimation method, or you can provide summary information about the limitations that cannot be indicated as validity conditions. Because it is a wiki input element, notes input can include links; therefore, you can refer to other records available in the system or external resources available on the Internet, if necessary.

The system allows validity conditions to be defined for property estimators to control the applicability of the estimators, as they may be valid only under certain conditions. For example, a plant unit volume estimator may be valid only for a certain plant unit shape (e.g. spherical) or a PGA estimator may be valid for earthquakes having a magnitude greater than a certain threshold value (e.g. 5.0 in moment magnitude scale). If such validity conditions exist, a validity test is performed automatically by the system by using the available data and the estimator is utilized only if the conditions are valid. See Conditions Input section for more details on the validity conditions.

Remark. Validity regions

Previously, property estimators were also featuring *validity regions* that specified the geographical extent for which the property estimator was valid. In the current version of RAPID-N, region records (e.g. countries, Flinn-Engdahl regions, Cratons) are converted into separate properties with geographic boundaries. Therefore, they can be specified as validity conditions instead of validity regions.

Example property estimators ranging from default value estimators to complex function estimators are given in Table 4.

Table 4. Example value and function property estimators

Description	Default ambient temperature
Estimator	`25 C`

Description	Wind speed
Estimator	`1.5 m/s`
Validity Conditions	RMP Scenario = Worst-case

Description	Storage condition from roof type
Estimator	Atmospheric
Validity Conditions	Roof Type = Floating Roof, = Internal Floating Roof, = Open Roof

Description	Diameter from volume
Estimator	`pow(6 * [V:m3] / M_PI, 1 / 3)`
Validity Conditions	Shape = Spherical

Description	Energy magnitude from radiated seismic energy
Estimator	`2 / 3 * log10([Es:J]) - 2.9`

Description	Peak Ground Acceleration
Estimator	`2000 * exp(0.8 * [M]) * pow([dh:km], -2)`
Validity Conditions	Flinn-Engdahl Region = [Washington, Oregon, Nevada, …]

Description	U.S. EPA RMP Liquid Factor Boiling
Estimator	`0.284 * pow([MW:g/mol], 2 / 3) * 760 / (82.05 * [Tb:K])`

Description	Duration of Fireball

Estimator	`if ([QFL:kg] > 30000) {`
	`  return 0.45 * pow([QFL:kg], 1 / 3);`
	`}`
	`else {`
	`  return 2.6 * pow([QFL:kg], 1 / 6);`
	`}`

Validity Conditions	Fire/Explosion Event = BLEVE

Source: Girgin and Krausmann, 2013a

3.3 Data Estimation Methodology

The data estimation framework of the system takes available property data as input and tries to calculate missing properties by using the available property estimators, taking validity conditions of the properties and property estimators into consideration. If a value of a missing property is calculated, it is added to the set of available data and the procedure is continued recursively until no further properties can be estimated with the available data, including recently estimated ones.

The steps of the data estimation algorithm are as follows:

1. User-defined property data of the record is retrieved and combined with the basic record data, which is entered by using input elements other that the properties list (e.g. name, coordinates, etc.).
2. Associated records of the record, which are explicitly indicated by the reference inputs (e.g. plant of a plant unit), are retrieved and their record data (i.e. basic record and property data) are merged with the available data set. The combined data set forms the data set that is initially available.
3. Property estimators that can be used to estimate properties related to the record are identified and added to the property estimators list. Property estimators which can estimate properties that are already available in the data set (i.e. which are user defined) are excluded.
4. Each property estimator in the property estimators list is examined to determine whether the available data is enough to evaluate the estimator (i.e. estimator is eligible):
   (a) Because value estimators do not require any other property data, they are automatically considered as eligible.
   (b) For function estimators, the syntax of the estimation function is analysed and the properties that are utilized in the estimation function are determined. If the available data include all required properties, the estimator is considered as eligible.
5. For each eligible estimator, conformity with the validity conditions is evaluated by using the available data. Eligible estimators having valid validity conditions are accepted for data estimation. See Conditions Input section for more details on the validation conditions.
6. For each accepted estimator:
   (a) If no previous estimate is available for the estimated property, the estimator is used to estimate the data and the estimated data is added to the available data set.
   (b) If a previous estimate is available (i.e. related property data exists in the data set):
      i. The priority of the estimators is compared. If the new estimator has a higher priority than the previous estimator, it is used to estimate data. The priority check is carried out by applying the following rules in the listed order:
         1. An estimator with a higher precedence is preferred.
         2. An estimator with more condition properties is preferred, because it is assumed to be more specialized (i.e. considers more properties for validity).
         3. An estimator with a lower validity condition score is preferred, which is calculated by multiplying the number of criteria per condition property. A lower score indicates that on average there is a lower number of criteria per condition property, which implies that the condition is more specialized as the criteria are evaluated with logical *OR* operator for each condition property.

4. An estimator with a lower dependency score is preferred, which is calculated by considering the properties utilized by the estimation function. Estimators that utilize more properties are considered to be better than the estimators utilizing less properties, as long as the property data utilized is exact (i.e. user-defined). If property data estimated in the previous steps is also utilized, a penalty is added for each estimated property as it is assumed that there is an accumulation of uncertainty due to successive estimations.

ii. If the estimator is used to estimate data, the estimated data is compared with the previous estimate:

1. If the estimates are different (i.e. the new estimate provides a value different that the previous value), all property data in the available data set which are related to the previous estimate are deleted, as they are based on a value which is changed (i.e. not valid anymore). Property data is considered as related, if it was estimated by using the previous estimate in the estimation function or in the validity conditions.
2. Property estimators related to the deleted properties are added back to the property estimators list.
3. The estimated data is added to the available data set.

(c) If an estimator is used to estimate the data, it is removed from the property estimators list.

7. If no new property data is estimated or the property estimators list is empty, the estimation procedure is terminated. Otherwise, the procedure is repeated starting from Step 3.

Remark. Estimation guarantee

Because it is repetitive, the estimation algorithm is exhaustive, i.e. it guarantees that all property data is estimated which can be estimated by using the initial data and the available property estimators.

The estimated property data is highlighted on the record information pages, so that it can be differentiated from the user-defined properties. An example record data view with estimated property data is given in Figure 17.

Figure 17. Example record data view with estimated property data

Ambient Pressure	1 atm
Ambient Temperature	25°C
Gravitational Acceleration	9.8067 m/s^2
NACE Code	Manufacture of refined petroleum products
NEHRP Site Class	Very dense soil and soft rock
Relative Humidity	50%
Topography	Urban

Source: JRC, 2018

Remark. Data access in estimation

The available initial data and list of property estimators that can be used for estimation depend on data access restrictions. Therefore, the final property data available for the visualisation and the analysis purposes might be different among the users. For example, private properties are only visible to their owners. Similarly, estimation of a private estimator is only performed if the active user is the owner of the estimator.

4 Risk Analysis Framework

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 utilizing 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.

The record types utilized by the system for performing the analysis as summarized above are described in the following sections. After the presentation of the steps of the risk analysis methodology, first the records related to natural hazards are explained in detail, which are followed by the records related to industrial plants, including hazardous substances. The record types used for damage and consequence analysis are also described. Finally, the risk analysis records that set-up the risk analysis process are explained, including important parameters that can be specified to customize the analysis.

4.1 Risk Analysis Methodology

The risk analysis procedure follows the following steps:

1. First, the plants units for which the risk analysis should be performed are identified. If a plant unit at a plant is specified explicitly, the analysis is limited to the specified plant unit. If only a plant is specified, the analysis is limited to the plant units located at the plant. Otherwise, the plant units are selected based on their location with respect to the extent of the natural hazard event (i.e. hazard boundary). All plant units within the hazard boundary are included in the analysis. 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). Plant units that are within the cut-off distance are selected for the analysis. If the "Enable Typical Plant Units" property is enabled, "virtual" plant units are generated for each plant in the proximity of the natural hazard event (i.e. inside the hazard boundary or cut-off distance) by using the typical plant unit definitions, and these virtual plant units are included in the analysis.
2. For each identified actual or virtual plant unit, on-site hazard parameters are calculated in the order listed below. If a parameter value is obtained by using a method, values obtained by the other methods are discarded (i.e. only the value of the preferred method is considered).
   (a) If manually entered on-site hazard data is available for the risk analysis record, they are included in the data set.
   (b) If on-site hazard data records are available for the specified natural hazard event which are valid for the plant unit (i.e. belong to the plant where the plant unit is located), they are included in the data set.
   (c) If a custom or default hazard map is specified, the hazard parameters found in the hazard map are extracted (i.e. interpolated) for the plant unit location and included in the data set. For virtual plant units, the location of the plant is utilized for the interpolation.
   (d) Hazard-specific property estimators available in the data estimation framework are utilized to estimate additional parameters by using the available data set.
3. For each identified plant unit, possible damage scenarios are assessed by using calculated on site hazard parameters and utilizing damage functions (i.e. damage-related property estimators) and fragility curves available in the system. For

this purpose, the validity conditions of the damage functions and fragility curves are tested by using the available data, and the valid ones are used to determine the extent and the probability of structural and functional damage states, each of which forms a specified damage scenario.

4. If the damage probability of a damage scenario cannot be calculated, the state of the scenario is set as "No Damage Estimate" and it is excluded from the analysis.
5. The calculated damage probability of each damage scenario is compared with the damage threshold probabilities. The state of the scenarios with a probability less than the value indicated by the "No Damage Probability" property is set as "No Damage" and is excluded from the analysis. The state of the scenarios with a probability less than the value indicated by the "Minimum Damage Probability" is set as "No Damage Expected" and is excluded from the consequence analysis.
6. If the substance present in a plant unit is not specified, the damage probabilities of the plant unit are reported and the unit is excluded from the consequence analysis.
7. Available risk states are identified for each damage scenario having an occurrence probability greater than the minimum threshold probability. For this purpose, risk states available in the system are examined and their validity conditions are evaluated by using plant unit, substance, and damage scenario properties. Risk and consequence scenario parameters specified in the risk states, for which validity conditions are fulfilled, are merged with the Natech scenario parameters. If the same parameter is found in multiple risk states, the value of the risk state having the highest precedence is utilized.
8. The final set of Natech scenario parameters, together with the scenario parameters indicated in the risk analysis record, are utilized to analyse the consequences. As a proof-of-concept, the data estimation framework of RAPID-N includes an implementation of the U.S. EPA RMP Guidance for Offsite Consequence Analysis (RMP*Comp) methodology (U.S. EPA, 1999) for consequence analysis. All equations and rules required for the analysis according to the methodology are available in RAPID-N as property estimators. Suitable combinations of equations are selected by the system automatically to construct the case-specific flowchart of the methodology for each Natech scenario, including enhancements provided by the additional methods and equations (i.e. property estimators) available in the system.
9. The results of the risk analysis are presented as summary reports and interactive risk maps showing Natech event probabilities and the areas possibly affected by the events.

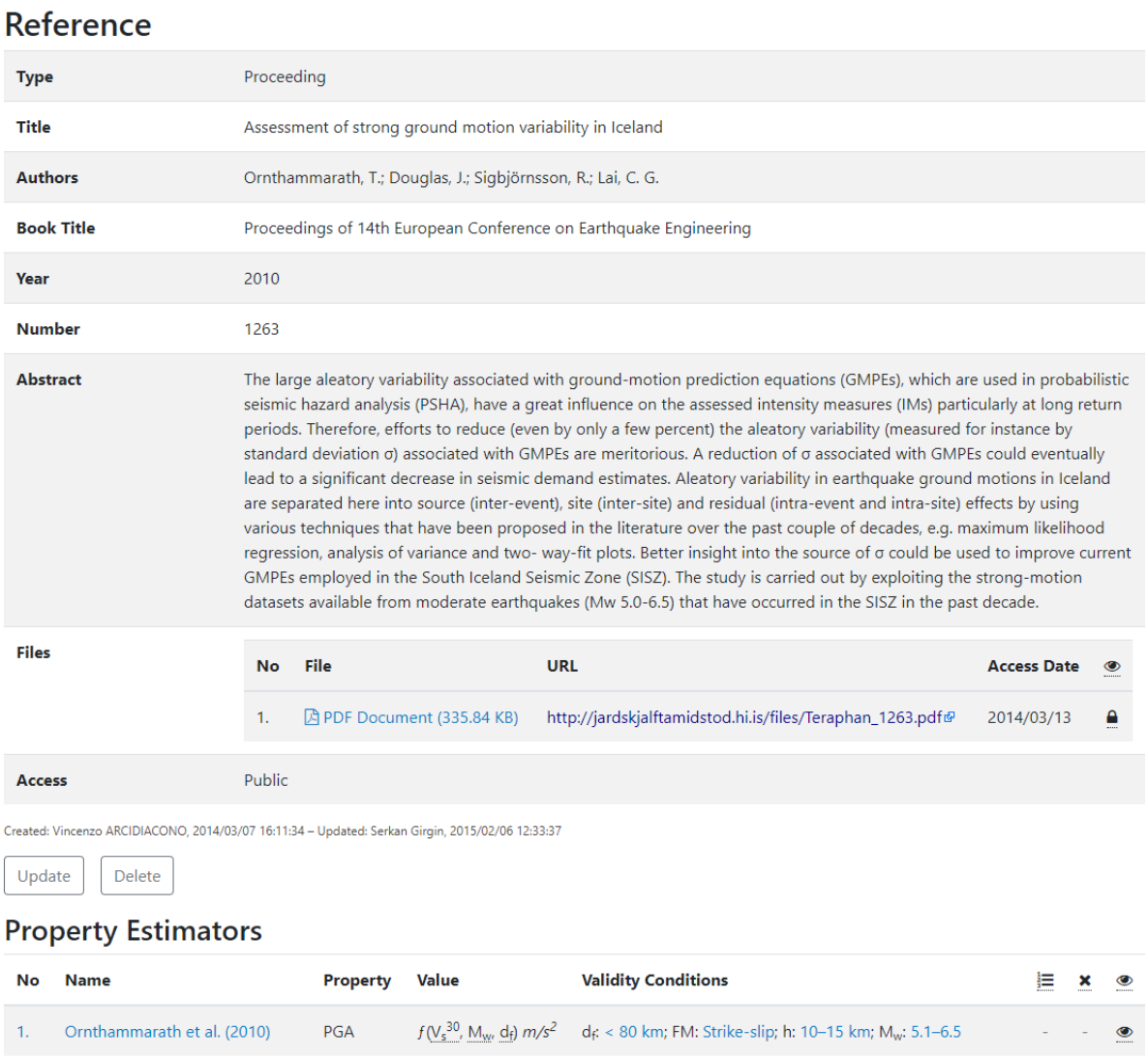
Use of the data estimation framework for the analysis allows parameters used by the equations to be modified and alternative equations to be substituted easily. For example, fire-related end-point distance criteria, which are set as second-degree burns, can be easily changed to first or third degree burns, or the atmospheric dispersion model, which uses lookup tables, can be substituted with a more advanced model if necessary. By modifying the damage parameters, different scenarios can be evaluated without any modifications to the system code and without any disturbance to the existing system functionality. Also customized versions of the models for different users are possible.

4.2 References

Many records in RAPID-N, which are utilized for risk analysis, are based on the information available in the scientific and technical literature. Specifying the original information sources is not only important for proper citation of the work, but also for quality control and assurance. It also allows users to access more detailed information when necessary. The system provides a bibliographic database, which allows detailed bibliographic information to be stored and linked to the related records. Reference records are used to store bibliographic information.

An example reference record is given in Figure 18. A wide variety of bibliographic references, such as journal articles, books, and technical reports are supported. Data fields of reference records depend on the reference type, i.e. different data field combinations are requested for each reference type. Reference types and their required and optional data fields are based on BibTex entry types, which is a widely used reference management system (Patashnik, 1988).

Figure 18. Example reference record view



Reference

Type	Proceeding
Title	Assessment of strong ground motion variability in Iceland
Authors	Ornthammarath, T.; Douglas, J.; Sigbjörnsson, R.; Lai, C. G.
Book Title	Proceedings of 14th European Conference on Earthquake Engineering
Year	2010
Number	1263
Abstract	The large aleatory variability associated with ground-motion prediction equations (GMPEs), which are used in probabilistic seismic hazard analysis (PSHA), have a great influence on the assessed intensity measures (IMs) particularly at long return periods. Therefore, efforts to reduce (even by only a few percent) the aleatory variability (measured for instance by standard deviation σ) associated with GMPEs are meritorious. A reduction of σ associated with GMPEs could eventually lead to a significant decrease in seismic demand estimates. Aleatory variability in earthquake ground motions in Iceland are separated here into source (inter-event), site (inter-site) and residual (intra-event and intra-site) effects by using various techniques that have been proposed in the literature over the past couple of decades, e.g. maximum likelihood regression, analysis of variance and two- way-fit plots. Better insight into the source of σ could be used to improve current GMPEs employed in the South Iceland Seismic Zone (SISZ). The study is carried out by exploiting the strong-motion datasets available from moderate earthquakes (Mw 5.0-6.5) that have occurred in the SISZ in the past decade.
Files	No. 1 — File: PDF Document (335.84 KB) — URL: http://jardskjalftamidstod.hi.is/files/Teraphan_1263.pdf — Access Date: 2014/03/13
Access	Public

Created: Vincenzo ARCIDIACONO, 2014/03/07 16:11:34 – Updated: Serkan Girgin, 2015/02/06 12:33:37

Update Delete

Property Estimators

No	Name	Property	Value	Validity Conditions
1.	Ornthammarath et al. (2010)	PGA	$f(V_s^{30}, M_w, d_f)$ m/s^2	d_f: < 80 km; FM: Strike-slip; h: 10–15 km; M_w: 5.1–6.5

Source: JRC, 2018

Remark. Author and editor names

The names of the authors and editors should be entered as separated by semi-colon (`;`). Do not use `and` as a separator, as it is not recognized by the system as a separator.

Hint. Full names

It is a good practice to provide full names instead of initials, whenever possible. The system automatically formats the names to shorten the list of authors and editors by using initials and "et al." postfix if necessary.

Hint. Combo boxes

Journal, institution, publisher, and school fields are provided as combo boxes listing previously entered values for selection and also allowing to enter new values, if necessary. Selecting an existing value not only facilitates data entry, but also helps standardisation of the values.

The system allows electronic copies of the references to be stored as files attached to the reference records. Multiple files can be uploaded for each reference. The source URL can be indicated and access rights can be set for each file separately. Public files are available to everyone for viewing or downloading, whereas private files can only be accessed by the user who uploaded the file (i.e. owner).

Remark. Document upload

Copyrighted documents should not be made publicly accessible. For documents that are already publicly available on the Internet, it is good practice to provide the URL address and also upload a copy of the document to the system. This ensures that the document is accessible to the users even if the original source becomes unavailable or inaccessible, which is quite common for URLs that are not permanent.

4.3 Hazards

Information on historical or scenario natural hazard events which can be used for Natech risk analysis purposes are stored in the hazard records.

An example hazard data entry form is given in Figure 19. For each hazard, the hazard type, a descriptive name, and the occurrence date should be specified. The location of the hazard can be stated by country and province. The country list is linked to the map and updates the map extent to display the selected country. The origin of the hazard can be indicated either by entering the coordinates manually or by marking them on the map. Similarly, the hazard area can be mapped as the hazard boundary. See the Mapping section for more details on the mapping support of the system and how to edit map features.

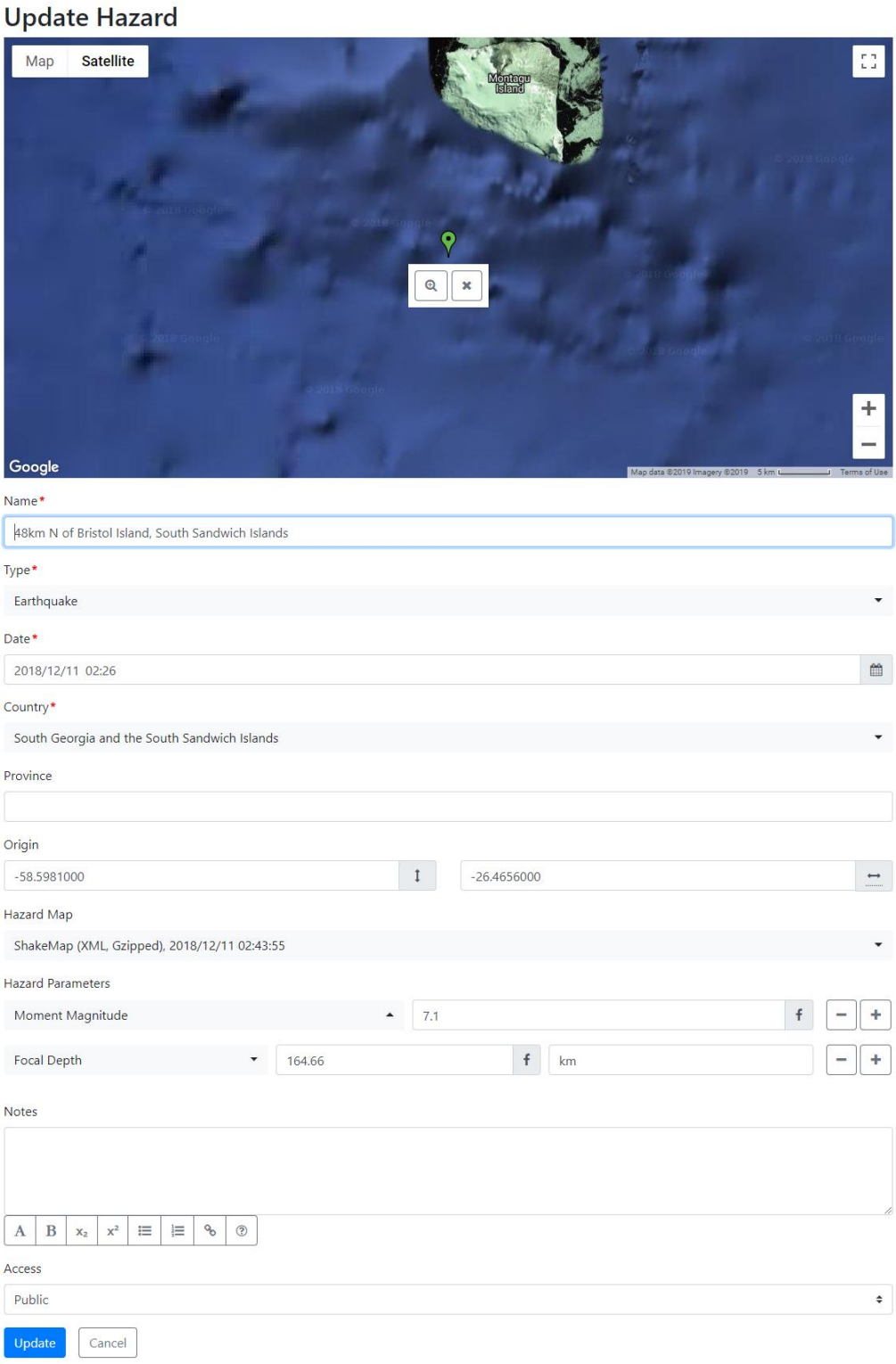
RAPID-N allows hazard maps to be defined for each hazard entity, which provide site-specific hazard severity data. One of the hazard maps associated to the hazard event can be selected as the default hazard map. The default hazard map is utilized to calculate on-site hazard parameters whenever necessary, unless a custom hazard map is selected by the user. Details on the hazard maps are given in the Hazard Maps section.

