METIS

Research and Innovation Action (RIA)

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Detailed work plan

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Summary

The purpose of this deliverable is to provide detailed information on the work program, in particular defining with precision the activities of each partner within each task and identifying the involved persons.

Approval

Date	By
2020-11-30 19:47:22	Dr. Irmela ZENTNER (EDF)
2020-11-30 19:48:13	Dr. Irmela ZENTNER (EDF)

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Abbreviations & Acronyms

Acronym	Description
WP	Work Package
WPL	Work Package Leader

Summary

The purpose of this deliverable D1.1 is to provide detailed information on the work program, in particular defining with precision the activities of each partner within each task and identifying the involved persons.

Keywords

Nuclear, seismic risk, safety, work plan, work package.

Introduction

The purpose of this deliverable D1.1 is to provide detailed information on the work program, in particular defining with precision the activities of each partner within each task and identifying the involved persons.

2 Description of WP1 Management activities

Start date: M1; End date: M48

Work Package Leader: Irmela Zentner (EDF)

Task 1.1 Project coordination

Start date: M1 End date: M48

Task Leaders: Irmela Zentner (EDF)

Contributors: Gilles Quénéhervé (LGI)

This task groups the coordinator's activity of organization and monitoring of the work progress:

- Elaboration of the detailed work plan, established at the beginning of the project by WPLs, defining with precision the activities of each Partner within each task and identifying the involved persons.
- Supervision of project deliverables, progress milestones, and planning;
- Risk analysis and management plan throughout the project;
- Performance indicators identification and follow up;
- Continuous monitoring of Partners' scientific achievements; in particular organize scientific review of the deliverables and work performed by the Partners; review of technical deliverables is performed, according to availability and required expertise, by IAB, EAB or other project partners

Actions	Start Date	Due Date	Responsible
Action 1: Establish report with Detailed Work plan	M1	M3	Irmela Zentner
Action 2: Organize scientific review of the deliverables	M1	M48	Irmela Zentner
Action 3: Supervision of project progress and performance	M1	M48	Gilles Quénéhervé &Irmela Zentner
Action 3: Risk analysis & management	M1	M48	Irmela Zentner together with WPLs

Task 1.2 Quality Management

Start date: M1 End date: M48

Task Leaders: Gilles Quénéhervé (LGI)

Contributors: Irmela Zentner (EDF)

This includes the following:

- Elaboration and application of a Project Quality Plan, internal guideline detailing project procedures (quality assurance, document management, document templates, etc.), in accordance with the project management and organisation defined in the Contract;
- Set-up and maintenance of a web-based document management tool for publishing and exchanging documents within the consortium;
- Monitoring of workflow and information management, ensuring good communication within the consortium.
- Maintenance of Partners' contact information, including emailing lists;

Actions	Start Date	Due Date	Responsible
Action 1: Prepare project quality plan	M1	M3	Gilles Quénéhervé
Action 2: Consolidate the mailing lists for each WP	M2	M3	Gilles Quénéhervé
Action 3: Support METIS partners in the use of METIS FLEXX	M1	M48	Gilles Quénéhervé

Task 1.3 Project Secretariat and meetings organisation

Start date: M1 End date: M48

Task Leaders: Gilles Quénéhervé (LGI)

Contributors: Irmela Zentner (EDF)

This includes the following:

- Preparation, organization and minutes of the kick-off meeting with all Partners at the beginning of the project;
- Preparation, organization and minutes of project meetings every year.
- Preparation, organization and minutes of ExCom meetings; physical meetings jointly with each project meetings and
- possible additional phone meetings;
- Preparation, organization and minutes of the Governing Board meetings (jointly with the project meetings);
- Handling of the project correspondence;
- Acting as entry point for the project for external bodies;

- Support to project Partners upon request;
- More generally, ensuring that all Partners share the same level of information on general issues concerning the project, i.e. contract and project management, work progress, dissemination, etc.

Actions	Start Date	Due Date	Responsible
Action 1: Minutes of meetings	M1	M48	Gilles Quénéhervé
Action 2: Project correspondence (logistics)	M1	M48	Gilles Quénéhervé
Action 3: Information sharing and Support to partners upon request	M1	M48	Gilles Quénéhervé & Irmela Zentner

Task 1.4 Contractual & Financial Management

Start date: M1 End date: M48

Task Leaders: Gilles Quénéhervé (LGI)

Contributors: Irmela Zentner (EDF)

This task comprises the management of the administrative and financial issues:

- Maintenance of the Grant and Consortium Agreements;
- Management of funds and maintenance of budget files;
- Coordination of the periodic (M18, M36 and M48) and final (M48) reports to the EC;
- Advice on contractual / financial matters to project Partners upon request.

Actions	Start Date	Due Date	Responsible
Action 1: Distribute consortium agreement to all partners	M1	M2	Gilles Quénéhervé
Action 2: Distribute EC payments to the partners	M1	M3	Gilles Quénéhervé
Action 3: Coordinate scientific & financial reportings	M12	M48	Irmela Zentner & Gilles Quénéhervé

Task 1.5 External & Internal Advisory Board

Start date: M1 End date: M48

Task Leaders: *Irmela Zentner (EDF)*

This task comprises the management of the External and Internal Advisory Boards:

- Organisation of yearly EAB & IAB meetings (jointly with the project meetings); the EAB recommendations will be summarized by the EAB chairman nominated at the beginning of each meeting and disseminated to project partners for discussion
- Monitor and propose participation of EAB to WP progress meetings for advise on scientific orientations and experience feedback, organization of participation of EAB to progress meetings if approved by Governing Board
- Organize IAB meetings separately or jointly with EAB meetings

Actions	**Start Date**	**Due Date**	**Responsible**
Action 1: Prepare first meeting of the EAB	M1	M3	Irmela Zentner
Action 2: Prepare ToR of the IAB & EAB including their role in revising the METIS deliverables	M1	M3	Irmela Zentner
Action 3: Organize the IAB & EAB meetings and disseminate reports	M1	M47	Irmela Zentner

Task 1.6 Data Management

Start date: M1 End date: M48

Task Leaders: Gilles Quénéhervé (LGI)

Contributors: Irmela Zentner (EDF)
LGI will develop and implement a data management plan (D1.4 month 6) that will include objectives and operational steps for METIS to ensure the security and availability (for consortium internal and external cooperation) of all types of data generated in METIS, not only during project life, but also as a long-term legacy (for more details see section 2.2)

Actions	**Start Date**	**Due Date**	**Responsible**
Action 1: Prepare the DMP	M1	M6	Gilles Quénéhervé

Deliverables

Number	**Title**	**Due Date**	**Responsible**
D1.1	Detailed work plan	M3	Irmela Zentner

D1.2	Project quality plan	M3	Gilles Quénéhervé
D1.3	Summary of the recommendations by the Advisory Board	M47	Irmela Zentner
D1.4	Data Management Plan	M6	Gilles Quénéhervé

Milestones of WP1

Number	Title	Verification mean	Due Date	Responsible
MS1	Kick off meeting	Minutes of the meeting	M2	Irmela Zentner & Gilles Quénéhervé
MS2	Detailed work plan	Report	M3	Irmela Zentner
MS3	First meeting of the External Advisory Board	Minutes of the meeting	M3	Irmela Zentner
MS4	Constitution of EAB	ToR	M6	Irmela Zentner

Interaction with other WPs

Number	Interaction description	Responsible
2	Task 1.1 Interaction with technical WP for production of deliverables	EDF
2	Task 1.6 Data sharing tool developed in WP3	LGI
3	Task 1.5 Interaction with technical WP to implement EAB recommendations	EDF

Risks of WP1

Contractual risks (number, descripTtion, risk-mitigation), probability (1=low; 5=high) that the risk occurs and impact (1=low; 5=high) if the risk occurs. Other risks (not in GA) can be added so they can be followed during the project. Risk mitigation: P=preventive actions / C=contingency actions.

Numb er	Risk description	Risk mitigation	Proba	Impact
1	Covid pandemic continues throughout 2021 and 2022	Organisation of the meetings online	5	3
2	WP1 is dependent on progress and outcomes of the other WPs and input of project partners	Clear overall plan for the METIS project managed	2	3
3	EAB not available for review of project outcome	IAB or experts among project partners contribute to revise deliverables	2	3

3 Description of WP2 "Dissemination, exploitation and training" activities

Start date: M01; End date: M48

Work Package Leader- co-Leader: Ionel Nistor, Simone Sullivan, EDF Energy R&D UKC Centre (UKC)

Task 2.1.: Project dissemination and communication plan (M01-M06)

Start date: M01 End date: M06

Task Leaders: Emma Luguterah **UKC**

Contributors: Mya Belden, **LGI**

This task includes the drafting and maintenance of the project's dissemination and communication plan, and the implementation of the associated activities. This plan will be developed at the start of the project and will detail the communication strategy, the target audiences, messages and end-user group, along with an assessment of their impact through key performance indicators.

The dissemination and communication plan will leverage the experience gained during previous H2020 projects and will be 'living' document which will be reviewed and revised periodically during the project.

The role of partner **UKC** is to lead on the drafting and maintenance of the project's dissemination and communication plan

The role of partner **LGI** is to support UKC to prepare the plan, leveraging experience of dissemination and communication planning for other H2020 projects

Actions	Start Date	Due Date	Responsible
▪ Action 1: Agree template / form of the Project dissemination and communication plan	M01	M02	UKC, LGI
▪ Action 2: Prepare draft plan and circulate to partners	M01	M03	UKC, LGI
▪ Action 3: Finalise plan and submit D2.2	M04	M06	UKC

Task 2.2: Communication

Start date: M01 End date: M48

Task Leaders: Mya Belden, **LGI**

Contributors: Clara Demange, **LGI**, Emma Luguterah, **UKC**, Irmela Zentner, **EDF**

The communication task will implement the actions detailed in the communication plan.

A series of tools and actions will be designed and rolled out:

- A project brand (logo and visual identity) will be designed, including presentation and document templates
- A project flyer and a roll-up (and/or posters) will be designed and distributed/displayed at events to promote the project
- A public website, integrating a document sharing platform for internal and external communication will be set up. This private area will also ease reporting/monitoring activities, meeting and event management, internal communication within the project. The public website will provide general information on the project, share news and announcements about the project's progress, give access to the publishable documents produced by the project, and communicate on the project's events. The content of the site will be maintained and updated monthly, in particular the publications and events sections according to the milestones achieved in the project and the needs of external communication.
- Press release at the beginning and the end of the project will be issued by UKC

- Professional social media accounts (Researchgate, LinkedIn) will be created and updated by EDF targeting the scientific community.

In addition, yearly newsletters will be drafted and distributed to inform stakeholders of the project's progress. It will include a word from the coordinator, a highlight per work package, relevant news, relevant workshops and conferences.

The role of partner **LGI** is to lead on the implementation of the communication and dissemination activities, including preparing the project branding and templates, public website, project flyer/posters, video, yearly newsletters and other activities included in the communication and dissemination plan

The role of partner **EDF** is to establish and maintain social media accounts for the project, as well as support LGI on project branding, templates and yearly newsletters

The role of partner **UKC** is to prepare a press release at the start and end of the project, to update the project website prepared by LGI, and to support LGI to execute the communication plan

Actions	Start Date	Due Date	Responsible
▪ Action 1: Prepare draft Project branding, document templates, base public website and collaborative tools and circulate to partners to review	M01	M02	LGI, EDF
▪ Action 2: Prepare press release at the start of the project	M01	M02	UKC
▪ Action 3: Finalise Project branding, document templates, base public website and collaborative tools and submit D2.1	M02	M03	LGI
▪ Action 4: Design and produce project flyer and a roll-up (and/or posters) for events	M01	M06	LGI
▪ Action 5: Prepare public website (D2.3)	M01	M06	LGI
▪ Action 6: Create social media accounts and update	M01	M48	EDF
▪ Action 7: Publish yearly newsletters	M01	M48	LGI
▪ Action 8: Prepare press release at the end of the project	M46	M48	UKC
▪ Action 9: Review and revise the plan periodically during the project.	M01	M48	LGI, UKC

Task 2.3: Scientific Dissemination

Start date: M01 End date: M48

Task Leaders: Emma Luguterah, **UKC**

Contributors: Konstantin Goldschmidt, **TUK**, Irmela ZENTNER **EDF**

The purpose of this task is to disseminate the results and progress of the work carried out in METIS to the project's stakeholders. Activities include:

- Identifying relevant events and coordinating the consortium's participation in submitting papers, presenting, promoting and disseminating the project's results at conferences, fairs, forums etc.
- Coordinating publications, including in specialised press, magazines and open access journals and online repositories such as Zenodo and Open Science Repository, Researchgate. Partners' repositories will also be used to archive and make publications accessible
- Coordinating exchanges and networking with European projects and international initiatives and SNETP

Obviously, the scientific communication through publications and communications within congresses/seminars/workshops will rely on all partners involved in technical WPs

The role of partner **UKC** is to coordinate the overall dissemination: identifying relevant events and coordinating the consortium's participation

The role of partner **TUK** is to build the network with European projects and international initiatives.

