Horizon 2020
Programme

METIS

Research and Innovation Action (RIA)

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 945121

Start date : 2020-09-01 Duration : 57 Months

Enhanced version of the PSA integrated modelling environment Andromeda (first version available from M12)

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METIS - Contract Number: 945121

Project officer: Katerina PTACKOVA

Document title	Enhanced version of the PSA integrated modelling environment Andromeda (first version available from M12)
Author(s)	Mrs. Claudia PICOCO, Thomas Friedlhuber (Edgemind)
Number of pages	25
Document type	Deliverable
Work Package	WP7
Document number	D7.5
Issued by	EDF
Date of completion	2024-11-22 11:23:46
Dissemination level	Public

Summary

One of the goals of the METIS project is to further develop and improve tools and methodologies employed in seismic safety assessments of nuclear reactors. METIS particularly aims at providing a new calculation framework for Seismic PSA, based on SCRAM code for Boolean computations, on Andromeda software for fault trees and event trees definition and user interface, and on a tool developed in the frame of METIS project for managing and generating seismic data (METIS Seismic database from WP 7.2). Within the context of the WP7 Task 3.1 an uncertainty propagation tool has been developed. This document presents the developed tool that, given the samples of basic events probabilities and the results of the Seismic PSA model in terms of cutsets, provides the value of the Core Damage Frequency (CDF) for each sample.

Approval

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METIS

Seismic Risk Assessment for Nuclear Safety

Research & Innovation Action

NFRP-2019-2020

Enhanced version of the PSA integrated modelling environment Andromeda (first version available from M12)

Version N°1

Authors: Claudia Picoco (EDF R&D),

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Document Information

Grant agreement	945121
Project title	Methods and Tools Innovations for Seismic Risk Assessment
Project acronym	METIS
Project coordinator	Dr. Irmela Zentner, EDF
Project duration	1st September 2020 – May 2025
Related work package	WP 7
Related task(s)	Task 7.3.1
Lead organisation	
Contributing partner(s)	
Due date	
Submission date	
Dissemination level	Confidential

History

Date	Version	Submitted by	Reviewed by	Comments
08.2024	N°1	Claudia Picoco	Oleksandr SEVBO (ER)	

Table of Contents

Abbreviations and Acronyms

Acronym	Description
BE	Basic Event
CCF	Common Cause Failure
CDF	Core Damage Frequency
MCS	Minimal Cut Sets
MCUB	Minimal Cut Upper Bound
MFT	Master Fault Tree
PGA	Peak Ground Acceleration
PSA	Probabilistic Safety Assessment
SSC	Structures, Systems and Components
SPSADB	Seismic PSA DataBase
WP	Work Package

Summary

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Within the context of the WP7 Task 3.1 an uncertainty propagation tool has been developed. This document presents the developed tool that, given the samples of basic events probabilities and the results of the Seismic PSA model in terms of cutsets, provides the value of the Core Damage Frequency (CDF) for each sample.

Keywords

Seismic, PSA, uncertainty, CDF, Tool

1. Introduction

One of the goals of the METIS project is to further develop and improve tools and methodologies employed in seismic safety assessments of nuclear reactors. METIS particularly aims at providing a new calculation framework for Seismic PSA, based on SCRAM code for Boolean computations, on Andromeda software for fault trees and event trees definition and user interface, and on a tool developed in the frame of METIS project for managing and generating seismic data (METIS Seismic database from WP 7.2).

Within the context of the WP7 Task 3.1, an uncertainty propagation tool has been developed. This document presents the developed tool that, given the samples of basic events probabilities and the results of the Seismic PSA model in terms of cutsets, provides the value of the Core Damage Frequency (CDF) for each sample.

The developed tool will be available on the openMETIS gitlab repository https://gitlab.pam-retd.fr/openmetis.

This document is organized as follows. Section 2 describes the developed tool in terms of input files, output files, technical specifications and use case. Section 3 presents some conclusions. In the Appendix, the user guide of the tool is provided.

2. Tool

Within the context of the METIS project, the WP7 Task 3.1 [1] aims at developing a method and an associated tool for propagating uncertainty within the Seismic PSA model.

The tools considered within the project are:

- Andromeda, a tool developed by EDF for editing and manipulating PSA models (see Figure 1),

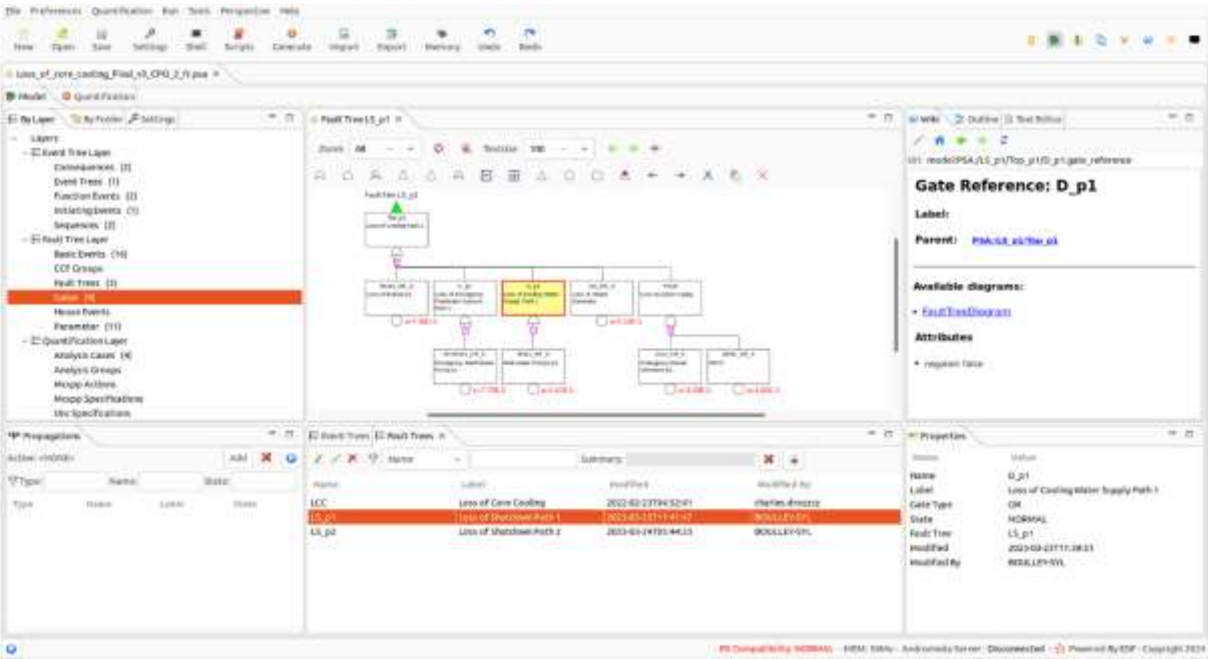


Figure 1. Screenshot of Andromeda

- SCRAM [3], an open-source computing tool which is coupled with Andromeda for the quantification of PSA models,

- Seismic PSA DataBase tool (SPSADB), an Excel macro developed by the IRSN that allows to perform MonteCarlo sampling on basic events probabilities (see Figure 2).

Figure 2. Seismic PSA DataBase tool [2]

As of today, the toolchain works as follows: Andromeda builds the Master Fault Tree (MFT), then it transfers it to the calculations tool, SCRAM in this case. SCRAM then generates the list of corresponding cutsets that are finally processed by Andromeda.

