NARSIS

New Approach to Reactor Safety Improvements

WP1: Characterization of potential physical threats due to different external hazards and scenarios

Del 1.8: An open-source generic software tool for understanding combined hazard scenarios

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PU	Public	**X**
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1 Executive Summary

The NARSIS Multi-Hazard Explorer is an entry-level tool to quickly review and assess multi-hazard scenarios. It was built on an open-source framework and can thus be extended with new features by any other developer. With its transparent data management and portable runtime structure it can be used on almost any operating system, or could be even considered as a browser application in the future.

Fundamentally, the NARSIS Multi-hazard Explorer was developed to provide a straightforward way to assess the linear combinations of independent hazards. Multi-hazard is hereby defined as the linear combination of 2 independent hazards. The hazard with the higher occurrence frequency is defined as the primary hazard and any other one is called the secondary hazard. The tool utilizes given hazard return period curves of independent hazards, which are needed as input for the software, and computes occurrence probabilities of for both happening in the same time window. Combining more than 2 hazards is not part of the software but can be integrated by rerunning analyses. Similarly dependent hazards can also be applied currently externally and brought in as stochastic event set probabilities on one component of the linear combination.

For understanding and quantifying the impact of multi-hazard scenarios, a clear working template and visualization tools are necessary. The software visualizes graphs of coinciding hazards for different return periods. The NARSIS Multi-hazard Explorer (NARSIS-MHE) is delivered in two different ways: The software can be downloaded as pre-compiled runtimes for different operating systems, or the source-code can be downloaded or forked to be compiled by the user or for further development.

To run the NARSIS Multi-hazard Explorer, no specific requirements are needed. A Github-repository provides runtimes for Windows and Linux operating systems, which can be downloaded directly. Those are provided in zip-archives which can be unpacked. No further installation is needed.

The link to the Github-repository is the following:

https://github.com/a-schaefer/NARSIS-MHE

For future development, it is recommended to maintain the open software structure. Its generic nature allows the software to be adopted outside the nuclear application, but also provides a standalone which can be adapted by plant operators or modellers for the component parts as well as hazards which affect a site where it is only for internal use. Multi-hazard modelling becomes more and more important as the quantification of singular hazards becomes better known.

2 Background and introduction

2.1 Scope and objectives of this deliverable

The assessment of multi-hazard scenarios is difficult and relies on the combination of various probability functions. To guide a multi-hazard assessment, a software tool has been developed to support users in creating independent multi hazard scenarios. It covers the assessment of different generic sites, hazard curves, vulnerability thresholds and hazard combinations. In addition, it allows for simple visualization of results. The methodology builds on the findings of deliverables D1.1 to D1.6 and provides a tool to support deliverable D1.7 (listed below) and the applications presented in deliverables D3.4 and D3.5.

The software is designed to be ready-to-use with a low entry-threshold that any user can start using it straight away. All relevant data and codes are provided as open source for future development of various elements of analysis, and it is envisaged that the extendibility will allow for modification and application to any site (although only certain sites are presented as part of this deliverable).

2.2 Organisation of the deliverable

This deliverable is split into 2 sections. The first one describes the software, its elements, and requirements. This part can be considered as a manual to start working whilst building on the findings of previous deliverables.

The second part guides the reader/user through a few tutorials addressing each major element of the software. These tutorials are meant for a quick start in working with the software. They can be used in conjunction with a video and descriptive PowerPoint, which can be found on the GitHub repository, together with the software:

https://github.com/a-schaefer/NARSIS-MHE

The software has been released under the GNU GPLv3.0 license. Thus, anyone can continue developing it after providing proper reference to the NARSIS project.

3 NARSIS Multi-Hazard Explorer (MHE)

3.1 Requirements

The NARSIS Multi-hazard Explorer (NARSIS-MHE) is delivered in two different ways: The software can be downloaded as pre-compiled runtimes for different operating systems, or the source-code can be forked to be compiled by the user or for further development.

To run the NARSIS Multi-hazard Explorer, no specific requirements are needed. The above linked Github-repository provides runtimes for Windows and Linux operating systems, which can be downloaded directly. Those are provided in zip-archives which can be unpacked. No further installation needed.

To run the source-code there is a variety of requirements necessary, which are listed below. The software was built in the Electron framework, which emulates a browser environment, thus the software developed solely using html, css and javascript. This enables it to be run on any operating system which supports the Chromium browser engine, which is used in Chrome, Edge and other browsers. If necessary, a future developer could even port the software for mobile devices.

The following requirements only apply when using the source code:

- bootstrap: 4.5.3
- csv-parser: 2.3.2
- electron: 6.0.0
- everpolate: 0.0.3
- jquery: 3.5.1
- leaflet: 1.5.1
- leaflet-map: 0.2.1
- logspace: 1.0.1
- plotly: 1.0.6
- plotly.js-dist: 1.49.1
- popper.js: 1.16.1

For release building use:

- electron-packager: 14.2.1

The source code should also work with newer releases.