The role of partner **EDF** is to coordinate the publications, including in specialised press, magazines and open access journals and online repositories

Actions	Start Date	Due Date	Responsible
▪ Action 1: Identify relevant scientific events	M01	M48	UKC
▪ Action 2: Coordinate the publication of the scientific papers	M01	M48	EDF
▪ Action 3: Build the network with European projects and international initiatives including SNETP	M01	M48	TUK
▪ Action 4: Prepare yearly reports summarising the list of Scientific publications	M01	M48	UKC

Task 2.4: Workshops and webinars

Start date: M06 End date: M48

Task Leaders: Clara Demange, **LGI**,

Contributors: Irmela ZENTNER, **EDF**, Konstantin Goldschmidt, **TUK**, Marco Pagani, Kendra Johnson, Robin Gee ***GEM***

The aim of this task is:

Workshops and webinars are essential ways for the progress of the work program within the team and knowledge dissemination. Internal webinars will be organized alongside with international ones open to the community.

There will be three international events with physical attendance where the consortium partners and external experts will be able to present and exchange about the latest project related matters and findings. Workshop proceedings will be published and widely distributed through the website. The topics, locations and partners hosting the workshop envisaged so far are:

- Workshop on site specific PSHA and ground motion organized by GEM (provisionally Spring 2023)
- Workshop dedicated to advances in seismic PSA organised by TUK in Kaiserslautern (provisionally March 2024)
- Final scientific symposium giving an overview of major scientific outcome of the project organised at EDF Lab Paris-Saclay

Webinars will be organized on a regular basis as well aiming to focus on the promotion of specific achievements of the project and conduct technical reviews before publication of the results. Target public are, in addition to the consortium members, the EUG and the IAB

The role of partner **LGI** is to coordinate the organisation and facilitation of workshops and webinars, including but not limited to, the establishment of an online registration platform, and the communication with participants.

The role of partner **EDF** is to organise and deliver a final scientific symposium giving an overview of major scientific outcome of the project organised at EDF Lab Paris-Saclay.

The role of partner **TUK** is to organise and deliver an international workshop dedicated to advances in seismic PSA organised in Kaiserslautern.

The role of partner **GEM** is to organise and deliver an international workshop on site specific PSHA and ground motion.

Actions	Start Date	Due Date	Responsible

Action 1: Prepare and deliver internal and external webinars with consortium partners	M06	M48	LGI
Action 2.1: Organise and deliver an international workshop on site specific PSHA and ground motion	M12	M30	GEM
Action 2.2: Organise and deliver an international workshop dedicated to advances in seismic PSA organised in Kaiserslautern (provisionally March 2024)	M30	M43	TUK
Action 2.3: Organise and deliver a final scientific symposium at the end of the project, giving an overview of major scientific outcome of the project organised at EDF Lab Paris-Saclay	M42	M48	EDF
Action 2.4 Prepare a summary report following each workshop, including the agenda, slides presented, list of attendees, and results of questionnaires to attendees	M06	M48	GEM, TUK, EDF

Task 2.5: Education and training

Start date: M06 End date: M48

Task Leaders: Philippe Martinuzzi - **UKC**

Contributors: Dimitrios Vamvatsikos/ Ms. Aggeliki Gerontati - **NTUA**, Irmela ZENTNER - **EDF**, Ms. Yulia Yesypenko - **SSTC-NRS**, Konstantin Goldschmidt - **TUK**, Paolo Bazzurro, Mohsen Kohrangi, Pablo Alfonso Garcia de Quevedo Iñarritu, Nevena Šipčić – **IUSS**, Marco Pagani, Kendra Johnson, Robin Gee - **GEM**, Matjaž Dolšek - **UL**

The aim of this task is:

The goals of this task are to prepare and disseminate guidelines using the outcomes of the projects, customized according to the specific context of each country involved, and to organize training sessions (on-site and on-line) on the scientific software which will capitalize the technical outcomes of the project: models, methods, and methodologies. The successful dissemination of the guidelines will be guaranteed by the rich networks of each consortium member.

Each year, summer schools, thematic training schools and regular software training sessions will be organized in different countries by the partners to disseminate results to practitioners and train a new generation of seismic safety engineers.

METIS international summer schools

The annual international METIS summer school are anticipated to take place in June or July. The duration of each summer school will be one week. The target audience are students (master and postgraduate) and early career engineers. MOOCs will be created and made available through the project website after the events. The lectures will be updated with new scientific input as the project progresses. The locations and hosting partners are:

- Athens, Greece, NTUA in 2021
- Pavia or Bergamo, Italy, GEM & IUSS in 2022
- Faculty of Civil and Geodetic Engineering, University of Ljubljana, Ljubljana, Slovenia, UL in mid-2023
- Athens, Greece, NTUA in 2024

<u>METIS thematic training schools</u>

The METIS training schools are designed for national public, but the events are open to any person interested. They will be held in English language. The target audience are practitioners and young engineers.

- UL will organize a Training school for engineers in NPP and for Slovenian Nuclear Safety Administration and other interested groups (provisionally for second half of 2023 or first half of 2024)
- SSTC-NRS will organize a training school on PSA in Kiev (tentatively in M37)
- UKC will organise a Training school on seismic analyses with code_aster in Manchester, UK
- TUK organizes a Training school in Germany on seismic hazard, fragility (including DEE/BEPU) and risk (provisionally for August 2023)

Moreover METIS results will be disseminated through the regular code training sessions that are already organised by the partners:

- Code_aster Paris or Lyon, EDF, France
- Openquake in Pavia, GEM, Italy (jointly organized with the GEM & IUSS summer school)
- Opensees in Athens, NTUA, Greece

The contribution of partner **UKC** is to organise a training session on seismic analyses with code_aster and Salome_meca in Manchester, UK

The contribution of partner **EDF** is disseminate the METIS results through the regular code training sessions that are already organised for Code_aster in Paris or Lyon, France, and to support UKC on the training session in Manchester UK

The contribution of partner **NTUA** is to organise an international summer school in Athens, Greece, in 2021 and 2024. In addition, NTUA will disseminate the METIS results through the regular code training sessions that are already organised for Opensees in Athens, Greece.

The contribution of partners **GEM & IUSS** is to organise an international summer school in Pavia or Bergamo, Italy, in 2022. In addition, **GEM** will disseminate the METIS results through the regular code training sessions that are already organised for Openquake in Pavia.

The contribution of partner **UL** is to organise an international summer school in Ljubljana, Slovenia, in 2023. UL will also organize a Training school for engineers in NPP and for Slovenian Nuclear Safety Administration and other interested groups

The contribution of partner **SSTC-NRS** is to organize a training school on PSA in Kiev.

The contribution of partner **TUK** is to organize a Training school in Germany on seismic hazard, fragility (including DEE/BEPU) and risk.

Actions	Start Date	Due Date	Responsible
▪ Action 1.1: Organise and deliver a summer school to train a new generation of seismic safety engineers in Athens, Greece, in 2021	M06	M10 or M14	NTUA
▪ Action 1.2: Organise and deliver a summer school on PSHA to train a new generation of seismic safety engineers in Italy, in 2022	M19	M24	GEM & IUSS
▪ Action 1.3: Organise and deliver a summer school to train a new generation of seismic safety engineers in Slovenia, in mid-2023	M06	M38	UL
▪ Action 1.4: Organise and deliver a summer school to train a new generation of seismic safety engineers in Athens, Greece, in 2024	M06	M46	NTUA
▪ Action 1.5 Prepare a summary report following each summer school, including the agenda, slides presented, list of attendees, and results of questionnaires to attendees	M06	M48	GEM & IUSS, UL, NTUA
▪ Action 2.1: Organise a Training school (on-site and on-line) for engineers in NPP and for Slovenian Nuclear Safety Administration and other interested groups	M06	M48	UL
▪ Action 2.2: Organise a Training school (on-site and on-line) on PSA in Kiev (tentatively in M37)	M30	M38	SSTC-NRS
▪ Action 2.3: Organise a Training school (on-site and on-line) on	M12	M24	UKC

seismic analyses with code_aster in Manchester, UK			
▪ Action 2.4: Organise a Training school (on-site and on-line) in Germany on seismic hazard, fragility (including DEE/BEPU) and risk	M23	M36	TUK
▪ Action 2.5 Prepare a summary report following each Training school, including the agenda, slides presented, list of attendees, and results of questionnaires to attendees	M06	M48	UL, SSTC-NRS, UKC, TUK

Task 2.6: METIS End Users Group

Start date: M01 End date: M48

Task Leaders: Ionel Nistor - **UKC**

Contributors: Irmela ZENTNER- **EDF**, Sylvain BOULLEY - **IRSN**

The aim of this task is:

The METIS End Users Group (EUG) will be set up and regular meetings will be organised. A specific survey will be built and distributed to the EUG in order to collect their needs at the beginning of the project

The role of partner **UKC** is to set up the METIS End User Group, organise EUG meetings and participate in the design and exploitation of the EUG survey.

The role of partner **IRSN** is to design of the EUG survey and the post-processing of the answers.

The role of partner **EDF** is to participate in the design and exploitation of the EUG survey.

Actions	**Start Date**	**Due Date**	**Responsible**
▪ Action 1: Set up METIS End Users Group	M01	M03	UKC
▪ Action 2: Organise first meeting of the End Users Group and agree Constitution (MS3)	M01	M12	UKC
▪ Action 3: Distribute End-users survey and exploitation of results (D2.4)	M01	M12	UKC
▪ Action 4: Draft and post-process EUG survey	M03	M12	IRSN

▪ Action 5: Organise meetings of the EUG	M01	M48	UKC

Task 2.7: Final Handbook

Start date: M45 End date: M48

Task Leaders: Philippe Martinuzzi, **UKC**

The aim of this task is to prepare the final handbook and deliver the conclusion and recommendations of the project by summarizing all project results. This document aims to foster the transfer and the implementation of the results across the wide community beyond the lifetime of the project.

The role of partner **UKC** is to extract the key results and recommendations from the other METIS Workpackages to collate and produce a final METIS project handbook

Actions	Start Date	Due Date	Responsible
▪ Action 1: Agree template and structure for the project handbook volume/s	M45	M45	UKC
▪ Action 2: Prepare draft handbook and circulate to the consortium	M45	M46	UKC
▪ Action 3: Finalise and Publish the METIS project handbook	M47	M48	UKC

Deliverables

Number	Title	Due Date	Responsible
D2.1	Project branding, document templates, base public website and collaborative tools	M3	Mya Belden, LGI
D2.2	Communication and Dissemination plan report	M6	Emma Luguterah UKC
D2.3	Project website on-line	M6	Mya Belden, LGI
D2.4	End-users survey and exploitation of results	M12	Emma Luguterah UKC

D2.5	Project final handbook	M48	Philippe Martinuzzi, UKC

Milestones of WP2

Number	Title	Verification mean	Due Date	Responsible
MS3	Constitution of EUG and survey, exploitation of responses	Constitution of EUG and survey, exploitation of responses	M12	UKC

Interaction with other WPs

Number	Interaction description	Responsible
Task 2.2	The communication via social accounts, newsletters, project website and press release will rely on inputs from all the technical WPs	EDF, UKC, LGI
Task 2.3	The scientific communication through publications and communications within congresses/seminars/workshops will rely on all partners involved in technical WPs	EDF, UKC
Task 2.4	International workshop to advances in PSA is dependent on the outcome of WP 6 Task 6.1 to 6.8 The PSHA workshop will have interactions with WP5.	TUK, GEM
Task 2.5	The training school on seismic hazard, fragility (including DEE/BEPU) and risk is dependent on the on the outcome of WP 6 Task 6.1 to 6.8 The summer school organised by NTUA will interact use outcomes from WP3. The summer school organised by GEM/IUSS will get inputs from WP4 and WP5 (possibly from WP3 as well) The summers school organised by SSTC-NRS will use inputs from WP4, WP5, WP6 and WP7 and the outcomes will be used in WP7	NTUA, GEM, IUSS, UL, SSTC-NRS, TUK

	OpenQuake training that will take place during the summer school organised in Italy in the summer of 2022, depends on the methods implemented in the WP4	
Task 2.7	The production of the project handbook will request inputs from all the technical WPs	UKC

Risks of WP2

Contractual risks (number, description, risk-mitigation), probability (1=low; 5=high) that the risk occurs and impact (1=low; 5=high) if the risk occurs. Other risks (not in GA) can be added so they can be followed during the project. Risk mitigation: P=preventive actions / C=contingency actions.