Detailed information on hazard properties at the source (e.g. magnitude, intensity) can be specified by entering property values to the properties list. Depending on the selected hazard type, the system only lists properties that are valid for the hazard type.

By using the property estimators, additional hazard parameters are calculated by the system and are displayed on the hazard information page. Other records related to the hazard can also be accessed from the information page, including catalogue data of the event, hazard maps which contain regional on-site hazard parameters for the event, Natechs that were triggered by the event, and risk analyses already performed by using the hazard event as the trigger. An example hazard information page is given in Figure 20.

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 that can be used for Natech risk analysis purposes. The system monitors online data feeds of the U.S. Geological Survey (USGS) and European-Mediterranean Seismological Centre (EMSC) in near real-time for earthquakes having a magnitude greater than M 5.5. Currently, the natural hazard database of RAPID-N contains information about 21,000 earthquakes, which is publicly available.

Figure 19. Example hazard data entry form



Source: JRC, 2018

Figure 20. Example hazard information page

Hazard



Name	5km WSW of Amatrice, Italy
Type	Earthquake
Status	Historical
Date	2017/01/18 10:14
Country	Italy
Origin	42.6014000, 13.2270000
Hazard Map	ShakeMap (XML, Gzipped), 2017/02/12 11:47:49
Body-wave Magnitude	5.7
Energy Magnitude	5.6361
Focal Depth	7 km
Moment Magnitude	5.7
Radiated Seismic Energy	6369714728856 J
Seismic Moment	$3.9811 \cdot 10^{24}$ dyn·cm ($3.9811 \cdot 10^{17}$ J)
Tectonic Setting	Active Shallow
Access	Public

Created: System

Update Delete

Catalog Data

No	Date	Epicenter	Focal Depth	Magnitude	Catalog
1.	2017/01/18 10:14:10	42.5300000, 13.2800000	9 km	5.7 mb	EMSC
2.	2017/01/18 10:14:11	42.6006000, 13.2406000	10 km	5.7 mb	USGS
3.	2017/01/18 10:14:10	42.6014000, 13.2270000	7 km	5.7 Mw	USGS

Create

Hazard Maps

No	Type	Date	File Size
1.	ShakeMap (XML, Gzipped)	2017/02/12 11:47:49	497.94 KB
2.	ShakeMap (XML, Gzipped)	2017/01/18 12:26:14	496.68 KB
3.	ShakeMap (XML, Gzipped)	2017/01/18 11:17:57	485.32 KB

Create

On-site Hazard Data

No on-site hazard data.

Create

Natechs

No natech.

Create

Risk Assessments

No risk assessments.

Create

Source: JRC, 2018

RAPID-N is also capable of estimating site-specific (i.e. on-site) hazard parameters (e.g. intensity, peak ground acceleration) based on the source parameters (e.g. location, magnitude, focal depth). For this purpose, hazard-specific property estimators available in the system are used. However, the system can also utilize pre-calculated or measured (for historical events) on-site hazard data if readily available. Such data can be entered in two ways:

- Regional hazard data can be uploaded to the system as hazard maps, which include multi variate hazard parameters.
- Site-specific hazard data can be entered manually as on-site hazard data records.

4.4 Hazard Maps

Hazard maps in various formats can be uploaded to the system as hazard map records. Each hazard map is linked to a single hazard, but each hazard may have multiple hazard maps which might have different extents, scales (i.e. resolutions), and accuracies. Hazard maps may be multi-variate, i.e. contain multiple on-site hazard parameter data in a single map.

Hint. Use of hazard maps

Hazard maps produced by systems or software packages specifically designed for this purpose usually provide better and more accurate data compared to the estimators available in RAPID-N. Therefore, whenever possible, use of hazard maps is recommended for the analysis.

Currently, three types of hazard maps are supported by the system: ShakeMap XML, Gzipped ShakeMap XML and ShakeMap Grid. All these types are used for earthquakes and include tabular peak ground acceleration (PGA), peak ground velocity (PGV), modified Mercalli intensity (MMI), and spectral acceleration (SA) data in a regular latitude and longitude grid. Details of the formats can be found in the ShakeMap Manual (Wald et al., 2005).

Remark. Large hazard maps

For processing a gridded hazard map which covers a large area in fine resolution (i.e. small grid size) the system needs a significant amount of memory. If you encounter problems during the analysis while using such a maps, please substitute the map with a smaller extent or coarser resolution map.

An example hazard map data entry form is given in Figure 21. For each hazard map, the associated natural hazard event should be selected from the list of hazards available in the system. The type of the hazard map should be specified, which has to be inline with the uploaded map file. Production date and source URL of the hazard map can be indicated and descriptive notes can be entered. At least one bibliographical reference should be provided for each hazard map.

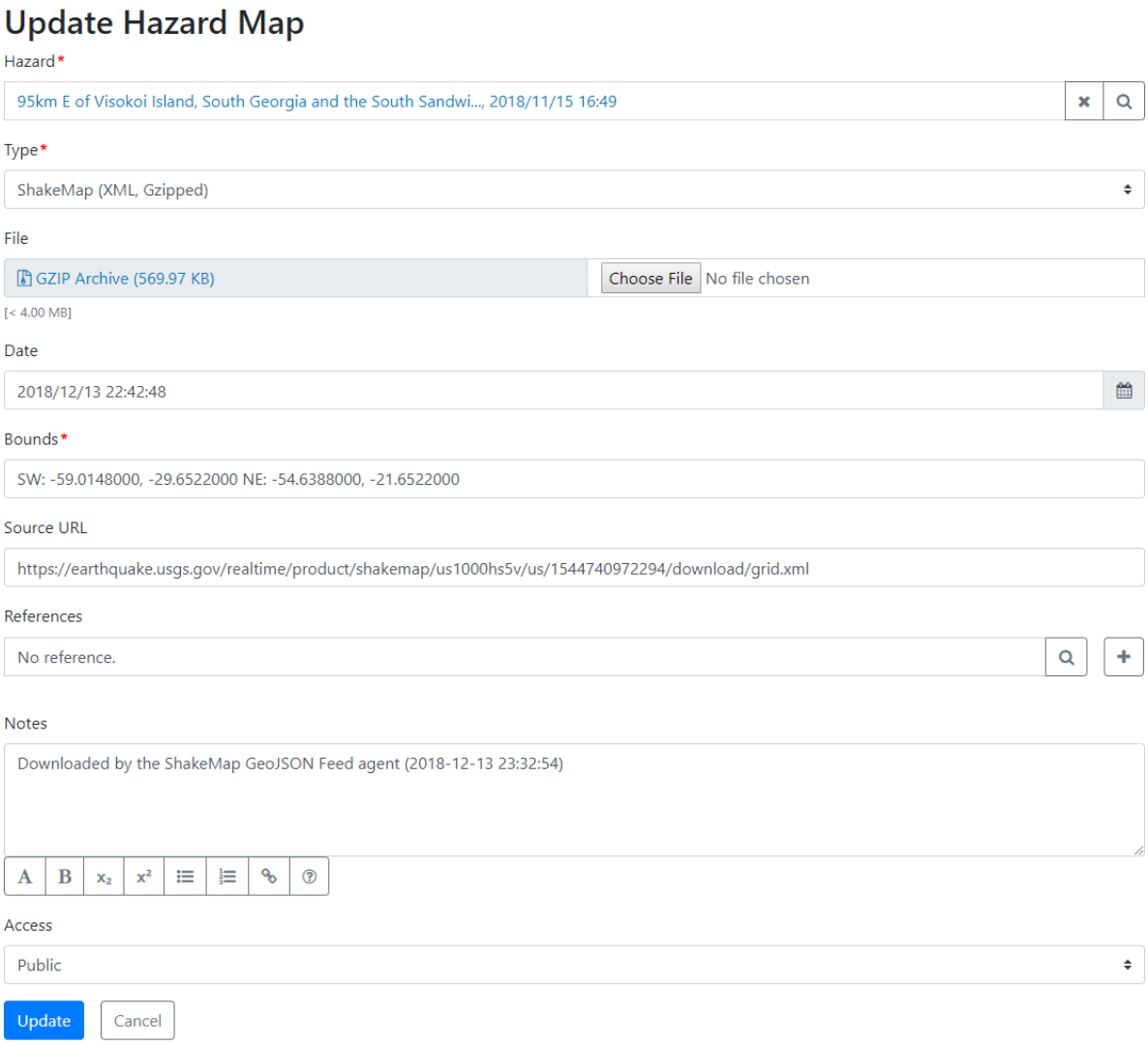
Remark. Hazard map boundaries

The boundaries of the hazard map are automatically calculated by the system. Available industrial plants within the map boundaries are also automatically determined and displayed on the hazard map information page.

Hint. Non-gridded hazard Maps

The system only supports maps in gridded format and calculates on-site values by using 2-D spatial interpolation. If you have hazard maps in other formats (e.g. vector, raster), you can use a GIS software to convert your files into one of the supported grid formats. Open-source GIS software (e.g. QGIS, GRASS GIS) can be used for this purpose.

Figure 21. Example hazard map data entry form



Source: JRC, 2018

RAPID-N periodically monitors the ShakeMaps archive of the USGS, downloads recently published ShakeMaps, and automatically creates the associated hazard map records in the system, which can be used for Natech risk analysis purposes. Currently, RAPID-N contains about 11,600 ShakeMaps, which can be used for Natech risk analysis purposes.

4.5 Industrial Plants

Information on industrial plants are stored in the system as plant records. Data on plants includes the name and the operator of the plant, descriptive and geographic location information, and the plant properties such as operational, environmental and meteorological conditions.

An example plant data entry form is given in Figure 22. For each plant, a plant name should be specified. The operator of the plant can be selected from the operator records entered into the system, which include the name of the operator, country of origin, and contact information including postal address, phone numbers, and web site. Descriptive location information of a plant includes country, province, city and address. The geographic location of the plant can be indicated as coordinates or mapped on the map as plant boundaries. See the Mapping section for more details on mapping plant coordinates and boundaries.

Delineation of the plant boundaries is useful for several purposes. Besides indicating the geographical extent of the plant, it also helps identification of on-site and off-site consequences of potential Natech accidents. Based on the boundary data, RAPID-N can also calculate some additional parameters, such as surface area, proximity to other plants, etc., which can be useful for the analysis. Finally, if boundary data exists, the system can automatically link plant units that are created through the plant unit data entry form or the mapping tool to the plant that they are physically located in. Hence, it facilitates data entry by getting rid of the need to manually indicate the relation between plant and plant units.

The characteristics of the plant can be indicated by adding property values to the properties list. Plant properties are divided into two groups: The first group is related to the physical and operational properties of the plant, such as industrial activity, year of construction, and number of employees. The second group is related to the plant site and its surroundings. Environmental (e.g. topography, soil class) and meteorological (e.g. ambient temperature) conditions can be given as examples of the properties in this group.

Remark. Activity and status of an industrial plant

You can indicate the type of industrial activity by using the "NACE Code" property. Similarly, the operational status of the plant (e.g. operational, shutdown) can be indicated by using the "Operational Status" property.

Hint. Site-related properties

Site-related plant properties are considered to be valid also for the plant units located at the plant, if plant-unit specific values are not provided. Because many site-related properties are not expected to change within a plant, it is good practice to enter such properties into plant records and to enter customized properties to the plant units only if it is necessary. Besides reducing data entry efforts, this practice also facilitates data updates as updating only the plant record will automatically affect all linked plant units.

The records related to the plant can be accessed from the plant information page, which include plant units of the plant, the on-site hazard specified for the plant for different natural hazard events, Natechs that occurred at the plant, and risk analyses that include the plant. An example plant information page is given in Figure 23.

The system includes data for more than 5,500 industrial plants world-wide, which is collected from public sources, such as the Global Energy Observatory. Basic information on all petroleum refineries and most of the power plants are available. However, due to confidentiality reasons this data is not publicly accessible. In order to access the data, please contact the administrators by using the Contact Form of RAPID-N.

Figure 22. Example plant data entry form

Update Industrial Plant



Name*

AB Nynas Petroleum Dundee Refinery

Operator

AB Nynas Petroleum

Country*

United Kingdom

Province

City

Dundee

Address

E Camperdown St, DD1 3LG

Coordinates

56.4645047

-2.9479789

Boundary

56.4630367, -2.9513821 56.4646015, -2.9525409 56.4658106, -2.9444745 56.4642458, -2.9431441 56.4639732, -2.9440771 56.4644593, -2.9452676

Properties

NACE Code

Manufacture of refined petroleum products

Notes

Access

Private

Update Cancel

Source: JRC, 2018

Figure 23. Example plant information page

Industrial Plant



Name	Example Plant
Operator	European Commission Joint Research Centre
Country	Italy
Province	Varese
City	Ispra
Address	Via E. Fermi, 2749, I-21027
Coordinates	45° 48.652200', 8° 38.240412'
Boundary	45° 48.624690', 8° 38.213868' 45° 48.666198', 8° 38.209686' 45° 48.678984', 8° 38.229534' 45° 48.680328', 8° 38.267730' 45° 48.627606', 8° 38.267892'
NEHRP Site Class	Soft soil profile
Surface Type	Commercial/Industrial
Gravitational Acceleration	9.8067 m/s^2
Topography	Rural
Ambient Temperature	25°C
Ambient Pressure	1 atm
Relative Humidity	50%
Year of Construction	1958
Number of Employees	> 2000
SPIRS Industry Type	Medical, research, education (including hospitals, universities,
Notes	This is an example industrial plant with **custom** property data.

Created: Serkan Girgin, 2019/01/03 15:48:37

Update Delete

Plant Units

No plant unit.

Create

On-site Hazard Data

No on-site hazard data.

Create

Source: JRC, 2018

4.6 Plant Units

The Natech risk analysis methodology of RAPID-N is based on the estimation of Natech scenarios for plant units located at industrial plants. Hence, the focus is on plant units and their characteristics, including their structural and functional behaviour against natural hazard impacts and the hazardous substances present therein.

Although there are different types of plant units in an industrial plant, Natech risk analysis methodologies developed so far mainly focused on storage tanks. Since Natech events are directly related with hazardous substances, and storage tanks generally contain such substances in large quantities, it is reasonable to give priority to storage tanks. However, other types of plant units are also important and may cause major Natech accidents. For this purpose, RAPID-N supports not only storage tanks, but also other types of plant units.

An example plant unit data entry form is given in Figure 24. For each plant unit, the type of unit (e.g. storage tank, reactor), the industrial plant that the unit belongs to, a unique plant unit code, descriptive and geographic location, and the substance contained within the unit can be indicated. Additional data, such as dimensions, structural characteristics, and safety measures, can be entered as property values in the properties list.

The system allows a plant unit to be present without being linked to a specific plant. This is mainly to support plant unit data originating from 3rd party sources, such as open collaborative mapping projects, which can provide geographic data on plant units (e.g. storage tanks) without explicit reference to associated plants. Therefore, only the unit type is mandatory as input. However, entry of other data including some properties is necessary for carrying out a risk analysis.

Remark. Associated plants

RAPID-N automatically transfers site-specific properties (e.g. on-site hazard parameters, meteorological conditions), from the related plant record to the plant unit record, if plant-unit specific values are not specified. Therefore, indicating the plant of the unit is useful for the analysis.

You can indicate the location of the plant unit and delineate its boundaries on the map as described in detail in the Mapping section. The delineation process is identical, but enhanced for plant units with circular cross section (e.g. cylindrical storage tanks). Because the boundaries of such plant units are better described by circles instead of polygons, the system automatically switches to circle editing mode based on the "Shape" property. Because the feature editing mode depends on the "Shape" property, but not the type of the plant unit, circular editing is not limited to storage tanks. You can also delineate other circular units, such as columns or stacks.

Hint. Plant unit location

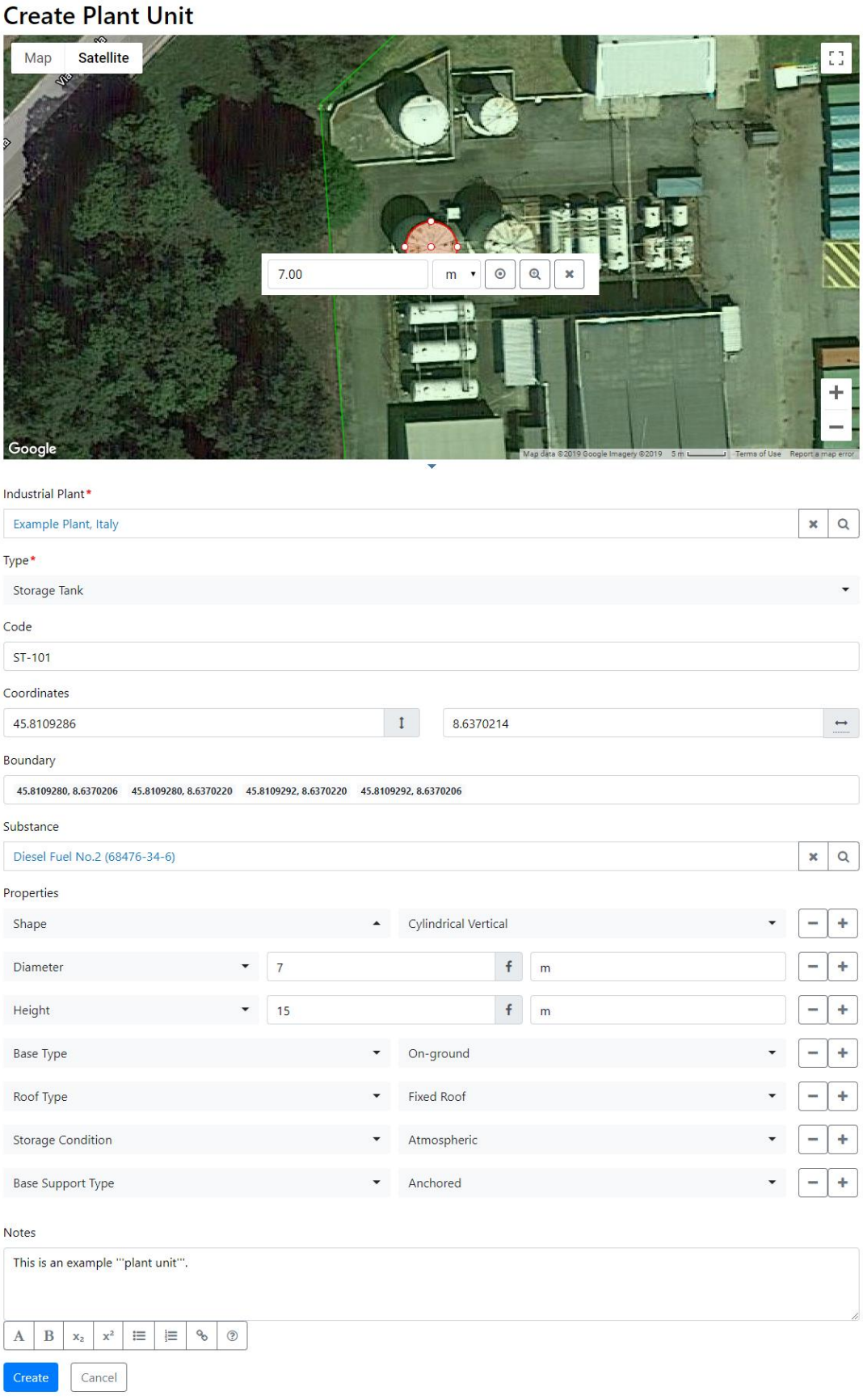
The location of the unit is used to map the extent of the estimated consequences as part of the Natech risk analysis. Hence, it is necessary to provide the location data to obtain proper Natech risk maps at the end of the analysis.

The substance stored in the plant unit can be specified by selecting a substance from the list of substances available in the system. If the substance stored in the plant unit is not specified, the system cannot determine the potential consequences during the Natech risk analysis. Therefore, in the absence of the substance information, consequence analysis cannot be performed and only the results of the damage analysis can be reported.

Hint. Substance data

For a complete risk analysis, the substance stored in the plant unit must be specified. If the substance cannot be identified with certainty, a substance that has similar hazardous characteristics to the actual substance can be specified as a substitute. For example, Kerosene can be used as a substitute for fuels which are not very volatile.

Figure 24. Example plant unit data entry form



Source: JRC, 2018

The availability of data on other plant characteristics is also important and directly affects the analysis process. Although the system tries to estimate the missing data, the more data is provided to the estimation framework as input, the better and accurate the estimates will be. Therefore, it is good practice to provide all available data for each plant unit to the system.

Remark. Plant unit type

The list of plant unit properties that can be entered for each unit depends on the type of the unit. Therefore, before entering the properties make sure that you choose the proper plant unit type.