3.2 Installation Guide

To install the software, go to the webpage provided hereafter and pick the version that suits the operating system of the computer:

https://github.com/a-schaefer/NARSIS-MHE/releases/tag/v1.0

After finishing the download, unzip the archive. No further installation steps are needed. You can start the software using e.g., narsis_mhe.exe (depending on operating system).

3.3 Methodology

On a technical level, the software needs two kinds of inputs. First, it needs multiple hazard curves, which should be independent from each other in the first instance. Such a hazard curve provides the occurrence probability or return period of one or more impact metrics. Those curves need to be computed independently, deliverables D1.2-D1.6 should be referred to for

additional information. Two of such curves are combined to calculate multi-hazard scenarios (cf. Figure 1).

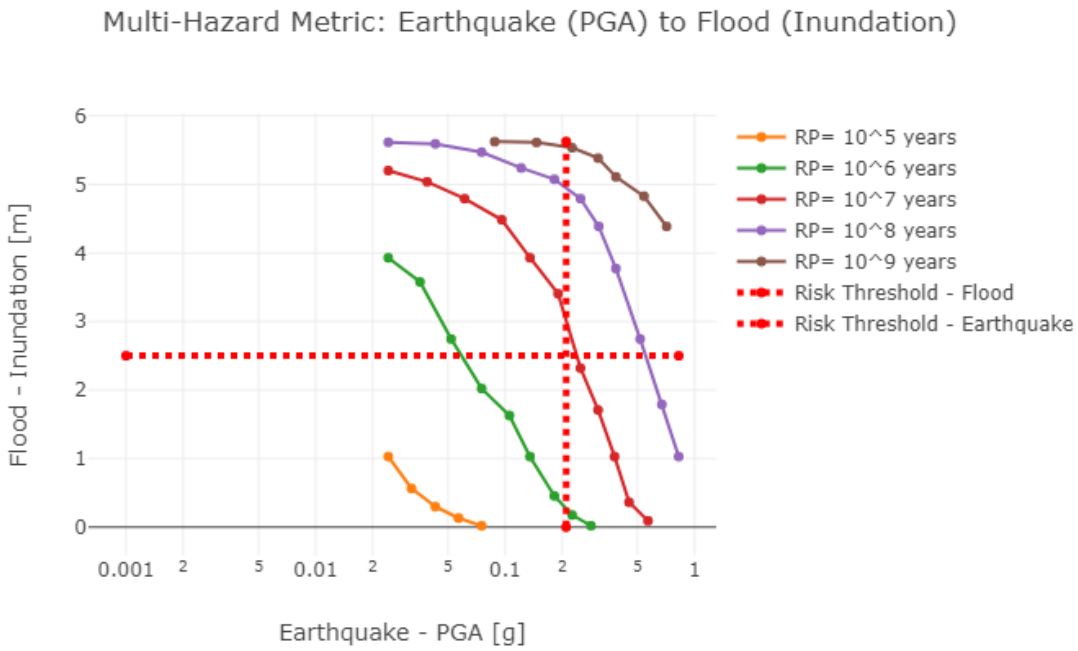

Figure 1: Plot of a multi-hazard combination using earthquake and flood hazards. Dashed lines indicate the respective vulnerability thresholds.

Independent of the hazard curves, components can be defined. Components describe structural elements on the assessed site like batteries or cooling systems. Each component in the software provides exceedance thresholds for different hazards at which for example, a critical vulnerability state is reached. These thresholds are used to identify dominating hazards which have the highest probability to exceed a critical vulnerability. By default 7 components are already provided by the software.

Finally, multi-hazard curves for different return periods are computed, by providing the relationship between 2 hazards with respect to a certain return periods like 10,000 years (adjustable via input). Only two hazards can be directly compared at once, however, multiple iterations could be made where the user output of two hazard is used as input vs. a third hazard. Since only one hazard is considered as primary or dominant it is then compared to all other available hazards. A multi-hazard combination relies on a so-called look-ahead-time or "hazard time window" which describes the time window after the occurrence of the primary hazard in which a second hazard event may happen.

The linear combination of 2 hazards can be broken down to the multiplication of 2 independent hazards. Here P_1 describes the primary hazard and P_2 is the secondary hazard.

(1) $$P_{12} = P_1 \times P_2$$

However, assuming events with probability P_2 can occur within a specific time window t after event 1 with probability P_1, the combined probabilities become:

(2) $$P_{12}(t) = P_1 \times P_2(t)$$

3.4 Software structure

To understand and quantify the impact of multi-hazard scenarios, a clear working templates and visualization tools are necessary. Thus, a software tool for multi-hazard analysis has been developed. The tool utilizes given hazard return period curves of independent hazards and computes occurrence probabilities of for both happening in the same time window. The software plots graphs of coinciding hazards for different return periods.

Multi-hazard is hereby defined as the linear combination of 2 independent hazards. The hazard with the higher occurrence frequency is defined as the primary hazard and any other one is called the secondary hazard. Combining more than 2 hazards is not part of the software but as previously mentioned can be integrated. Similarly dependent hazards can also be applied currently externally and brought in as stochastic event set probabilities on one component of the linear combination.