Number	Risk description	Risk mitigation	Proba	Impact
1	Events are less effective, as planned Face to Face sessions have to be held virtually due to COVID-19 restrictions	Use tools/technology for the virtual events that all participants are able to to use	3	3
2	Training is less effective, as planned Face to Face sessions have to be held virtually due to COVID-19 restrictions and attendees might not have the right software / tools installed locally	Have a cloud-based solution tested and ready ahead of the scheduled training sessions.	4	3
3	WP2 success is reduced as it is dependent on progress and outcomes of the other WPs and input of project partners	Clear overall plan for the METIS project managed by EDF	2	3

4. Description of WP3 "Case study for implementation and application of METIS results" activities

Start date: September 2020; End date: September 2024

Work Package Leader- co-Leader: Gloria SENFAUTE - EDF

Task 3.1.: Definition of requirements

Start date: 01/09/2020 End date: 01/03/2021

Task Leaders: Gloria Senfaute EDF (1)

Contributors: M. Pagani - GEM (0.5); P. Bazzurro - IUSS (0.5); K. Goldschmidt - TUK (0.5); S. Sevbo - ER (0.5); M. Dolšek - UL (0.5); D. Ryzhov - SSTC (0.5)

Objective: The aim is to define the needs of each WPs for implementing the results in a real case study. The task will make sure that all final outputs produced by WPs 4 to 6 are consistent to enable the proper implementation of the full and final seismic Probabilistic Safety calculations performed in WP7.

Output of the task: technical note with needs of each WP for selecting the case study. The final set of requirements will be completed by 01/01/2021.

Actions	Start Date	Due Date	Responsible
▪ Action 1: Definition of WP4 Inputs and Outputs	01/09/2020	01/11/2020	Marco Pagani
▪ Action 2 Definition of WP5 Inputs and Outputs	01/09/2020	01/11/2020	Paolo Bazzurro
▪ Action 3: Definition of WP6 Inputs and Outputs	01/09/2020	01/11/2020	Hamid Sadegh-Azar
▪ Action 4: Definition of WP7 Inputs and Outputs	01/09/2020	01/11/2020	Oleksandr Sevbo
▪ Action 5: Report on final sets of requirements for each WP.	01/10/2020	01/01/2021	Gloria Senfaute

Task 3.2: Selection of a case study and data sharing

Start date: 01/09/2020 End date: 01/09/2021

Task Leaders: Gloria Senfaute - EDF (2), S. Boulley - IRSN (1)

Contributors: M. Pagani - GEM (0.5); P. Bazzurro – IUSS (0.5); K. Goldschmidt – TUK(0.5); S. Sevbo - ER (0.5), G. Queneherve – LGI(0.5); D. Ryzhov - SSTC (0.5)

Objective: The aim of this task is to: 1) select a realistic case study to integrate and apply the final products delivered by WPs 4 to 7; 2) Implement a platform for data sharing

Outputs of the task:

-Technical note with advantages & disadvantages of two potential sites and associated criteria to make the final selection.

- Development of a platform project for storing and transferring data

Actions	Start Date	Due Date	Responsible
▪ Action 1: Evaluation of Zaporizhzhya Nuclear Power Plant (ZNPP)	01/09/2020	01/01/2021	Dmytro Ryzhov
▪ Action 2: Evaluation of Kashiwazaki-Kariwa Nuclear Power Plant (KK NPP)	01/09/2020	01/01/2021	Benjamin Richard
▪ Action 3: Synthesis and final selection of METIS case study.	01/01/2021	01/03/2021	Gloria Senfaute
▪ Action 4: Developing a platform project for storing and transferring data	01/09/2020	01/03/2021	Gilles Queneherve

Task 3.3: Supervision of analysis chain

Start date: 01/09/2021 End date: 01/09/2024

Task Leaders: G. Senfaute EDF (0.5)

Contributors: M. Pagani GEM (1), P. Bazzurro IUSS (1), K. Goldschmidt TUK (1), S. Sevbo ER (1)

Objective
1) to check the coherence of individual WPs needs and developments;
2) to assure the information transfer between WPs to facilitate the implementation.

Output of the task: a Gantt chart with integration of all expected WPs results necessary for the case study implementation.

Actions	Start Date	Due Date	Responsible
▪ Define a Gantt chart for integrating all WPs expected results regarding the implementation.	01/03/2021	01/09/2024	Gloria Senfaute

Task 3.4: Peer review group

Start date: 01/09/2023 End date: 01/01/2024

Task Leaders: G. Senfaute (0.5)

Contributors: D. Vamvatsikos - NTUA (0.5); P. Bazzurro IUSS (0.5); H. Sadegh-Azar - TUK (0.5); D. Beaumont GDS (0.5); B. Richard - IRSN (0.5); F. Cotton - GFZ (0.5); I. Zentner EDF (1); E. Viallet – EDF (0.5).

Objective
To organize a peer review group for assessing the technical quality of the final seismic PSA study. The peer review group has to cover all competences from hazard to risk and will be composed of the members of the IAB, the EAB and the project leader.

Actions	Start Date	Due Date	Responsible
▪ Action 1: Set up and animation of the peer review group	01/09/2023	01/01/2024	Gloria Senfaute
▪ Action 2: Peer review of METIS case study application	01/01/2024	01/08/2024	NTUA, IUSS, TUK, GDS, IRSN, GFZ

Task 3.5: Guidelines and Recommendations for seismic PSA implementation

Start date: <u>01/09/2023</u> End date: <u>01/01/2024</u>

Task Leaders: Gloria Senfaute EDF (1)

Contributors: M. Pagani GEM (0.5); P. Bazzurro IUSS (0.5); K. Goldschmidt TUK (0.5); S. Sevbo ER (0.5).

Objective
To coordinate the preparation of the final guidelines and the main operational recommendations produced by the METIS project. The guidelines will describe how to address a seismic Probabilistic Safety Assessments for NNPs considering the complete analyses chain.
The output of the task is the final Guidelines & Recommendations of how to address a seismic Probabilistic Safety Assessments for NNPs considering the complete analyses chain. The Guidelines & Recommendations will be based on the technical guidelines produced by WPs 4-7 and the results of the peer review.

Actions	Start Date	Due Date	Responsible
▪ Action 1: Final guidelines based on the Peer Review of the METIS PSA case study	01/09/2023	01/09/2024	Gloria Senfaute

Deliverables

Number	Title	Due Date	Responsible
D3.1	Description of case study and collection of data and reports	01/03/2021	Gloria Senfaute
D3.2	Report from Peer review group meetings	01/01/2024	Gloria Senfaute
D3.3	Final Guidelines and Recommandations	01/09/2024	Gloria Senfaute

Milestones of WP3

Number	Title	Verification mean	Due Date	Responsible
D3.1	METIS case study defined	METIS case study defined	01/03/2021	Gloria Senfaute
D3.3	Peer review of PSA application case study completed	Peer review of PSA application case study completed	01/01/2024	Gloria Senfaute

Interaction with other WPs

Number	Interaction description	Responsible
1	Task 3.1 Definition of requirements for implementation of results Interaction with all WPs leaders	EDF
3	Task 3.2 Selection of a case study and data sharing Interaction with IRSN - SSTC – LGI	EDF
4	Task 3.4 and 3.5 Peer review of METIS case study and guidelines: results of PSA applications carried out in WP 4-7 are reviewed	EDF

Risks of WP3

Contractual risks (number, description, risk-mitigation), probability (1=low; 5=high) that the risk occurs and impact (1=low; 5=high) if the risk occurs. Other risks (not in GA) can be added so they can be followed during the project. Risk mitigation: P=preventive actions / C=contingency actions.

Number	Risk description	Risk mitigation	Proba	Impact
1	Data of METIS case study not available or incomplete	Two potential case study selected. Possibility to give complmentarity of data.	2	5

5. Description of WP4 "Seismic Hazard" activities

Start date: 01/09/2020; End date:_31/08/2023

Work Package Leader: Marco Pagani (GEM)

Task 4.1.: SEISMICITY MODEL CHARACTERISATION

Start date: 01/09/2020 End date: 01/04/2022

Task Leaders: Thomas Chartier (GEM)

Contributors: Marco Pagani, Richard Styron, Robin Gee, Kendra Johnson (GEM)

The aim of this task is to develop methods for seismic source characterisation. The contribution of each partner is described below for each sub-task.

Task 4.1.1.: Methodology for Earthquake Catalogue Declustering

Sub-Task Leaders: Thomas Chartier (GEM)

Contributors: Marco Pagani, Richard Styron, Robin Gee, Kendra Johnson (GEM)

The goal of this sub-task is to develop a catalogue declustering algorithm tailored to the specific needs of Probabilistic Seismic Hazard Analysis (PSHA). In PSHA, catalogue-declustering is a component of the traditional procedure used for the characterisation of earthquake sources based on past seismicity. Declustering is applied to select the earthquakes that occurred independently from the ones that happened nearby in space and time and, its results can impact extensively on the values of hazard computed. Two are the main issues of the declustering procedure, the complexity of the underlying physical process and a certain level of arbitrary intrinsic to the criteria used to filter out foreshocks and aftershocks. The introduction of stochastic approaches (Van Stiphout et al., 2012) partly attenuated the latter, although the use of stochastic methods in PSHA is still quite limited.

In our research, we will tackle the catalogue-declustering problem following a more practical approach that strives to create the best catalogue for mainshock hazard analysis, that is, the catalogue with the highest number of independent events. With this goal in mind, we will define declustering as an optimisation problem that computes the parameters minimising cost functions specifying the extent to which the calculated catalogue is Poissonian and, the number of earthquakes removed. In an initial stage, we will use this procedure with the Gardner and Knopoff (1974) declustering algorithm and, we will consider expanding it to other more recent approaches. In the second stage, we will test the computed catalogue by generating ground motion fields at a set of target locations and analysing the sequence of shaking values recorded. We plan to conduct the test in at least two regions, one located in the active and one in the stable shallow crust.

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- Van Stiphout, T., J. Zhuang, D. Marsan (2012). Seismicity Declustering. Community Online Resource for Statistical Seismicity Analysis. doi:10.5078/corssa-52382934. Available at http://www.corssa.org.

Actions	Start Date	Due Date	Responsible
▪ ACTION 1: Implement the declustering procedure	01/09/2020	31/08/2021	GEM
▪ ACTION 2: Test the declustering procedure	1/9/2021	31/12/2021	GEM
▪ ACTION 3: Writing documentation and paper	1/1/2022	31/03/2022	GEM

Task 4.2: GROUND MOTION MODELLING

Start date: 01/09/2020 End date: 01/04/2022

Task Leaders: Norman A. Abrahamson (PEER)

Contributors: Marco Pagani, Michele Simionato (GEM), Paola Traversa (EDF), Norman Abrahamson, Grigorios Lavrentiadis (PEER)

The aim of this task is to develop methods for ground-motion characterisation. The contribution of each partner is described below for each sub-task.

Task 4.2.1.: Improved site-specific ground motion models

Sub-Task Leaders: Norman A. Abrahamson (PEER)

Contributors: *Grigorios Lavrentiadis* (PEER), Marco Pagani, Michele Simionato (GEM), Paola Traversa (EDF)

PEER will improve the current methodology used to create non-ergodic models, will prepare programs to efficiently estimate non-ergodic GMMs and will use California data to test the method. In first phase PEER will develop non-ergodic GMMs for Fourier Amplitude Spectra (FAS) to allow use of small magnitude data to constrain linear site, source, and path terms. In a second step, using RVT, the FAS GMM will be converted to a PSA GMM for use in non-ergodic PSHA. The expected results are a methodology for non-ergodic GMM for PSA and example implementation for California.

GEM will implement the new ground-motion models into the OpenQuake Engine and will perform cross validations in collaboration with PEER.

The role of **EDF** will be to support the activities in this task by providing data and other methodological input.