The final goal of this activity under the Task 7.3.1 [1] is to develop a “SEISMIC PRA TOOL” within this context, capable of propagating uncertainties of basic events (Bes) in CDF.

2.1. Goal of the tool

The Seismic PSA DataBase tool is able to sample uncertainty parameters from their probability distributions and to propagate them (while accounting for dependencies) up to Basic Event probabilities. It produces a txt file where each line corresponds to a sample of the different selected basic event probabilities:

$$\text{Nom } BE_1,\ \text{Nom } BE_2,\ \dots,\ \text{Nom } BE_n$$

$$V_1,\ V_2,\ \dots\ V_n$$

(where V_i is the sampled value of the BE_i probability)

The Seismic PRA Tool has to quantify the CDF for each line of the text file (corresponding to a different MonteCarlo sample). This CDF quantification must be performed by post processing the cutsets without regenerating them. The Seismic PRA Tool has to use the provided MCS list in order to quantify the CDF for each line, and thus for the different Peak Ground Accelerations (PGA). The requantified CDF for each line should finally be added as a new column to the original sampling file.

2.2. Input and output data of the Seismic PRA Tool

The inputs to Seismic PRA Tool are:

- The text file generated by the Seismic PSA DataBase tool:

$$\text{Nom } BE_1,\ \text{Nom } BE_2,\ \dots,\ \text{Nom } BE_n$$

$$V_1,\ V_2,\ \dots\ V_n$$

The size of the text file depends on the number of considered equipment (number of columns of the file) and on the number of samples set by the user (number of lines of the file).

Indicatively, a mean amount of equipment between 600 and 800 (i.e., which translates in at least 600 columns in the file) is considered. The consequent matrix size would be: 12000 octets x Nb samples. For 10000 samples, therefore, this means about 14 Giga octets[1].

- SCRAM Results file[2] containing the list of Minimal Cut Sets (MCS) and mean values for BEs and Common Cause Failure events: this file in XML format is generated by Andromeda/SCRAM.

The outputs from Seismic PRA Tool are:

- The original text file but with the added column of the quantified CDF:

  Nom BE_1, Nom BE_2, …, Nom BE_n

  V_1, V_2, … V_n

  Where the order of the lines of the original file is maintained, as the order of the lines is the link to the PGA value.

- A log file with errors, if any.

2.3. Additional tool specifications

For the tool development, the specifications of the model to be used within the METIS project have been adopted, thus:

- Number of minimal cutsets: between 1000 and 2000
- Number of equipment (number of values per sampling): between 600 and 800
- Maximum number of samples: 10000

The tool is standalone (Seismic PSA DataBase tool will remain standalone and independent as well as Andromeda).

2.4. Tool functioning

The tool, developed by Edgemind, works as follows (see the Annexe for further detail):

- Phase I: Initialization
  - Read SCRAM result of Seismic PSA model quantification
  - Read SPSADB sampling file
  - Construct internal cutset list
  - Construct mapping between SCRAM cutset events and SPSADB sampling events (pattern matching)
- Phase II: CDF calculation
  - For each sampling (Iteration):
  - For mapped events: Apply values from sampling to cutset events
  - For all others: Apply MEAN value from SCRAM result

[1] Data provided by IRSN partners.
[2] SCRAM results file has to be generated using the version SCRAM 0.16.2 of SCRAM.

- Calculate CDF value with MCUB algorithm (see CDF Calculation)
- Support for probability and frequency calculations (see CDF Calculation)

- Phase III: Result Export
  - Export new sampling file with additional CDF column
  - Print CDF value for each sampling in additional column

The global toolchain is shown in Figure 3 :

- From the PSA model, Andromeda creates an encoded MFT (Master Fault Tree) (by renaming BEs and CCFs) and a mapping file that allows to encode/decode the element names. After SCRAM calculations, Andromeda takes the results and creates a second XML file with names decoded. The SCRAM results file to consider for the project is this second file.
- From the Seismic PSA DataBase tool, the user generates the second file containing the MonteCarlo sampling propagated up to the Bes.
- The two files constitute the input to the Seismic PRA Tool.

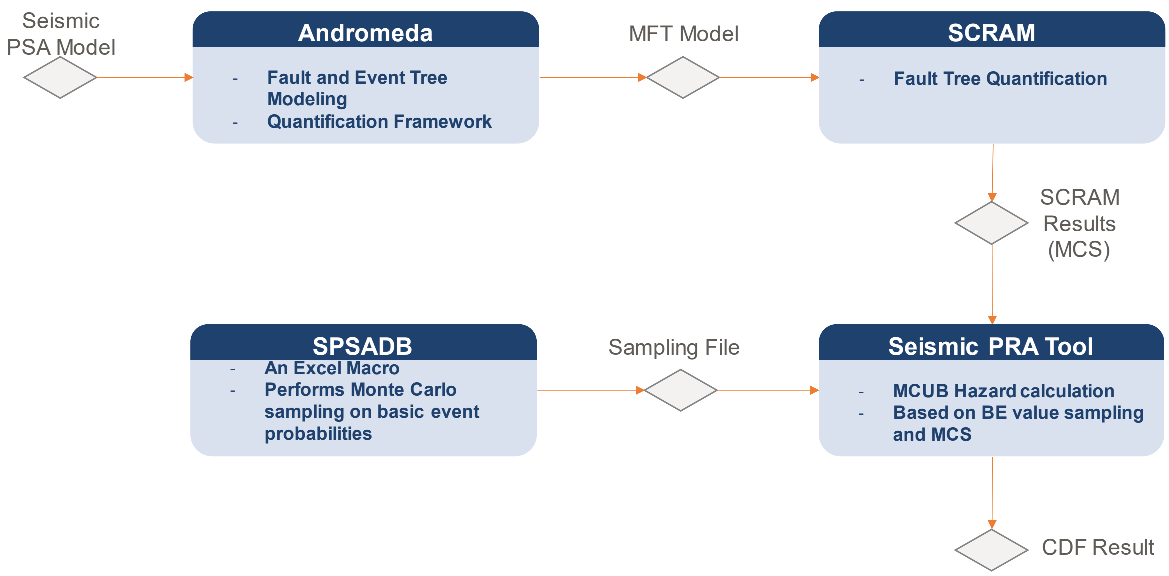


Figure 3. Seismic PRA Toolchain

2.5. CDF Algorithm

The user can refer to the documentation in Annexe for further detail.

3. Use case

For testing the Seismic PRA Tool, the model of WP7.3 was used as well as the macro provided within the Task.

The user generates:

- XML file from Andromeda-SCRAM, containing the cutsets
- Excel Macro containing the sampling values for basic events

Then, the user precises these files as inputs by using the graphical interface of the tool, together with the path and name of the folder, as shown in Figure 4. Finally, the "Run" button starts the quantification.