The NARSIS Multi-hazard Explorer was developed to provide a straightforward way to assess the linear combinations of independent hazards. To guide the user through the methodology, the software was split into 5 individual elements as shown in Figure 2. Each element covers a specific part of the multi-hazard methodology and is introduced in the next sections.

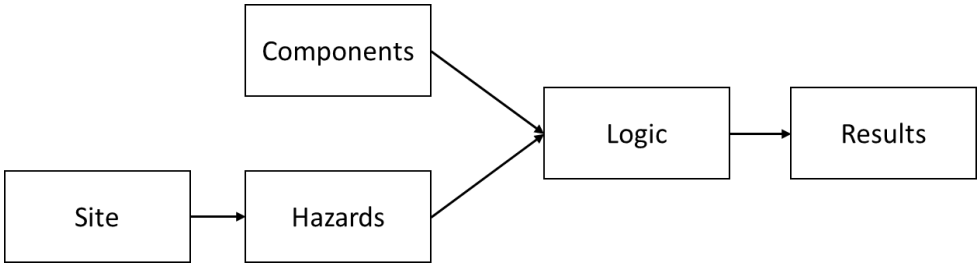

Figure 2: Workflow through all software elements. Sites & hazard and Components can be handled individually are combined in the Logic step.

The software is delivered with some sample data for a few selected, decommissioned reactor sites: Trino Vercellese in Italy; Muelheim Kaerlich and Biblis in Germany. All sites are delivered with 2-4 per-selected independent hazards of interest (Table 1).

Table 1: Overview of hazard developed for each site

Site	Latitude	Longitude	Earthquake	Flood	Volcano	Lightning	Tornado
Trino Vercellese (IT)	45.18313°N	8.27677°E	X	X		X	X
Muelheim Kaerlich (DE)	50.40799°N	7.48921°E	X	X	X		
Biblis (DE)	49.70879°N	8.41449°E	X				X

3.4.1 Orientation

The software layout is split into three segments, as it can be seen in Figure 3:

1. *The top panel:*

This panel provides access to the basic input and output functions like save/load options of the current sites and hazards.

2. *The navigation bar:*

This bar links all 5 software elements.

3. *The main area:*

All necessary functions of the currently selected software element are shown here.

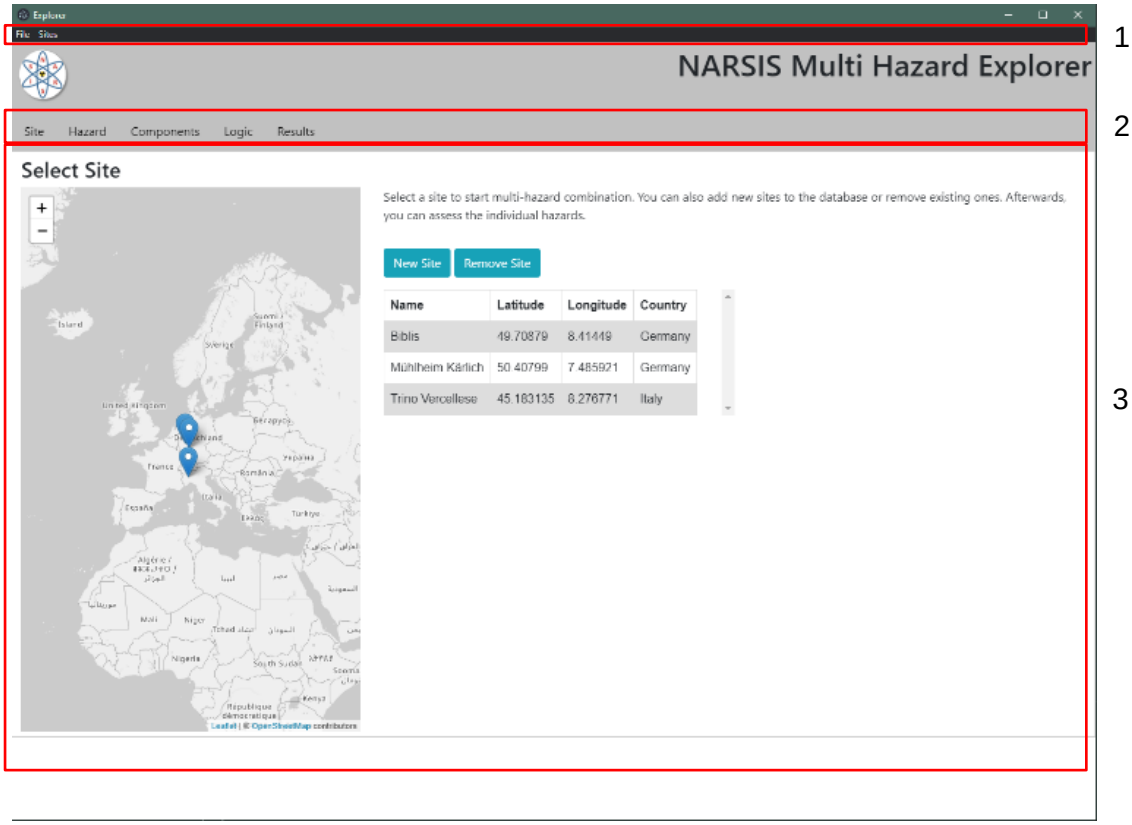

Figure 3: NARSIS MHE Start screen.