Actions	Start Date	Due Date	Responsible
▪ ACTION 1: Implement the non-ergodic GMM	01/09/2020	31/08/2021	PEER
▪ Action 2: Testing calculation of seismic hazard using the non-ergodic model	31/12/2021	31/12/2021	PEER
▪ ACTION 3: Writing documentation and paper	1/1/2022	31/03/2022	PEER

Task 4.2.2.: V&V for sites-specific ground-motion models

Sub-Task Leaders: Norman A. Abrahamson (PEER)

Contributors: Norman A. Abrahamson (PEER)

The aim of this sub task is to develop a methodology for testing the non-ergodic GMMs against macroseismic intensity (MSI) data from historical earthquakes using California as an example application. Initially PEER will compile a database from large historical earthquakes in California, including consistent estimates of MSI observations, earthquake source parameters and site conditions. PEER will use this database to develop models for estimation of MSI from PSA and will test available GMMs (ergodic and non-ergodic). The comparison will require the calculation of the MSI residuals using ergodic and non-ergodic GMMs to determine if the non-ergodic GMM improves the prediction of the MMI data in different regions of California. The result of this research will be a quantitative evaluation of the ability of the non-ergodic model to estimate spatial differences in the ground motion models for large earthquakes.

Actions	Start Date	Due Date	Responsible

ACTION 1: Collect macroseismic observations for past events in California	01/09/2020	31/08/2021	PEER
Action 2: Compare MSI residuals using ergodic and non-ergodic models	31/12/2021	31/12/2021	PEER
ACTION 3: Writing documentation and paper	01/01/2022	31/03/2022	PEER

Task 4.3: LOGIC TREE AND EPISTEMIC UNCERTAINTY IN PSHA

Start date: 01/09/2020 End date: 31/08/2022

Task Leaders: David Baumont (GDS)

Contributors: Thomas Chartier, Marco Pagani, Kendra Johnson (GEM), Gabriele Ameri (GDS), Abhinav Gupta, Saran Srikanth Bodda (NCSU), Gloria Senfaute, Irmela Zentner (EDF)

The aim of this task is to improve the modelling of epistemic uncertainty in probabilistic seismic hazard analysis. The contribution of each partner to each sub-task is described below.

Task 4.3.1.: Logic trees and Bayesian approaches to estimate weights for input modelling choices

Sub-Task Leaders: David Baumont, GDS

Contributors: Gabriele Ameri (GDS), Abhinav Gupta, Saran Srikanth Bodda (NCSU), Gloria Senfaute (EDF)

Recent national and site-specific hazard models showed and increased complexity. This complexity arises from the fact that not only modelling choices are treated in the framework of logic trees, but also uncertain parameter distributions are discretized and full factorial sampling is applied and implemented via logic trees. Correlation between uncertain parameters are not accounted for. This task improves the way to construct logic trees for model choice uncertainty and develops smart sampling and uncertainty propagation approaches for continuous parameter uncertainty.

NCSU will develop a complete Bayesian estimation procedure to compute weights of PSHA logic tree. Bayesian update of the recurrence parameters within each zone of seismotectonical model was studied in detail in Keller et al. (2014), based on the Poisson occurrence and Gutenberg-Richter assumptions. An importance sampling solution was proposed, which generates a weighted sample from the posterior distribution of model parameters, from which any desired characteristic (such as posterior mean estimates) can easily be deduced. For estimation of GMPE weights, we propose to use the Bayesian model averaging (BMA) framework by Bertin et al. (2019) to update the several GMPEs issued from several database and then provides a hierarchy with associated weights of GMPEs. In Keller et al. (2018), a complete Bayesian update and testing procedure for the PSHA logic tree is proposed, meaning that along with the posterior distribution of model parameters, posterior weights could be attributed to every branch of the logic tree, i.e. every possible choice of seismotectonical model and ground motion prediction equation (GMPE) models. Such weights can be used to prune the logic tree, that is, discard the a-posteriori most improbable models to save computation load, while modulating the contribution of the most probable ones to the output hazard curve. In this sub-task, we will explore how the Bayesian approaches can improve accuracy and reliability of ground-motion prediction in a PSHA.

EDF will participate in the supervision of the work conducted by NCSU (postdoc).

GDS will improve the characterization of low-to-moderate seismicity rates and related epistemic uncertainties. In regions of moderate to low seismicity, the data are too sparse to derive robust annual seismicity rates. To overcome the issues raised by the lack of data at local-to-regional scale, a common strategy consists to aggregate regions with similar seismotectonic characteristics into super-domains (e.g. Grünthal et al., 2018). This is mandatory in Stable Continental Regions where the scarcity of the data questions the statistical significance of standard approaches. Seismicity rate models for SCR were developed by Johnston et al. (1994) for different regions, among which Europe. However, the models published by the authors rely on a limited dataset. We propose to further investigate the characteristics of the seismicity in SCR at the European scale based on the most recent information. Results will be used to develop a logic-tree to formally account for the epistemic uncertainties (e.g aggregation schemes, completeness periods, minimum magnitude for the Gutenberg-Richter fitting). The correlation between the parameters will be accounted for to avoid underestimating the overall hazard variability. A specific attention will be paid to the magnitude homogenization and potential biases that can arise due to the uncertainties associated to the calibration dataset and affect the seismicity rate estimates. The NUREG-2115 developed a mathematical framework to account for the uncertainties associated with the magnitude conversion relationships and limit the bias due to the uncertainties affecting the calibration dataset used to develop the magnitude conversion relations. We plan to evaluate and adapt if necessary, the NUREG-2115 methodology to the European context.
Finally, there are also many challenges in the seismic hazard related to the evaluation of the plausibility of the combinations of various alternative interpretations in terms of maximum magnitude and seismicity rates implemented in standard SSC logic-tree. We propose to investigate the impact of the sampling strategy of the revised epistemic uncertainties on the hazard estimates.

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the range of epistemic uncertainties and aleatory variability. Bulletin of Earthquake Engineering, 16, 10, 4339-4395.
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- Keller, M., Mayor, J., Damblin, J., and Senfaute, G. (2018) Optimal use of Bayes' method for the computation of seismic hazard curves and application to PSHA testing. IAEA workshop on PSHA testing, Saclay, France.
- NUREG-2115 - Technical Report: Central and Eastern United States Seismic Source Characterization for Nuclear Facilities. EPRI, Palo Alto, CA, U.S. DOE, and U.S. NRC: 2012.

Actions	Start Date	Due Date	Responsible
ACTION 1: Development of the Bayesian estimation procedure.	01/10/2020	31/12/2021	NCSU
ACTION 2: Improving the characterization of low-to-moderate seismicity rates and related epistemic uncertainties.	01/10/2020	31/12/2021	GDS
ACTION 3: Documentation	1/1/2022	1/8/2022	NCSU
ACTION 4: Documentation	1/1/2022	1/8/2022	GDS

Task 4.3.2.: Epistemic uncertainty propagation

Sub-Task Leaders: Marco Pagani (GEM)

Contributors: Thomas Chartier, Richard Styron, Robin Gee, Kendra Johnson (GEM), Irmela Zentner (EDF), Norman A. Abrahamson, Maxime Lacour (PEER) (PEER), David Baumont (GDS)

Over the last couple of decades, the complexity in logic trees used in Probabilistic Seismic Hazard Analysis (PSHA) increased steadily. This trend stems from the need to account for epistemic uncertainty comprehensively and it demands more powerful software and access to large computational infrastructures.

GEM implements progress on the methodological and software components by introducing more efficient approaches for the treatment of uncertainty and for performing sensitivity analysis. The former increases our ability to deal with more complex models while the latter helps in reducing complexity by choosing the elements most influential on the overall variability of results.

In ordinary PSHA software, the general strategy used to sample the full set of end-branches admitted by a logic tree is the crude Monte Carlo approach whose accuracy is proportional to the number of samples produced. For example, the root mean squared error on the expected mean obtained with the crude Monte Carlo approach scales with the inverse of the square root of the number of samples (e.g. Owen, 2013). Hence a sizable increase in the samples provides just a small accuracy improvement.

In the first stage of this task, we will implement and test more advanced and efficient sampling strategies, starting, for example, with Latin Hypercube (LHS) and Orthogonal Sampling (OrS). Moreover, we will add methods to the OQ Engine to estimate the number of samples required to obtain a given accuracy of the estimate. In the second phase, we will tackle the problem of the correlation between different components of a logic tree structure. Similarly to what is just explained, we will first work with a crude Monte Carlo approach and will successively use more complex sampling techniques.

EDF will participate in the definition of advanced sampling strategies for correlated variables, in particular based on LHS sampling (simple Python routines already available).

The method of Lacour and Abrahamson (2019) creates a metamodel using polynomial chaos expansion to propagate the epistemic uncertainty in the median ground motion. It is an intrusive uncertainty propagation approach that requires modifications to the code used to compute probabilistic seismic hazard. In the final part of this task, GEM will implement this methodology in the OpenQuake Engine (we will complete this activity in coordination with Task 4.2.1) and explore the possibility of extending this methodology with the adoption of non-intrusive uncertainty propagation approaches. In particular, we will aim to generalize the method to other input variables and to support sensitivity analyses to identify the main contributor to the overall variability.

PEER will expand the current method of using polynomial chaos for propagating the epistemic uncertainty for median ground motion to include the epistemic uncertainty in the size of the aleatory variability. The procedure will be based on an intrusive uncertainty propagation approach to approximate the change in the hazard for a change in the size of the aleatory variability. This will result in a methodology and a functional form for use in PSHA to efficiently propagate epistemic uncertainty in both the median and aleatory variability of ground motions from GMPEs.

GDS will provide support the activities of this work package.

Bibliography:

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Actions	Start Date	Due Date	Responsible
ACTION 1: Implement new sampling methods in OQ Engine	01/09/2020	31/08/2021	GEM
ACTION 2: Add support for sensitivity analysis to the OQ Engine	01/03/2021	31/12/2021	GEM

ACTION 3: Test the use of non-intrusive approaches for the propagation of uncertainty	01/09/2021	31/03/2022	GEM
ACTION 4: Writing documentation and paper	1/04/2022	31/08/2022	GEM
ACTION 5: Expand the Lacour and Abrahamson (2019) method	01/09/2020	31/12/2021	PEER
ACTION 6: Writing documentation and paper	1/1/2022	31/08/2022	PEER

Task 4.4: EXTENDED PSHA METHODOLOGY AND TOOLS

Start date: 01/09/2020 (M1) End date: 31/01/2023

Task Leaders: Marco Pagani (GEM)

Contributors: Michele Simionato, Thomas Chartier (GEM), Paolo Bazzurro, Mohsen Kohrangi (IUSS), Norm Abrahamson, Tessa Williams (PEER), Irmela ZENTNER, Guillaume DANIEL, Paola TRAVERSA (EDF)

Within this task we will develop methodologies for site-specific probabilistic seismic hazard analysis involving complex and possibly spatially distributed facilities. The contribution of each partner is described below for each sub-task.

Task 4.4.1.: Vector-valued PSHA and CS Approach

Sub-Task Leaders: Marco Pagani (GEM)

Contributors: Michele Simionato, Thomas Chartier (GEM), Paolo Bazzurro, Mohsen Kohrangi (IUSS), Norm Abrahamson, Tessa Williams (PEER), Irmela ZENTNER, Guillaume DANIEL, Paola TRAVERSA (EDF)

GEM implements into the OpenQuake Engine the methodologies needed for the calculation of seismic hazard results underpinning the design and the structural analysis of complex multimodal engineering structures, namely Vector-Valued PSHA (i.e. VPSHA; Bazzurro, 1998; Bazzurro and Cornell, 2001) and the Conditional Mean Spectrum approach (e.g. Baker, 2010).

In an initial phase, we will add to the OpenQuake Engine some inter-period correlation models which are required by both the approaches. We will start with the Jayaram and Baker (2008) and the Khorangi et al. (2020) models. The design of this component will be as much as possible general to allow for the implementation of additional models.

We will add VPSHA capabilities to the OpenQuake Engine using a couple of approaches. GEM will implement the so-called indirect methodology (Bazzurro et al., 2010) which requires for the selected IMTs the collective calculation of the hazard curves, variance-covariance matrix and, the joint distribution of the descriptive variables that the selected GMM necessitate for computing hazard. The latter will require an extensive improvement of the capabilities of the OQ Engine given the RAM demand that this approach entails. We will tackle the problem by using GMM with an easy functional form and will improve performance and capabilities in due course. EDF will provide python source-codes for the so-called direct methodology for VPSHA calculations based on the Bazzurro and Cornell (2002) formulation. Assessment of the accuracy of this approach with respect to the indirect method will be addressed.