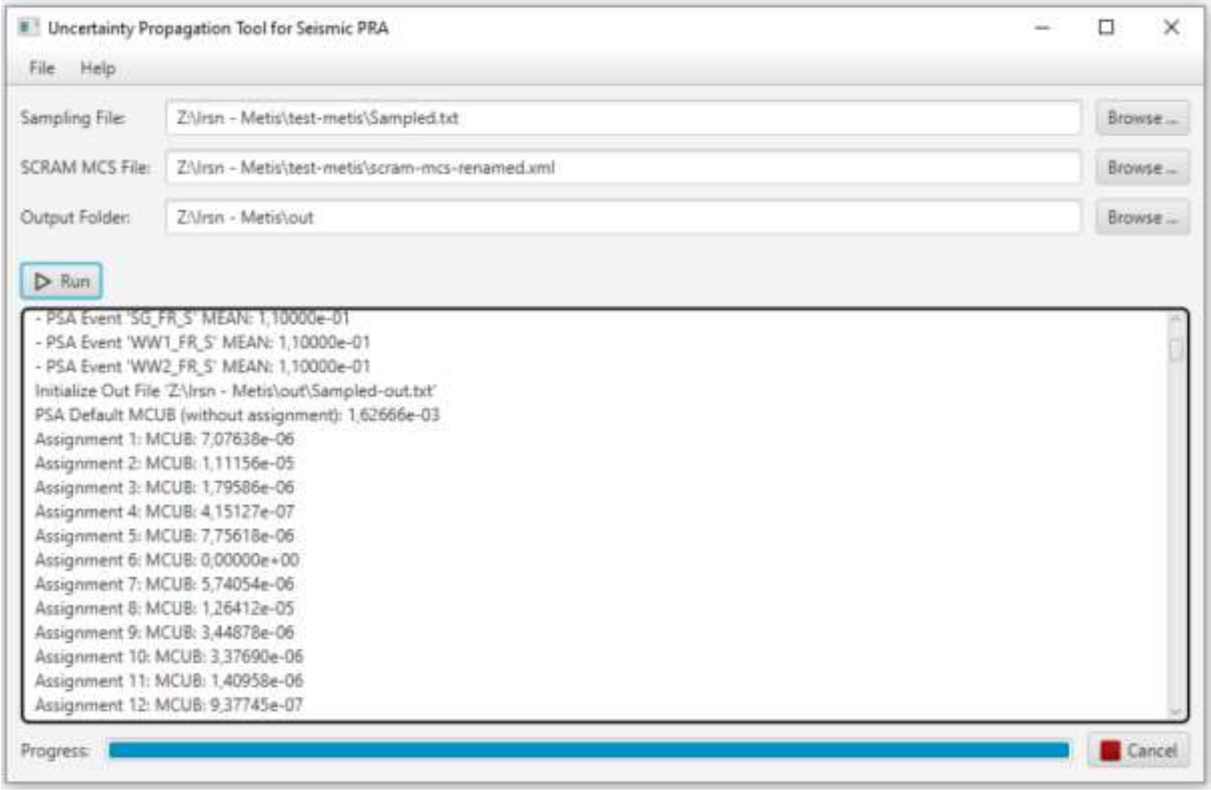


Figure 4. GUI of Seismic PRA Tool

The tool generates a file similar to the original sampling file but with an additional MCUB column containing the calculated CDF values, as shown in Figure 5.

PGA	BUS#_FR_S	DG#_FR_S	EFWSP#_FR_S	IE_EARTHQUAKE	GRID_FR_S	WW#_FR_S	SG#_FR_S	MCUB
6,31766e-01	9,58545e-01	7,35170e-01	9,00945e-03	2,08239e-06	9,99396e-01	1,35866e-04	4,99665e-01	7,07638e-06
8,95216e-01	1,00000e+00	6,39757e-01	9,99995e-01	7,80496e-07	1,00000e+00	9,99200e-01	9,99779e-01	1,11156e-05
3,69309e-01	1,02537e-03	4,87146e-05	6,31158e-02	6,15700e-06	9,08419e-01	2,51771e-03	2,87228e-01	1,79586e-06
2,18589e-01	2,49967e-06	1,14132e-05	6,02964e-04	2,93340e-05	2,91031e-01	3,19433e-06	1,41514e-02	4,15127e-07
4,30864e-01	3,00009e-01	3,86963e-04	5,77370e-01	4,54443e-06	9,41130e-01	1,39969e-01	6,71010e-01	7,75618e-06
8,19944e-03	0,00000e+00	0,00000e+00	0,00000e+00	6,23755e-01	0,00000e+00	0,00000e+00	0,00000e+00	0,00000e+00
1,20135e+00	1,00000e+00	9,73998e-01	9,99628e-01	3,44844e-07	1,00000e+00	9,82004e-01	9,99817e-01	5,74054e-06
4,55248e-01	3,95575e-01	7,42995e-03	7,98971e-01	4,02447e-06	9,91575e-01	3,30811e-01	7,91865e-01	1,26412e-05
1,44961e+00	1,00000e+00	9,98798e-01	9,94345e-01	2,13908e-07	1,00000e+00	8,95683e-01	9,99788e-01	3,44878e-06
1,50816e+00	9,99999e-01	9,68788e-01	1,00000e+00	2,01592e-07	1,00000e+00	9,99989e-01	9,99999e-01	3,37690e-06
3,93867e-01	3,61669e-01	3,92175e-02	2,37030e-04	5,46115e-06	9,85541e-01	9,18263e-07	9,76433e-02	1,40958e-06
4,05701e-01	1,88769e-04	1,02978e-03	3,35699e-03	5,15154e-06	9,99278e-01	3,35509e-05	1,82011e-01	9,37745e-07
5,82249e-01	9,96806e-01	1,02936e-01	9,98552e-01	2,45300e-06	9,99592e-01	9,55711e-01	9,84349e-01	2,52928e-05
1,19282e+00	1,00000e+00	9,99507e-01	9,99533e-01	3,50660e-07	1,00000e+00	9,79017e-01	9,99787e-01	5,89974e-06
6,65194e-02	0,00000e+00	0,00000e+00	0,00000e+00	2,17278e-02	1,22076e-10	0,00000e+00	1,21569e-14	2,22045e-16
1,35515e+00	1,00000e+00	9,88524e-01	9,98035e-01	2,55086e-07	1,00000e+00	9,46102e-01	9,99814e-01	4,20015e-06
4,28031e-01	6,60457e-01	1,72199e-01	8,58955e-01	4,60906e-06	8,93371e-01	4,20743e-01	7,90843e-01	2,38676e-05
3,45032e-01	2,58214e-02	4,08261e-03	3,87153e-04	6,93202e-06	7,11796e-01	1,76369e-06	7,15073e-02	5,01590e-07
4,50778e-01	6,32397e-02	5,71735e-03	4,94185e-01	4,11512e-06	9,98654e-01	9,84899e-02	6,66422e-01	4,54378e-06
4,17928e-01	5,79467e-03	1,31893e-01	1,11959e-02	4,84703e-06	9,88430e-01	1,85936e-04	2,50296e-01	1,31967e-06
1,02336e-01	5,55112e-17	1,12577e-13	0,00000e+00	2,76438e-03	2,01280e-04	0,00000e+00	1,65978e-14	0,00000e+00

Figure 5. Generated results file

Further, a log file is generated to indicate calculation details and warnings, if any. A global log file is generated as well in case of tool errors.

4. Conclusions

This document describes the tool developed within the WP7 Task 3.1. The goal of the tool is to quantify the CDF for each sample provided by the Seismic PSA DataBase tool for uncertainty propagation. The user guide to use the tool is provided in the Appendix.