The extent and severity of the Natech-related consequences mainly depend on the hazard characteristics and amount of the hazardous substance stored in the plant unit. Therefore, plant unit properties that allow the calculation of this information are important for the analysis. Besides the substance, at minimum the following properties should be provided for a proper analysis:

- Volume (either directly or by providing unit dimensions, e.g. diameter and height)
- Filling level (either directly or by providing filling percentage or filled volume)
- Storage condition (either as category, e.g. atmospheric or pressurised, or by providing storage pressure and temperature)

Providing the following properties is also highly recommended to increase the accuracy of the analysis:

- Shape
- Dimensions (e.g. height, length, diameter)
- Base type (e.g. on-ground, above ground)
- Base support (e.g. anchorage)
- Mitigation measures (e.g. secondary containment or dike, if possible with dimensions)

Although the data in the form given in Figure 24 is not complete, it illustrates the minimum information which should be provided. As indicated before, the system is capable of estimating additional property data by using the available data. Figure 25, which is the information page corresponding to the plant unit data entered in Figure 24, illustrates this capability. In the figure, the properties indicated in red are estimated by the system.

The system includes data on more than 64,000 plant units, mainly storage tanks, world-wide, which is collected from public sources, such as OpenStreetMap. However, due to confidentiality reasons this data is not publicly accessible. In order to access the data, please contact the administrators by using the Contact Form of RAPID-N.

4.7 Typical Plant Units

As indicated before, RAPID-N requires plant unit data for the estimation of Natech risk, which can be entered as plant unit records. However, plant unit data may not be available for each industrial plant. Especially for regional studies, it is quite common to have only summary plant information with some indicators such as industrial activity, production capacity, and total amount of hazardous substances present, but without specific details of the plant units. For such plants, RAPID-N can assume which kind of plant units might be present based on standard plant configurations and can perform the risk analysis accordingly. Typical plant unit records are used to provide information on such representative plant units, including characteristic properties, related hazardous substance, and validity conditions.

Figure 25. Example plant unit data information page



Industrial Plant	Tutorial Plant B, Italy
Type	Storage Tank
Coordinate	45.8110869, 8.6371263
Substance	Diesel Fuel No.2 (68476-34-6)
Shell Thickness	5 mm
Bottom Shell Thickness	5 mm
Roof Shell Thickness	5 mm
Shape	Cylindrical Vertical
Volume	226.19 m^3
Height	8 m
Diameter	6 m
Radius	3 m
H/D Ratio	1.3333 m/m
Boundary Distance	3 m
Obstruction Class	Obstructed
Status	Operational
Tank Weight	8086.5 kg
Shell Density	7800 kg/m^3
Roof Type	Fixed Roof
Roof Area	28.274 m^2
Base Type	On-ground
Base Area	28.274 m^2
Base Support Type	Unanchored
Construction Material	Steel
Storage Height	8 m
Storage Volume	226.19 m^3
Storage Capacity	205837 kg
Storage Condition	Atmospheric
Storage Temperature	25°C
Storage Pressure	1 atm
Gauge Pressure	atm
Storage State	Liquid
Fill Percent	85 %v
Fill Height	6.8 m
Stored Volume	192.27 m^3
Stored Quantity	174962 kg
Equivalent Dike Diameter	12 m
Equivalent Dike Length	10.635 m
Enclosure	Dike
Dike Depth	2 m
Dike Area	113.1 m^2
Effective Dike Area	113.1 m^2
Dike Volume	226.19 m^3
Effective Dike Volume	226.19 m^3
Passive Release Mitigation Factor	1
Active Release Mitigation Factor	1

Source: JRC, 2018

Similar to plant units, for each typical plant unit the type of the plant unit should be specified. A descriptive code number (e.g. TPU-001) can be indicated. The substance stored in the typical plant unit can be specified by selecting a substance from the list of substances available in the system. The characteristics of the typical plant unit, including dimensions, storage conditions, and amount of the substance stored, can be indicated by entering property values in the properties list. Similar to the plant units, the system only lists properties valid for the selected plant unit type. See Properties Input section for more details on property data entry.

Different from the plant units, validity conditions can be specified for each typical plant unit to indicate their applicability. All plant properties are available as condition properties. Hence, a typical plant unit can be defined, for example, for plants with specific type of activity, location, production capacity, construction date, or combinations thereof. See the Conditions Input section for more details on the validity conditions.

Hint. Benefits of typical plant units

Typical plant units can be very useful to obtain a preliminary Natech risk analysis without having to collect detailed information on the actual plant units. By creating various typical plant units representative of different industrial activities and carefully setting their validity conditions, regional preliminary risk analysis studies can be performed easily and quickly. For example, you can specify "NACE Code" properties as validity conditions to limit typical plant units to specific industrial activities.

Remark. Location of typical plant units

Although the typical plant units are processed like the actual plant units and yield similar analysis results, they don't have physical coordinates because they are "virtual". Therefore, they are listed in the risk reports, but cannot be shown on the risk maps. Because they do not have location information, in order to estimate location-related properties (e.g. distance to the hazard origin) the coordinates of the plant are utilized for all typical units of the plant.

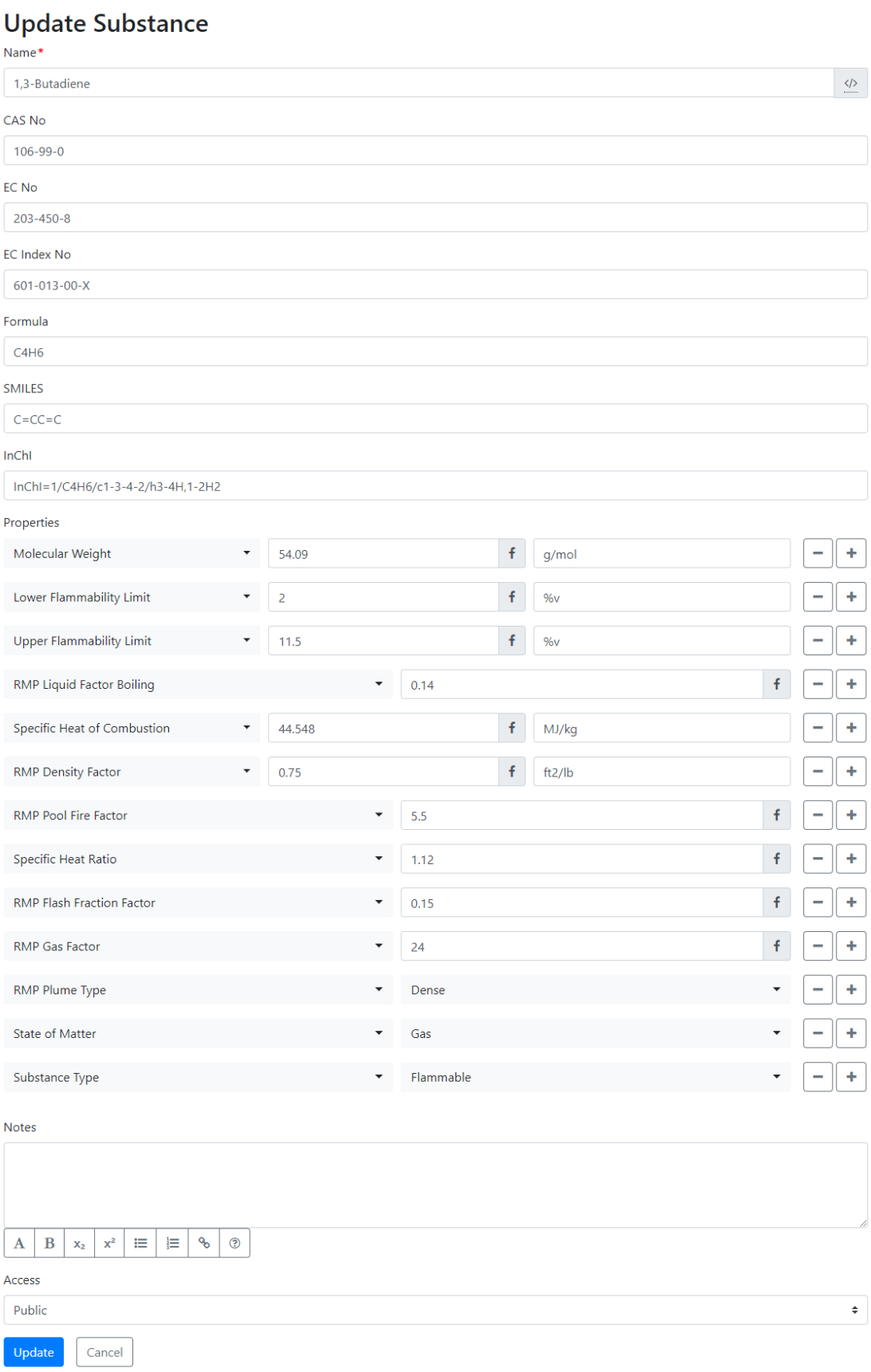
4.8 Substances

The consequences of Natech events mainly depend on the quantity, storage conditions, and hazardous characteristics of the substances involved in the event. For example, fire is probable only if the released substance is flammable. For volatile liquids, the amount that will be dispersed into the atmosphere is a function of boiling point and vapour pressure. The threshold concentrations of toxic substances also differ from substance to substance. In order to provide such substance data required for the analysis, RAPID-N features a substance database that includes information on the physical, chemical, and hazardous properties of the substances.

An example substance data entry form is given in Figure 26. The information on substances includes name, identifier and structure data. Substance names may contain symbols and special formatting, such as italic, subscript and superscript. Multiple names of a substance can be entered by using semi-colon (;) as separator. Frequently used chemical identifiers can also be indicated to facilitate access to substances. Supported identifiers are:

- CAS No: Chemical Abstracts Service (CAS) Registry number of the American Chemical Society,
- EC No: European Inventory of Existing Chemical Substances (EINECS), and European List of Notified Chemical Substances (ELINCS) number of the European Union,
- EC Index No: 67/548/EEC Directive Annex I index number.

Figure 26. Example substance data entry form



Source: JRC, 2018

Information on the structure of the substance is stored as textual chemical formula and formatted strings in International Chemical Identifier (InChI) (Stein et al., 2003) and Simplified Molecular Input Line Entry Specification (SMILES) (Weininger, 1988) notations. Besides giving insight into the chemical structure of the substance, these identifiers can also be used to estimate chemical properties by using structure-property relationships.

The properties of a substance can be indicated by using the properties list. There are three types of substance properties which are used for the analysis. The first one is physicochemical properties, such as molecular weight and boiling point. The second one is hazard properties, which includes toxic concentration thresholds and other hazardous characteristics (e.g. flammability limits). The last category is specific to the consequence calculations by using U.S. EPA's RMP Guidance for Offsite Consequence Analysis (RMP*Comp) methodology (U.S. EPA, 1999) and includes properties related to substance-specific factors, which are utilized to facilitate computations. See Properties Input section for more details on property data entry.

Remark. Temperature-dependent properties

For temperature-dependent properties, such as density or viscosity, the value at a reference temperature (25ºC) should be provided. The system utilises correction factors to calculate the corresponding values in different temperatures according to the RMP*Comp methodology. See U.S. EPA (1999) for more details.

The minimum data required for calculating the extent of consequences (i.e. heat radiation, overpressure, toxic concentration) depends on the type of consequence and models used for the computation. However, as a rule of thumb, the following properties should be provided for a substance to make the consequence analysis possible:

For all substances:

- Molecular Weight
- Density
- Vapour Pressure
- Boiling Point
- Heat of Vaporisation

For toxic substances:

- Toxic Threshold Concentration

For flammable substances:

- Heat of Combustion
- Heat Capacity
- Specific Heat Ratio
- Lower Flammability Limit
- Upper Flammability Limit

4.9 Damage Classifications

The estimation of the potential damage to a plant unit due to a natural hazard event is based on the calculation of the probabilities of certain damage scenarios given a set of on-site natural hazard parameters. Because the extent of damage is highly case-specific and varies significantly, a simplification is usually necessary to facilitate the analysis. Generally, this is done by grouping similar damage scenarios into a set of damage states, ranging from no damage to complete damage gradually in several steps (U.S. FEMA, 1997). Damage states also form the basis of fragility curves, which are frequently used for damage assessment. Therefore, they are supported by RAPID-N.

An example damage classification record is given in Figure 27. Since damage states are natural hazard specific, a hazard type should be selected for each damage classification record. The name of the damage classification and a short description should be provided. By default, the damage classification is valid for all plant unit types. A plant unit type can be specified explicitly, if the damage classification is only valid for that plant unit type (e.g. storage tank).

Multiple damage states can be defined for each damage classification. They are identified by damage classification-specific unique codes. Common practice is to use sequential numbers prefixed by "DS", e.g. DS1, DS2, etc. If available, short labels such as "None", "Light", "Moderate" can also be specified. A description of each damage state should be provided to indicate the type and extent of damage defined by the damage state.

Bibliographic references of the damage classification can be indicated by selecting the references from the reference records available in the system or by entering a new reference. At least one reference is mandatory.

Figure 27. Example damage classification

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

Source: JRC, 2018

Hint. Alternatives to damage classifications

Although they are frequently used, damage states are not the only way to describe the possible damage. There are also other methods available, which allow better quantification of the damage. It is good practice to utilize such methods instead of damage states, as quantitative damage scenarios can be more easily and accurately linked to the related consequence scenarios.

4.10 Fragility Curves

Fragility curves are X-Y plots relating a hazard parameter (e.g. PGA) to the damage probability of a structure for a certain damage state (U.S. FEMA, 1997). They 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). RAPID-N supports fragility curves in the damage estimation part of the risk analysis.

An example fragility curve data entry form is given in Figure 28. For each fragility curve, a descriptive name and an abbreviation should be provided. The damage classification that the fragility curve is based on should be selected. The type of plant unit, for which the fragility curve is valid (e.g. storage tank), should be specified. The hazard parameter (i.e. independent variable) of the fragility curve should be selected from the list of hazard parameters (e.g. PGA). If the parameter is a numerical property with a reference unit, the unit used for the fragility curve should also be indicated.

Curve data should be entered separately for each damage state. The system supports different functional forms for the curves, each of which require a different set of parameters. The supported functional forms with required parameters and corresponding functions are listed in Table 5.

Table 5. Functional forms supported for fragility curves

Functional Form	**Parameters**	**Equation**
Log-normal (median)	Median (m) Standard deviation (σ)	$\frac{1}{2}\left[1+\text{erf}\left(\frac{\ln x-\ln m}{\sigma\sqrt{2}}\right)\right]$
Log-normal (mean)	Mean (μ) Standard deviation (σ)	$\frac{1}{2}\left[1+\text{erf}\left(\frac{\ln x-\mu}{\sigma\sqrt{2}}\right)\right]$
Probit	k_1 k_2	$\frac{1}{2}\left[1+\text{erf}\left(\frac{(k_1+k_2\ln(x)-5}{\sqrt{2}}\right)\right]$
Dataset	Parameter values Probabilities	Quadratic Interpolation

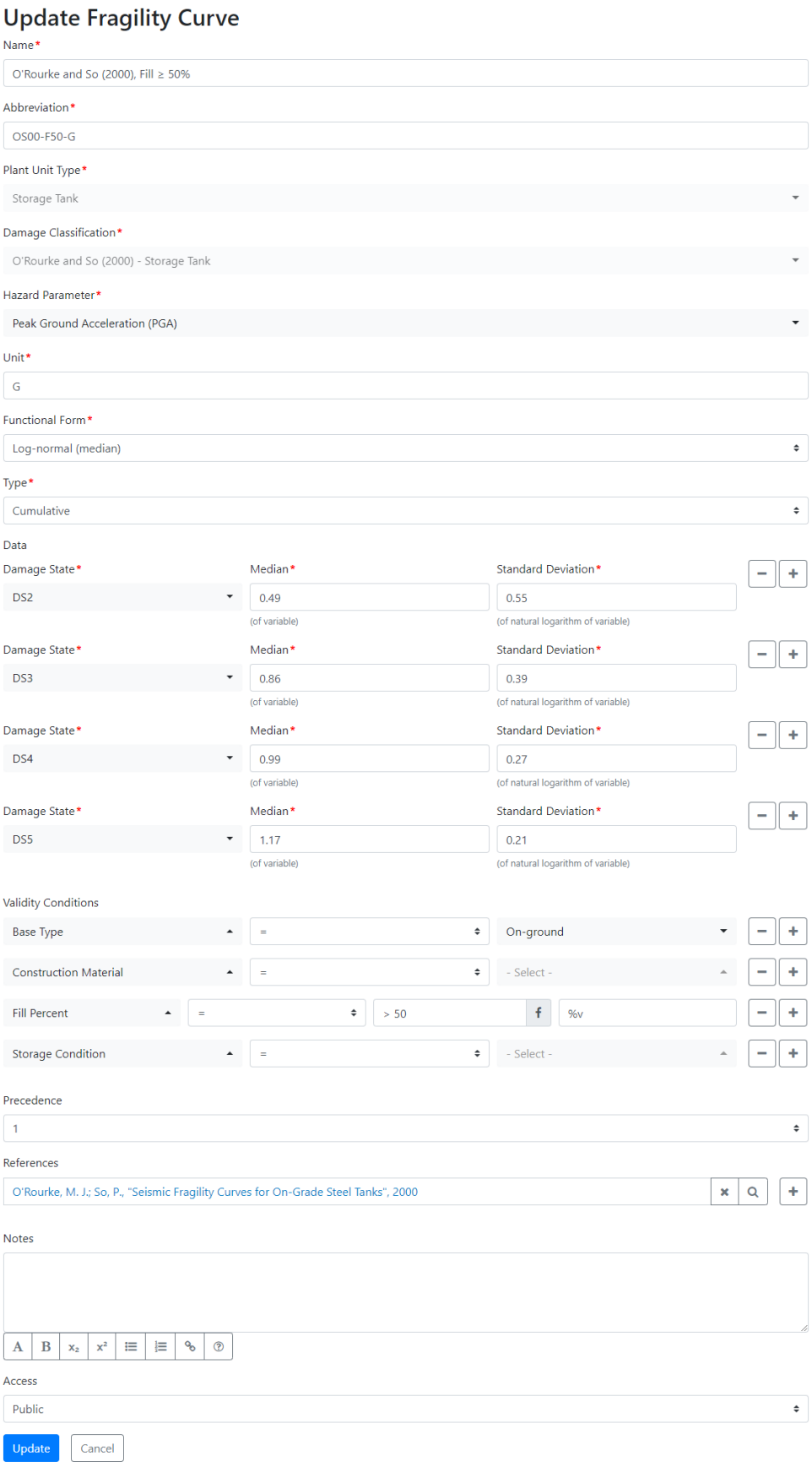
Source: Girgin, 2012

In addition to different functional forms, the system also supports two different types of curves which are *discrete* and *cumulative*. A discrete curve defines the damage probability only for the specified damage state. Therefore, it defines an "equal" condition, e.g. = DS2. On the other hand, a cumulative curve defines the overall damage probability for the specified damage state and all other damage states above it. Therefore, it defines a "greater than or equal" condition, e.g. ≥ DS2. The proper curve type should be selected depending on the available curve data.

Remark. Discrete and cumulative curves

The system utilizes discrete curves for the analysis. But it also has the capability to transform cumulative curves into discrete curves, and vice versa. Therefore, the curve type does not affect the analysis.

Figure 28. Example fragility curve data entry form



Source: JRC, 2018

Remark. Damage states

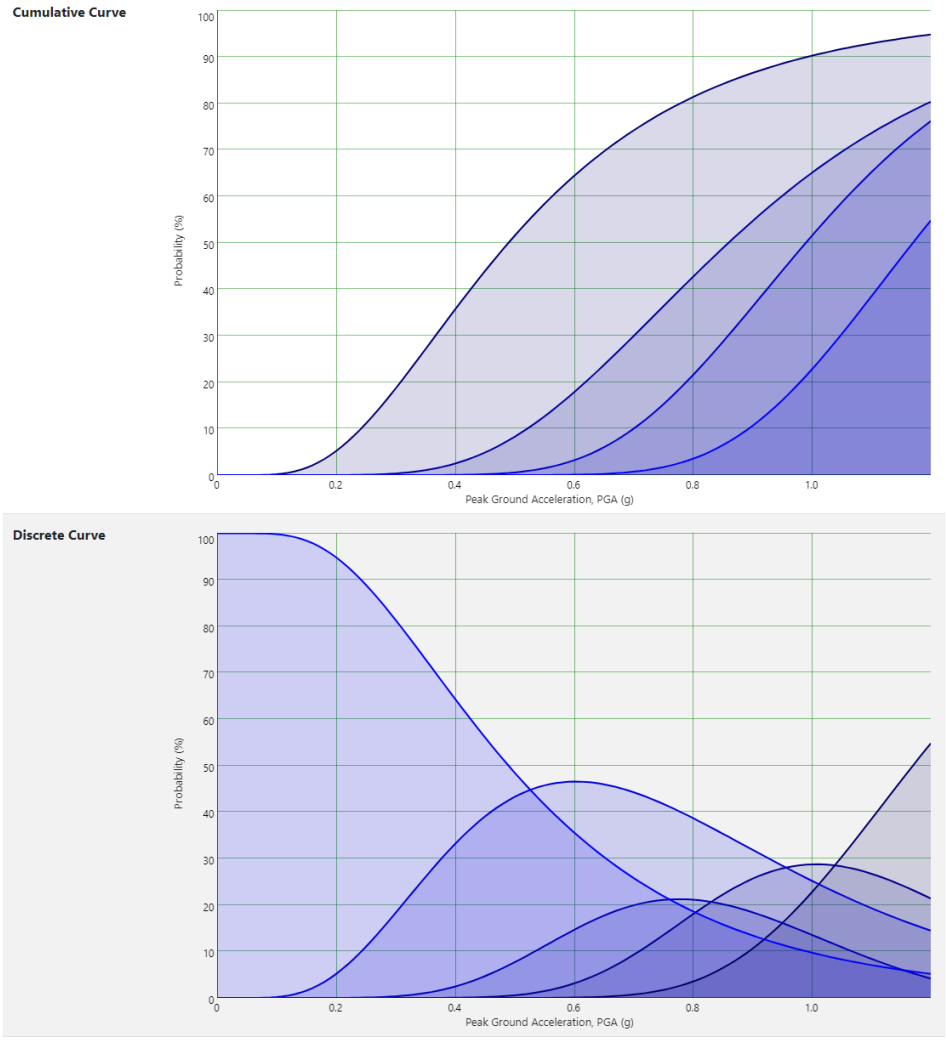
Curve data is not mandatory for all damages states. Therefore, a subset of the damage states can be used for data entry. However, it is good practice to provide data for all damage states, so that the probability of each damage state can be explicitly calculated. Otherwise, the system cannot successfully develop Natech scenarios, and also curve transformation cannot be performed.