GEM will implement the Conditional Mean Spectrum (CMS) approach following the approach proposed by Baker (2011). In the second phase, we will possibly consider other CMS methodologies to allow comparisons and tests. Moreover, the methods implemented will be to the extent possible general in order to support various intensity measure types that may be important to the response of the structure as identified in WP5 and WP6.

PEER will expand the Conditional Spectrum approach to include secondary parameters such as PGV, duration, Arias Intensity, and CAV. This will be achieved by modifying the current methods for selecting time histories and optimizing the activity rates to reproduce the PSA(T) hazard to also include the secondary parameters as part of the selection and rate optimization, The new methodology will generate a suite of time histories that reproduces the hazard for the secondary parameters as well as the PSA at multiple periods for hazard levels from 1-E3 to 1E-6.

EDF will implement and compare target spectra obtained by means of CS-based and VPSHA-based approaches. One major conceptual difference in the two approaches is the introduction of correlation.

In the CS approach, the correlation of spectral accelerations is introduced at hazard curve level (it is generally acknowledged that correlation models do not significantly depend on the scenario), engineering hazard spectra for different return levels can then be deduced as conditional probabilities using the lognormal distributions predicted by GMM. This is why a pertinent scenario has to be deduced by means of hazard disaggregation. In the so-called VPSHA approach, the correlation of spectral acceleration values is introduced from the start in the hazard integral leading to multidimensional hazard curves. The latter approach is however computationally very expensive, and might become unfeasible if more than a few dimensions are considered.

Conceptually, both approaches can be extended to other indicators than PSA. In both cases, one key issue is the definition of the design level (typically in terms of return period) and the according definition of target spectra useful for engineering. In current practice, hazard spectra are defined as a set of response spectral acceleration with common target design return period. In consequence, the return period of the conjunct occurrence is much higher than the target.

Regarding the VPSHA approach, and with a particular focus on (multidimensional) seismic hazard spectra, we will investigate which constraints can be set on the infinite set of solutions at a given return period to obtain realistic and usable correlated hazard spectra in an earthquake engineering perspective.

We propose to start with a bibliographical study on VPSHA and CS approaches and applications in PSHA. We develop and provide a python tool for the definition of target engineering spectra by CS approach and comparison of the two methods (accuracy, computation time, and compliance with engineering needs). It is expected that CS approach provides target spectra at lower computational cost than VPSHA.

IUSS will provide assistance regarding the activities just described.

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- Kohrangi, M., Papadopoulos, A. N., Bazzurro, P., & Vamvatsikos, D. (2020). Correlation of spectral acceleration values of vertical and horizontal ground motion pairs: Earthquake Spectra. https://doi.org/10.1177/8755293020919416

Actions	Start Date	Due Date	Responsible
ACTION 1: Implement into the OQ Engine more advanced logic-tree sampling techniques	01/09/2020	31/05/2021	GEM
ACTION 2: Exploring the use of non-intrusive uncertainty propagation techniques for the processing of the logic-tree	01/06/2021	31/03/2022	GEM
ACTION 3: Writing documentation and paper	01/04/2022	31/08/2022	GEM
ACTION 4: Bibliographical study on VPSHA and CS approaches and applications in PSHA	01/02/2021	01/12/2021	EDF
ACTION 5: Python tool for VPSHA approach	1/10/2020	1/06/2021	EDF
ACTION 6: Python code for the definition of target engineering spectra by CS approach and comparison of the two methods (accuracy, computation time,	1/02/2021	1/06/2022	EDF

compliance with engineering needs)			
ACTION 7: Extend the CS methodology	01/09/2020	31/08/2022	PEER
ACTION 8: Writing documentation	01/09/2022	31/12/2022	PEER

Task 4.4.2: Modelling earthquake sequences for considering aftershocks

Sub-Task Leaders: Paolo Bazzurro (IUSS)

Contributors: Richard Styron, Marco Pagani, Robin Gee, Thomas Chartier, Kendra Johnson (GEM), Nevena Sipcic, Mohsen Kohrangi (IUSS)

This sub-task aims to develop a framework for considering aftershocks in the PSHA chain. Clustered seismicity model will be assembled on the assumption that the mainshock events occur according to a homogenous Poisson process, while the aftershock occurrence is nonhomogeneous and conditional on the mainshock's magnitude and location. The temporal distribution will be modelled via commonly used modified Omori law while different spatial distributions will be investigated to develop an approach that can take the pattern of faults into account. Sets of stochastic catalogues of future clustered seismicity will be generated with the proposed model for the purpose of testing for a specific area of Europe (e.g., Central Italy) and then used for computing seismic hazard.

GEM will work on aftershock sequence modeling following, perhaps broadly, the methods developed by Boyd (2012) and Iervolino et al. (2014), which create sets of aftershock sequences that are associated with a given mainshock, and are treated as a coherent unit. The mainshocks may or may not be Poissonian or independent of other mainshocks, and aftershocks may not generate mainshocks or additional aftershock sequences. This is in contrast to ETAS-type approaches where aftershocks are not bound to their triggering shocks, and aftershocks generate additional aftershock sequences. While much of the implementation strategy remains to be defined, the kernel that will necessarily be present regardless of strategy will be to define a method of accounting for aftershocks produced by any given mainshock. It is here proposed that this method will perform the following actions:

- Find all ruptures from the Seismic Source Model (SSM) that fall within some credible triggering distance of the mainshock rupture. These ruptures will then form the set of ruptures that may be given non-zero probabilities of rupturing as aftershocks of the mainshocks.
- Ascribe probabilities to each of the aftershock ruptures based on criteria such as distance to the rupture edges, kinematic or stress compatibility, etc. These probabilities will be scaled so that they reflect the probability of rupturing within a time interval corresponding to a large part of the CDF of the Omori time

sequence (for most events, this is ideally a short time compared to the investigation time).

Bind the rupture IDs and associated probabilities to each mainshock, so that ground motions can be computed from each. This step may be seen as a sort of pre-processing step of the SSM (it is probably too computationally demanding to be run during the PSHA itself). It may result in an extended SSM that defines clusters (as previously implemented in the engine). Regardless of the processing and output of this step, it results in a situation where the mainshocks and aftershocks can be treated in an extended Classical PSHA approach, or in a stochastic approach, depending on the needs of the user.

The role of **IUSS** will be to test the outcomes of the proposed predictive model vis-à-vis historical data using various Turing style tests. These tests intend to investigate whether the simulated stochastic catalogues of events are statistically consistent with the observed seismicity in the previous decades. In these tests magnitude distribution, seismicity rates, the productivity of aftershocks, clustering behavior, temporal and spatial distribution will be evaluated and compared.

To additionally test the suitability of the proposed framework, IUSS will statistically compare the simulated catalogues results in terms of occurrence rates and hazard with the ones obtained using the in-house, Python-based toolkit that simulates stochastic catalogues of future events using the Epidemic-Type Aftershock Sequence model (ETAS). ETAS, which can be considered as the state-of-the-art approach in modelling clustered seismicity belongs to the class of self-exciting Hawkes processes, and it is based on the assumption that the total rate of events at the particular point in space and time is the sum of the background rate and the rate of the offspring events that can be triggered by either mainshock, foreshock or the aftershock events. The catalogues of simulated clustered seismicity produced by ETAS, which have the memory of the past seismicity as initial condition, have shown encouraging results in recent studies and will be used here only as independent check to validate the simpler proposed framework.

Actions	Start Date	Due Date	Responsible
▪ ACTION 1: Implementation of a prototype	01/09/2020	30/09/2021	GEM
▪ ACTION 2: Testing the prototype	01/10/2021	30/09/2022	GEM
▪ ACTION 3: Finalisation of the model	01/10/2021	31/12/2022	GEM
▪ ACTION 4: Evaluation of the proposed framework by the comparison with the observed and ETAS seismicity.	01/03/2021	31/01/2022	IUSS
▪ ACTION 5: Documentation and preparation of papers	01/01/2022	30/06/2022	GEM and IUSS

Task 4.5: SIMULATION OF STRONG GROUND-MOTION ON BEDROCK

Start date: 01/09/2020 End date: 31/10/2022

Task Leaders: Hoby Razafindrakoto, Dino Bindi (GFZ)

Contributors: Ming-Hsuan Yen, Fabrice Cotton (GFZ), Ken Miyakoshi, Kazuhiro Somei, Kojiro Irikura (GRI), David Baumont, Gabriele Ameri (GDS), Ludivine Saint-Mard, Luis Alvarez Sanchez, Irmela Zentner, Paola Traversa, Gloria Senfaute (EDF), Norman A. Abrahamson, Camilo Pinilla Ramos (PEER)

The aim of this task is to develop methods to generate synthetic ground motion time histories on bedrock using source and path terms consistent with the ones used to compute seismic hazard and we will develop a suite of open-source tools to perform physics-based simulations for engineering application. Both stochastic and empirical models will be tested and further developed for use in low to moderate seismicity areas such as encountered in most European nuclear countries:

- Source models
  - Deterministic source models: Irikura recipe
  - Stochastic source models: von Karman with uniform propagation, fractal distribution with non-uniform propagation
- Propagation models
  - Empirical Greens functions (EGF - i.e. recordings of small earthquakes)
  - Stochastic models: 3D model due to Otarola et al (2018), EXSIM (Boore, 2012)
  - No site term is considered since, according to the rationale of METIS, hazard curves and corresponding GMTH are defined on bedrock

The methodologies considered build on existing approaches using stochastic FAS and empirical Green's functions and different methods for rupture modelling. When considering EGF, then special attention has to be paid to site effects that are already included in these recordings. The stochastic models can be compared to empirical Fourier models developed for ground motion prediction in engineering seismology (SIGMA-2). The opportunity to use general inversion techniques developed in the SIGMA-2 project to constrain the models for the METIS study case is assessed and implemented if applicable.

The deterministic Japanese source model, known as the Irikura recipe, is further developed to match both particular features of Japanese earthquakes as well as low to moderate seismicity contexts often encountered in European nuclear countries.
Coupled with the propagation of the uncertainty on model parameters such models allow for simulating large databases. The suitability of these databases for ground motion selection for engineering analyses will be assessed in WP5.
The first step is the creation & animation of a working group, led by partner GFZ. The working group ensures regular exchanges on approaches, data and results and allows the different teams to discuss their advances and results. Within the working group, it is foreseen the development of criteria to evaluate the performance of the simulations (both from a seismological and engineering point of view) and the definition of a common application case to allow for comparison. This application case can be from

METIS case study or another case if more appropriate. The recent Le Teil (11/11/2019) Earthquake (SE France) may provide the necessary data to investigate the most efficient approach to predict the ground motions from shallow, moderate events. However, this earthquake is very shallow and might not be representative of events expected in Europe.

The working group will also assess the opportunity to use general inversion techniques developed in the SIGMA-2 project to constrain the models for the METIS study case. In particular, the stochastic models are compared to empirical Fourier models developed for ground motion prediction in engineering seismology (SIGMA-2).

Existing stand-alone tools such as SCEC and GRIs in-house software will also be further developed/calibrated for the European context and applied for V&V in the frame of the METIS case study. The resulting parameters for physics-based strong-motion simulation in Europe, the methods and/or to the links to the repositories/websites describing the methods developed in the projects will be disseminated through METIS website.

The contributions of partner **GRI** are:

- GRI will compute the time series of the broadband earthquake ground motion on the engineering bedrock by a hybrid approach of the deterministic method for long-period (>1s) and the Stochastic Green's Function method for short-period (<1s) ranges, respectively. The long- and short- period components are super-positioned in the time domain to create time histories of a broadband earthquake ground motion at the crossover period (1s) after applying a pair of high- and low- cut filters. Broadband ground motions calculated by the characterized source model using Irikura recipe are compared with observed ones.

EDF develops two approaches: one is based on stochastic description of source and wave propagation, and the second on EGF and the deterministic Irikura source model

- The stochastic model is based on Otarola et al. (2016) who modified the finite fault method by including the FAS of the complete body-wave field while the previous point-source and finite-fault method considered only SH-waves. The FAS of each body-wave (P, SV and SH-waves) is computed and aggregated following the same principles as in the finite-fault method. The inclusion of the complete body-wave field allows for 3D signals (i.e. North – South, East – West, Up-Down) with a more realistic description of the waveforms by modelling the different wave arrivals and frequency content observed in natural ground motions. A stochastic source model is used. The initial model is improved by introducing interfrequency correlation and by developing an efficient method for the estimation of model parameters from observations and GMM. This model could be complemented by a deterministic description of the low frequency part (cf. GRI)
- The deterministic model is based on Empirical Green's Function which already contains propagation and site effect and allows to compute realistic time histories. The source model is built following the "Irikura recipe". The synthesis formulation for summation follows the one developed by Irikura (1997). This methodology will be applied on the study case defined in the METIS project.