3.4.2 Site

The first software element a user starts to work with is the site element. Here, the user can define locations as sites which will handle the individual multi-hazard cases. For each site, the user can provide a unique set of hazard curves. For better visual discrimination, each site is associated to a specific geographic location given by latitude and longitude coordinates. Those coordinates are technically not relevant for the following calculations. But they help to differ between different sites and are shown on an overview map.

The site element window (Figure 4) has 3 different data panels:

1. *Site map:*

The first panel provides a map for all given sites. Each site is shown as an individual marker. There is no further functionality, but helps to visually differentiate between all sites.

2. *Site list:*

The site list shows all available sites. By clicking on one of the entries, the site panel (3) will provide further details. By clicking on either "New site" or "remove site", the currently selected site is either deleted or a new blank site is added.

3. *Site panel:*

The list panel lists all hazards associated to the selected site. Meta information of the site including name and coordinates can be changed by clicking on "edit site". Via “next step” the user is guided to the hazard element.

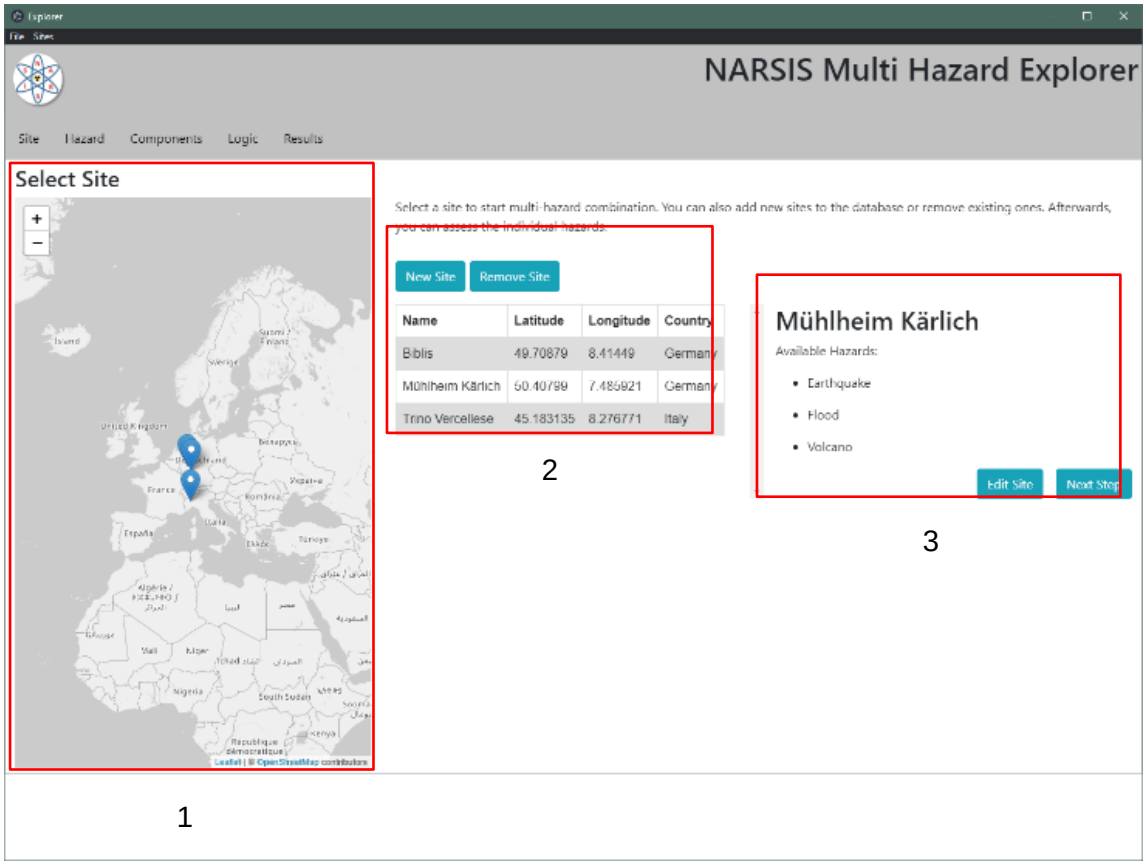

Figure 4: NARSIS MHE Site window.

3.4.3 Hazard

The second element of the software covers the site-specific hazards. For each site, a set of hazard curves can be provided. Each hazard can have one or multiple impact metrics. Each impact metric will be considered later on as an independent hazard which can be combined with any other hazard, except with the impact metrics of the same hazard.

The hazard window (Figure 5) covers 3 different panels:

1. *The control panel:*

Here, the user can add new hazard to the selected site using the "Add Hazard" button where a *.csv can be imported containing the hazard curve(s). Further details can be found in Chapter 3.5. Using "Next Step", the user is guided to the components elements

2. *The hazard panel:*

In the hazards panel, the user can review and alter the provided hazards. If necessary, a hazard can be removed using the "Delete" button. With "Edit", the user can adjust the meta data, as described in Chapter 3.5.1. "Show" will display the respective impact metric on the plot panel.