As discussed in [4], in order to propagate the uncertainty in the results of the seismic model, it is necessary to make the Andromeda/SCRAM framework interact with the SPSADB Tool. The Seismic PRA Tool address this need, however the two software interact within the tool through their results. In particular, in the considered toolchain:

- The SPSADB generates the sampled set of Structures, Systems and Components (SSC) failure probability using a MonteCarlo approach. It is therefore responsible of handling the mathematical laws and the dependencies correlating the SSC failure probability to the level of seismic hazards.
- Andromeda/SCRAM provides the list of the cutset as well as the list of all the basic events that are not included in the SPSADB results (i.e., that are not sampled).

Although, this interaction between the two software (Andromeda/SCRAM and SPSADB) is realized via the tool, the Seismic PRA Tool remains external and independent from the two softwares which have not been modified.

Future work could include developing features to:

- Visualize results (e.g., plot chart),
- Calculate measures to characterize the uncertainty (e.g., error factor, kurtosis, skewness).

5. References

[1] Detailed Work Plan, METIS D1.1, Irmela ZENTNER

[2] Development of seismic database management tool, METIS D7.2, Nicolas DUFLOT

[3] Enhanced version of the PSA calculation engine SCRAM, METIS D7.3, Charles DROSZCZ

[4] Development of an open-source representation format for PSA, METIS D7.1, Mohamed HIBTI

6. Appendix: User Guide

User Guide for Uncertainty Propagation Tool for Seismic PRA

Date : June 25, 2024

Version : 1.0

Summary

This document describes the software tool that performs uncertainty propagation for seismic PRA for software users. This tool is part of the Metis project (WP 7.3, 2024).

Contents

1 Introduction

1.1 Description

The tool calculates CDF values for sets of basic event values (samples) that have been simulated for seismic PRA uncertainty study. Each sample leads to another CDF value. A CDF value represents the top event probability or frequency of an unwanted situation (hazard).

It is not the purpose of the tool to interpret calculated CDF values, the tool rather calculates and exports them. Further CDF analysis would require an external tool.

Please note that the basic event samples are provided by an external tool, the *Seismic PSA DataBase tool (SPSADB)* (developed by IRSN). Appendix 4.1 provides a screenshot of the SPSADB and Appendix 4.2 shows a sample that has been generated from this tool.

Note that the samples are not required to contain values for all PSA basic events (i.e. samples can be *partial*). If not stated, mean values from Scram result are automatically applied by default.

The tool requires further a MCS (Minimal Cut Sets) file. This file contains sets of basic event combinations that may lead to a seismic hazard, what allows the tool to re-calculate a CDF value given per basic event sample.

Currently, exclusively *Scram* MCS results are supported. Scram is an open source fault tree quantification engine (`https://github.com/SCRAM-NG`), that has been used within the Metis project (`https://metis-h2020.eu/`), likewise this tool. An example of a Scram result file (a XML file) is provided in Appendix 4.3.

1.2 Interfaces

Figure 1 summarises the tool interfaces.

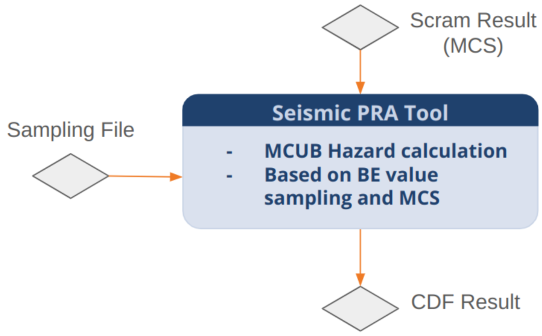


Figure 1: The tool requires a Scram MCS Result and an SPSADB Sampling File and writes finally the CDF Result.

The following interfaces are to consider:

- (Input) Scram Result (MCS): Minimal cutset analysis result obtained from Scram when quantifying a seismic PSA Model.
- (Input) Sampling File: Sampling File that has been generated with SPSADB.
- (Output) CDF Result: Result file produced by the application to store calculated CDF values.

1.3 PRA Toolchain

Figure 2 presents the complete toolchain to consider.

Because Scram is a low level fault tree quantification engine not designed to quantify a PSA model directly, an additional software "Andromeda" is to consider in interaction with Scram: First, Andromeda calculates a MFT (Master Fault Tree) which is then processed by Scram and

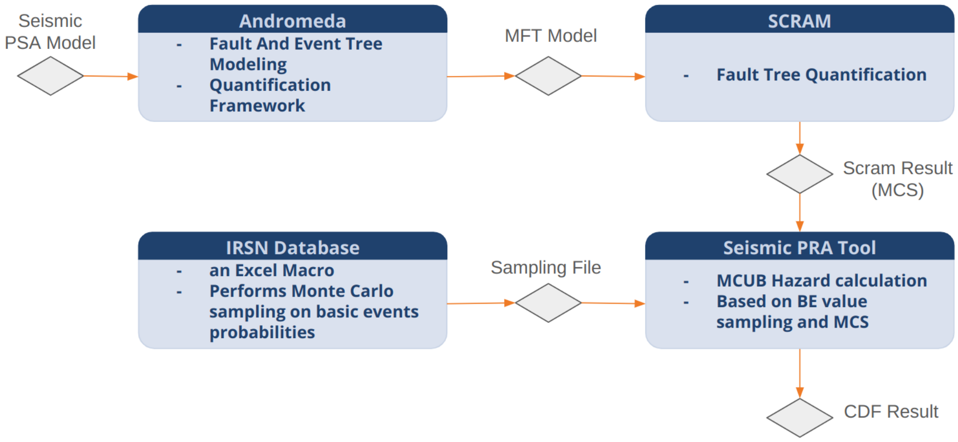


Figure 2: Complete Toolchain: Andromeda and Scram produce the MCS Result and SPSADB the Sampling file. Both are input for this tool.

finally post treated by Andromeda in order to inject frequency information (and to perform some other actions Scram is not capable of).

In order to generate the basic event samples, SPSADB performs Monte Carlo simulations and finally exports the sampling file.

1.4 Frequency vs Probability

The tool supports *frequency* and *probability* CDF calculations, depending to whether the Scram MCS file is of type frequency or probability.

Please note that Scram does not support the notion of *frequencies* (as many other fault tree quantification engines). This is why Andromeda performs a post processing in order to inject frequency information into Scram result files (as mentioned in 1.3).

Andromeda min 2.16.1 is needed for frequency injection. Scram results calculated with previous Andromeda versions will always lead to probability CDF calculations.

A Scram MCS of type frequency is given in Appendix 4.4.

2 Application

2.1 Setup

The application is delivered as zip file, which contains the following items:

- uncertainty-propagation-tool-seismic-pra.exe: Application Starter
- jre/: Directory that contains the Java 17 JRE (Java Runtime Environment version 17)

- test-metis/: Directory that contains test files for the Metis project

To install the application, unzip the file in a directory of choice.

To start the application, execute the application starter (the exe file).

2.2 Execution

The application provides a graphical user interface (GUI) which is illustrated in Figure 3.