Within sub-task 4.5.1, GFZ aims to calibrate further and investigate the uncertainties in Empirical Green's Function (EGF) Simulations. In EGF simulation, the primary input information is the stress drop and the GF. The stress drop, for instance, is used to estimate the fault dimension. In our research, we would primarily focus on elaborating on a regional model for stress drop and its corresponding distribution for Europe. Through spectral decomposition method (e.g., Bindi and Kotha, 2020), We would also develop a scaling correction, which would help in constraining/boundary condition for EGF application.
Within sub-task 4.5.2, **GFZ** aims to adapt and calibrate the existing tools in the SCEC Broadband platform to be applicable to Europe. This platform was set to validate ground motion simulation in California and in a comparable active tectonic region. Its applicability for Europe and the low-seismicity area requires further adaptation. In our research, we would focus on the hybrid method of Graves & Pitarka (2010) and implement modifications suitable to the conditions in Europe and to small-to-moderate events.
A simulation database would be generated in a region still to be defined. A comparison with the results from other simulation techniques [e.g., Stochastic Method (Atkinson & Assatourians, 2015)] calibrated to Western Europe, and the latest generation of empirical GMMs (regionalized SERA logic tree model) would be performed for that particular region.
Within sub-task 4.5.3, GFZ would contribute to investigating further the ground-motion variability. The aim is to validate/calibrate ground-motion simulation based on parameters that are relatively well established in the empirical ground motion model, including the between-event (related to stress parameter) and the within-event at a distance range 25 to 30km.

GDS applies and further improve the EGF-based simulation approach by Dujardin et al. (2020) which couples EGFs with a k-2 kinematic rupture model. This methodology will be applied on the study case defined in the METIS project and compared with empirical GMM at European level.
In particular, the following topics are identified for improvement and investigation:

- In the EGF approach (Hartzell 1978) small magnitude events are used as EGFs to allow implicit consideration of the characteristics of the propagation medium. Recent studies have shown that the source process of small events (typically used as EGF) can be characterized by complexities such as rupture directivity affecting the acceleration source spectrum beyond the corner frequency. The effect of potential rupture directivity on the apparent corner frequency is generally neglected in standard EGF-based simulation approaches when the source contribution is deconvolved from the recordings to isolate the propagation term. This may lead to source directivity effects being treated as path effects and incorporated into the Green's function, especially in case a single or few EGFs are considered (as it is often the case in low-to-moderate seismicity regions). GDISIS will investigate this source of uncertainties in the EGF approach applied to a specific test case to be defined.
- A second source of uncertainties is related to the correction that needs to be applied to account for the distance between the EGF hypocenter and each sub-fault of the target event to be simulated. This correction typically accounts for

geometric and anelastic attenuation based on previous seismological studies in the target region. Distances between the EGF and the target-event fault are typically short in case of an appropriate EGF selection, however, geometrical spreading decay can vary substantially at short distances and it is generally constrained by few data making such distance correction a relevant source of uncertainties.

These analyses could take benefit from the results of the spectral decomposition applied at European level by GFZ (task 4.5.1).

The developed approaches and software will be compared for a test case to be defined by the partners at the beginning of the task.

The ground motion simulation methods will then be applied to the METIS case study.

The assessment of adequacy for engineering use of the sets of synthetic ground motions is part of WP5. WP4 focusses on the 'seismological' validation of the ground motion simulation models and on the comparison of the different approaches and outcome.

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Actions	Start Date	Due Date	Responsible
▪ ACTION 1: Creation and animation of a working group	01/10/2020	M26	GFZ
▪ ACTION 2: Definition of a common test case (can be METIS case study)	1/10/2020	31/12/2020	GFZ (with EDF, GRI, GDS)
▪ ACTION 3: Preparation of a regional stress drop map for Europe	01/10/2020	28/02/2021	GFZ
▪ ACTION 4: Scaling correction for EGF application	01/10/2020	01/04/2021	GFZ
▪ ACTION 5: Enhanced SCEC broadband simulation platform adapted for application in Europe	01/02/2021	30/06/2021	GFZ
▪ ACTION 6: Generate Simulation Database for the case study defined in action2 using a stochastic catalogue and compare the simulation with other methods and recent Empirical GMMs	01/07/2021	31/10/2021	GFZ
▪ ACTION 7: Parameterization of Otarola method accounting for uncertainty in input parameters	1/01/2021	01/12/2021	EDF
▪ ACTION 8: Analyse and propose approach to improve time evolution properties of the stochastic simulations to be in better agreement with recorded waveforms	1/10/2020	1/12/2021	EDF
▪ ACTION 9: Simulated database for case study	01/01/2021	31/06/2021	EDF
▪ ACTION 10: Optimization of the EGF-based simulation approach	01/10/2020	31/12/2021	GDS

▪ ACTION 11: Compare 3D GMTH models to empirical non-ergodic GMPEs to assess performance	01/01/2021	01/10/2022	PEER
▪ ACTION 12: Modelling of the characterized source model using Irikura recipe	01/03/2021	31/05/2021	GRI
▪ ACTION 13: Comparison of results for test case defined in action 2	01/11/2021	01/03/2022	GRI, EDF, GFZ
▪ ACTION 14: Create data base for METIS case study (see ACTION 2)	01/06/2021	01/10/2022	GRI, EDF, GFZ
▪ ACTION 15: Validate ground-motion simulation based on previous knowledge from empirical ground motion model.	01/11/2021	30/11/2021	GFZ

Task 4.6: PSHA TESTING and V&V

Start date: 01/09/2021 End date: 31/08/2023

Task Leaders: Graeme Weatherill, Fabrice Cotton (GFZ)

Contributors: Irmela Zentner, Guillaume Daniel, Emmanuel Viallet (EDF), Richard Styron, Marco Pagani (GEM)

Task 4.6.1: Implement Current State-of-the-Art Procedures for PSHA Testing

Sub-Task Leaders: Graeme Weatherill (GFZ)

Contributors: Guillaume Daniel, Emmanuel Viallet, Irmela Zentner (EDF), Richard Styron (GEM)

The aim of this task is to develop an open-source toolkit, to be disseminated via the METIS website (or similar open code platform) in which current state-of-the-art procedures for PSHA testing and updating are implemented. Feasible procedures are identified from the scientific literature, comprising three workflows: i) testing of PSHA against accelerometric data, ii) testing of PSHA against macroseismic data and iii) Bayesian updating of logic trees using accelerometric and/or macroseismic data. Hazard data are input in OpenQuake formats, including the complete logic tree in high density binary format. Other PSHA software may be supported. A general schematic of the toolkit is shown in Figure 1.

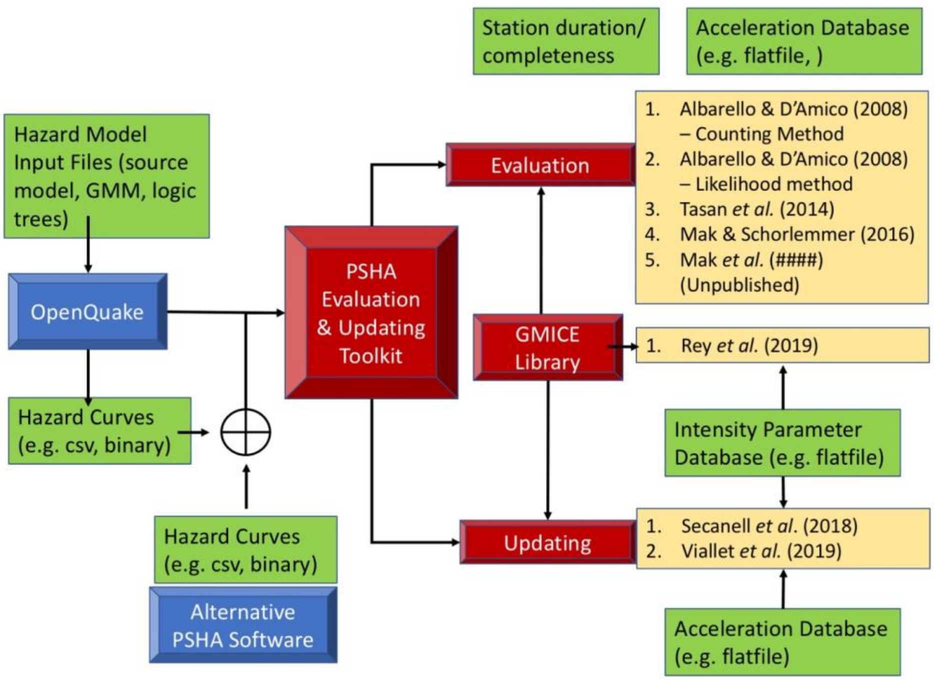

Figure 1: Schematic of the PSHA Evaluation & Updating Toolkit

The role of GFZ will be the primary development of the toolkit, while EDF will provide their own Python tools for adaptation into this toolkit and GEM to provide support to ensure compatibility of formats with OpenQuake.

Actions	Start Date	Due Date	Responsible
▪ Action 1: Provide existing Python tools for testing procedures	01/09/2021	30/09/2021	EDF
▪ Action 2: Develop preliminary code base for current state-of-the-art procedures, including unit testing, packaging and *basic* user documentation	01/10/2021	31/12/2021	GFZ

Task 4.6.2 Extend Existing methodology to include the spatial dimension

Sub-Task Leaders: Graeme Weatherill (GFZ)

Contributors: Graeme Weatherill (GFZ)

The aim of this task is to explore and integrate spatial information into the PSHA testing and updating process and understand its impact. Spatial information comprises two forms: i) the explicit modelling of spatial correlation and, where appropriate, spatial-cross correlation of ground motion residuals at multiple sites in order to account for the spatial dependencies between sites within PSHA, ii) application of partially- and/or fully-ergodic ground motion models (and correlation models) that use repeated source, path and site observations in a region to identify geographically calibrated models of ground motion, usually reducing the corresponding aleatory uncertainty when doing so. Using existing seismic hazard models within Europe, we aim to generate jointly distributed seismic hazard curves across a spatial region incorporating existing spatial correlation models to explore the sensitivity of the spatially aggregated hazard tests to the incorporation of spatial dependencies. We then aim to implement non-ergodic PSHA, initially using models of repeated source, path and site effects (e.g. Sgobba et al., 2019) and subsequently using varying coefficient models (e.g. Landwehr et al., 2016) if available in the OpenQuake-engine and determine what impact the use of non-ergodic ground motion models have in PSHA testing.

Actions	Start Date	Due Date	Responsible
▪ ACTION 1: Development of seismic hazard analysis accounting for spatial correlation, and application of state-of-the-art testing procedures	01/01/2022	15/02/2022	GFZ
▪ ACTION 2: Development of seismic hazard analyses using non-ergodic ground motion models, and application of state-of-the-art testing procedures	16/02/2022	31/03/2022	GFZ
▪ ACTION 3: Preparation of documentation and scientific publication	01/01/2022	31/03/2022	GFZ

Task 4.6.3 Case studies and methods to constrain branches of hazard models by means of historical data

Sub-Task Leaders: *Graeme Weatherill (GFZ)*

Contributors: Guillaume Daniel, Emmanuel Viallet, Irmela Zentner (EDF)

This task focuses on the use of testing against historical data (i.e. "back testing") as a means of simplifying logic trees in PSHA. Two steps are anticipated within this task, with potential case study applications to be identified. The first step will explore the application of "back testing" as a means of identifying combinations of seismogenic source and ground motion model that are inconsistent with, or highly improbable with respect to, observations. The second step aims to address the problems of complex source model logic trees, i.e. those in which distributions of the epistemic uncertainty on parameters such as magnitude frequency distribution, are characterised on a source-by-source basis. Such logic trees can rapidly blow up into impossibly large numbers of end branches, particularly when applied at regional scale, while common modelling steps taken to avoid this (such as assuming full correlation in the epistemic uncertainty in the sources, or collapsing subsets of branches) will affect the resulting epistemic uncertainty distribution. We therefore explore the application of dimensionality and data reduction techniques to complex logic trees, preserving the intended correlation in epistemic uncertainties within- and between-sources, in order to define a simplified source- and ground-motion model that samples efficiently the model space within a more manageable number of branches. From this point, back testing and/or Bayesian updating (e.g. Secanell, *et* al., 2018; Viallet et al. 2019) can be used to weight the branches within the simplified logic tree.