3. *The plot panel:*

This panel visualizes the selected hazard cuves. By hovering with a mouse on the plot, additional options will be visible to interact with the plot, including an export option.

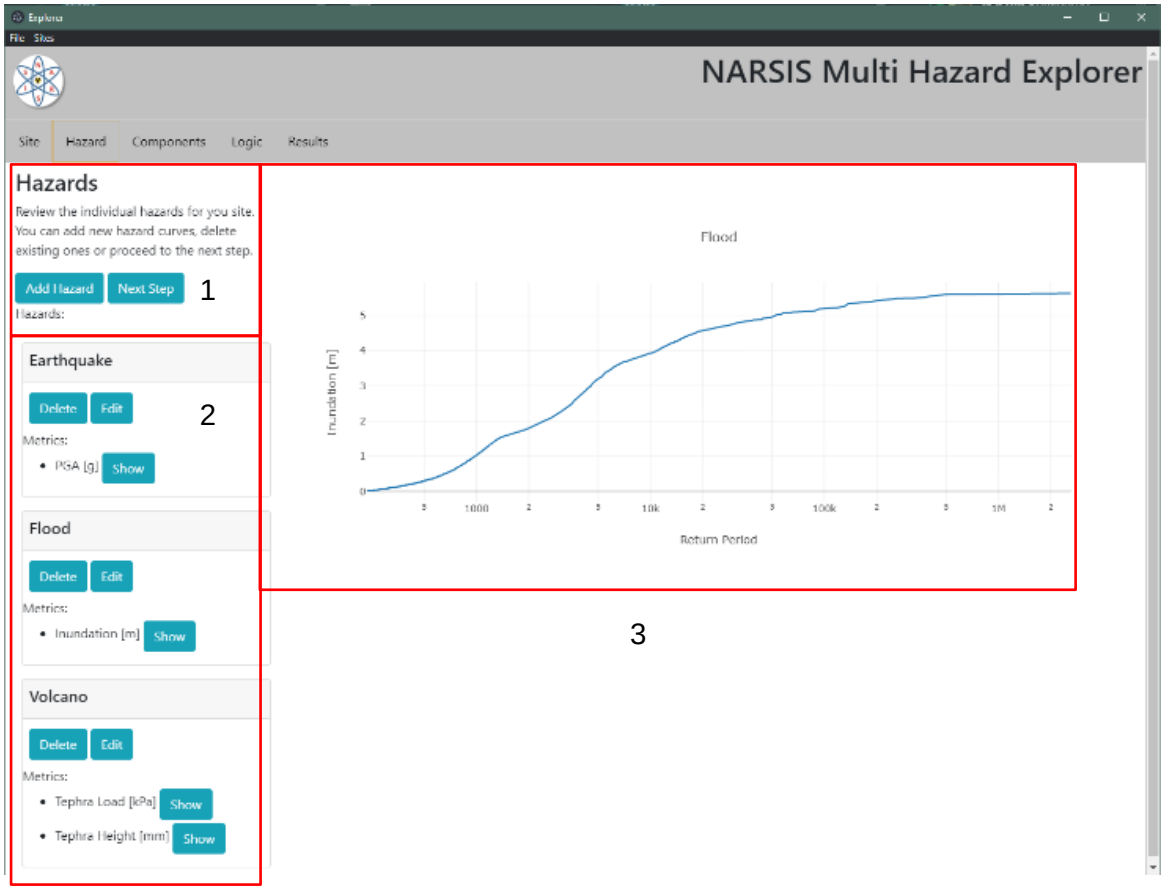

Figure 5: NARSIS MHE Hazard window.

3.4.4 Components

In the components area, vulnerability thresholds for different, user- and pre-defined site components can be assessed. Site components are independent from the selected site and stored in separate files. For each site component thresholds are listed for each known hazard. If the site provides hazards not covered by the components, new entries are appended. Both hazard and component meta data provides so-called “label” which are used to link hazard curves and vulnerability thresholds together in the forthcoming calculations.

The components window (Figure 6) provides 2 panels to review all site components:

1. *The components panel:*

In this panel, all available components are listed. They can be either selected to assess their vulnerability thresholds using the "Select" button, or their meta data can be changed by clicking on "Edit". The "Delete" button deletes the respective component.

Components can be saved and loaded using the respective button in the top part. In addtion, new components can be appended using the "Add" button. Via "Next Step" the Logic window can be reached.

2. *The threshold panel:*

This panel lists all known and provided hazards. Hazards and components are linked by using the label meta data. The value column provides the respective threshold. Changes are saved using the »Save Changes« button.