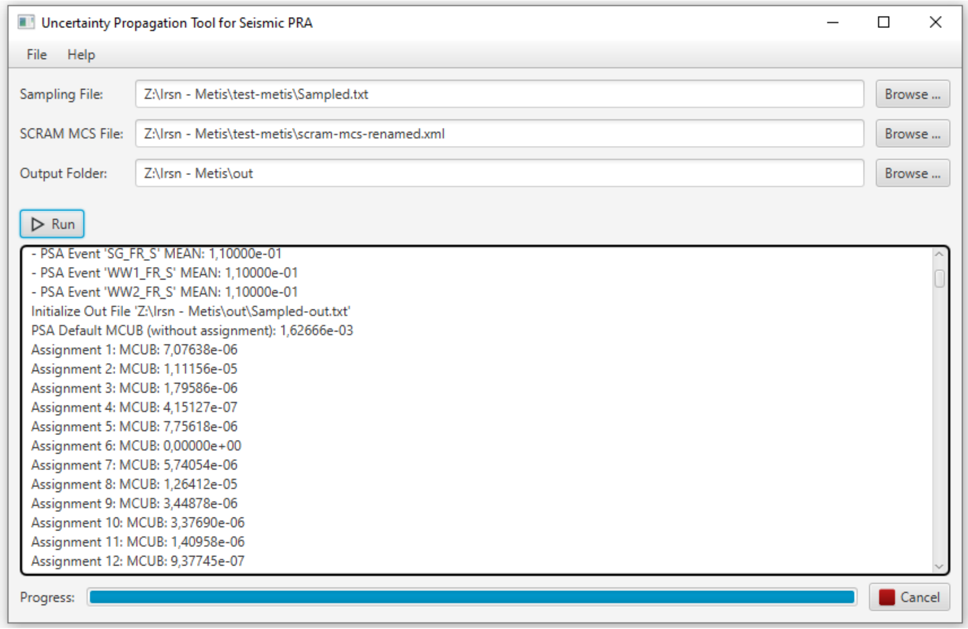


Figure 3: Graphical User Interface of the application

Configuration:

- Sampling File: The sampling file that has been exported by SPSADB.
- SCRAM MCS File: Andromeda / Scram Result file "mcs-result-renamed.xml" (*).
- Output Folder: A folder of choice to store the result.

(*) Note that Andromeda / Scram creates also another file "mcs-result.xml". This is the raw Scram file. Please use exclusively file "mcs-result-renamed" that has been post-processed by Andromeda.

Execution: Button **RUN** triggers the execution.

Log: A log area below the run button displays the application log, see Section 2.4 for more information.

2.3 Result

After successful execution, the tool creates a result file in the output folder. The name of the result file is <SAMPLING-INPUT-FILE>-out.txt, where SAMPLING-INPUT-FILE corresponds to the Metis sampling filename that has been specified as input parameter.

The result file is a new sampling that provides an additional MBUC column. This column indicates the CDF top event result for each sampling line, as illustrated in Figure 4.

PGA	BUS#_FR_S	DG#_FR_S	EFWSP#_FR_S	IE_EARTHQUAKE	GRID_FR_S	WW#_FR_S	SG#_FR_S	MCUB
6,31766e-01	9,58545e-01	7,35170e-01	9,00945e-03	2,08239e-06	9,99396e-01	1,35866e-04	4,99665e-01	7,07638e-06
8,95216e-01	1,00000e+00	6,39757e-01	9,99995e-01	7,80496e-07	1,00000e+00	9,99200e-01	9,99779e-01	1,11156e-05
3,69309e-01	1,02537e-03	4,87146e-05	6,31158e-02	6,15700e-06	9,08419e-01	2,51771e-03	2,87228e-01	1,79586e-06
2,18589e-01	2,49967e-06	1,14132e-05	6,02964e-04	2,93340e-05	2,91031e-01	3,19433e-06	1,41514e-02	4,15127e-07
4,30864e-01	3,00009e-01	3,86963e-04	5,77370e-01	4,54443e-06	9,41130e-01	1,39969e-01	6,71010e-01	7,75618e-06
8,19944e-03	0,00000e+00	0,00000e+00	0,00000e+00	6,23755e-01	0,00000e+00	0,00000e+00	0,00000e+00	0,00000e+00
1,20135e+00	1,00000e+00	9,73998e-01	9,99628e-01	3,44844e-07	1,00000e+00	9,82004e-01	9,99817e-01	5,74054e-06
4,55248e-01	3,95575e-01	7,42995e-03	7,98971e-01	4,02447e-06	9,91575e-01	3,30811e-01	7,91865e-01	1,26412e-05
1,44961e+00	1,00000e+00	9,98798e-01	9,94345e-01	2,13908e-07	1,00000e+00	8,95683e-01	9,99788e-01	3,44878e-06
1,50816e+00	9,99999e-01	9,68788e-01	1,00000e+00	2,01592e-07	1,00000e+00	9,99989e-01	9,99999e-01	3,37690e-06
3,93867e-01	3,61669e-01	3,92175e-02	2,37030e-04	5,46115e-06	9,85541e-01	9,18263e-07	9,76433e-02	1,40958e-06
4,05701e-01	1,88769e-04	1,02978e-03	3,35699e-03	5,15154e-06	9,99278e-01	3,35509e-05	1,82011e-01	9,37745e-07
5,82249e-01	9,96806e-01	1,02936e-01	9,98552e-01	2,45300e-06	9,99592e-01	9,55711e-01	9,84349e-01	2,52928e-05
1,19282e+00	1,00000e+00	9,99507e-01	9,99533e-01	3,50660e-07	1,00000e+00	9,79017e-01	9,99787e-01	5,89974e-06
6,65194e-02	0,00000e+00	0,00000e+00	0,00000e+00	2,17278e-02	1,22076e-10	0,00000e+00	1,21569e-14	2,22045e-16
1,35515e+00	1,00000e+00	9,88524e-01	9,98035e-01	2,55086e-07	1,00000e+00	9,46102e-01	9,99814e-01	4,20015e-06
4,28031e-01	6,60457e-01	1,72199e-01	8,58955e-01	4,60906e-06	8,93371e-01	4,20743e-01	7,90843e-01	2,38676e-05
3,45032e-01	2,58214e-02	4,08261e-03	3,87153e-04	6,93202e-06	7,11796e-01	1,76369e-06	7,15073e-02	5,01590e-07
4,50778e-01	6,32397e-02	5,71735e-03	4,94185e-01	4,11512e-06	9,98654e-01	9,84899e-02	6,66422e-01	4,54378e-06
4,17928e-01	5,79467e-03	1,31893e-01	1,11959e-02	4,84703e-06	9,88430e-01	1,85936e-04	2,50296e-01	1,31967e-06
1,02336e-01	5,55112e-17	1,12577e-13	0,00000e+00	2,76438e-03	2,01280e-04	0,00000e+00	1,65978e-14	0,00000e+00

Figure 4: Sampling Result File with additional MCUB column

Please note that the tool uses scientific representation for all floating numbers. This may not be the case with the input sampling file.