Similar to the property estimators, validity conditions can be specified for fragility curves. Therefore, a fragility curve can be restricted to a specific plant unit type with certain characteristics (e.g. atmospheric fixed-roof cylindrical storage tanks). See Conditions Input section for more details on the validity conditions.

For each fragility curve, bibliographic references should be indicated to provide information on the origin of the curve data. At least one reference is mandatory.

Fragility curve information is presented in tabular form together with curve data, validity conditions, and bibliographic references. Interactive fragility curve plots are provided for each damage state. The curves are plotted on the same graph, so that they can be compared easily. By moving the mouse pointer over the curves, numerical values of damage probabilities can be obtained. Based on the available data, both cumulative and discrete curves are calculated automatically and displayed separately. Example fragility curves, which are based on the data given in Figure 28, are shown in Figure 29.

Figure 29. Example cumulative and discrete fragility curves



Source: JRC, 2018

Hint. Alternatives to fragility curves

Use of fragility curves is not the only way to provide damage data. Damage-related property estimators can also be used for the same purpose.

4.11 Risk States

In order to estimate the risk of Natech events, damage scenarios which are calculated by using on site hazard parameters and damage functions, have to 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 as risk states to facilitate the analysis.

In the past, simple one-to-one relations were used in the literature to relate damage states to risk states (Salzano et al., 2003; Fabbrocino et al., 2005). Going one step further, RAPID-N supports conditional risk state definitions for each damage scenario. 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).

For each risk state, a damage classification and related damage state should be specified. Scenario parameters, which should be taken into consideration during consequence analysis, can be 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. fire/explosion event, threshold concentration). See Properties Input section for more details on property data entry.

The possibility to indicate custom scenario parameters allows damage-scenario specific non-linear damage-consequence relations to be defined in RAPID-N. This results in a more realistic risk analysis, for example in the case of damage to piping with significant loss of content which is generally regarded as minor structural damage, or elephant-foot buckling with minor loss of content which is generally regarded as major structural damage. In such cases, classical damage-consequence relations would result in the over- or under-estimation of the Natech risk due to their linear behaviour, where a higher damage implies a higher consequence.

Similar to the case of property estimators, validity conditions of a risk state can be indicated by selecting the appropriate condition properties and setting the criteria. Because consequence scenarios strongly depend on plant unit conditions and substance characteristics, both plant unit and substance related properties can be specified as conditional properties. For example, risk states can be defined for atmospheric floating roof tanks constructed before a certain date, in which substances with a high heat of combustion are stored. See Conditions Input section for more details on the validity conditions.

Remark. Multiple risk states

For a specific damage scenario, all risk states that fulfil the validity conditions are merged by the system while developing the final consequence scenario. Therefore, more complex scenarios can be obtained by the combination of simpler risk states.

Hint. Use of multiple risk states

Combination of various risk states allows very detailed and case-specific Natech scenarios to be defined, without disabling generic risk state definitions applicable to other common situations. It is good practice to define less complex, but multiple risk states, which can be combined by the system whenever necessary.

4.12 Risk Analyses

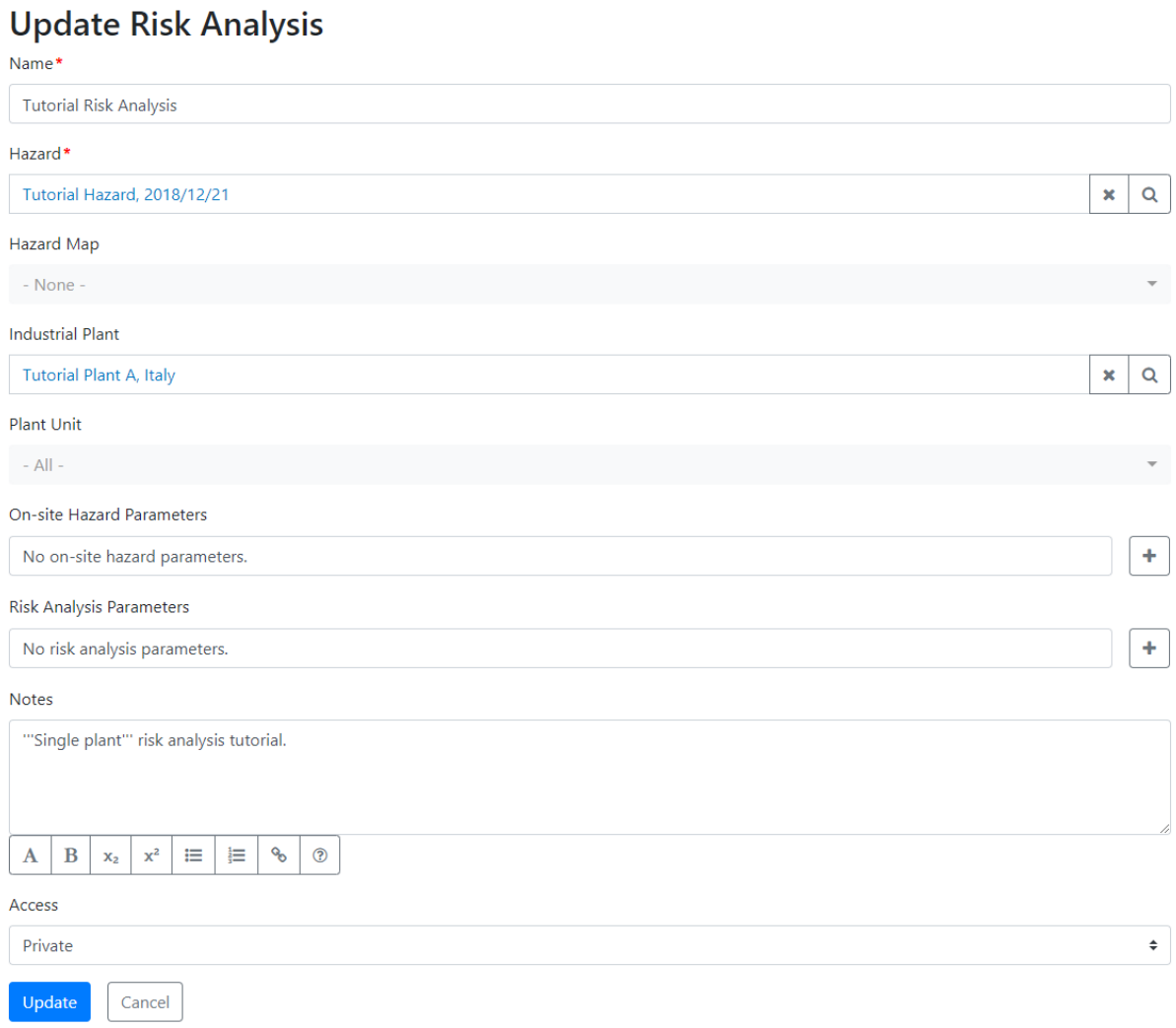
Natech risk analysis is highly automatized in RAPID-N. The risk analysis data entry form is rather simple and involves only a couple of input elements. But customisation of the various stages of the analysis, including hazard analysis, damage analysis, and consequence analysis, is also possible through several mechanisms and also by setting the values of related risk analysis properties.

Remark. Authorisation

Authorisation is required to create new risk analyses.

An example risk analysis data entry form is given in Figure 30. For each risk analysis, only the name of the analysis and the triggering natural hazard event are necessary. The natural hazard event can be selected from the hazard records available in the system. See the Hazards section for detailed information on natural hazard records, including how to define custom hazard events. Once the hazard record is selected, the system automatically lists available hazards maps related to the hazard record. Selecting a map from the list enforces the system to use the indicated hazard map to calculate on-site hazard parameters. If the "Default" option is selected, the default hazard map indicated in the hazard record is utilized.

Figure 30. Example risk analysis data entry form



Source: JRC, 2018

Remark. Use of hazard maps

The specified hazard map is only used to calculate the on-site hazard parameters available in the hazard map (e.g. PGA, PGV, MMI, and SA for a ShakeMap). Other on-site hazard parameters, which can be estimated by using available data, including data originating from the hazard map, are estimated by the data estimation framework and included in the analysis. Therefore, use of a hazard map does not limit the calculated on-site hazard parameters to certain parameters. Instead, it supports further estimation of other parameters by providing accurate input data.

Hint. Default hazard map

For the hazard records publicly available in the system, the default hazard map is updated automatically by the system whenever a new hazard map becomes available. Therefore, a default hazard map is usually the best available hazard map for a hazard record. Hence, the use of default maps is suggested for the analysis.

If the analysis should be restricted to a specific industrial plant (i.e. plant units located at the plant), the plant can be selected from the plant records available in the system. See Industrial Plants section for detailed information on plant records. If necessary, the analysis can be further restricted to a specific plant unit located at the plant by selecting the plant unit from the list of plant units. By default, all plant units of the plant are included in the analysis.

If a plant is selected, the system allows site-specific hazard parameters to be entered manually in the risk analysis data entry form. Therefore, in addition to the hazard maps and on-site hazard data, risk-analysis specific on-site hazard data can also be specified to further customize the risk analysis.

For the consequence analysis part of the risk analysis, RAPID-N uses the scenario parameters specified in the risk states as the seed parameters in forming the consequence scenarios. It is also possible to enter custom scenario parameters specifically for each risk analysis. If they are available, custom scenario properties overwrite damage and consequence parameters obtained from the risk states.

Hint. End-point distance criteria

RAPID-N estimates the end-point distances by using threshold values referring to the intensities of hazardous effects. The effects that are considered are the heat radiation intensity for fires, peak overpressure for blast waves (i.e. explosions) and the toxic concentration for atmospheric dispersions. You can customize threshold values by using the following parameters:

— Endpoint Radiation Intensity (default value is 5 kW/m²)

— Endpoint Overpressure (default value is 1 psi)

— RMP Toxic Endpoint Concentration (default value is based on Emergency Response Planning Guideline 2 (EPRG-2) or Immediately Dangerous to Life and Health (IDLH) concentrations)

Remark. Thresholds of specific substances

Toxic concentration thresholds of some substances (e.g. Chlorine and Ammonia) are embedded in the RMP*Comp methodology and cannot be changed (see U.S. EPA, 1999 for details).

In addition to the scenario-related parameters, it is also possible to set parameters related to the risk analysis itself. Some important risk analysis parameters are as follows:

- *Enable Private Estimators*: User-specific property estimators, which are set as private, are normally used for estimation of on-demand record properties, which are displayed on the record information pages. However, due to the sensitivity of the risk analysis calculations, which require validated estimation methods to obtain accurate and reliable results, private estimators are normally not used for the risk analysis. In order to enable private estimators also for the risk analysis, you can set the "Enable Private Estimators" property. By default, it is disabled.
- *Enable Hazard Maps*: If you want to prevent the use of hazard maps for the calculation of on-site hazard parameters, you can disable this feature by setting the "Enable Hazard Maps" property. By default, it is enabled.
- *Enable Typical Plant Units*: Normally, risk analysis is not possible without plant unit data. However, as described in the Typical Plant Units section, the system has the capability to perform the analysis by using "virtual" units defined by the typical plant units to provide approximate, but still useful results. If this feature is not needed, it can be disabled by the "Enable Typical Plant Units" property. By default, it is enabled.
- *Cut-off Distance*: If no other impact area information is available (e.g. hazard boundaries), the system identifies the plant units to be considered for the analysis based on a cut-off distance from the origin (i.e. source) of the natural hazard event. By setting the "Cut-off Distance" property you can define this maximum distance. Setting a bigger cut-off distance allows consideration of more plant units, but it may significantly increase the analysis time. By default, it is set to 200 km.

Once the risk analysis is initiated by creating the risk analysis record, RAPID-N gathers all data available about the natural hazard event and the industrial plant units, including virtual units defined by the typical plant unit records, if necessary. It performs natural hazard impact analysis to quantify possible natural-hazard related damage at each plant unit, constructs probable Natech scenarios, and analyses their consequences by following the steps described in the Risk Analysis Methodology section.

Once the analysis is completed, the results are presented as a risk report and an interactive risk map showing the extent of potential Natech events and their related probabilities. An example risk analysis report with the corresponding risk map is given in Figure 31.

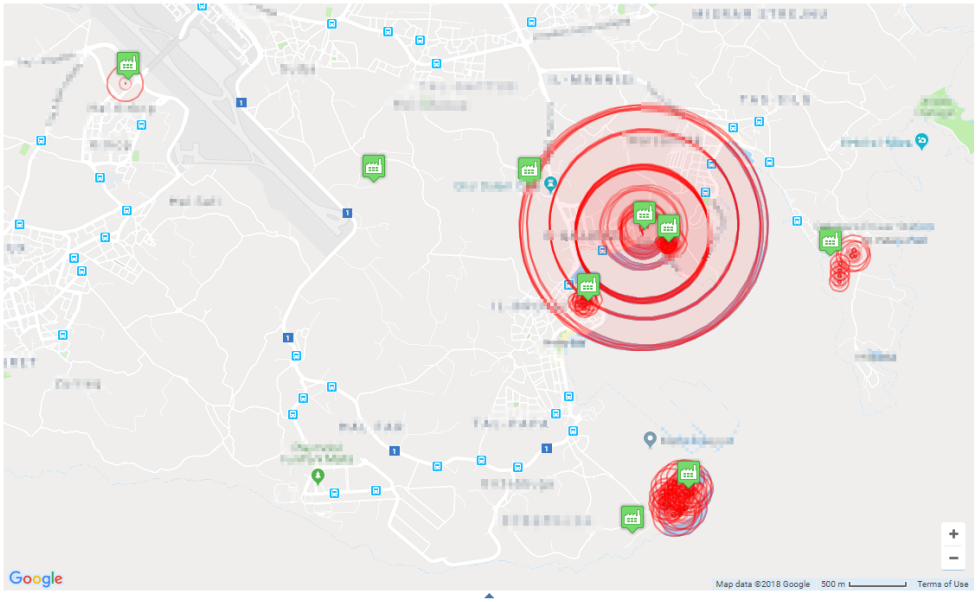
The risk analysis map shows circles around the units that may experience a Natech accident. Concentric circles with different diameters represents different scenarios. The colour of a circle indicates the type of consequence: red for fire and explosion events, and orange for toxic dispersions. Each circle's radius is equivalent to the end-point distance calculated by the system for the specific Natech scenario. The opacity of the circles indicates the probability of the event. The transparency of the circles increases as the occurrence probability decreases. You can download a KML file of the risk map by clicking on the "Download KML" link and open it in a GIS software or Google Earth for further examination or analysis.

The risk analysis record table summarizes the risk analysis settings and the data provided to the system, including user-defined and estimated risk analysis parameters.

The risk analysis report summarizes the results and provides detailed information on the different phases of the risk analysis process for each plant unit and grouped by industrial plants (Figure 31). Plant units without related plant information are listed at the end of the report as separate entities.

Analysis results are reported in 4 different columns, which display values of properties related to each analysis phase, including user-defined and estimated data. In order to simplify the report, only values of the most important properties are directly shown at each column. Values of the other properties can be accessed by clicking the "View More" icons indicated by a right arrows.

Figure 31. Example risk analysis report and risk map



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(1.6998·10^{-6})
				DS3: P(2.5095·10^{-5})	Fire/Explosion Event: Pool Fire; $Q_{released}$: 4769.1 kg ❯	22.58 m, P(< 1·10^{-6})
				DS4: P(1.1644·10^{-6})	Fire/Explosion Event: Pool Fire; $Q_{released}$: 228918 kg ❯	92.69 m, P(< 1·10^{-6})
				DS5: P(< 1·10^{-6})	Fire/Explosion Event: Pool Fire; $Q_{released}$: 31850000 kg ❯	92.69 m, P(< 1·10^{-6})

Source: JRC, 2018

The columns contain the following information:

- The *Plant Unit* column contains all information about the plant unit or the typical plant unit. Plant unit code, substance name and its quantity (as mass or volume) are directly displayed as primary information.
- The *Hazard Analysis* column contains the on-site natural hazard parameters as defined or estimated for each unit. Hazard severity parameters are directly displayed as primary information.
- The *Damage Analysis* column contains one or more rows per unit. Each row contains the damage analysis results related to a possible damage scenario. Damage state, probability, and severity parameters are displayed as primary information.
- The *Consequence Analysis* column contains one or more rows per damage analysis row of each plant unit. Each row contains the consequence analysis results linked to the associated damage scenario. Multiple consequence scenario rows might be available, depending on the hazard characteristics of the substance and the risk states utilized for the analysis. For example, for a substance which is both toxic and flammable, there might be both fire and toxic dispersion scenarios. Consequence type (e.g. pool fire, explosion, toxic dispersion), release quantity (as mass or volume), distance at which hazardous effects are expected with a specific severity (i.e. end-point distance), corresponding severity criteria (i.e. end-point criteria) and probability of occurrence of the Natech event, which is obtained by multiplying the conditional occurrence probabilities of all events leading to a Natech event, are displayed as primary information.

Example risk analyses with step-by-step instructions are provided in the Tutorials section.

5 Estimation Functions

An estimation function utilized by the property estimators of RAPID-N, which form the basis of the data estimation and risk analysis frameworks, is typically composed of a series of statements, which calculate or estimate the value of the related property by using the values of other available properties and by utilizing expressions, control structures, and functions of the supported programming language. Currently, RAPID-N uses the PHP language for computations. Therefore, the estimators should be developed by using the PHP syntax as extended by the features specific to the data estimation framework of RAPID-N.

Giving detailed information on PHP is beyond the scope of the guide, but a short introduction with examples highlighting important topics is provided in this section to facilitate the understanding of the existing estimators and development of additional estimators by the users, whenever necessary. Some features of the language are deliberately excluded from the guide to enable a more simple and standardized estimation function syntax. For detailed information on PHP, including additional features of the language, you can consult books, documents, and tutorials which are readily available. An excellent resource is the PHP Manual provided by the PHP Documentation Group (2018).

5.1 Syntax

Each statement of an estimation function should be terminated with a semicolon (`;`) at the end of the statement, which can be spread to multiple lines. The execution of the estimation function can be terminated and the result of the computation can be passed to the estimation framework by using the `return` keyword followed by the estimate. Therefore, the simplest estimation function possible in the framework is a function that is composed of a return statement with a constant value:

```
return 20;
```

Such estimators are identical to the value estimators and can be used to set the default values of some parameters, such as ambient temperature or pressure. Instead of returning a constant value, an estimator can also return the value of an expression that is composed of some constants, operators, variables, data parameters and internal functions. For example, the following function calculates the diameter of a cylindrical horizontal storage tank from its volume and length:

```
return 2 * sqrt([volume:m3] / (M_PI * [length:m]));
```

In this function, `M_PI` is a mathematical constant with a value equal to π (i.e. 3.14159…), `sqrt()` is an internal function call which calculates the square root of the expression indicated between the parenthesis, `*` and `/` are multiplication and division operators, and `[volume:m3]` and `[length:m]` are property data parameters that refer to the existing values of volume and length properties of the storage tank (i.e. plant unit) entity.

If no estimate is available, the function should return a no value simply by omitting the value of the `return` statement.

```
if (([height:m] / [diameter:m]) > 0.5)
  return 1;
else
  return;
```

If the function terminates without a return statement, it automatically returns a no value. Therefore, the following function is identical to the previous one:

```
if (([height:m] / [diameter:m]) > 0.5) return 1;
```

Multiple statements can be grouped by encapsulating them with curly braces ({}) which itself forms a statement.

```
if (([height:m] / [diameter:m]) > 0.5) {
  return 1;
}
```

5.1.1 Comments

For documenting the estimation functions, both single and multiple line comments are supported. A single line comment starts with double slash (//) and comment to the end of the line. A multiple line comment starts with slash asterisk (/*) and ends at the first encountered asterisk slash (*/).

```
// This is a single line comment

/* This is a single line comment in multiple line syntax */

/* This is a multiple line comment
   with a second line */

// This is a multiple line comment in single line syntax
// with a second line
```

Remark. Nested comments

Nested multiple line comments are not supported.

5.1.2 Constants

A constant identifies a special value, which cannot be changed. Instead of writing the value each time, the corresponding constant identifier can be utilised which not only leads to standardized and easily understandable functions, but it might also reduce problems due to typing errors.

Available predefined mathematical constants are listed in Table 6 with their corresponding values.

Remark. Use of constants

PHP allows definition of custom constants by using the `const` keyword. However, due to the distributed and self-contained nature of the property estimators, use of user-defined constants is not recommended. Variables with constants values can be utilized instead of constants whenever it is necessary.

Table 6. Available mathematical constants

Constant	Value	Description
M_PI	3.14159265358979323846	π
M_E	2.7182818284590452354	e
M_LOG2E	1.4426950408889634074	$\log_2 e$
M_LOG10E	0.43429448190325182765	$\log_{10} e$
M_LN2	0.69314718055994530942	$\ln 2$
M_LN10	2.30258509299404568402	$\ln 10$
M_PI_2	1.57079632679489661923	$\pi/2$
M_PI_4	0.78539816339744830962	$\pi/4$
M_1_PI	0.31830988618379067154	$1/\pi$
M_2_PI	0.63661977236758134308	$2/\pi$
M_SQRTPI	1.77245385090551602729	$\sqrt{\pi}$
M_2_SQRTPI	1.12837916709551257390	$2/\sqrt{\pi}$
M_SQRT2	1.41421356237309504880	$\sqrt{2}$
M_SQRT3	1.73205080756887729352	$\sqrt{3}$
M_SQRT1_2	0.70710678118654752440	$1/\sqrt{2}$
M_LNPI	1.14472988584940017414	$\ln \pi$
M_EULER	0.57721566490153286061	Euler's constant (γ)

Source: PHP Manual, 2018

5.1.3 Data Parameters

As an extension to the standard language syntax, estimation functions support the use of record and property data values inside the functions as parameters. Termed as data parameters, these parameters allow estimation functions to perform calculations by utilizing available record-specific data, which also includes data from associated records (e.g. industrial plant for plant units).

In order to use a property data value in a function, the code of the property should be entered in square brackets (`[]`), e.g. `[diameter]`. For numerical properties, the value of the property can be obtained in a specific unit compatible with the reference unit of the property by indicating the unit within the bracket after the property code, separated by a colon (`:`), e.g. `[diameter:ft]`. The units can be specified by using the unit notation described in the Unit Input section.