Actions	Start Date	Due Date	Responsible
▪ ACTION 1: Identification and preparation of PSHA models and observed data for testing	01/04/2022	30/04/2022	EDF
▪ ACTION 2: Application of hazard testing and data reduction to complex logic trees	01/05/2022	30/06/2022	GFZ
▪ ACTION 3: Preparation of report/scientific publication	01/06/2022	30/06/2022	GFZ

Task 4.6.4 Production of tools for testing intermediate and final results of PSHA models

Sub-Task Leaders: Graeme Weatherill (GFZ)

Contributors: Guillaume Daniel, Emmanuel Viallet (EDF), Richard Styron (GEM)

This task develops upon the preliminary Python toolkit for evaluation and updating of seismic hazard constructed in Task 4.6.1 to incorporate the outcomes of the sub-tasks 4.6.2 and 4.6.3 into an open source framework compatible with the OpenQuake-engine.

Actions	Start Date	Due Date	Responsible
▪ ACTION 1: Implementation of complete suite of testing tools into the toolkit, including user documentation and example applications	01/07/2022	28/02/2023	GFZ
▪ ACTION 2: Construction of Deliverable 4.4: "Report and code developments for PSHA Testing"	01/07/2022	28/06/2023	GFZ
▪ ACTION 3: Participation in the development of the test cases, testing of the tool	01/07/2022	28/06/2023	EDF

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Task 4.7: APPLICATION TO METIS STUDY and GUIDELINES

Start date: M20 End date: M28

Task Leaders: Kendra Johnson (GEM)

Contributors: Thomas Chartier, Marco Pagani, Richard Styron, Robin Gee (GEM), David Beaumont, Gabriele Ameri (GDS)

The aim of this task is to prepare guidelines illustrating the application in real cases of the methods developed within this work package and to apply them top the METIS case study.

GEM and GDS will jointly work at preparing the documentation requested as well as at implementing in the METIS application tests case the methods and findings of WP4.

This task will be developed in close collaboration with METIS work package 3 and 5.

Actions	Start Date	Due Date	Responsible
▪ ACTION 1: Define the characteristics of the METIS case study	1/9/2020	31/12/2020	GEM and GDS
▪ ACTION 2: Develop the METIS case study along with WP4 activities	01/01/2021	31/08/2023	GEM and GDS
▪ ACTION 3: Preparation of PSHA guidelines with the contribution of all the WP4 participants	01/01/2021	31/08/2023	GEM and GDS

Deliverables

Number	Title	Due Date	Responsible
D4.1	Seismic source characterizations methodologies and applications	30/04/2022	GEM
D4.2	Improved non ergodic GMPEs and V&V	30/04/2022	PEER
D4.3	Physics-based simulation of ground motion tools and database	01/10/2022	EDF
D4.4	New PSHA methodologies: code developments and documentation	31/01/2023	GEM
D4.5	Report and code developments for PSHA testing	31/01/2023	GFZ
D4.6	Application to METIS study case	31/10/2022	GEM
D4.7	Guidelines for PSHA	31/12/2021	GEM

Milestones of WP4

Number	Title	Verification mean	Due Date	Responsible
M5	Improved and new tools to compute PSHA with clustered seismicity and vector valued IMs in Openquake	Code and documentation available on github and Openquake website	M20	GEM
M6	New ground motion simulation tools	Codes & documentation available to public	M20	EDF
M7	PSHA output for METIS case study	Report and data	M20	GEM

Interaction with other WPs

Number	Interaction description	Responsible
1	Task 2.4 "Workshops and webinars" – Participants to WP4 will contribute to the workshop on site specific PSHA and ground motion	GEM

2	Task 2.5 "Education and training" – Participants to WP4 will contribute to the summer school on PSHA	GEM and IUSS
3	Task 3.2: *"Selection of a case study and data sharing"* – Goal in this case is to choose an appropriate site where to apply the methods developed in METIS WP4	GEM + WP4 participants
4	Task 3.3 "Supervision of analysis chain" – The goal is to ensure that the results and methods produced by work package 4 are aligned with the needs of the other technical tasks.	GEM
5	Task 5.1 "Methodology for site-specific rock-hazard-consistent record selection for mainshock-only seismicity" – Goal is to guarantee homogeneity in the definition of components of seismicity sequences.	GEM and IUSS
6	Task 5.2 "Methodology for site-specific rock-hazard-consistent record selection for clustered seismicity" – Goal is to guarantee homogeneity in the definition of components of seismicity sequences.	GEM and IUSS
7	Task 5.2.2 "T5.2.2 Preparation of clustered seismicity ground motion DBs and selection of hazard consistent ensembles of ground motions for engineering analyses" – GFZ will coordinate the interaction with IUSS and IRSN on the simulated time histories for mainshocks and aftershocks.	GFZ

Risks of WP4

Contractual risks (number, description, risk-mitigation), probability (1=low; 5=high) that the risk occurs and impact (1=low; 5=high) if the risk occurs. Other risks (not in GA) can be added so they can be followed during the project. Risk mitigation: P=preventive actions / C=contingency actions.

Number	Risk description	Risk mitigation	Prob	Impact
1	Delay or failure in implementing some of the PSHA methodologies required for producing the results required by WP5	Prioritise implementation, starting from the most consolidated and robust approaches	2	4
2	Delay or failure in delivering the simulated time histories required by WP5	Follow progress closely. Concentrate efforts on best performing approaches	2	5

3	Difficulty in applying comprehensively the methods proposed in WP4 to the METIS case study.	Concentrate on the most relevant and impactful ones	3	4
4	N. Abrahamson leaves UC Berkeley before the METIS project is completed	Prof. Athanasopoulos-Zekkos is being kept up to date on the PEER tasks and can assume the leadership for PEER in the METIS project	2	3

6. Description of WP5 "Ground motion selection for engineering analyses including site response" activities

Start date: September 2020; End date: February 2024

Work Package Leader- co-Leader: *Paolo Bazzurro (IUSS)*

Task 5.1: Methodology for site-specific rock-hazard-consistent record selection for mainshock-only seismicity

Start date: September 2020; End date: August 2023

Task Leaders: *Paolo Bazzurro (IUSS)*

Contributors: Paolo Bazzurro, Mohsen Kohrangi, Nevena Šipčić, Pablo Garcia (IUSS), Irmela Zentner, Vinicius Alves Fernandes, Gloria Senfaute, Paola Traversa (EDF), Dimitrios Vamvatsikos, Aggeliki Gerontati (NTUA), Maria Lancieri (IRSN), Marco Pilz, Graeme Weatherill, Fabrice Cotton (GFZ), Ken Miyakoshi, Kojiro Irikura, Takashi Akazawa, Masato Tsurugi (GRI), Marco Pagani (GEM)

The current state-of-the-art in the evaluation of the earthquake risk of structures and components of any kind stands on the framework known as Performance-Based Earthquake Engineering (PBEE). This approach separates the contributions to risk calculations deriving from site hazard, traditionally carried out by seismologists, to those from vulnerability assessment performed by engineers. The site hazard is usually distilled into the likelihood of exceedance of ground motion intensity measures (IMs), here tackled in WP4. The seismic response instead is traditionally condensed into sets of IM-based fragility functions for different limit states (e.g., operability and failure) of interest for the functionality and safety of the structure/equipment under consideration or of the system in which it is integrated. This task is handled in WP6 here. The link between seismology and engineering is left to sets of ground motion records, that are intended to be statistically similar to that structure may experience at the site in its intended lifetime. This similarity should be ensured by careful ground motion selection procedures that guarantee, to the extent possible, consistency with the site hazard. If site hazard consistency is not preserved, fragility functions may very inaccurately estimate the likelihood that the structure/equipment may exceed the given limit state for different levels of IMs.

Task 5.1.1: Definition of "site-specific rock-hazard consistency" for mainshock-only seismicity

Sub-Task Leaders: *Paolo Bazzurro (IUSS)*

Contributors: Paolo Bazzurro (IUSS), Irmela Zentner (EDF), Maria Lancieri (IRSN), Marco Pagani (GEM), Dimitrios Vamvatsikos, Aggeliki Gerontati (NTUA)

The scope of the task is to provide appropriate sets of earthquake ground motions for rock conditions that are consistent with the site-specific seismic hazard for any combination, either in a scalar or vectorial format, of relevant IMs.

Given the diverse nature of the fragility analyses that will be performed on the SSC structures and the possible variations within these structure types, several IMs may be considered, such as spectral accelerations, Sa(T), at different oscillator periods, (T), average spectral acceleration (AvgSa) in a given period range, Arias Intensity (AI), duration, cumulative absolute velocity (CAV), for the horizontal and possibly vertical directions of motions. This will allow investigating the adequacy of different metrics to predict the structural response for different structures subjected to different hazard levels.

The definition of what constitutes hazard consistency of an IM, or a group of IMs, and how to achieve it are not well defined. For this purpose, we will consider different variants of existing methodologies, such as the conditional spectrum (CS) approach and the Generalized Conditional Intensity Measure (GCIM) approach and extend them to multiple directions of ground motions. The application of these methodologies, in general, requires the knowledge of the variance-covariance matrix of the different IMs that come into play. We envisage that the correlation structure of several IMs that the fragility computations in WP6 will adopt has not yet been investigated.

The role of IUSS is to lead the task by leveraging on the research work on the subject done in the previous years. Specifically, IUSS will define the hazard consistency criteria, develop the tools for ensuring it, and help develop the correlation structure among IMs not already available.
The role of IRSN is to investigate the physics behind the correlations structure among IMS and provide recommendations that may help improving ground motion record selection.
The role of NTUA is to provide assistance in the definition of hazard consistency and in the development of tools for enforcing it.

The role of GEM is to provide support in the development and ensure that the hazard consistency in ground motion selection uses the same definitions of IMs adopted in WP4 and that the hazard calculations provide all the IMs needed for such activities in that work package.

Actions	Start Date	Due Date	Responsible
▪ **Action 1**: Define the hazard consistency for different IMs, both in scalar and vectorial sense for one or more directions of motion	M1	M15	IUSS, IRSN
▪ **Action 2**: Develop the correlation structure for different combinations of IMs	M1	M15	IUSS, IRSN
▪ **Action 3**: Develop the methodologies and tools for enforcing the hazard consistency for the different variants considered in Action 1	M1	M20	IUSS

Task 5.1.2: Identification and development of rock ground motions from recorded ground motion DB

Sub-Task Leaders: *Marco Pilz (GFZ)*

Contributors: *Marco Pilz, Graeme Weatherill (GFZ), Ken Miyakoshi, Kojiro Irikura, Takashi Akazawa, Masato Tsurugi (GRI), Vinicius Alves Fernandes, Paola Traversa (EDF)*

Modern DB contains a significant number of GMTH, but only a few are recorded on rock sites and do not feature site effects. In order to obtain GMTH in agreement with bedrock conditions, the following tasks are performed:

- Development and application transparent and clear criteria to identify rock stations which are free of local amplifications or resonance peak (both at short and long periods) to be used as references (*Pilz et al. (2020), Identification of seismic reference stations in Europe, GJI);*
- Only a small subset of GMTH in the DBs is recorded on rock sites. In order to increase the number of available records, the soil surface GMTH are transferred to bedrock using (complex) transfer functions computed by 1D site response when soil column data is available;
- Input from Task 5.3.3 (empirical site response transfer functions directly obtained by seismic records, GRI) can also be used.

The role of GFZ is to provide criteria for identification of rock stations and to apply it to the DBs of ground motion recordings utilized in this study

The role of EDF is to develop a methodology for transferring ground motions recorded, from soil to rock conditions, as defined in this task.

The role of GRI is to obtain the empirical site response transfer functions by seismic records from Task 5.3.3.

Actions	Start Date	Due Date	Responsible
▪ **Action 1:** Criteria to identify rock stations	M1	M18	GFZ
▪ **Action 2:** Identify sites with soil column available and computation of numerical transfer functions	M1	M18	EDF
▪ **Action 3:** Compute rock motion with empirical or numerical transfer functions	M1	M24	GFZ

Task 5.1.3: Appropriateness of recorded and synthetic ground motions for engineering analyses

Sub-Task Leaders: *Paolo Bazzurro (IUSS), Maria Lancieri (IRSN)*

Contributors*: Mohsen Kohrangi, Nevena Šipčić, Pablo Garcia, Paolo Bazzurro (IUSS), Gloria Senfaute, Irmela Zentner (EDF), Dimitrios Vamvatsikos, Aggeliki Gerontati (NTUA), Maria Lancieri (IRSN)*

The methodologies for rock hazard consistent ground motion selection developed in Task 5.1.1 ideally would need the availability of large databases of ground motions recorded on rock conditions. These recordings, however, are not plentiful. The scarcity of the real rock recordings has been historically circumvented by either a) using real recordings on both rock and soil conditions (either as-is or sometimes deconvolved to rock conditions) appropriately scaled to the amplitude levels desired by the application at hand, or b) by using synthetic rock ground motions, or c) by adopting a combination of the previous two. These practical but sub-optimal approaches deserve some scrutiny before they are applied for the rock-hazard-consistent ground motion record selection techniques to be developed in WP5.