2.4 Logging

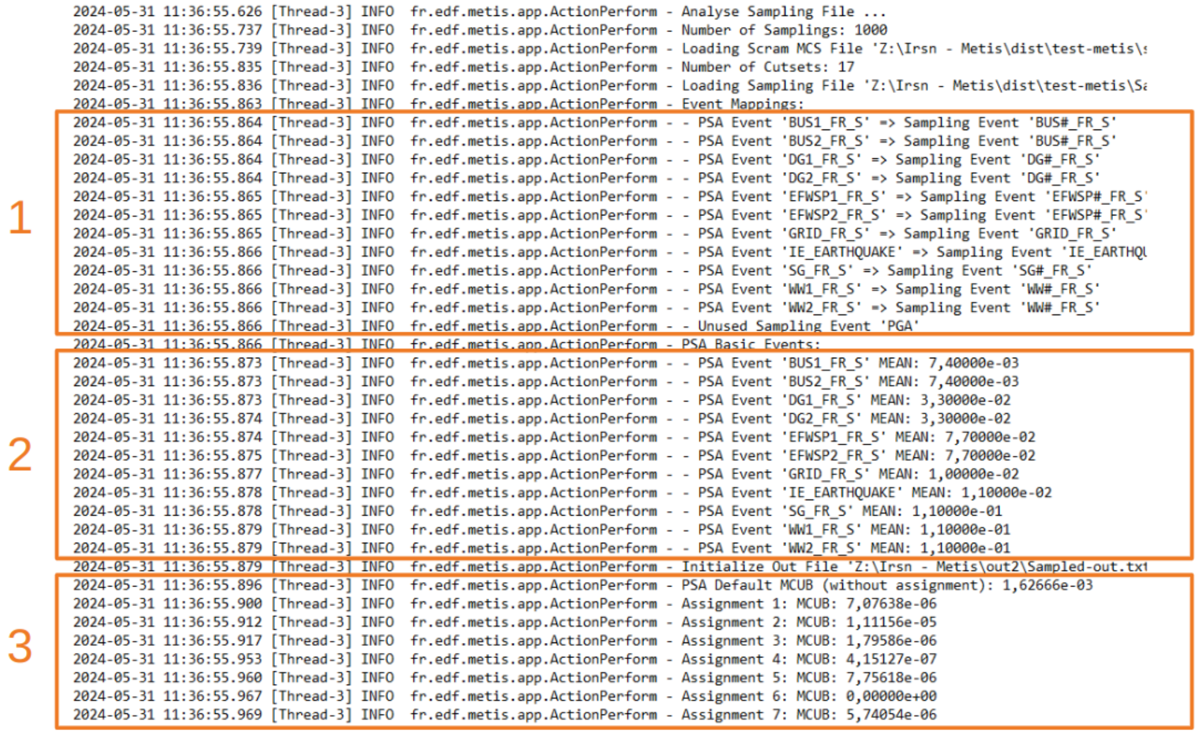
A detailed log is created per generation, in order to identify potential problems and to control the execution. An example log is illustrated in Figure 5.

Different log sections are of interest (as numbered in the example log):

1. Mapping between PSA Events and Sampling Patterns: Indicates for each PSA Basic Event to which Sampling Basic Event Pattern it has been mapped to. In case no mapping applies the MEAN value from Scram result is applied.

2. Mean values of Scram PSA result: Indicates the MEAN values of PSA Basic Events that have been read from Scram result.

3. MCUB value for each sample iteration: The CDF quantification result obtained for each sampling line by applying MCUB algorithm (see Section 3.2).




```
2024-05-31 11:36:55.626 [Thread-3] INFO  fr.edf.metis.app.ActionPerform - Analyse Sampling File ...
2024-05-31 11:36:55.737 [Thread-3] INFO  fr.edf.metis.app.ActionPerform - Number of Samplings: 1000
2024-05-31 11:36:55.739 [Thread-3] INFO  fr.edf.metis.app.ActionPerform - Loading Scram MCS File 'Z:\Irsn - Metis\dist\test-metis\
2024-05-31 11:36:55.835 [Thread-3] INFO  fr.edf.metis.app.ActionPerform - Number of Cutsets: 17
2024-05-31 11:36:55.836 [Thread-3] INFO  fr.edf.metis.app.ActionPerform - Loading Sampling File 'Z:\Irsn - Metis\dist\test-metis\Sa
2024-05-31 11:36:55.863 [Thread-3] INFO  fr.edf.metis.app.ActionPerform - Event Mappings:
2024-05-31 11:36:55.864 [Thread-3] INFO  fr.edf.metis.app.ActionPerform - - PSA Event 'BUS1_FR_S' => Sampling Event 'BUS#_FR_S'
2024-05-31 11:36:55.864 [Thread-3] INFO  fr.edf.metis.app.ActionPerform - - PSA Event 'BUS2_FR_S' => Sampling Event 'BUS#_FR_S'
2024-05-31 11:36:55.864 [Thread-3] INFO  fr.edf.metis.app.ActionPerform - - PSA Event 'DG1_FR_S' => Sampling Event 'DG#_FR_S'
2024-05-31 11:36:55.864 [Thread-3] INFO  fr.edf.metis.app.ActionPerform - - PSA Event 'DG2_FR_S' => Sampling Event 'DG#_FR_S'
2024-05-31 11:36:55.865 [Thread-3] INFO  fr.edf.metis.app.ActionPerform - - PSA Event 'EFWSP1_FR_S' => Sampling Event 'EFWSP#_FR_S'
2024-05-31 11:36:55.865 [Thread-3] INFO  fr.edf.metis.app.ActionPerform - - PSA Event 'EFWSP2_FR_S' => Sampling Event 'EFWSP#_FR_S'
2024-05-31 11:36:55.865 [Thread-3] INFO  fr.edf.metis.app.ActionPerform - - PSA Event 'GRID_FR_S' => Sampling Event 'GRID_FR_S'
2024-05-31 11:36:55.866 [Thread-3] INFO  fr.edf.metis.app.ActionPerform - - PSA Event 'IE_EARTHQUAKE' => Sampling Event 'IE_EARTHQU
2024-05-31 11:36:55.866 [Thread-3] INFO  fr.edf.metis.app.ActionPerform - - PSA Event 'SG_FR_S' => Sampling Event 'SG#_FR_S'
2024-05-31 11:36:55.866 [Thread-3] INFO  fr.edf.metis.app.ActionPerform - - PSA Event 'WW1_FR_S' => Sampling Event 'WW#_FR_S'
2024-05-31 11:36:55.866 [Thread-3] INFO  fr.edf.metis.app.ActionPerform - - PSA Event 'WW2_FR_S' => Sampling Event 'WW#_FR_S'
2024-05-31 11:36:55.866 [Thread-3] INFO  fr.edf.metis.app.ActionPerform - - Unused Sampling Event 'PGA'
2024-05-31 11:36:55.866 [Thread-3] INFO  fr.edf.metis.app.ActionPerform - PSA Basic Events:
2024-05-31 11:36:55.873 [Thread-3] INFO  fr.edf.metis.app.ActionPerform - - PSA Event 'BUS1_FR_S' MEAN: 7,40000e-03
2024-05-31 11:36:55.873 [Thread-3] INFO  fr.edf.metis.app.ActionPerform - - PSA Event 'BUS2_FR_S' MEAN: 7,40000e-03
2024-05-31 11:36:55.873 [Thread-3] INFO  fr.edf.metis.app.ActionPerform - - PSA Event 'DG1_FR_S' MEAN: 3,30000e-02
2024-05-31 11:36:55.874 [Thread-3] INFO  fr.edf.metis.app.ActionPerform - - PSA Event 'DG2_FR_S' MEAN: 3,30000e-02
2024-05-31 11:36:55.874 [Thread-3] INFO  fr.edf.metis.app.ActionPerform - - PSA Event 'EFWSP1_FR_S' MEAN: 7,70000e-02
2024-05-31 11:36:55.875 [Thread-3] INFO  fr.edf.metis.app.ActionPerform - - PSA Event 'EFWSP2_FR_S' MEAN: 7,70000e-02
2024-05-31 11:36:55.877 [Thread-3] INFO  fr.edf.metis.app.ActionPerform - - PSA Event 'GRID_FR_S' MEAN: 1,00000e-02
2024-05-31 11:36:55.878 [Thread-3] INFO  fr.edf.metis.app.ActionPerform - - PSA Event 'IE_EARTHQUAKE' MEAN: 1,10000e-02
2024-05-31 11:36:55.878 [Thread-3] INFO  fr.edf.metis.app.ActionPerform - - PSA Event 'SG_FR_S' MEAN: 1,10000e-01
2024-05-31 11:36:55.879 [Thread-3] INFO  fr.edf.metis.app.ActionPerform - - PSA Event 'WW1_FR_S' MEAN: 1,10000e-01
2024-05-31 11:36:55.879 [Thread-3] INFO  fr.edf.metis.app.ActionPerform - - PSA Event 'WW2_FR_S' MEAN: 1,10000e-01
2024-05-31 11:36:55.879 [Thread-3] INFO  fr.edf.metis.app.ActionPerform - Initialize Out File 'Z:\Irsn - Metis\out2\Sampled-out.txt
2024-05-31 11:36:55.896 [Thread-3] INFO  fr.edf.metis.app.ActionPerform - PSA Default MCUB (without assignment): 1,62666e-03
2024-05-31 11:36:55.900 [Thread-3] INFO  fr.edf.metis.app.ActionPerform - Assignment 1: MCUB: 7,07638e-06
2024-05-31 11:36:55.912 [Thread-3] INFO  fr.edf.metis.app.ActionPerform - Assignment 2: MCUB: 1,11156e-05
2024-05-31 11:36:55.917 [Thread-3] INFO  fr.edf.metis.app.ActionPerform - Assignment 3: MCUB: 1,79586e-06
2024-05-31 11:36:55.953 [Thread-3] INFO  fr.edf.metis.app.ActionPerform - Assignment 4: MCUB: 4,15127e-07
2024-05-31 11:36:55.960 [Thread-3] INFO  fr.edf.metis.app.ActionPerform - Assignment 5: MCUB: 7,75618e-06
2024-05-31 11:36:55.967 [Thread-3] INFO  fr.edf.metis.app.ActionPerform - Assignment 6: MCUB: 0,00000e+00
2024-05-31 11:36:55.969 [Thread-3] INFO  fr.edf.metis.app.ActionPerform - Assignment 7: MCUB: 5,74054e-06
```