An example estimation function with data parameters is given below:

```
return 2 * sqrt([volume:m3] / (M_PI * [length:m]));
```

Remark. Value data types

The data type of the property value in the function is set according to the data type of the related property. For example, integer, numeric, and tabular properties are specified as integer, float, and string values, respectively. Point approximations as float values are used for fuzzy numerical values. See the Data Types section for details of the data types supported by the estimation functions.

Similar to the property data values, record data values (e.g. name) can also be utilized in the estimation functions. For this purpose, the name token of the record data field prefixed with exclamation mark (`!`) should be specified inside the square brackets instead of the property code, e.g. `[!name]`. The data types of the record data values are determined according to their native data type used for the storage in the database.

Remark. Constant values

Values of data parameters are considered to be constant within an estimation function. Therefore, they cannot be modified.

5.1.4 Operators

An operator takes one or more values or expressions (i.e. statements) and yields another value. There are unary operators that take only one value, binary operators that take two values, and a ternary operator that takes three values.

The supported operators are listed in Table 7. The list is not exhaustive and only includes the operators useful for the estimation functions. See the PHP Manual for the complete list of operators.

Table 7. Supported operators

Operator	Example	Name	Operator	Example	Name
=	$a = $b	Assignment	*Logical operators*		
Bitwise operators			!	! $a	Not
&	$a & $b	And	&&	$a && $b	And
|	$a | $b	Or (inclusive or)	||	$a || $b	Or
^	$a ^ $b	Xor (exclusive or)	*Increment/decrement operators*		
~	~ $a	Not	++	++$a	Pre-increment
<<	$a << $b	Shift left	++	$a++	Post-increment
>>	$a >> $b	Shift right	--	--$a	Pre-decrement
Arithmetic operators			--	$a--	Post-decrement
-	-$a	Negation	*Comparison operators*		
-	$a - $b	Subtraction	==	$a == $b	Equal
+	$a + $b	Addition	===	$a === $b	Identical
*	$a * $b	Multiplication	!=	$a != $b	Not equal
/	$a / $b	Division	<>	$a <> $b	Not equal
%	$a % $b	Modulus	!==	$a !== $b	Not identical
**	$a ** $b	Exponentiation	<	$a < $b	Less than
String operators			>	$a > $b	Greater than
.	$a . $b	Concatenation	<=	$a <= $b	Less than or equal to
.=	$a .= $b	Concatenating assignment	>=	$a >= $b	Greater than or equal to

Source: PHP Manual, 2018

The precedence of an operator determines how it binds two values or expressions together. For example, the expression `1 + 2 * 3` evaluates to 7 and not 9 because the precedence of the multiplication operator (`*`) is higher than the addition operator (`+`). Parentheses may be used to force precedence wherever necessary. For example, `(1 + 2) * 3` evaluates to 9. Table 8 lists the supported operators in the order of precedence with associativity information. Operators listed on the same row have equal precedence.

Table 8. Precedence and associativity of the supported operators

Operators	**Associativity**
`**`	right
`++ -- (int) (float) (string) (array) (bool)`	right
`!`	right
`* / %`	left
`+ - .`	left
`<< >>`	left
`< <= > >=`	none
`== != === !== <>`	none
`&`	left
`^`	left
`|`	left
`&&`	left
`||`	left
`? :`	left
`= += -= *= **= /= .= %= &= |= ^= <<= >>= =>`	right

Source: PHP Manual, 2018

When operators have equal precedence their associativity decides how the operators are grouped. For example, `1 * 2 / 3` is grouped as `(1 * 2) / 3`, because multiplication (`*`) and division (`/`) operators are left-associative. On the other hand, assignment operators are right-associative and `$a = $b = $c` is grouped as `$a = ($b = $c)`. Non-associative operators that have equal precedence cannot be used next to each other, for example `1 < 2 > 1` is not a valid expression.

Hint. Use of parentheses

Use of parentheses is highly recommended as it can prevent potential errors and increase code readability by making grouping explicit rather than implicit by operator precedence and associativity.

5.1.5 Variables

Variables, which keep values that are not constant (i.e. can be changed during the execution of the function) are represented by a dollar sign (`$`) followed by the name of the variable. A valid variable name should begin with a letter or underscore, followed by a series of letters, numbers, or underscores. It is not necessary to initialize variables. Data types of the variables are also not specified, as the language is capable of determining the data type of variables and does type conversion (i.e. type casting) automatically.

Remark. Variable names

The variables names are case-sensitive, e.g. `$var` and `$Var` denote different variables.

```
$var = "variable";
$Var = "another variable";
```

By default, variables are always assigned by value, i.e. when an expression is assigned to a variable, the entire value of the original expression is copied into the destination variable. This means that after assigning one variable's value to another, changing one of those variables will have no effect on the other.

```
// Set value of a as 10
$a = 10;
// Set value of b as equal to a (= 10)
$b = $a;
// Change value of a to 20
$a = 20;
// Value of b is still 10
```

5.2 Data Types

Variables that are used in an estimation function can store values in various data types. Although there are some similarities, variable data types are different from the property data types of the system which are described in the Properties section. The following data types are supported:

5.2.1 boolean

A boolean expresses a binary value, which can be either `TRUE` or `FALSE`.

```
$val = TRUE;
$val = FALSE;
```

5.2.2 integer

An integer expresses a number without a fractional component, i.e. $\mathbb{Z}$ = {…, -2, -1, 0, 1, 2, …}. They are 32 bits signed values with minimum and maximum values of `-2147483647` and `2147483647`, respectively. A number beyond these values, including one originating from an expression, is interpreted as a float.

```
$val = 123;
$val = -123;
```

5.2.3 float

A float expresses a number with decimal points, e.g. `1.2345`. Float values can be assigned by using the decimal or scientific syntaxes:

```
$val = 1.23;
$val = 1.23e3;
$val = -6.5E-10;
```

A float approximates a real number by using a fixed number of significant digits that are scaled using an exponent in base 2. Therefore it has limited precision. The IEEE 754 double precision format is used internally by PHP, which gives a maximum relative error due to rounding in the order of 1.11^{-16}. Moreover, rational numbers that are exactly representable as floating point numbers in base 10 (e.g. `0.1`) do not have an exact representation in base 2. Therefore, results involving floats should not be trusted to the last digit and they should not be directly used for comparison. For example, the following expression evaluates to `FALSE` instead of `TRUE` as expected normally due to the base 2 rounding:

```
$sum = 0.1 + 0.2;
$equal = ($sum == 0.3);
```

In order to test the equality of two float numbers, a custom relative error value that is acceptable for the calculation should be used. For example, the previous comparison can be done properly by using the subtraction operator (`-`) and the absolute value function `abs()` as follows, which evaluates to `TRUE`:

```
$sum = 0.1 + 0.2;
$equal = (abs($sum - 0.3) < 1e-10);
```

Some numeric operations can result in an undefined or unpresentable value, which is denoted by the constant `NAN`. Such results should be checked by using `is_nan()` function:

```
$div = 0 / 0;
if (is_nan($div)) $msg = "not a number"; else $msg = "a number";
```

5.2.4 string

A string expresses a series of characters in quotation marks (`""`), which is usually used to denote text messages. Single quotations (`''`) can be used to define strings containing quotation marks.

```
$text = "This is a string";
$text = 'This is another text with "quotes"';
```

5.2.5 array

An array expresses a series of other values, which may include values having data types of null, boolean, integer, float, string, or even nested arrays. Array elements are defined between square brackets (`[]`) and separated by commas (`,`). Both sequential and associative (i.e. composed of key and value pairs) arrays are supported. For associative arrays, `=>` operator is used to indicate the value of a key:

```
// Sequential array
$list = [1, 2, 3, 4, 5];
// Sequential array with mixed data type elements
$list = ["A", 1, 'B', 1.23, NULL, [1, 2, 3]];
// Associative array
$list = ["A" => "AA", "B" => "BB", "C" => "CC"];
```

5.2.6 null

The special `NULL` value represents a variable with no value. A variable which has not been set to any value or explicitly set to the constant `NULL` is considered to be null.

```
$val = NULL;
```

5.3 Control Structures

Various control statements (i.e. structures), which allow branching or selective execution of the statements are supported in the estimation functions.

5.3.1 if … else if … else

```
if (expr)
  statement
else if (expr)
  statement
:
else
  statement
```

The if … else if… else … statement allows conditional execution of statements. The *expression* following the `if` keyword is evaluated to its boolean value and if it is `TRUE`, then the subsequent *statement* is executed. For example, the following if statement assigns a value to `$msg`, if `$val` is bigger than `$otherVal`:

```
if ($val > $otherVal) $msg = "value is bigger than other value";
```

In order to execute another statement when the *expression* of the if statement evaluates to `FALSE`, the related statement can be specified after the `else` keyword:

```
if ($val > $otherVal) {
  $msg = "value is bigger than other value";
}
else {
  $msg = "other value is bigger than or equal to value";
}
```

The `else if` keyword can be used to write successive if statements, which should be evaluated only if the previous if statement is `FALSE`:

```
if ($val > $otherVal) {
  $msg = "value is bigger than other value";
}
else if ($val < $otherVal){
  $msg = "other value is bigger than value";
}
else {
  $msg = "value and other value are equal";
}
```

5.3.2 switch

```
switch (expr)
  case val1:
    statement
  case val2:
    statement
  ⋮
  default:
    statement
```

The switch statement can be used to compare the same *expression* with multiple values and evaluate the *statement* related to the value it equals to. It is like a series of if statements, but the *expression* used for the comparison is only evaluated once and it also allows other applications, such as branching and partial evaluation of the statements by using selective use of the `break` and `continue` keywords. More detailed information on the switch statement can be found in the PHP Manual.

```
switch ($val) {
case 1:
  $msg = "value is one";
  break;
case 2:
  $msg = "value is two";
  break;
default:
  $msg = "value is unknown";
  break;
}
```

5.4 Loops

Various loop statements are available for executing expressions and statements multiple times, altering some variables if it is necessary.

5.4.1 while

```
while (expr)
   statement
```

while executes the *statement* as long as the *expression* evaluates to `TRUE` at the beginning of each iteration. If the *expression* evaluates to `FALSE` at the very beginning, the *statement* is not executed at all. The following function returns the sum of the values between 1 and 9 (inclusive), which is 45.

```
while ($val < 10) {
  $sum += $val;
  $val++;
}
return $val;
```

5.4.2 do ... while

```
do
  statement
while (expr)
```

do … while is similar to while, but the *expression* is evaluated at the end of each iteration; hence, the *statement* is executed at least once. The following function is identical to the while function given previously:

```
do {
  $sum += $val;
  $val++;
} while ($val < 10);
return $val;
```

The loop below would run only once, because after the first iteration the *expression* evaluates to `FALSE`. Therefore the $sum will be equal to `$val`, which is 5. A similar while loop will leave `$sum` with no value, because the check will be done at the beginning.

```
$val = 5;
do {
    $sum += $val;
} while ($val > 10);
```

5.4.3 for

```
for (expr1; expr2; expr3)
  statement
```

The for loop is composed of three expressions and a statement. The *first expression* is evaluated at the very beginning, which is usually used to initialize the variables used in the loop. The *second expression* is evaluated at the beginning of each iteration. If it evaluates to `FALSE`, the loop is terminated. Otherwise, the *statement* is executed, which is followed by the evaluation of the *third expression* at the end of the iteration. The following function loops through the numbers 1 to 9 and returns the sum:

```
for ($val = 1; $val < 10; $val++) {
  $sum += $val;
}
return $sum;
```

Each *expression* can be left empty or contain multiple expressions separated by commas. If the *second expression* is empty, its value is considered as `TRUE`; hence, the loop continues infinitely.

5.4.4 foreach

```
foreach (array as $val)
  statement
```

```
foreach (array as $key => $val)
  statement
```

The foreach loop provides a simple mechanism to iterate over arrays, either providing value or key and value pair at each iteration evaluating the *statement* and advancing to the next item in the array until reaching the end of the array.

```
$list = [1, 3, 5, 7, 9];
foreach ($list as $val) {
  $sum += $val;
}
// Returns 25
return $sum;
```

```
$list = [1, 3, 5, 7, 9];
foreach ($list as $key => $val) {
  $sum += $key * $val;
}
// Returns 70
return $sum;
```

5.4.5 Nested Loops

Loops can be nested if required:

```
// First loop
for ($i = 1; $i < 10; $i++) {
  // Second loop
  for ($j = 1; $j < 10; $j++) {
    $sum += $i * $j;
  }
}
// Returns 2025
return $sum;
```

5.4.6 Controlling Loops

Execution of a loop can be terminated by using the `break` keyword. The following infinite loop terminates when the sum exceeds 100:

```
for ($num = 1; ; $num++) {
  $sum += $num;
  if ($sum > 100) break;
}
return $sum;
```

If more than one loop should be terminated within nested loops, a numeric argument can be specified to indicate the number of loops to be terminated. The following infinite loop terminates when the sum exceeds 1,000:

```
for ($i = 1; $i < 10; $i++) {
  for ($j = 1; $j < 10; $j++) {
    $sum += $i * $j;
    if ($sum > 1000) break 2;
  }
}
return $sum;
```

In the above example, use of the `break` keyword without `2` will only break the nested loop. Hence, the outside loop will continue to iterate although the sum is greater than 1,000, which is not the intended behaviour.

In order to skip to the next iteration without terminating the loop, but only skipping the execution of the rest of the statements in the loop, the `continue` keyword can be utilized. Similar to `break`, the number of loops to be skipped can be indicated. The following function returns the sum of a range of numbers, except the even values:

```
for ($num = 1; $num < 20; $num++) {
  if ($num % 2 == 0) continue;
  $sum += $num;
}
return $sum;
```

5.5 Functions

```
function name(arguments) {
   statement
}
```

Functions allow performing repetitive tasks or calculations, which are based on values of some variables. In RAPID-N, each estimation function is itself a function, which is dynamically generated on demand by the data estimation framework. Following the distributed and atomic logic of the framework, it is good practice to define a custom estimator whenever there is a need for a computation function to perform a specific computation. However, in some cases it might be necessary to perform repetitive calculations inside an estimation function (e.g. root finding, matrix operations, time-dependant analysis, etc.) which cannot be done by simple looping statements. For such cases, it is possible to define a custom function using the function syntax.

Information is passed to functions via the argument list (i.e. *arguments*), which is a comma-delimited list of expressions. The arguments are evaluated from left to right and by default passed by value. Variable-length argument lists, default argument values, and passing arguments by reference are also supported by PHP, details of which can be found in the PHP Manual.

Functions may contain any valid code statements, including control structures, loops, and nested functions. Function names follow the same rules as variables, but they are not case sensitive. Therefore, `foo()` and `Foo()` refer to the same function.

Remark. Function overloading

Function overloading is not supported, i.e. it is not possible to redefine previously declared functions. Hence, it is necessary to choose a unique name for a custom function. As good practice, it is suggested to name custom functions starting with an underscore (_) and the name of the property that is estimated, followed by a unique name specific to the estimator (e.g. `_volumeIterate`).

Similar to the embracing estimation function, the result of the custom function can be returned by the `return` keyword. An example estimator with a custom function is given below, which calculates the sum of squares of number between 1 and 10 (exclusive):

```
function _square($val) {
  return $val * $val;
}
for ($num = 1; $num < 10; $num++) {
  $sum += _square($num);
}
return $sum;
```

Remark. Recursive functions

It is possible to call functions recursively. But calls with over 100-200 recursion levels should be avoided as it can crash the stack and cause a termination of the data estimation framework.

5.6 Example Estimation Functions

Example estimation functions, illustrating the syntax and the features of the programming language, as extended by the data estimation framework are given below:

Function 1. Endpoint distance for confined vapour cloud explosion (Multi-energy model)

```
// Calculate energy of blast (3.5 Mj/m3 = average for most hydrocarbons)
$E = [VCVo:m3] * 3.5e6;
// Calculate scaled pressure
$Ps1 = [ePd:Pa] / [PA:Pa];
// Calculate scaled distance (for class 10)
$r1 = max(0.4096 * pow($Ps1, -0.859), 0.6829 * pow($Ps1, -0.414));
// Calculate explosion radius
$r = $r1 * pow($E / [PA:Pa], 1/3);
// Return distance in m
return $r;
```

Function 2. Storage height from storage volume and diameter for spherical plant units

```
// Return zero if stored volume is zero
if (\Scientific::equals([VST:m3], 0)) return 0.0;
// Return unit height if stored volume equals unit volume
if (\Scientific::equals([VST:m3], [V:m3])) return [D:m];
// Solve by Newton's rule
$x = [D:m] / 2;
while (TRUE) {
  $y = M_PI * $x * $x * ([D:m] / 2 - $x / 3) - [VST:m3];
  if (\Scientific::equals($y, 0)) return $x;
  $x = $x - $y / (M_PI * $x * ([D:m] - $x));
}
```

Function 3. Flame tilt angle from Froude and Reynolds numbers (TNO method)

```
// Kinematic viscosity of air (m2/s, at 300K)
$v = 1.568e-5;
// Froude number
$Fr = pow([u:m/s], 2) / (9.80665 * [DP:m]);
// Reynolds number
$Re = [u:m/s] * [DP:m] / $v;
// tan(theta) / cos(theta)
$c = 2/3 * pow($Fr, 1/3) * pow($Re, 0.117);
// Theta (rad)
$theta = asin((pow(4 * pow($c, 2) + 1, 0.5) - 1) / (2 * $c));
// Return tilt angle in degrees
return rad2deg($theta);
```

6 Tutorials

In order to demonstrate 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 (i.e. natural hazard event, industrial plants, and plant units) and 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 involving the step, but they are also usually repeated in the subsequent tutorials so that each tutorial can be used separately. Still, it is suggested to follow the tutorials in the given order.

6.1 Creating Natural Hazard Data

RAPID-N provides an extensive 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 into 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 the home or personal pages, or the bottom directory available at each 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. You can also use the following link: http://rapidn.jrc.ec.europa.eu/hazard/create.

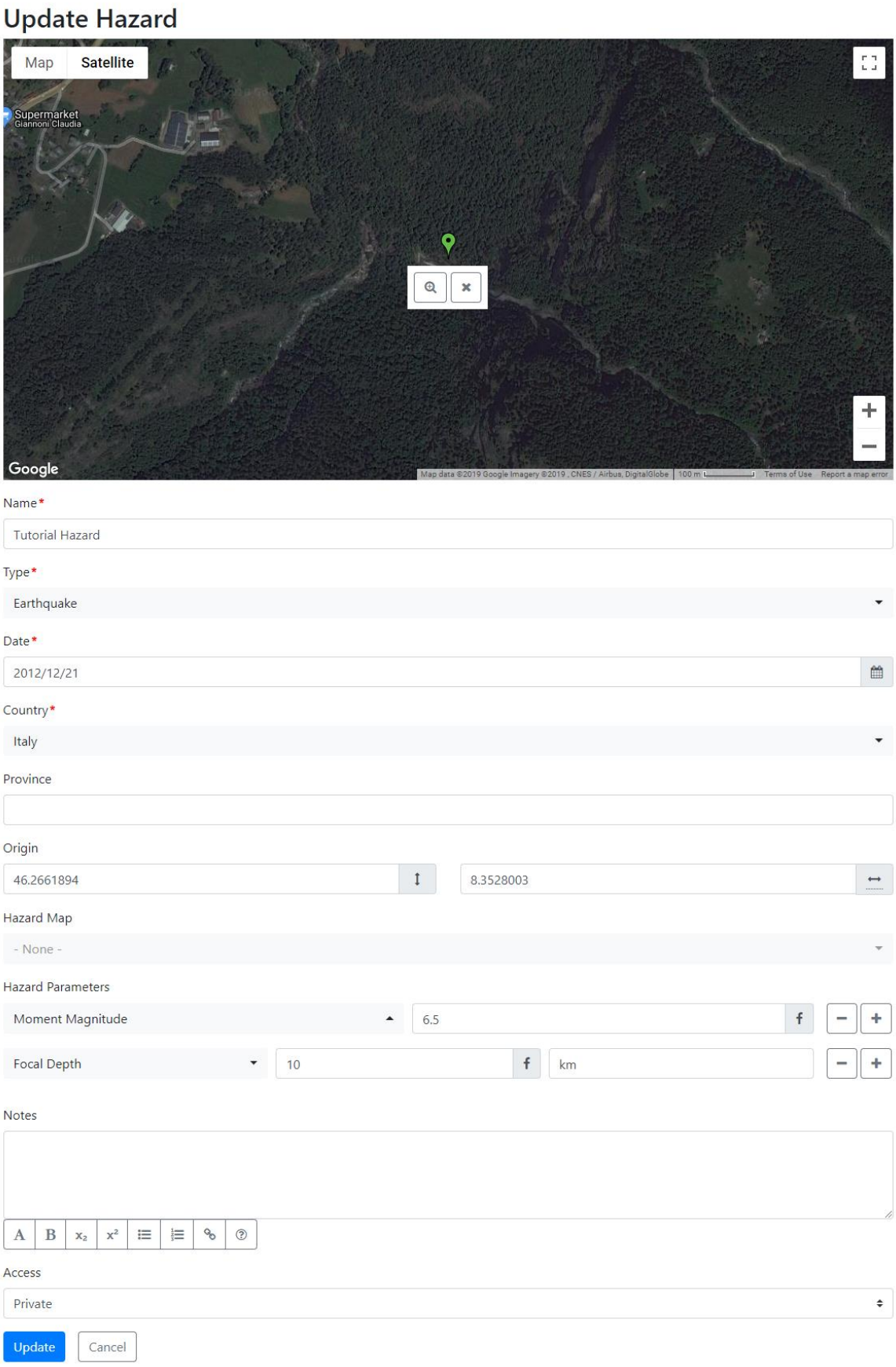
Remark. Access to the "Create Hazard" page

Because only registered users are allowed to create new records, the "Create" button and the "Create Hazard" page are only available if you sign-in to the system. See User Access and Data Access sections for more details.

The natural hazard data entry form is composed of a map from which you can set the geographic location and extent of the natural hazard event, and a series of input elements through which you can enter natural hazard event data.

Detailed information on hazard records is given in the Hazards section. An example data entry form is given in Figure 32, 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.