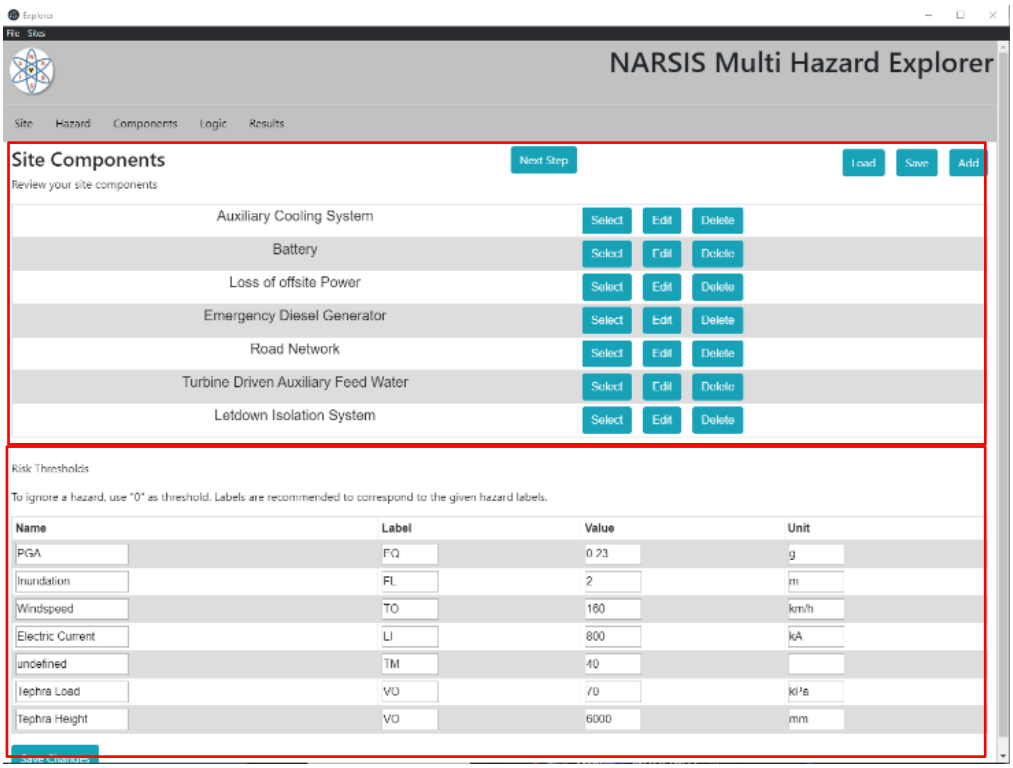

Figure 6: NARSIS MHE Components window.

3.4.5 Logic

The logic area is the key element of the tool where both hazards and components finally come together. Here, a component can be selected for assessment and the software directly computes the expected return period when a vulnerability threshold is reached. The software then recommends the hazard for which the threshold is reached first as the primary hazard to which all other hazards are compared. It is still possible to select another primary hazard instead. In addition, the look-ahead time can be manually adjusted and is given by default as 365 days.

The logic window (Figure 7) provides 3 panels to combine hazards and components for the final computation:

1. *The components panel:*

This panel lists again all available components, which can be selected for the multi-hazard assessment. Only one component can be selected at once.

2. *The threshold panel:*

This panel provides the list of available hazards and thresholds for the current site. Here, thresholds can be changed again, but changes will not be saved to the components file.

3. *The computation panel:*

This panel provides the overview of available hazards and lists the return periods at which the vulnerability thresholds are expected to be reached. Based on these initial calculations, the primary hazard is selected. In addition, the time window can be adjusted in the bottom left field. By clicking on "compute" the multi-hazard calculation takes place and leads to the results window.