Figure 5: Log shows mapping of basic events, PSA MEAN values and calculated CDF values.

The log is shown in the GUI log area and also printed into a log file. This logfile is created next to the result file.

Another log file, an application log "application.log", is created next to the application starter as soon as the application starts. It provides principal information of each generation and indicates the path of detailed log files.

3 Technical Insights

3.1 Sample Processing

3.1.1 Phase I: Initialization

In the first phase, the tool performs the following:

- Read Scram result of seismic PSA model quantification
- Read SPSADB sampling file
- Construct internal cutset list
- Initialize cutset list with basic event MEAN values according to Scram MCS result (the Scram result provides these values)

- Construct mapping between cutset events and sampling events (by using pattern matching)

The initialisation of basic events by their MEAN values allows samples to be *partial*: Samples are not required to contain all basic events of a PSA model. Mean values are applied by default.

The matching between cutset and sampling events supports special character '#' (hash). The hash is a placeholder for zero or more alphabetical characters (including '-' and '_') and digits.

3.1.2 Phase II: CDF calculation

The second phase processes the samples one by one, as shown in Figure 6:

- Apply basic event values from the current sample to cutset list
- Calculate probability / frequency values of all cutsets
- Calculate CDF value with MCUB algorithm (see CDF Calculation)

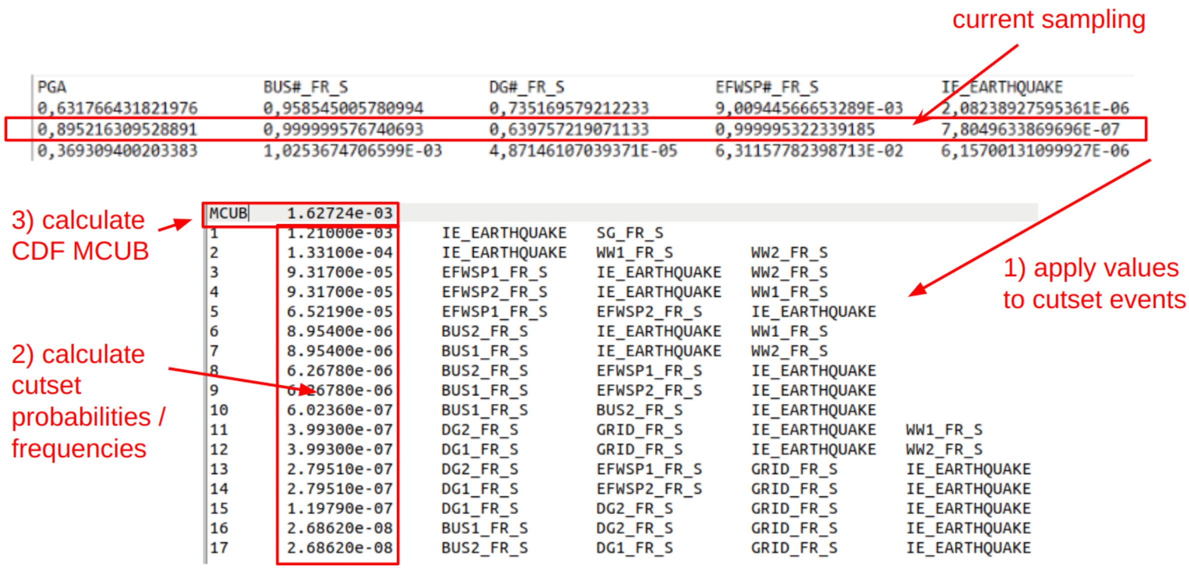


Figure 6: Phase II: At each iteration, basic event values from the current sample are applied (1) in order to re-calculate cutset values (2) and the final CDF value (3).

3.1.3 Phase III: Result Export

The third phase does the following:

- Export a new sampling file with additional CDF column
- Print CDF value for each sampling in the additional column

3.2 MCUB Algorithm

The top event CDF is calculated by using the *MCUB* (min cut upper bound) algorithm. This algorithm is quite popular in fault and event tree assessment mainly because it provides a good comprise between rapid execution time and approximation quality (the algorithm does not calculate the exact value but an approximation). It fits in particular for low probability / frequency quantification.

Depending on whether the quantification is of type 'probability' or 'frequency', the algorithm works slightly different.

3.2.1 Probability

The probability of each cutset is:

$$P(MCS_i) = P(e_{i1}) \times P(e_{i2}) \times \cdots \times P(e_{ik})$$

The CDF MCUB probability of the top event is:

$$P_{MCUB} = 1 - \prod_i (1 - P(\mathrm{MCS}_i))$$

3.2.2 Frequency

For frequency quantifications, the algorithm becomes more specific.

Hypothesis: The hypothesis is that there is exactly one frequency basic event in each cutset. Cutsets that do not satisfy this hypothesis are ignored.