Figure 32. Natural hazard data entry form of the tutorial hazard



Source: JRC, 2018

For the tutorial, please follow the following 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 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 to 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 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 utilized by the system for the calculation of on-site hazard parameters as indicated in the Hazards section. 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. has not been created), there are no hazard maps available; hence, the list is empty. Select "None".
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 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 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 for the 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 entry input, 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 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. To quickly access the listing page, you can use the following link: http://rapidn.jrc.ec.europa.eu/property/list.

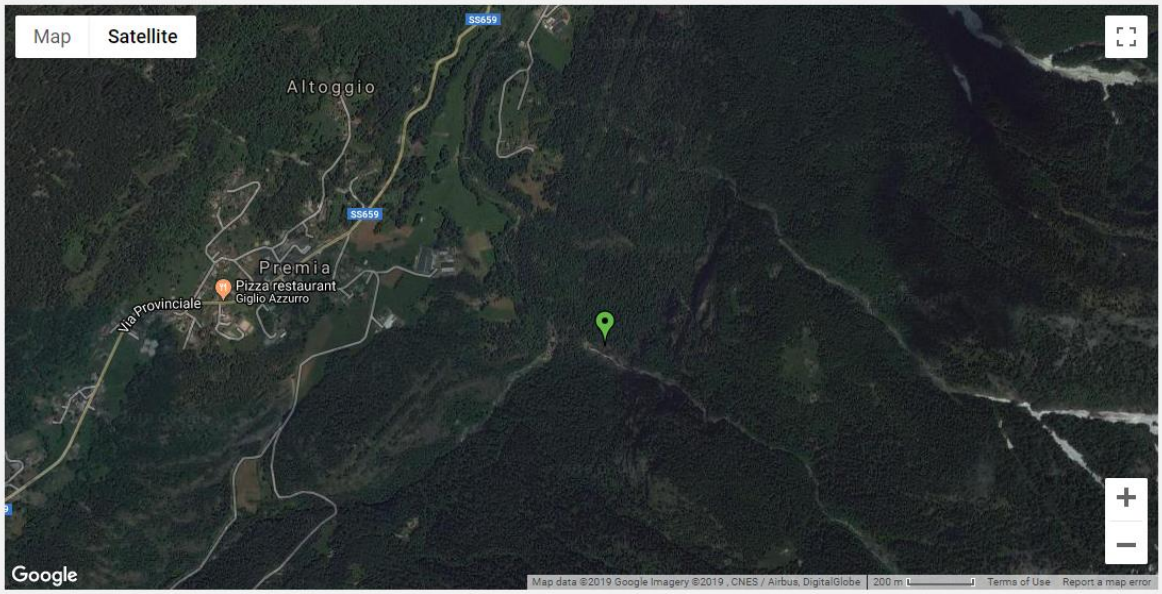
9. You can specify some notes or remarks about the natural hazard event by using the *Notes* wiki input field. See the Wiki Input section for more details on wiki inputs, which support formatted output, including emphasis, subscript, superscript, sorted and unsorted lists, and links. For this tutorial, 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 available only to you. See the Data Access section for a detailed description of the available states 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 analyses. The page should be similar to the one given in Figure 33.

Besides the data that you entered, you will also see additional data related to the event that is obtained by the system automatically by using the data estimation framework. The estimated data is shown together with the user-defined data, but highlighted in red (Figure 33). By hovering the mouse pointer over the estimated value you can see how the data was estimated (i.e. which property estimator is utilized). Also by clicking on the value, you can access to the Property Estimator information page of the associated estimator which provides detailed data on the estimation method. See the Data Estimation Framework section for more details on the data estimation capabilities of RAPID-N.

Figure 33. Natural hazard information page of the tutorial hazard

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

Update Delete

Source: JRC, 2018

6.2 Creating Industrial Plant and Plant Unit Data

RAPID-N requires data on the hazardous installations to analyse the Natech risk. This includes information related to the hazardous materials and the plant units. Thus, it is necessary to define case-specific industrial data. 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.

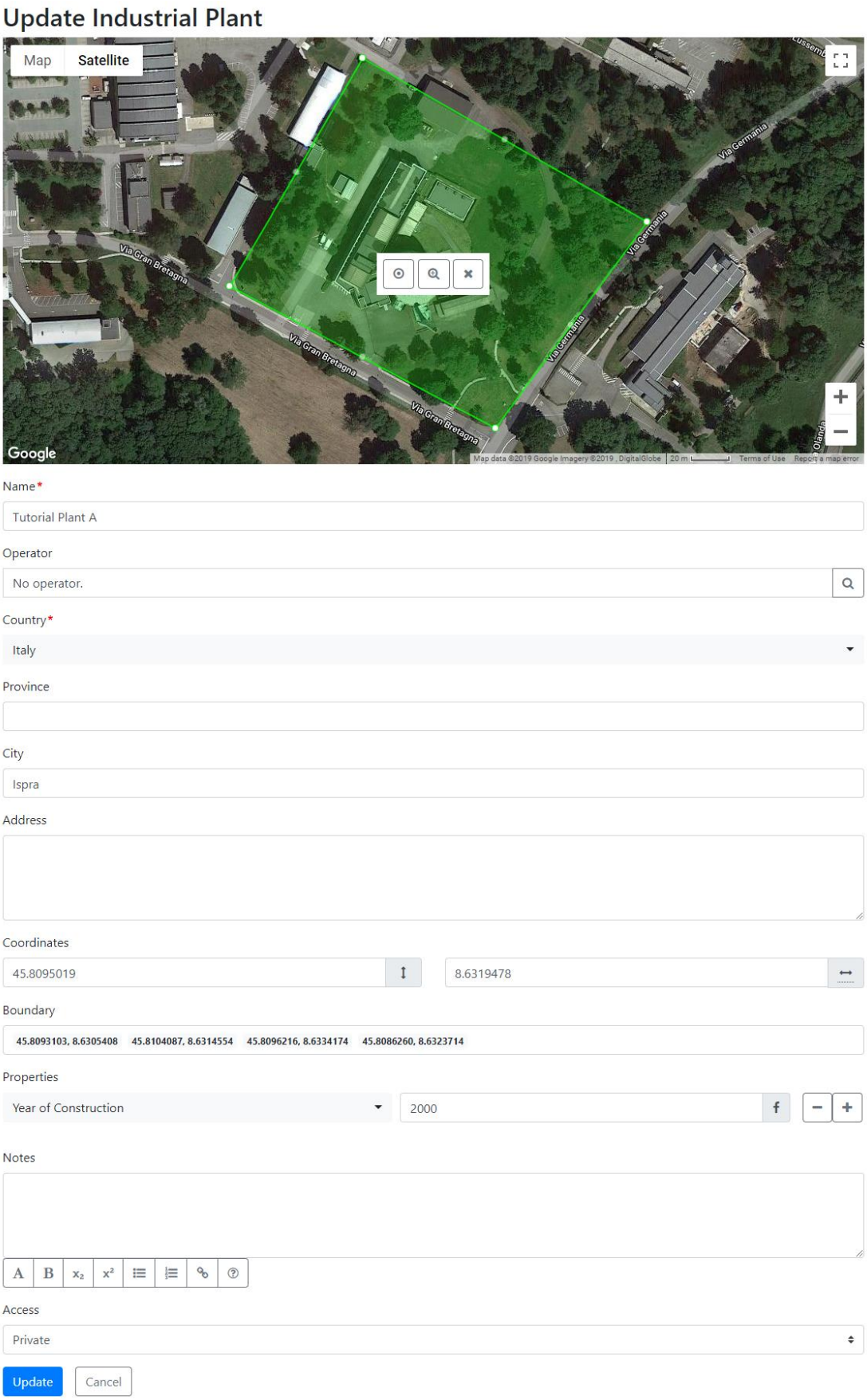
6.2.1 Industrial Plant

The Industrial Plants listing page, which is accessible through the home or personal pages, or is available 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. You can also use the following link: http://rapidn.jrc.ec.europa.eu/plant/create.

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 industrial plant, and a series of input elements through which you can enter industrial plant data.

Detailed information industrial plant records is given in the Industrial Plants section. An example industrial plant data entry form is given in Figure 34, 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.

Figure 34. Industrial plant data entry form of the tutorial plant



Source: JRC, 2018

For the tutorial, please 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 "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 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 mirrors the polygon on Figure 34. See the Mapping section 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 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 entry input 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. To quickly access the listing page, you can use the following link: http://rapidn.jrc.ec.europa.eu/property/list.

9. You can specify some notes or remarks about the industrial plant by using the *Notes* wiki input field. See the Wiki Input section for more details on wiki inputs, which support formatted output, including emphasis, subscript, superscript, sorted and unsorted lists, and links. 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 given in Figure 35.

Besides the data that you entered, you will also see additional data related to the event that is obtained by the system automatically by using the data estimation framework. The estimated data is shown together with the user-defined data, but highlighted in red (Figure 35). By hovering the mouse pointer over the estimated value you can see how the data was estimated (i.e. which property estimator is utilized). 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 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 plant units 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 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 35. Industrial plant information page of the tutorial plant

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

Source: JRC, 2018

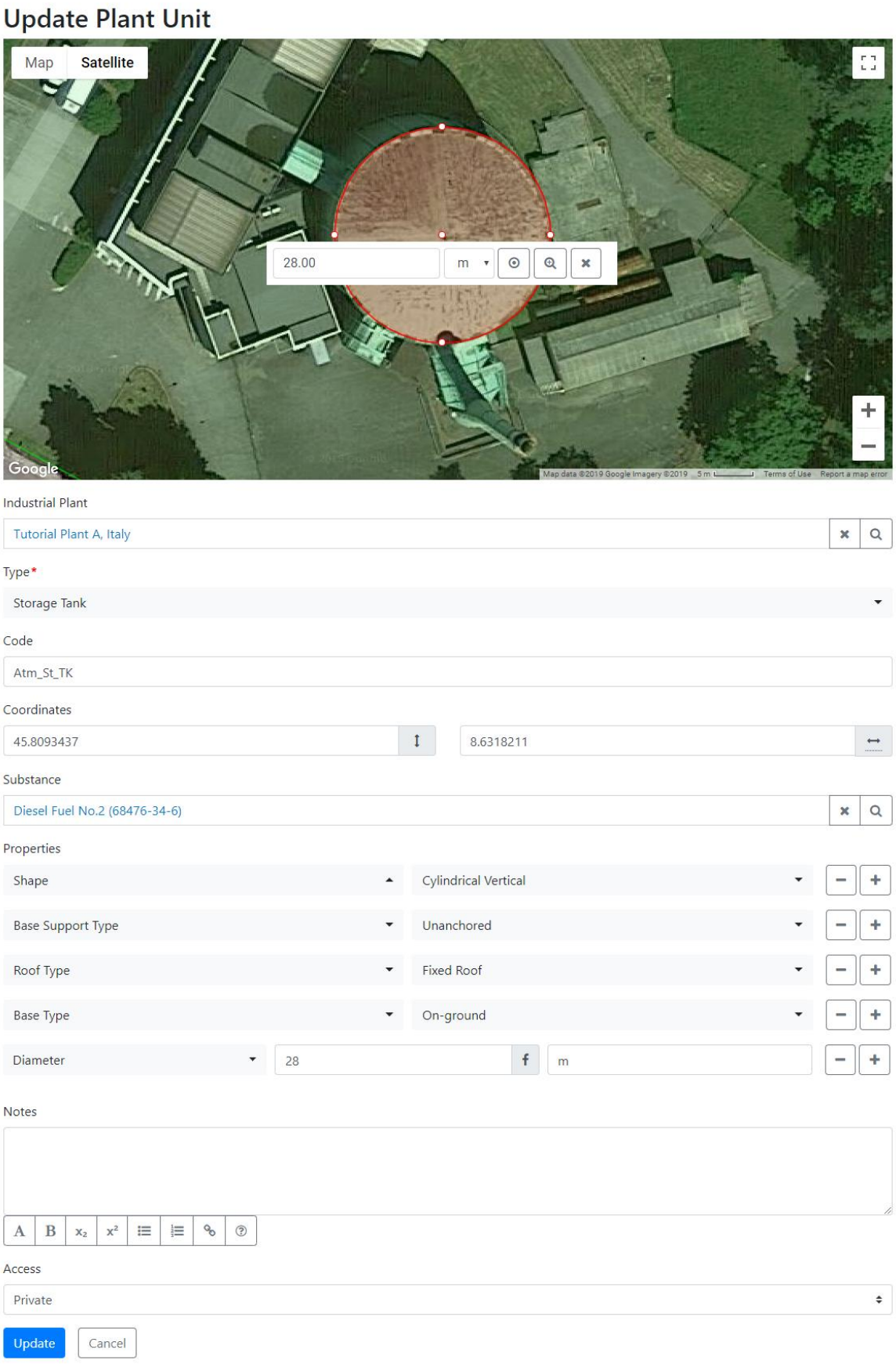
6.2.2 Plant Units

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. 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 industrial plant of the unit will be set automatically.

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. An example plant unit data entry form is given in Figure 36, 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 be in a similar state; therefore, you can use the figure to check and validate your data entry steps.

Figure 36. Plant unit data entry form of the tutorial plant unit



Source: JRC, 2018

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, please 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 at 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 for a detailed description on how to edit features on the map.
4. The substance can be indicated by pressing "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 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 characteristic parameters 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 for the details of property data entry.

   For this unit, you will add five properties:

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

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

> **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. To quickly access the listing page, you can use the following link: http://rapidn.jrc.ec.europa.eu/property/list.

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 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. See the Wiki Input section for more details on wiki inputs, which support formatted output, including emphasis, subscript, superscript, sorted and unsorted lists, and links. 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. For the time being, the table contains only one record row, which describes the plant unit you just created.

For the data entry of the second unit, please 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 "Select" button in the *Substance* input field, to open the Substances listing page. Because 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 entry input 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 entry input (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 describes the plant units you created in the tutorial.

The map view of the plant should also display the two units as shown in Figure 37.

Figure 37. Map of the tutorial plant and plant units

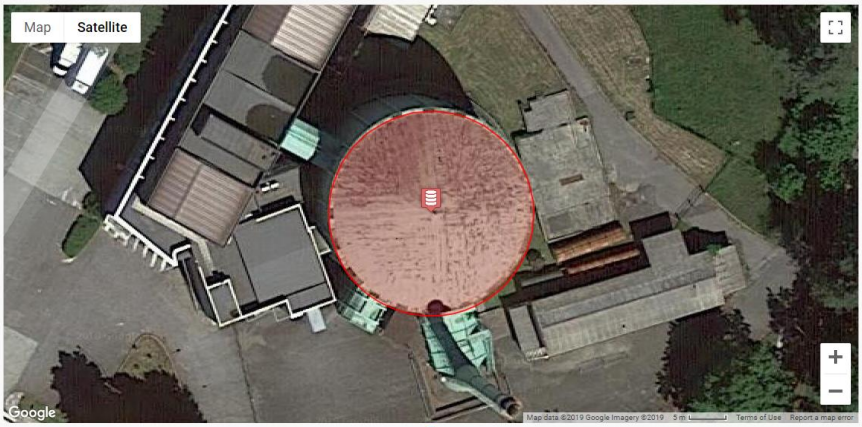


Source: JRC, 2018

If you click on one of the two plant units listed, the system will open the Plant Unit page, which will display the detailed record information and provide access to associated actions, such as updating or deleting of the record, or creating related records.

Besides the data that you entered, you will also see additional data related to the selected plant unit that is obtained by the system automatically by using the data estimation framework. The estimated data is shown together with the user-defined data, but highlighted in red (Figure 38). By hovering the mouse pointer over the estimated value you can see how the data was estimated (i.e. which property estimator is utilized). 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 for more details on the data estimation capabilities of the system. The map shows the industrial plant unit location and shape in red.

Figure 38. Plant unit information page of the tutorial 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)
Shell Thickness	6 mm
Bottom Shell Thickness	6 mm
Roof Shell Thickness	5 mm
Shape	Cylindrical Vertical
Volume	8312.7 m^3
Height	13.5 m
Diameter	28 m
Radius	14 m
H/D Ratio	0.4821 m/m
Boundary Distance	14 m
Obstruction Class	Obstructed
Status	Operational
Tank Weight	108408 kg
Shell Density	7800 kg/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
Fill Height	11.475 m
Stored Volume	7065.8 m^3
Stored Quantity	6429838 kg
Equivalent Dike Diameter	72.746 m
Equivalent Dike Length	64.47 m
Enclosure	Dike
Dike Depth	2 m
Dike Area	4156.3 m^2
Effective Dike Area	4156.3 m^2
Dike Volume	8312.7 m^3
Effective Dike Volume	8312.7 m^3
Passive Release Mitigation Factor	1
Active Release Mitigation Factor	1

Source: JRC, 2018

6.3 Single Plant Natech Risk Analysis

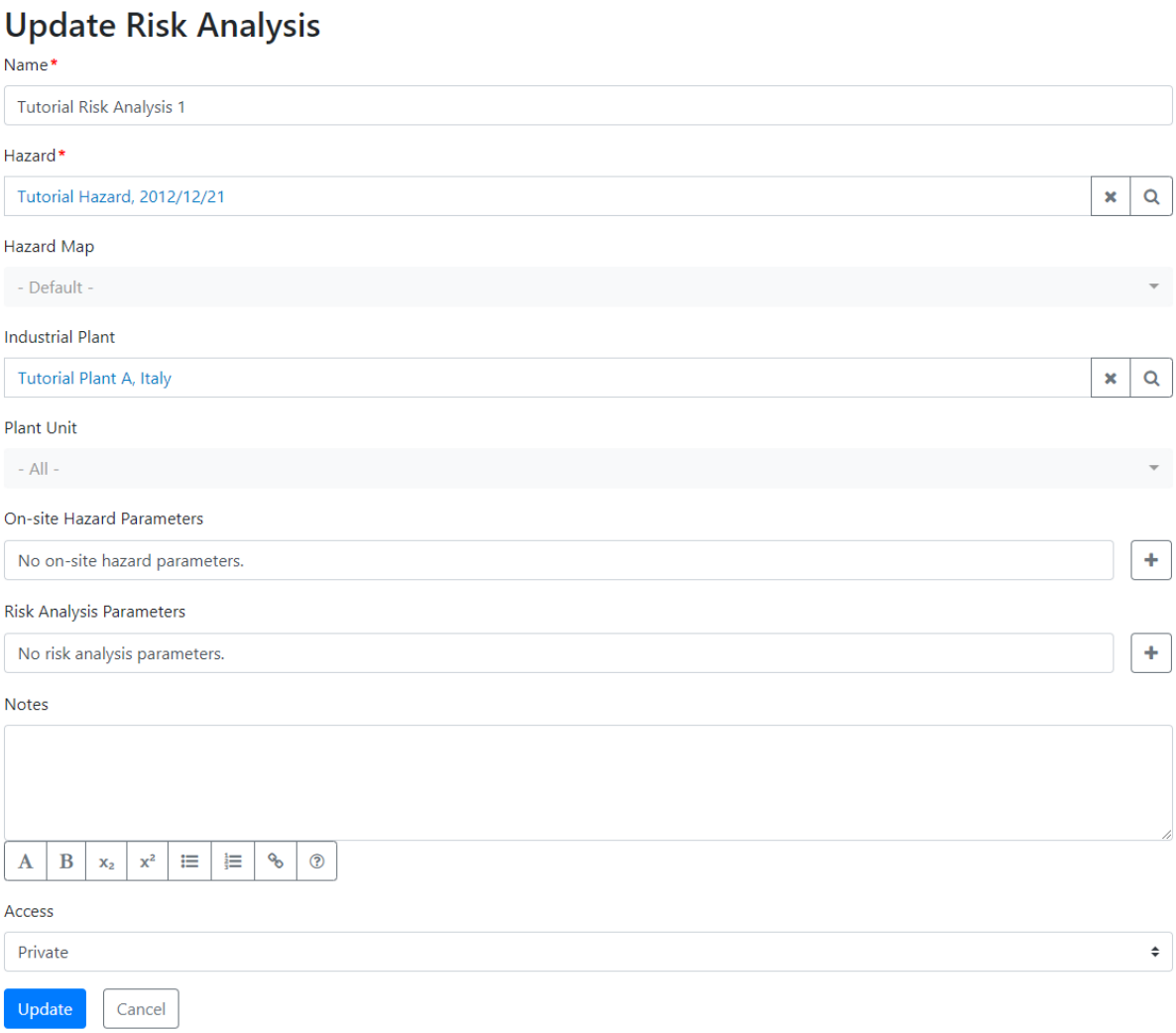
A risk analysis study involving a single plant can be a useful tool for plant operators and engineering companies to identify Natech hazards and quantify Natech risks. It can be also useful for public authorities that want to investigate the Natech risks of a hazardous installation in their territory.

In this tutorial, you will learn the basics of Natech risk analysis by using RAPID-N and following a step-by-step guided procedure. All the resources needed for this exercise are publicly available in RAPID-N and are composed of a fictional natural hazard event named "Tutorial Hazard", which is created in the first tutorial, and a fictional industrial plant named "Tutorial Plant A", which is created in the second tutorial. Completed risk analysis is also available publicly as "Tutorial Risk Analysis 1". You can find detailed information on the risk analysis methodology of RAPID-N in the Risk Analysis Methodology section.

6.3.1 Data Entry

The risk analysis data entry form is composed of a series of input elements through which you can enter risk analysis information and setup risk analysis parameters. Detailed information on risk analysis records is given in the Risk Analyses section. An example data entry form is given in Figure 39.

Figure 39. Risk analysis data entry form of the tutorial risk analysis



Source: JRC, 2018

For the data entry and analysis, please follow the following steps:

1. From the home or personal pages, click on the "Risk Analyses" icon to access the Risk Analyses listing page. You can also use the following link to access the listing page directly: http://rapidn.jrc.ec.europa.eu/risk_analysis/list.
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 we will use the name "Tutorial Risk Analysis 1".
4. 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 from the *Hazard Maps* drop-down list, which will provide pre-calculated on-site hazard parameters for the analysis. If set 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 utilizing the data estimation framework.