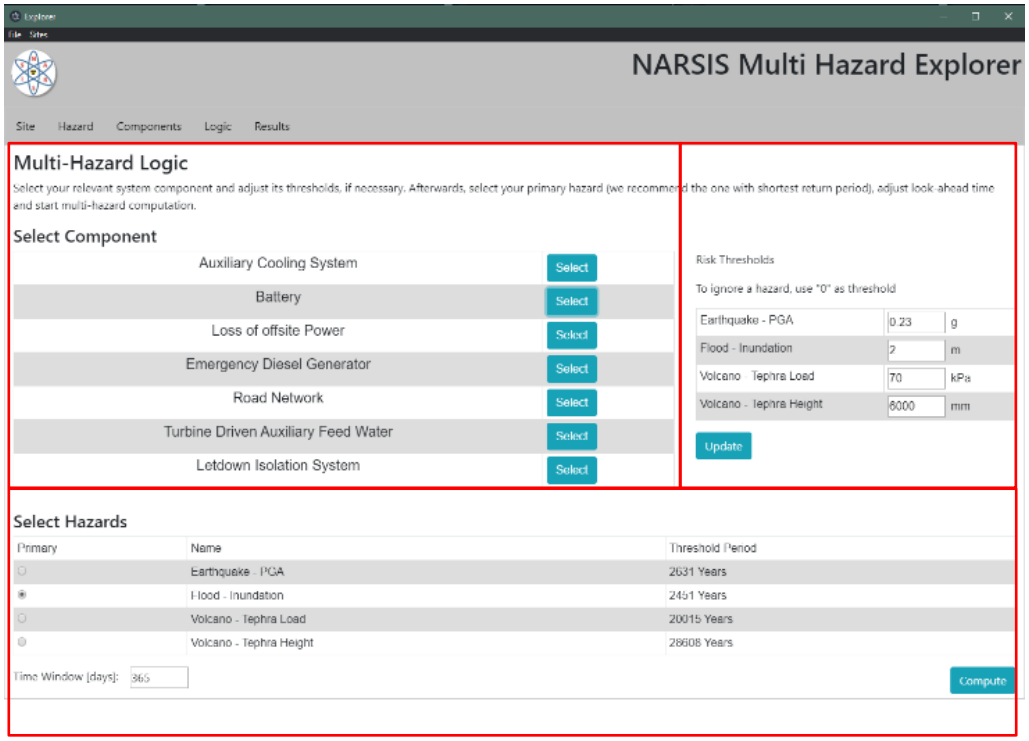

Figure 7: NARSIS MHE Logic window.

3.4.6 Results

The results window summarizes the multi-hazard computation. Here, it is possible to select different multi-hazard combinations based on the pre-selected primary hazard, to visualize them and to export all results into a 'json-file'.

The results window (Figure 8) provides 2 panels to interact:

1. *The dropdown menu:*

This menu allows to select computed multi-hazard combinations with respect to the previously select primary hazard. The plot below will be automatically updated. Via "export results", it is possible to export the computed results into a *.json file, see Chapter 3.5.2 for more details

2. *The plot area:*

This area allows to interact with the data and also to export the graph, similar to the plots in the hazards window.

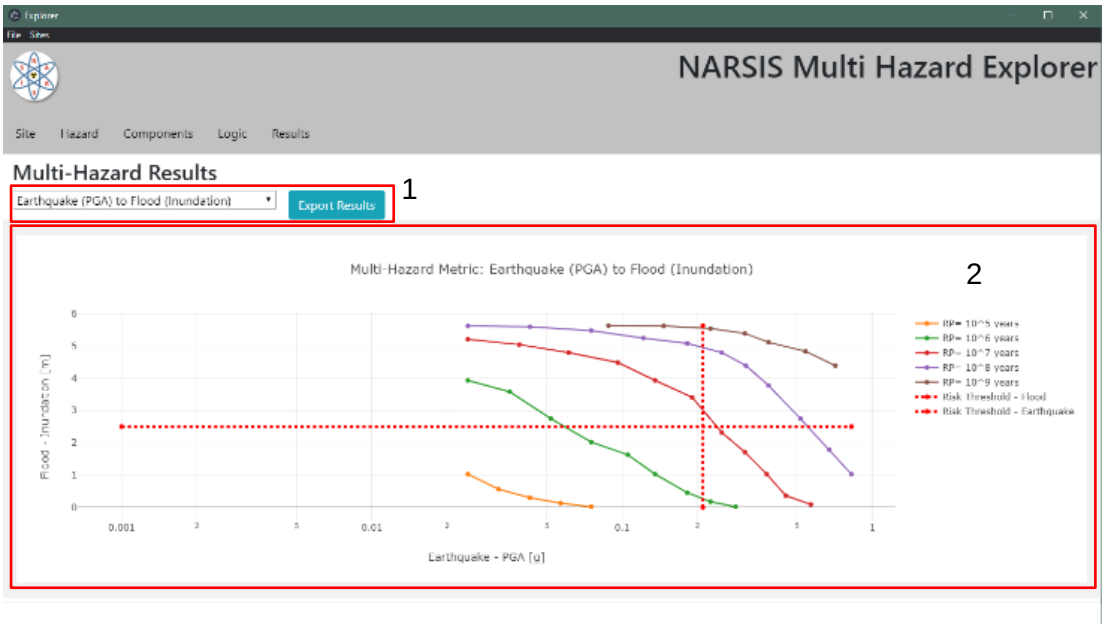

Figure 8: NARSIS MHE Results window.

3.5 Data formats

3.5.1 Meta Data

Each element in the software (site, hazard, component) is described by meta data to either better differentiate between different data entries or to provide calculation-relevant information.

Site

Label	Data type	Description
Name	String	Descriptive information
Country	String	Descriptive information
Latitude	Float	Descriptive information, used for map on site window, in degrees
Longitude	Float	Descriptive information, used for map on site window, in degrees

Hazard

Label	Data type	Description
Name	String	Descriptive information
Label	String	Used to link hazard and component in the logic window and calculation. To be linked, strings need to be identical. If multiple metrics are available, label is appended by “Metric-Name”.
Metrics	List	For each impact metric, the following 2 entries are repeated.
Metric-Name	String	Additional label for each metric, used to identify each impact in addition to the label above. Used to link impact metric to component
Unit	String	Description information for each metric, used in the y-axis when plotting the hazard.