Three steps are to consider:

- Step 1: Group cutsets by frequency event
  - Identify frequency event of each cutset
  - Create one group of cutsets per frequency event j
  - Calculate P(MCS_ij) by ignoring frequency events
- Step 2: Calculate MCUB_j for each cutset group:

$$P_{MCUB,j} = 1 - \prod_i (1 - P(\mathrm{MCS}_{ij}))$$

- Step 3: Calculate CDF MCUB frequency for top event:

$$P_{MCUB} = \sum_j (freq_j \times P_{MCUB,j})$$

4 Appendix

4.1 Seismic PSA DataBase tool (SPSADB)

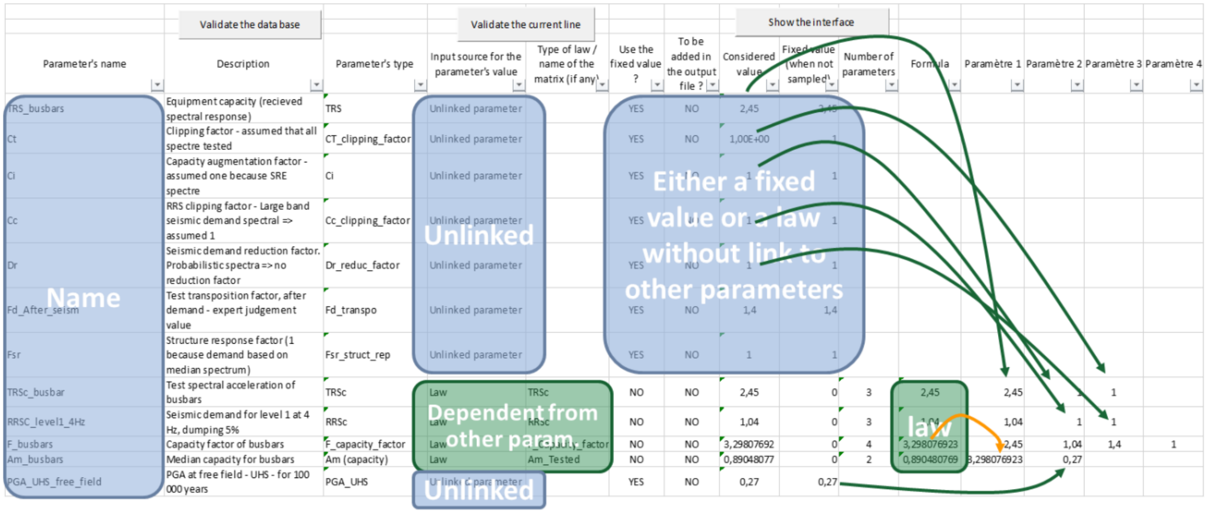


Figure 7: SPSADB permits to model seismic related dependencies between basic events and to generate basic event values (samples) based on a Monte Carlo approach.

4.2 Sampling File Example

PGA	BUS#_FR_S	DG#_FR_S	EFWSP#_FR_S	IE_EARTHQUAKE
0,631766431821976	0,958545005780994	0,735169579212233	9,00944566653289E-03	2,08238927595361E-06
0,895216309528891	0,999999576740693	0,639757219071133	0,999995322339185	7,8049633869696E-07
0,369309400203383	1,0253674706599E-03	4,87146107039371E-05	6,31157782398713E-02	6,15700131099927E-06
0,218589120332249	2,49966501342236E-06	1,14132384433918E-05	6,02964350335355E-04	2,93340233496909E-05
0,430864131657383	0,300008750271856	3,86963069182289E-04	0,577369888045874	4,54443312188294E-06
8,19944339915807E-03	0	0	0	0,623754820591077
1,20135036624116	0,99999999997932	0,973998169926467	0,999627763602484	3,44843730685638E-07
0,455247607068944	0,395574587696237	7,42994679091913E-03	0,798971259680444	4,02447282822789E-06
1,44960897232129	0,999999999999998	0,998798286941402	0,99434475895857	2,1390809308244E-07
1,50815833988487	0,999998602201665	0,968787666670655	0,999999982658829	2,01592375751637E-07
0,393866876749989	0,361669136461354	3,92174948192753E-02	2,37029888751017E-04	5,46114800997863E-06
0,405701444503897	1,88769252081999E-04	1,02977925612913E-03	0,003356988908855	5,15153676405453E-06
0,582248787465256	0,996806394779048	0,102935603809089	0,998552054440125	2,45300439608298E-06
1,19281770930444	0,999999996942478	0,999507402598436	0,999532662486534	3,50660143024719E-07
6,65193855072379E-02	0	0	0	2,17277803528363E-02
1,35515228980344	0,999999736132938	0,988523778405945	0,998035493753599	2,55086099765215E-07
0,428030645902329	0,660457093378856	0,172198571313121	0,858954590691097	4,6090555913516E-06
0,34503226398094	2,58214324628961E-02	4,08261046359215E-03	3,87152515720135E-04	6,93202237520494E-06
0,450777783787752	6,32396668487856E-02	5,71734740960561E-03	0,494184679651703	4,11512082345022E-06
0,417928076787056	5,79466589059419E-03	0,131893058044493	1,11959209348384E-02	4,84703243815676E-06
0,102336103841326	5,55111512312578E-17	1,12576614696991E-13	0	2,76437784686122E-03
0,463727700192256	0,360119285262963	2,00182949989153E-03	8,73111805668292E-04	3,85794811142817E-06

Figure 8: Example of a sample file (generated by SPSADB): Rows represent samples, columns represent basic events. The header line provides basic event name patterns.

4.3 Scram Result Example (Probability)

```
<results>
  <sum-of-products name="top" basic-events="11" products="17" probability="0.00162666" distribution="0 1 9 7">
    <product order="4" probability="1.1979e-07" contribution="7.36156e-05">
      <basic-event name="GRID_FR_S"/>
      <basic-event name="DG2_FR_S"/>
      <basic-event name="DG1_FR_S"/>
      <basic-event name="IE_EARTHQUAKE"/>
    </product>
    <product order="4" probability="2.6862e-08" contribution="1.65077e-05">
      <basic-event name="GRID_FR_S"/>
      <basic-event name="DG2_FR_S"/>
      <basic-event name="BUS1_FR_S"/>
      <basic-event name="IE_EARTHQUAKE"/>
    </product>
```

Figure 9: Example of a Scram MCS result of type probability: all basic events are of type probability.

4.4 Scram Result Example (Frequency)

```
<results>
  <sum-of-products name="top" basic-events="11" products="17" probability="0.00162666" distribution="0 1 9 7">
    <product order="4" probability="1.1979e-07" contribution="7.36156e-05">
      <basic-event name="GRID_FR_S"/>
      <basic-event name="DG2_FR_S"/>
      <basic-event name="DG1_FR_S"/>
      <basic-event name="IE_EARTHQUAKE" isFreq="true"/>
    </product>
    <product order="4" probability="2.6862e-08" contribution="1.65077e-05">
      <basic-event name="GRID_FR_S"/>
      <basic-event name="DG2_FR_S"/>
      <basic-event name="BUS1_FR_S"/>
      <basic-event name="IE_EARTHQUAKE" isFreq="true"/>
    </product>
```

Figure 10: Example of a Scram MCS result of type frequency: each product (minimal cutset) contains IE-EARTHQUAKE of type frequency (indicated by is-freq="true").