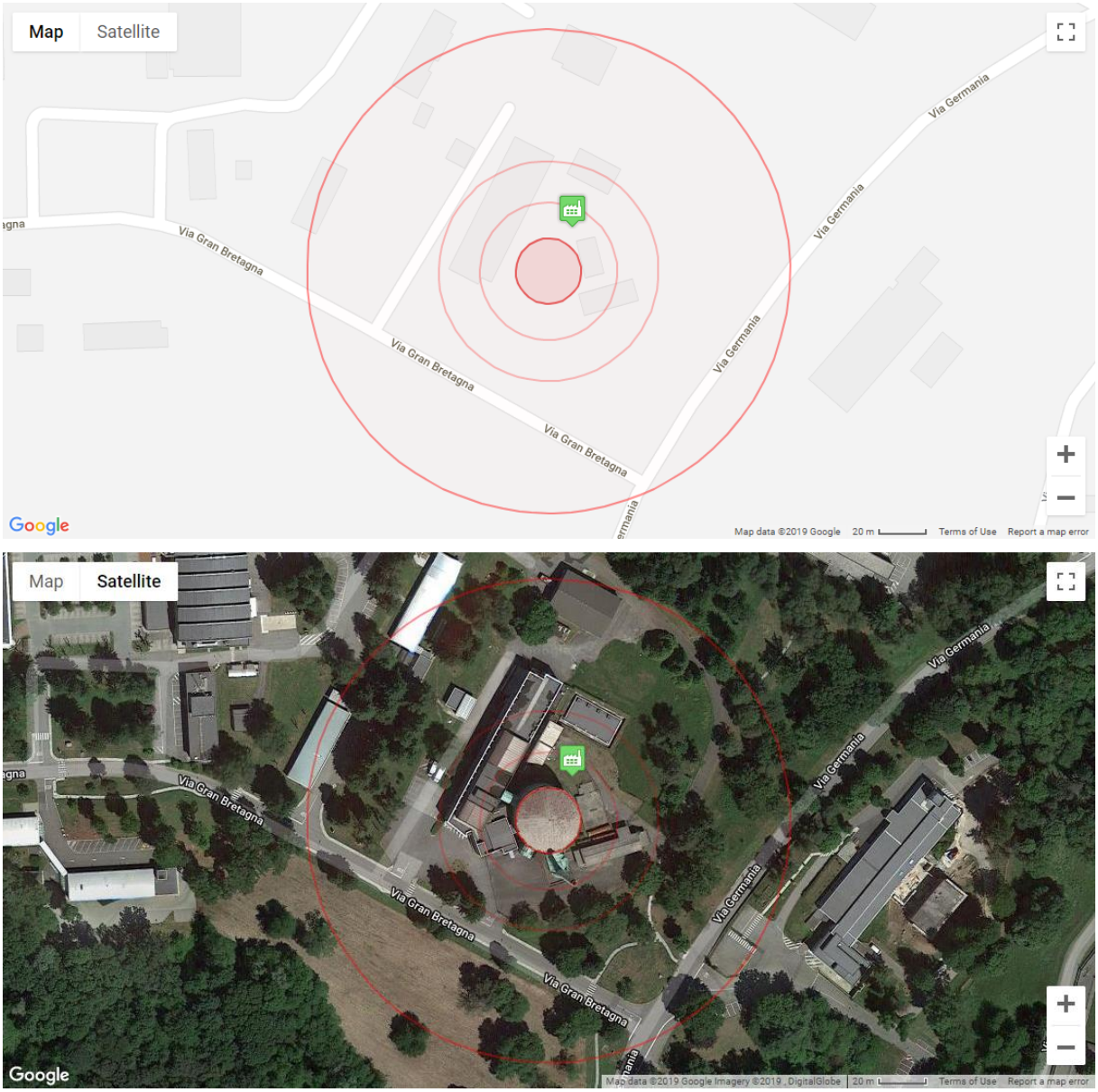
6. You can choose a specific industrial plant for the analysis or let RAPID-N identify and consider all the plants located in the natural hazard area. For this tutorial, you must select a case-study plant. Click on the "Select" button in the *Industrial Plant* input to open the Industrial Plants listing page. Search for the industrial plant named "Tutorial Plant A" and select it from the list by clicking its name.
7. The Create Risk Analysis page should look like the Figure 39 above after the hazard and the industrial plant are selected. 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 plant, or 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* input. For this tutorial, do not add any on-site hazard parameters.
10. You can specify *Risk Analysis Parameters*, which allow you to customize the risk analysis process. 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.

6.3.2 Results

The Tutorial Plant A is a simple plant, which is composed of only two units: an unanchored atmospheric storage tank and a stack identified as "Atm_St_TK" and "Stk" respectively (Figure 37). The analysis results are shown on the reference map and on the satellite image in Figure 40, whereas Figure 41 represents the same results in the detailed tabular form. For simplicity, the detailed consequence analysis results are shown in the table only for DS2.

Figure 40. Risk analysis map



Source: JRC, 2018

Figure 41. Risk analysis results

Name	Tutorial Risk Analysis 1
Date	2018/12/04 18:46:38
Hazard	Tutorial Hazard, 2012/12/21
Industrial Plant	Tutorial Plant A, Italy
Plant Unit	All
Cut-off Distance	200 km
Enable Hazard Maps	Yes
Enable Private Estimators	No
Enable Typical Plant Units	Yes
Access	Private

1. Tutorial Plant A, Italy

No	Plant Unit	Hazard Analysis	Damage Analysis	Consequence Analysis
1.	Storage Tank (Atm_St_TK) Diesel Fuel No.2, Q_{stored}: 6429838 kg; V: 8312.7 m^3; $f_{m,\ active}$: 1 ; A_{base}: 615.75 m^2; Base Support Type: Unanchored; Base Type: On-ground; $t_{k,b}$: 6 mm; d_b: 14 m; Construction Material: Steel; d: 28 m; A_{dike}: 4156.3 m^2; h_{dike}: 2 m; V_{dike}: 8312.7 m^3; A_{dike}^0: 4156.3 m^2; V_{dike}^0: 8312.7 m^3; Enclosure: Dike; D_{dike}: 72.746 m; $l_{dike,\ eq.}$: 64.47 m; h_{fill}: 11.475 m; Fill Percent: 85 %v; P_g: 0 atm; φ_{hd}: 0.4821 m/m; h: 13.5 m; Obstruction Class: Obstructed; $f_{m,\ passive}$: 1 ; r: 14 m; A_{roof}: 615.75 m^2; $t_{k,r}$: 5 mm; Roof Type: Fixed Roof; Shape: Cylindrical Vertical; ρ_{shell}: 7800 kg/m^3; t_k: 6 mm; Status: Operational; $Q_{storage}$: 7564515 kg; Storage Condition: Atmospheric; $h_{storage}$: 13.5 m; $P_{storage}$: 1 atm; Storage State: Liquid; $T_{storage}$: 25°C; $V_{storage}$: 8312.7 m^3; V_{stored}: 7065.8 m^3; w_{tank}: 108408 kg «	PGA: 0.1044 g; d_e: 55.238 km; PGA_h: 1147.3 m/s^2; d_h: 56.136 km «	DS1: P(0.6745)	Consequence: No Consequence; Fire/Explosion Event: No Fire; d_e: 0 m »
			DS2: P(0.3125)	Fire/Explosion Event: Pool Fire; $V_{released}$: 0.5651 m^3; d_e: 15.363 m; P_{natech}: $9.376 \cdot 10^{-5}$; τ_a: 1 ; u_c: 1.5591 m/s; q_c: 3.0484 kg/s; $P_{c,\ ignition}$: 0.1%; $P_{c,\ release}$: 30%; $d_{consequence}$: 16.965 m; P_{damage}: 0.3125 ; C_d: 0.8; c_d: 1.8; t_{exp}: 40 s; Δp: 1 psi; q_R: 5000 W/m^2; l_{pool}: 7.5176 m; f_{yield}: 0.1 ; $h_{fill,\ hole}$: 11.475 m; h_{flame}: 13.745 m; S_{flame}: Cylindrical; ζ_{soot}: 0.6387 ; Θ: 37.833°; Q_{fuel}: 514.27 kg; A_{hole}: 0.7854 cm^2; d_{hole}: 10 mm; h_{hole}: 0 m; $P_{ignition}$: 0.009376%; $t_{ignition}$: 10 min; LOC State: Minor; $t_{release,\ max}$: 6 h; SEP_{max}: 129.78 kW/m^2; $h_{pool,\ min}$: 1 cm; A_{pool}: 56.514 m^2; h_{pool}: 0.01 m; d_{pool}: 8.4826 m; R: 0.4 ; $t_{release}$: 10 min; $P_{release}$: 9.3765%; $q_{release}$: 113.38 lb/min; Release State: Liquid; $T_{release}$: 25°C; $Q_{released}$: 514.27 kg; $f_{Q,\ released}$: 0.007998%; $f_{V,\ released}$: 1 %v; $Q_{stored,\ hole}$: 6429838 kg; $V_{stored,\ hole}$: 7065.8 m^3; SEP: 59.668 kW/m^2; D_T: 342 TDU «
			DS3: P(0.01108)	Fire/Explosion Event: Pool Fire; $V_{released}$: 3.5321 m^3; d_e: 32.988 m; P_{natech}: $5.539 \cdot 10^{-6}$ »
			DS4: P(0.000424)	Fire/Explosion Event: Pool Fire; $V_{released}$: 169.54 m^3; d_e: 89.293 m; P_{natech}: $3.392 \cdot 10^{-7}$ »
			DS5: P(0.001433)	Fire/Explosion Event: Pool Fire; $V_{released}$: 7065.8 m^3; d_e: 89.293 m; P_{natech}: $1.433 \cdot 10^{-6}$ »
2.	Stack (Stk) V: 137.44 m^3 »	PGA: 0.1044 g »	DS1: P(0.9976)	Consequence: No Substance »
			DS4: P(0.002392)	Consequence: No Substance »

Source: JRC, 2018

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. The intensity is the same for both units, because they are located next to each other. For units scattered around a large facility, the results might be different.

Damage assessment

RAPID-N chose a fragility curve for each unit 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).

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. 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 rare.

Consequences

The gravity 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. 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. In case the fuel spill ignites, the resulting fire can affect humans as far as 15.4 m away in case of minor damage and as far as 89 m away in case of complete damage. Damage classes "Extensive" and "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.

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. However, there were cases in the past which involved secondary damage to plant units due to impact of collapsed stacks (Girgin, 2011). Hence, such non-hazardous units might be included into domino scenarios, especially if the damage probability is high.

6.4 Single Plant Natech Risk Analysis with Custom Parameters

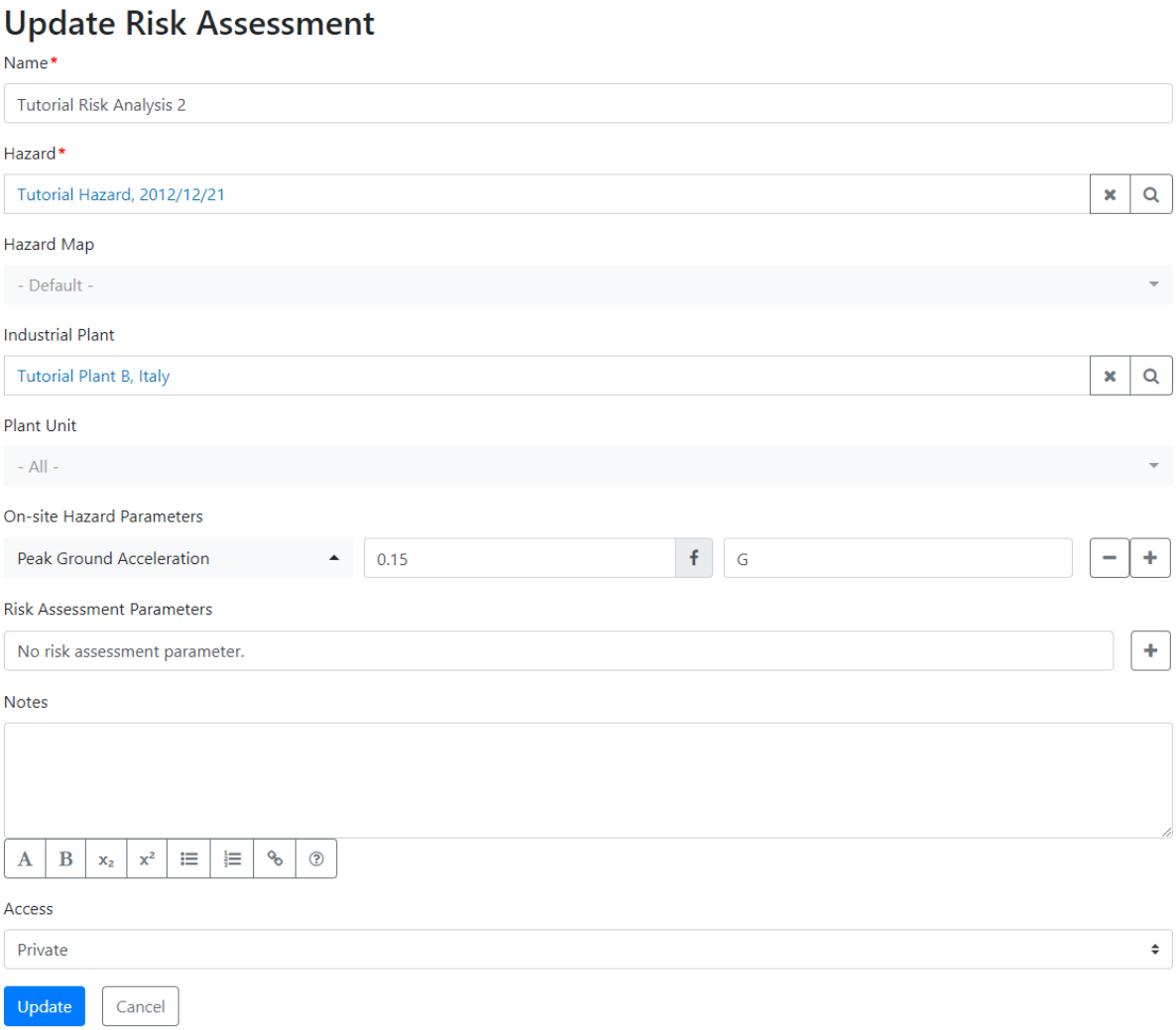
In the previous tutorial, on-site hazard intensity parameters were estimated automatically by RAPID-N by using available property estimators, which correspond to ground motion prediction equations (GMPE) for earthquakes. However, these parameters can also be specified manually for the analysis. This tutorial will demonstrate how to customize natural-hazard related data. A custom Peak Ground Acceleration (PGA) value of 0.15 g will be used for this purpose.

All the resources needed for this exercise are publicly available in RAPID-N and are composed of a fictional hazard named "Tutorial Hazard", which was created in the first tutorial, and a fictional industrial plant named "Tutorial Plant B". Completed risk analysis is also available publicly as "Tutorial Risk Analysis 2". You can find detailed information on the risk analysis methodology of RAPID-N in the Risk Analysis Methodology section.

6.4.1 Data Entry

Steps 1-8 are similar to the previous tutorial. Please read the previous tutorial before this one to obtain more detailed information. Detailed information on risk analysis records is given in the Risk Analyses section. At the end of the data entry, the risk analysis data entry form should be similar to Figure 42.

Figure 42. Risk analysis data entry form with custom hazard data



Source: JRC, 2018

For the data entry and analysis, please follow the following steps:

1. From the 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, we will use "Tutorial Risk Analysis 2".
4. Select the natural hazard scenario by clicking on "Select" button of 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 utilize 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. Select industrial plant named "Tutorial Plant B" by clicking on the "Select" button of the *Industrial Plant* input, performing a search by name, and clicking the name of the plant on the table listing the search results.
7. At this point, you can click on their names of the hazard and the industrial plant selected in the *Hazard* and *Industrial Plant* inputs to access corresponding information pages, which provide detailed information.
8. By using the *Plant Unit* drop-down list, you can choose whether the analysis should consider all plant units located at the plant, or 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* input. For this tutorial, click on the "Add" button in *On-site Hazard Parameters* input. Select the property "Peak Ground Acceleration" from the property drop-down list. Type "0.15" in the value field and "G" in the unit field.
10. You can specify risk analysis parameters, which allow you to customize the risk analysis calculations. For this tutorial, leave the *Risk Analysis Parameters* input empty.
11. Click on the "Create" button to save the risk analysis record and perform the analysis.

6.4.2 Results

The Tutorial Plant B is a more complex plant compared to the Tutorial Plant A. It is divided into four areas as shown in Figure 43.

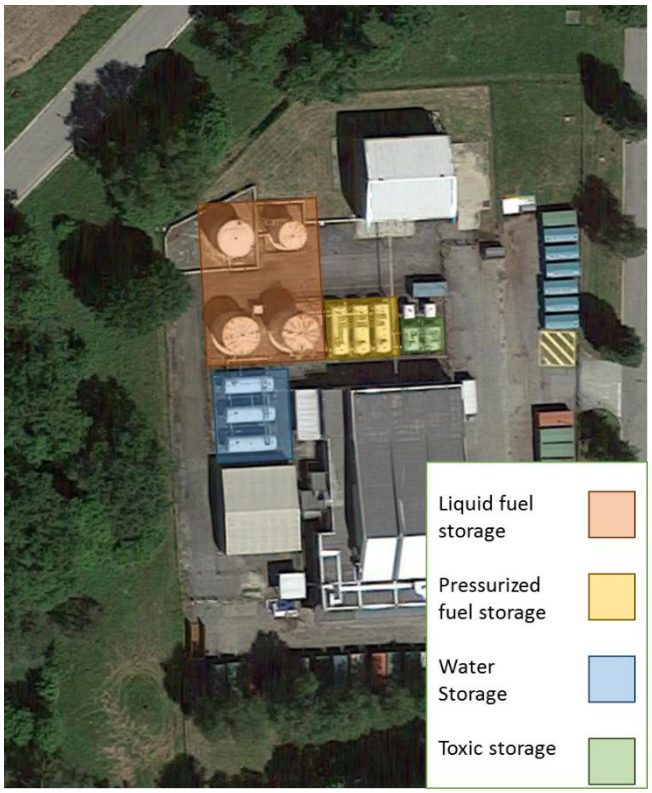
The *liquid fuel storage area* includes four cylindrical vertical atmospheric storage tanks containing flammable liquids. Two of the storage tanks contain gasoline and are anchored, while the other two contain diesel and are unanchored. For each couple, one of the storage tanks is filled to the 45% of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

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

The *water storage area* contains three horizontal cylindrical tanks with water at atmospheric pressure, one of which lies directly on the ground and the other two are 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, the other tank contains chlorine and lies on the ground.

Figure 43. Tutorial plant units



Source: JRC, 2018

A summary of the plant units that contains their descriptions is provided in Figure 44.

Figure 44. 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

Source: JRC, 2018

For each unit, the same considerations as described in the previous tutorial apply. However, the results are different due to different physical, operational, and hazardous characteristics of the units. Since the impact areas are significantly different, some specific results will be commented for each area separately.

Figure 45 reports the 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 on their support type (i.e. anchored or unanchored). For the two tanks with filling level at 45%, RAPID-N selected the same fragility curve, this means that their damage and Natech probabilities will be identical. 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.