Component

Label	Data type	Description
Name	String	Descriptive information
Label	String	Descriptive information
Thresholds	List	For each component, the following 4 entries are repeated
Name	String	Descriptive information, used to component to impact metric
Label	String	Descriptive information, used to component to impact metric
Value	Float	Threshold value
Unit	String	Descriptive information

3.5.2 File formats

To allow a transparent access of data outside of the software *.json-files were used as the default data type. Json-files can be edited, if necessary, with any text editor and can be processed by almost all common programming languages used for data processing. This allows the user to modify data elements, if necessary, and to further process calculation results.

Json-files support nested data structures as they are commonly used in e.g. python dictionary.

Config-file (*.json)

Default file path: assets/data/sites.json

This file hosts all site data including hazards and its meta data (Figure 9). If hazard data is already available, it is also stored here.


```
{
  "type": "FeatureCollection",
  "features": [
    {
      "name": "Biblis",
      "country": "Germany",
      "latitude": 49.70879,
      "longitude": 8.41449,
      "hazards": [
        {
          "name": "Earthquake",
          "label": "EQ",
          "metrics": [
              "PGA"
            ],
          "units": [
              "g"
            ],
            "values": [
              […]
            ],
            "rate": [
              […]
            ]
          }
      }
    ]
}
```


Figure 9: NARSIS MHE Config-file example.

Hazard file (*.csv)

No default file path.

A hazard follows the principle of xyz-data (Figure 10). The first column always describes the return period data of the hazard curve while each following column corresponds to an impact metric.


```
Rate,Value
100000,0.668
50000,0.632
33333.33333,0.579
25000,0.516
20000,0.479
16666.66667,0.413
14285.71429,0.404
```


Figure 10: NARSIS MHE Hazard file example.

Components file (*.json)

Default file path: assets/data/components.json

The component file hosts all data and meta data to quantify site components (Figure 11).

```
{
  "features": [
    {
      "label": "ACS",
      "name": "Auxiliary Cooling System",
      "thresholds": [
        {
          "label": "EQ",
          "metric": "PGA",
          "unit": "g",
          "value": 0.2
        },
        […]
        }
      ]
    },
    {
      "label": "BATT",
      "name": "Battery",
      "thresholds": [
        {
          "label": "EQ",
          "metric": "PGA",
          "unit": "g",
          "value": 0.23
        },
      ]
    },
    […]
  ]
}
```

Figure 11: NARSIS MHE Components file example.

Results file (*.json)

No default file path.

The results file contains all calculation results after a successful multi-hazard computation. For each multi-hazard combination, a set of return period curves is computed. For each of them a combination of x and y values is given, where x corresponds to the primary and y to the secondary hazard (Figure 12).


```
{
  "primary": {
    "label": "EQ",
    "name": "Earthquake",
    "metric": "PGA",
    "unit": "g",
    "maximum": 0.824,
    "minimum": 0.001,
    "threshold": 2239.0572389999998,
    "thval": 0.21
  },
  "secondary": [
    {
      "name": "Flood",
      "label": "FL",
      "metric": "Inundation",
      "unit": "m",
      "maximum": 5.625562337,
      "minimum": 0.02,
      "threshold": 3550.2166391413507,
      "thval": 2.5,
      "rp_target": [
        10000,
        100000,
        1000000,
        10000000,
        100000000,
        1000000000
      ],
      "x": […],
      "y": […]
    },
    {…}
  ]
}
```


Figure 12: NARSIS MHE Results file example.

4 Conclusions and recommendations

The NARSIS Multi-Hazard Explorer is an entry-level tool to quickly review and assess multi-hazard scenarios per site of interest. It was built on an open-source framework and can thus be extended with new features by any other developer and can be used internally. With its transparent data management and portable runtime structure it can be used on almost any operating system, or could be even considered as a browser application in the future.

It allows for users to choose different plant component thresholds and operational time windows for integration within existing PSA frameworks or operational plans.

For future development, it is recommended to maintain the open software structure. Its generic nature allows the software to be adopted outside the nuclear application, but also provides a standalone which can be adapted by plant operators or modellers for the component parts as well as hazards which affect a site where it is only for internal use. Multi-hazard modelling becomes more and more important as the quantification of singular hazards becomes better known and quantifiable and could be applied also in a humanitarian context to assess multi-hazard scenarios e.g. for critical infrastructure in developing countries.

5 References

NARSIS EU Deliverables in WP1: New Approach to Reactor Safety ImprovementS | NARSIS Project | H2020 | CORDIS | European Commission (europa.eu)

D1.1: Review of state-of the art for hazard and multi-hazard characterisation

D1.2: Improved methodologies for tsunami hazard assessment

D1.3: Improved methodologies for extreme weather and flooding hazard assessment

D1.4: Flooding impact on industrial facilities via advanced numerical modelling

D1.5: Improved methodologies for extreme earthquake hazard assessment

D1.6: Development of single and secondary effect hazard assessment methodologies including uncertainty quantification and comparison

D1.7: Production of an integrated hazard framework for combined hazard scenarios for Safety Assessment

D3.4: Description of the approach for integration of individual subnetworks and risk interdependency

D3.5: PhD narrative on the hazard integration and risk analysis for NPPs through a Bayesian approach

Electron Framework (2021): GitHub - electron/electron: Build cross-platform desktop apps with JavaScript, HTML, and CSS