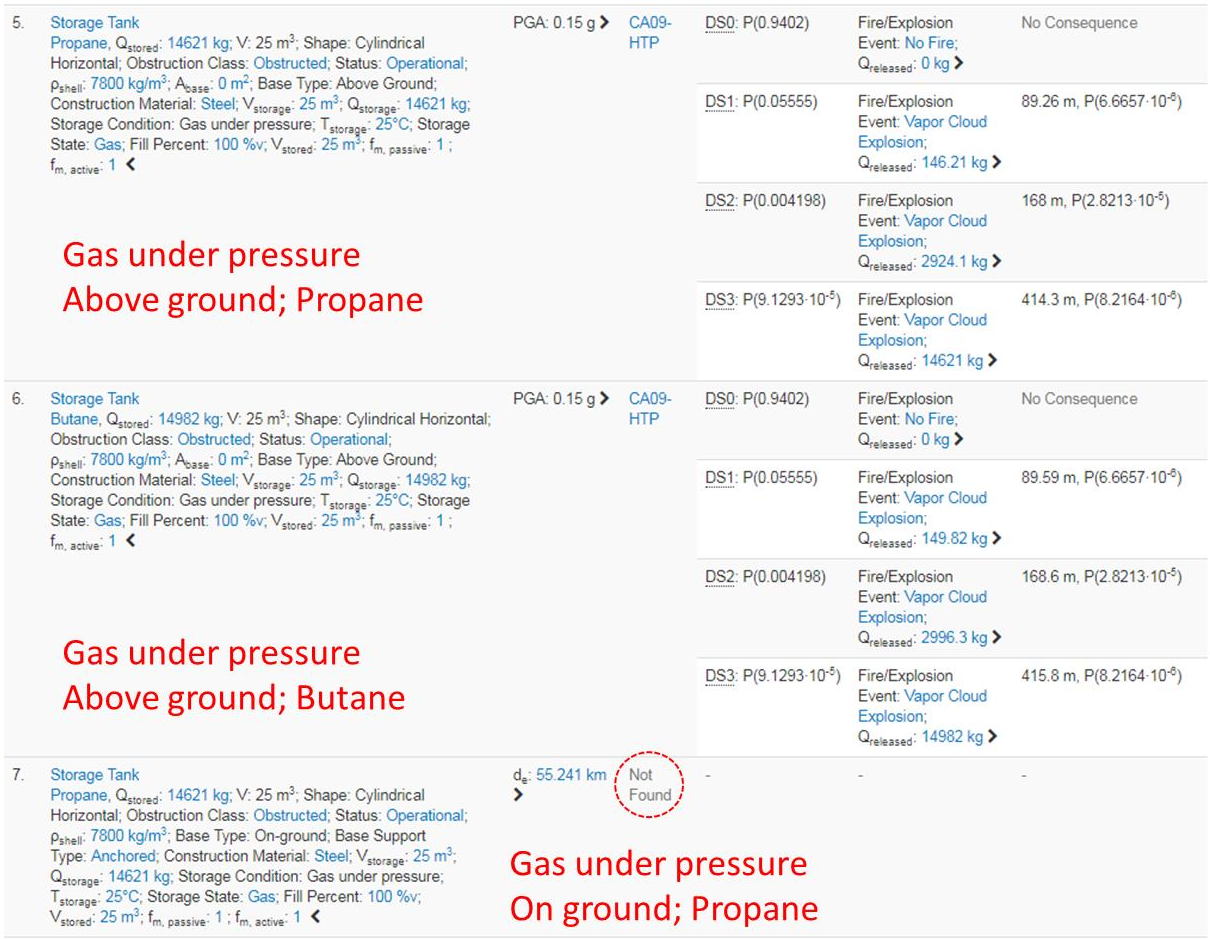
Figure 45. Results of the analysis for atmospheric storage tanks

No	Plant Unit	Hazard Parameters	Fragility Curve	Damage Estimate	Scenario Parameters	End-point Distance
1.	Storage Tank Gasoline, Q_{stored}: 115244 kg >	PGA: 0.15 g >	ALA-L50	DS1: P(0.9502)	Fire/Explosion Event: No Fire; $Q_{released}$: 0 kg >	No Consequence
				DS2: P(0.0498)	Fire/Explosion Event: Pool Fire; $Q_{released}$: 241.45 kg >	12.2 m, P(0.0001494)
				DS3: P(0*)	Fire/Explosion Event: Pool Fire; $Q_{released}$: 1509.1 kg >	No Consequence
	Anchored 45% fill			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 >	PGA: 0.15 g >	ALA-G50A	DS1: P(0.9741)	Fire/Explosion Event: No Fire; $Q_{released}$: 0 kg >	No Consequence
				DS2: P(0.02566)	Fire/Explosion Event: Pool Fire; $Q_{released}$: 331.84 kg >	13.94 m, P(7.6979·10^{-5})
				DS3: P(0.0002498)	Fire/Explosion Event: Pool Fire; $Q_{released}$: 2074 kg >	23.96 m, P(1.249·10^{-6})
	Anchored 85% fill			DS4: P(1.5057·10^{-5})	Fire/Explosion Event: Pool Fire; $Q_{released}$: 99552 kg >	23.96 m, P(< 1·10^{-6})
				DS5: P(1.3941·10^{-5})	Fire/Explosion Event: Pool Fire; $Q_{released}$: 205757 kg >	23.96 m, P(< 1·10^{-6})
3.	Storage Tank Diesel Fuel No.2, Q_{stored}: 133955 kg >	PGA: 0.15 g >	ALA-L50	DS1: P(0.9502)	Fire/Explosion Event: No Fire; $Q_{released}$: 0 kg >	No Consequence
				DS2: P(0.0498)	Fire/Explosion Event: Pool Fire; $Q_{released}$: 296.92 kg >	12.2 m, P(1.4939·10^{-5})
				DS3: P(0*)	Fire/Explosion Event: Pool Fire; $Q_{released}$: 1855.7 kg >	No Consequence
	Unanchored 45% fill			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 >	PGA: 0.15 g >	ALA-G50U	DS1: P(0.5)	Fire/Explosion Event: No Fire; $Q_{released}$: 0 kg >	No Consequence
				DS2: P(0.462)	Fire/Explosion Event: Pool Fire; $Q_{released}$: 395.89 kg >	13.76 m, P(0.0001386)
				DS3: P(0.03081)	Fire/Explosion Event: Pool Fire; $Q_{released}$: 2474.3 kg >	20.54 m, P(1.5403·10^{-5})
	Unanchored 85% fill			DS4: P(0.001455)	Fire/Explosion Event: Pool Fire; $Q_{released}$: 118766 kg >	20.54 m, P(1.1642·10^{-6})
				DS5: P(0.005747)	Fire/Explosion Event: Pool Fire; $Q_{released}$: 174962 kg >	20.54 m, P(5.7469·10^{-6})

Source: JRC, 2018

Figure 46 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 each 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, this means that their damage and Natech probabilities will be identical. However, for the third tank on the ground, RAPID-N was not able to find any fragility curve and did 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 46. Results of the analysis for pressurised storage tanks



Source: JRC, 2018

Figure 47 reports the result 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 and Natech probabilities. However, the third tank that 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, "No consequence" is reported as water is not a hazardous material.

Figure 47. Analysis results for water storage area



Source: JRC, 2018

Figure 48 reports 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 this case the Natech scenario is not indicated. 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), endpoint distances are of the order of tens of kilometres.

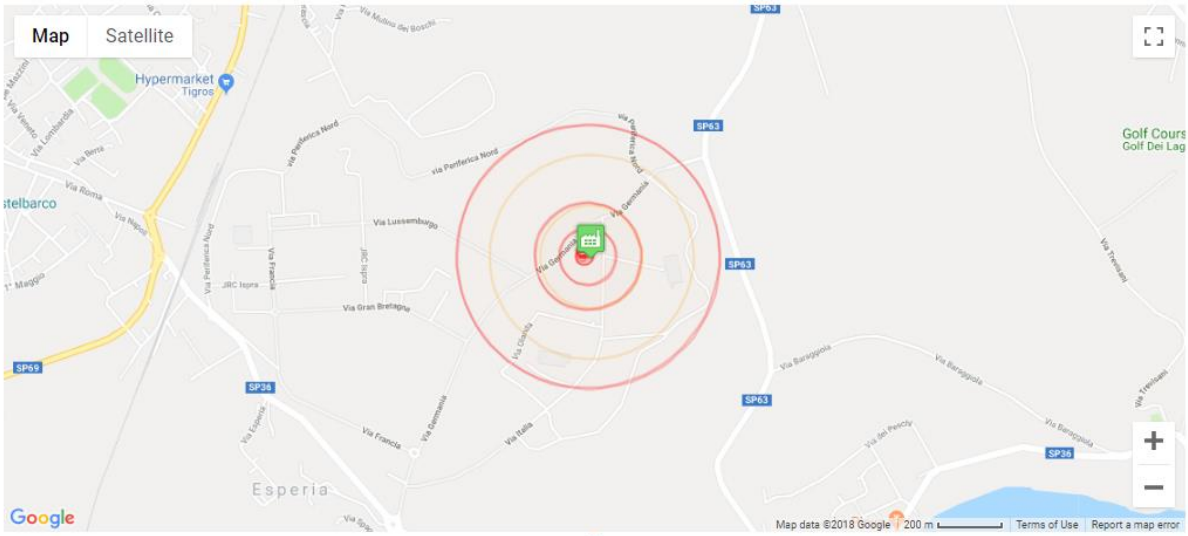
Figure 48. Analysis results for the toxic area

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 >	0 m, P(0.9402)
				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(9.1293·10^{-5})	$Q_{released}$: 5469.4 kg; P_{damage}: 9.1293·10^{-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(9.1293·10^{-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	

Source: JRC, 2018

Figure 49 reports the results on a map. Endpoint distances are reported as circles around each unit. Fire and explosion scenarios have red circles, while toxic dispersion scenarios have orange circles.

Figure 49. Risk analysis map



Source: JRC, 2018

6.5 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.

All the resources needed for this tutorial exercise are publicly available in RAPID-N and are composed of a fictional natural hazard event named "Tutorial Hazard", which is created in the first tutorial, and two fictional industrial installations named "Tutorial Plant A" and "Tutorial Plant B". Completed risk analysis is also available publicly as "Tutorial Risk Analysis 3". You can find detailed information on the risk analysis methodology of RAPID-N in the Risk Analysis Methodology section.

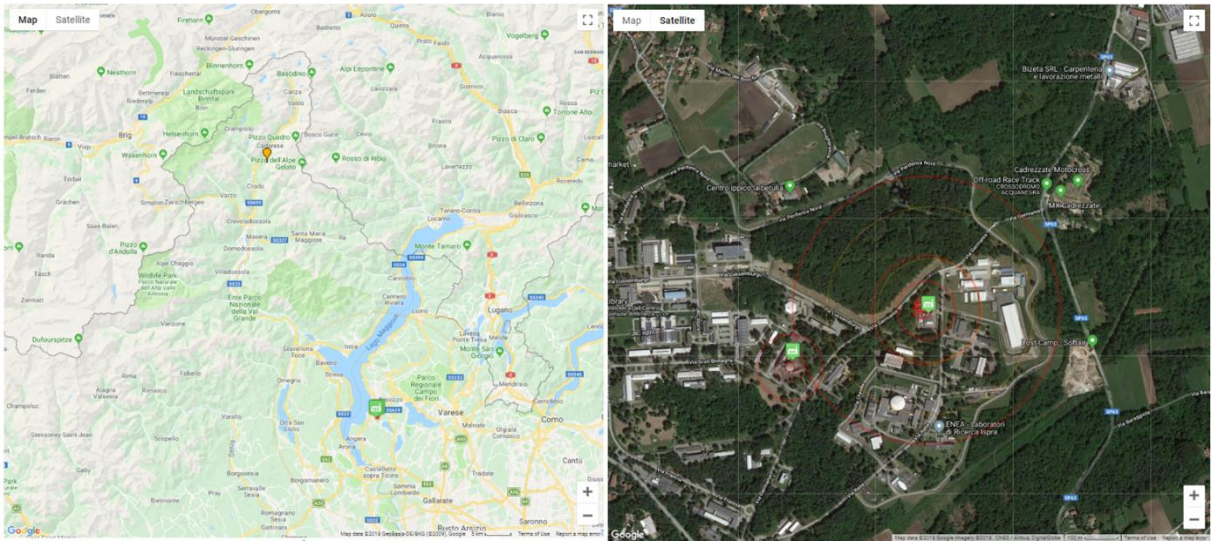
6.5.1 Data Entry

1. From the 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, we will use "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 utilize 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 the cut-off distance. For this tutorial, do not select an industrial plant.
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 customize 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.

6.5.2 Results

RAPID-N identified the industrial plants within the cut off distance, carried out the risk analysis using the tutorial hazard, and displayed the analysis results on a map. Figure 50 shows a zoomed view of the area with the plants that shows their Natech risk at local level. It is important to highlight that there are areas in which the risk due to different plants can overlap.

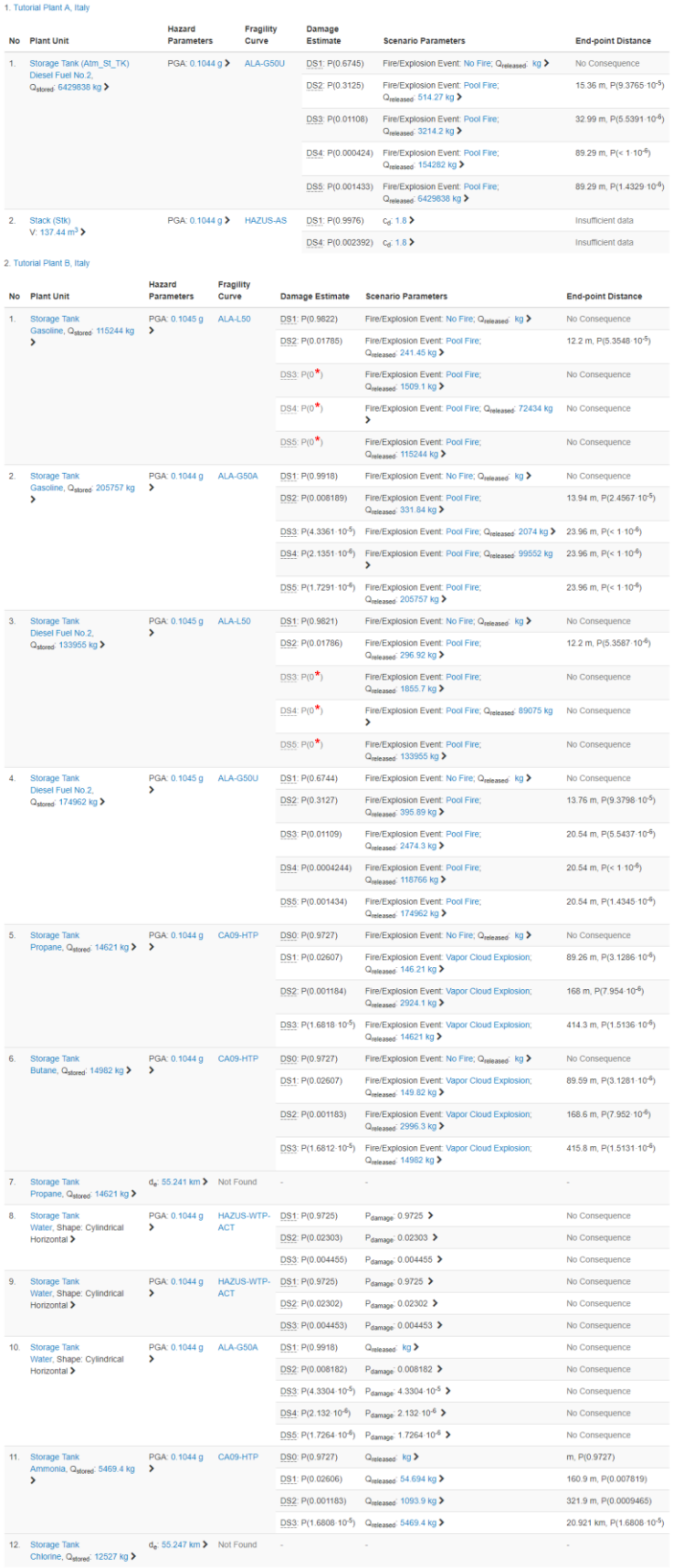
Figure 50. Risk analysis map



Source: JRC, 2018

In addition, results for all the plants (Tutorial Plant A and Tutorial Plant B) are listed in the analysis results table (Figure 51).

Figure 51. Risk analysis results



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	ALA-G50U	DS1: P(0.6745)	Fire/Explosion Event: No Fire; $Q_{released}$: kg	No Consequence
				DS2: P(0.3125)	Fire/Explosion Event: Pool Fire; $Q_{released}$: 514.27 kg	15.36 m, P(9.3765·10^{-5})
				DS3: P(0.01108)	Fire/Explosion Event: Pool Fire; $Q_{released}$: 3214.2 kg	32.99 m, P(5.5391·10^{-6})
				DS4: P(0.000424)	Fire/Explosion Event: Pool Fire; $Q_{released}$: 154282 kg	89.29 m, P(< 1·10^{-6})
				DS5: P(0.001433)	Fire/Explosion Event: Pool Fire; $Q_{released}$: 6429838 kg	89.29 m, P(1.4329·10^{-6})
2.	Stack (Stk) V: 137.44 m^3	PGA: 0.1044 g	HAZUS-AS	DS1: P(0.9976)	c_d: 1.8	Insufficient data
				DS4: P(0.002392)	c_d: 1.8	Insufficient data

2. Tutorial Plant B, Italy

No	Plant Unit	Hazard Parameters	Fragility Curve	Damage Estimate	Scenario Parameters	End-point Distance
1.	Storage Tank Gasoline, Q_{stored}: 115244 kg	PGA: 0.1045 g	ALA-L50	DS1: P(0.9822)	Fire/Explosion Event: No Fire; $Q_{released}$: kg	No Consequence
				DS2: P(0.01785)	Fire/Explosion Event: Pool Fire; $Q_{released}$: 241.45 kg	12.2 m, P(5.3548·10^{-5})
				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	PGA: 0.1044 g	ALA-G50A	DS1: P(0.9918)	Fire/Explosion Event: No Fire; $Q_{released}$: kg	No Consequence
				DS2: P(0.008189)	Fire/Explosion Event: Pool Fire; $Q_{released}$: 331.84 kg	13.94 m, P(2.4567·10^{-5})
				DS3: P(4.3361·10^{-5})	Fire/Explosion Event: Pool Fire; $Q_{released}$: 2074 kg	23.96 m, P(< 1·10^{-6})
				DS4: P(2.1351·10^{-6})	Fire/Explosion Event: Pool Fire; $Q_{released}$: 99552 kg	23.96 m, P(< 1·10^{-6})
				DS5: P(1.7291·10^{-5})	Fire/Explosion Event: Pool Fire; $Q_{released}$: 205757 kg	23.96 m, P(< 1·10^{-6})
3.	Storage Tank Diesel Fuel No.2, Q_{stored}: 133955 kg	PGA: 0.1045 g	ALA-L50	DS1: P(0.9821)	Fire/Explosion Event: No Fire; $Q_{released}$: kg	No Consequence
				DS2: P(0.01786)	Fire/Explosion Event: Pool Fire; $Q_{released}$: 296.92 kg	12.2 m, P(5.3587·10^{-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	PGA: 0.1045 g	ALA-G50U	DS1: P(0.6744)	Fire/Explosion Event: No Fire; $Q_{released}$: kg	No Consequence
				DS2: P(0.3127)	Fire/Explosion Event: Pool Fire; $Q_{released}$: 395.89 kg	13.76 m, P(9.3798·10^{-5})
				DS3: P(0.01109)	Fire/Explosion Event: Pool Fire; $Q_{released}$: 2474.3 kg	20.54 m, P(5.5437·10^{-6})
				DS4: P(0.0004244)	Fire/Explosion Event: Pool Fire; $Q_{released}$: 118766 kg	20.54 m, P(< 1·10^{-6})
				DS5: P(0.001434)	Fire/Explosion Event: Pool Fire; $Q_{released}$: 174962 kg	20.54 m, P(1.4345·10^{-6})
5.	Storage Tank Propane, Q_{stored}: 14621 kg	PGA: 0.1044 g	CA09-HTP	DS0: P(0.9727)	Fire/Explosion Event: No Fire; $Q_{released}$: kg	No Consequence
				DS1: P(0.02607)	Fire/Explosion Event: Vapor Cloud Explosion; $Q_{released}$: 146.21 kg	89.26 m, P(3.1286·10^{-6})
				DS2: P(0.001184)	Fire/Explosion Event: Vapor Cloud Explosion; $Q_{released}$: 2924.1 kg	168 m, P(7.954·10^{-6})
				DS3: P(1.6818·10^{-5})	Fire/Explosion Event: Vapor Cloud Explosion; $Q_{released}$: 14621 kg	414.3 m, P(1.5136·10^{-6})
6.	Storage Tank Butane, Q_{stored}: 14982 kg	PGA: 0.1044 g	CA09-HTP	DS0: P(0.9727)	Fire/Explosion Event: No Fire; $Q_{released}$: kg	No Consequence
				DS1: P(0.02607)	Fire/Explosion Event: Vapor Cloud Explosion; $Q_{released}$: 149.82 kg	89.59 m, P(3.1281·10^{-6})
				DS2: P(0.001183)	Fire/Explosion Event: Vapor Cloud Explosion; $Q_{released}$: 2996.3 kg	168.6 m, P(7.952·10^{-6})
				DS3: P(1.6812·10^{-5})	Fire/Explosion Event: Vapor Cloud Explosion; $Q_{released}$: 14982 kg	415.8 m, P(1.5131·10^{-6})
7.	Storage Tank Propane, Q_{stored}: 14621 kg	d_e: 55.241 km	Not Found	-	-	-
8.	Storage Tank Water, Shape: Cylindrical Horizontal	PGA: 0.1044 g	HAZUS-WTP-ACT	DS1: P(0.9725)	P_{damage}: 0.9725	No Consequence
				DS2: P(0.02303)	P_{damage}: 0.02303	No Consequence
				DS3: P(0.004455)	P_{damage}: 0.004455	No Consequence
9.	Storage Tank Water, Shape: Cylindrical Horizontal	PGA: 0.1044 g	HAZUS-WTP-ACT	DS1: P(0.9725)	P_{damage}: 0.9725	No Consequence
				DS2: P(0.02302)	P_{damage}: 0.02302	No Consequence
				DS3: P(0.004453)	P_{damage}: 0.004453	No Consequence
10.	Storage Tank Water, Shape: Cylindrical Horizontal	PGA: 0.1044 g	ALA-G50A	DS1: P(0.9918)	$Q_{released}$: kg	No Consequence
				DS2: P(0.008182)	P_{damage}: 0.008182	No Consequence
				DS3: P(4.3304·10^{-5})	P_{damage}: 4.3304·10^{-5}	No Consequence
				DS4: P(2.132·10^{-6})	P_{damage}: 2.132·10^{-6}	No Consequence
				DS5: P(1.7264·10^{-6})	P_{damage}: 1.7264·10^{-6}	No Consequence
11.	Storage Tank Ammonia, Q_{stored}: 5469.4 kg	PGA: 0.1044 g	CA09-HTP	DS0: P(0.9727)	$Q_{released}$: kg	m, P(0.9727)
				DS1: P(0.02606)	$Q_{released}$: 54.694 kg	160.9 m, P(0.007819)
				DS2: P(0.001183)	$Q_{released}$: 1093.9 kg	321.9 m, P(0.0009465)
				DS3: P(1.6808·10^{-5})	$Q_{released}$: 5469.4 kg	20.921 km, P(1.6808·10^{-5})
12.	Storage Tank Chlorine, Q_{stored}: 12527 kg	d_e: 55.247 km	Not Found	-	-	-

Source: JRC, 2018

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List of abbreviations and definitions

ADAM	Accident Damage Analysis Module
CAS	Chemical Abstracts Service
DS	Damage State
EC	European Commission
EINECS	European Inventory of Existing Chemical Substances
ELINCS	European List of Notified Chemical Substances
EMSC	European-Mediterranean Seismological Centre
EPA	U.S. Environmental Protection Agency
EPRG	Emergency Response Planning Guideline
EPSG	European Petroleum Survey Group
FEMA	U.S. Federal Emergency Management Agency
GIS	Geographic Information Systems
GMPE	Ground Motion Prediction Equations
GPS	Global Positioning System
HTML	Hypertext Markup Language
IDLH	Immediately Dangerous to Life and Health
IEEE	Institute of Electrical and Electronics Engineers
InChI	International Chemical Identifier
JRC	European Commission Joint Research Centre
KML	Keyhole Markup Language
MMI	Modified Mercalli Intensity
NACE	Statistical Classification of Economic Activities in the European Community
PGA	Peak Ground Acceleration
PGV	Peak Ground Velocity
PHP	PHP: Hypertext Preprocessor
RAPID-N	Rapid Natech Risk Analysis and Mapping System
RMP	Risk Management Plan
SA	Spectral Acceleration
SI	International System of Units
SMILES	Simplified Molecular Input Line Entry Specification
TUBITAK	Scientific and Technological Research Council of Turkey
URL	Uniform Resource Locator
USGS	United States Geological Survey
UTC	Coordinated Universal Time
WGS	World Geodetic System
XML	Extensible Markup Language

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