Regarding the real ground motions four are the main aspects to be investigated: a) is the use of soil ground motions blended with rock ones legitimate for this application from an engineering seismology perspective? What is the impact of mixing soil and rock GM on signal features, such as frequency content at low and high frequencies? To do so, we will study similarities and differences between waveforms belonging to given sets of selected hazard consistent GM. b) are rock motions obtained from deconvolution of soil motions using empirical transfer functions, as explained in Task 5.1.2, statistically and seismologically indistinguishable from those that were recorded on the rock? c) Are real ground motions, scaled in amplitude to fulfil the requirements dictated by site-specific rock hazard consistency, seismologically similar to those naturally at those amplitudes? Are the scaled ground motions statistically similar in terms of duration and frequency content to those naturally at that amplitude? If there are differences, how are they reflected in the response of simple SSCs? Can the bias, if any, and possibly uncertainty estimates be corrected? d) Are there any ground motion IMs (e.g., average spectral acceleration, AVGSa, in a given oscillator period range) that require a lower level of scaling for hazard consistency but are still good predictors of structural response in simple SSCs?

To estimate the appropriateness of the synthetic ground motions, we will devise and conduct a battery of seismological and engineering tests to investigate whether the characteristics of these motions (e.g., in terms of correlation of spectral quantities in the three components, duration, amplitude, polarization, non-stationary behavior, and energy release) are consistent with those of real records from similar scenarios and whether they induce responses in simple SSCs that are statistically similar to those of real ground motions.

The role of IUSS is to lead the engineering work on the legitimacy of including scaled ground motions and soil ground motions, either as is or after being modified to rock conditions, in the rock-hazard-consistent ensembles that will be used for fragility computations. IUSS will carry out the same activities related to the legitimacy of using synthetic ground motions as well. The role of NTUA is assisting in such activities.

The role of IRSN is to lead the seismological work on the legitimacy of scaling and mixing rock motions and soil motions, either as is or after being modified to rock conditions, for generating richer ensembles of ground motions to be used for site-specific fragility curve computations. IRSN's role is also to seismologically scrutinize the synthetic ground motions to ensure that they are statistically similar to real ones belonging to the same scenarios.

The role of EDF is to participate in the work on the definition of selection criteria for synthetic and recorded ground motion and to assess feasibility and appropriateness for nuclear engineering applications.

Actions	Start Date	Due Date	Responsible
▪ **Action 1:** Assembling DBs of real ground motions for both rock and soil conditions and synthetic ground motions developed in WP4 (Task 4.5)	M1	M18	IUSS, IRSN
▪ **Action 2:** Assessing the adequacy from both seismological and engineering viewpoints of using scaled motions for fragility analysis	M6	M20	IUSS, IRSN
▪ **Action 3:** Assessing the adequacy from both seismological and engineering viewpoints of using soil motions, either as recorded or deconvolved to rock conditions, for fragility analysis	M6	M24	IUSS, IRSN
▪ **Action 4:** Investigation of the use of alternative IMS that are efficient predictors of structural response in simple SSCs but require lower scaling for making ground motions hazard consistent	M1	M20	IUSS, IRSN
▪ **Action 5:** Assessing the adequacy from both seismological and engineering viewpoints of using	M6	M20	IUSS, IRSN

synthetic ground motions for fragility analysis	

Task 5.1.4: Preparation of mainshock ground motion DBs for improving hazard consistency

Sub-Task Leaders: *Paolo Bazzurro (IUSS), Maria Lancieri (IRSN)*

Contributors: *Mohsen Kohrangi, Nevena Šipčić, Pablo Garcia (IUSS), Maria Lancieri (IRSN)*

In light of the findings of Tasks 5.1.1, 5.1.2, and 5.1.3, three databases of ground motions will be assembled:

a) Real ground motions: recorded on both rock and soil with guidelines on their applicability for fragility analysis;
b) Real ground motions that were recorded on rock conditions or were transferred to rock conditions with guidelines on their applicability for fragility analysis;
c) Synthetic rock ground motions with guidelines on their applicability for fragility analysis.

From these databases, rock-hazard-consistent ground motions will be selected and used in Task 6.3 to test whether the responses of simple SSCs to ground motions from these three datasets are statistically indistinguishable and appropriate for fragility analysis.
The role of IUSS and IRSN is to assemble the ground motion DBs. Besides, the role of IUSS also includes the extraction of hazard consistent ensembles of ground motions for fragility calculations.

Actions	Start Date	Due Date	Responsible
▪ **Action 1**: Assemblage of the three ground motion databases;	M1	M18	IUSS, IRSN
▪ **Action 2:** Extracting hazard-consistent ensembles of ground motion records for fragility calculations.	M1	M18	IUSS, IRSN

Task 5.1.5: Selection of the kind of ground motions most appropriate for engineering analyses

Sub-Task Leaders: *Paolo Bazzurro (IUSS), Dimitrios Vamvatsikos (NTUA)*

Contributors: Mohsen Kohrangi, Nevena Šipčić, Pablo Garcia, Paolo Bazzurro (IUSS), Aggeliki Gerontati (NTUA), Irmela Zentner (EDF)

The scope within this task is to investigate the robustness of fragility curves obtained using a practical number of ground motions that the previous Tasks 5.1.1 through 5.1.4 have identified as appropriate for engineering response analysis calculations. This task will investigate the variability of fragility curves of simple SSCs generated by large ensembles of real and synthetic ground motions and will study the impact of the reduction in the number of records (both real and synthetic, if appropriate) on such fragility curves.

To reduce the number of records, we will also investigate filtering techniques to prevent using "weak" ground motions, that will unlikely cause damage in the structures of interest.

The role of IUSS is to investigate the robustness of fragility curves to the sample size and the usage of real and synthetic ground motions. EDF and NTUA will provide the necessary assistance in such activities.

Actions	Start Date	Due Date	Responsible
Action 1: Assessment of the variability in the fragility curves (obtained with different IMs) of simple SSCs generated by large ensembles of hazard consistent real and synthetic ground motions;	M6	M20	IUSS, EDF
Action 2: Quantification of the effect on fragility curves (obtained with different IMs) of simple SSCs of the ground motion ensemble size;	M9	M20	IUSS, EDF
Action 3: Investigating the need and, if appropriate, developing a procedure for filtering out non-damaging records, prior to fragility curve investigation.	M9	M20	IUSS, EDF

Task 5.2: Methodology for site-specific rock-hazard-consistent record selection for clustered seismicity

Start date: M6; End date: M36

Task Leaders: *Paolo Bazzurro (IUSS)*

Contributors: *Mohsen Kohrangi, Nevena Šipčić, Pablo Garcia, Paolo Bazzurro (IUSS), Maria Lancieri (IRSN), Marco Pagani (GEM), Dimitrios Vamvatsikos, Aggeliki Gerontati (NTUA)*

Task 5.2.1: Definition of "site-specific rock-hazard consistency" for clustered seismicity

Sub-Task Leaders: *Paolo Bazzurro (IUSS)*

Contributors: *Mohsen Kohrangi, Nevena Šipčić, Pablo Garcia, Paolo Bazzurro (IUSS), Maria Lancieri (IRSN), Marco Pagani (GEM), Dimitrios Vamvatsikos, Aggeliki Gerontati (NTUA)*

The objective of this task is to define a methodology for selecting hazard-consistent-aftershock ground motion records to be used to estimate damage-state dependent fragility curves of SSCs subject to earthquake sequences. We will investigate whether the consistency should be guaranteed with the mainshock-only hazard or with the clustered seismicity hazard from WP4. Also, we will empirically develop correlation structures of IMs of mainshock-aftershock real ground motion pairs, as needed in WP6 for fragility computations. The correlation between different IMs of mainshock and aftershocks ground motions is, in general, not known except for spectral accelerations.

The role of IUSS is to define the hazard consistency criteria for mainshock-aftershock ground motions and to investigate the correlation structure of the IMs used for damage-state-dependent fragility curve computations. NTUA will assist in such activities.

The role of IRSN is to assist in the IM correlation structure empirical estimation

Actions	Start Date	Due Date	Responsible
▪ Action 1: Define the ground motion hazard consistency for different definitions of hazard (mainshock only and clustered seismicity);	M6	M22	IUSS
▪ Action 2: Investigate the statistical correlation between the IMs of mainshock –aftershock pairs.	M6	M22	IUSS

Task 5.2.2: Preparation of clustered seismicity ground motion DBs and selection of hazard consistent ensembles of ground motions for engineering analyses

Sub-Task Leaders: *Paolo Bazzurro (IUSS)*

Contributors: *Mohsen Kohrangi, Nevena Šipčić, Pablo Garcia, Paolo Bazzurro (IUSS), Maria Lancieri (IRSN)*

The objective of this task is to assemble DBs of ground motions from earthquake sequences that can be used for developing damage-state dependent fragility curves to be used for clustered seismicity risk assessment. These DBs intend to include both real ground motions and simulated ground motions. As in the case of mainshock only seismicity, the simulated ground motions will be included if they pass a battery of tests that establish their appropriateness from both an engineering and a seismological viewpoint. These additional tests will investigate whether mainshock-aftershock ground motion pairs have a realistic correlation between IMs of a different kind across records. When the DBs are established, the last action item consists of extracting hazard consistent ground motions according to the methodology developed in task 5.2.1. These ground motions will then be used in Task 6.7 of the WP6 to evaluate the importance of the consistent mainshock-aftershock pair selection by comparison with the fragility estimates that exploit the set of randomly matched record pairs, which is current practice in risk assessment that accounts for seismic clustering.

The role of IUSS is to assemble the DB of real and synthetic ground motions, to assist in devising the battery of tests for simulated ground motions, to develop the correlation structure of mainshock-aftershock IMs and to extract the fine ensembles of ground motions.

The role of IRSN is to lead the tests of mainshock-aftershock pairs and to provide assistance in the empirical evaluation of the correlation structure of IMs.

Actions	Start Date	Due Date	Responsible
▪ **Action 1**: Assembling DBs of real and simulated ground motions for damage-state-dependent fragility curve computations.	M6	M18	IUSS
▪ **Action 2:** devising and applying a battery of tests to gauge the applicability of simulated ground motions for the computation of damage-dependent fragility curves.	M18	M22	IUSS
▪ **Action 3:** Extracting ground motion records from earthquake sequences that fulfil the ground motion record selection devised in task 5.2.1.	M18	M22	IUSS

Task 5.3: Site response modelling to obtain surface ground motions from rock-hazard consistent ground motions

Start date: M01 End date: M36

Task Leader: *Vinicius Alves Fernandes and Irmela Zentner (EDF)*

Contributors: *Vinicius Alves Fernandes, Stefano Cherubini, Irmela Zentner (EDF), Takashi Akazawa, Masato Tsurugi (GRI), Marco Pilz (GFZ), Matjaž Dolšek, Jure Zizmond (UL), Paolo Bazzurro (IUSS)*

In order to obtain soil surface GMTH from the bedrock GMTH databases (simulated or recorded), site response analysis needs to be performed. Indeed, in order to perform structural response and SSI analyses, engineers need a description of equivalent 1D soil profiles (so-called soil columns) as well information on the ground motion to be considered for the analyses. Typically, a probabilistic description of the soil profile and a set of GMTH are required for the probabilistic analyses.

Key points to be addressed in this task are:

- Assess the uncertainty to be considered in 1D and 2D site response and develop an approach for uncertainty propagation in site response, coherent with the following SSI analyses where 1D soil columns are considered.
- The development of 2D and 3D wave propagation computations is always challenging, for numerical reasons and because of the difficulty to build reliable 2D/3D models. We

develop criteria based on-site records (noise and weak motions) and the site configuration (distance to the basin edge, basin depth) on identifying if 1D modelling is enough or should be replaced by 2D/3D models.

- Numerical site response analyses require costly numerical computations. Simplified models and empirical models might help to reduce computational cost.

Task 5.3.1: Uncertainty propagation and nonlinearity in 1D site response

Sub-Task Leaders: Irmela Zentner EDF, Matjaž Dolšek UL

Contributors: Stefano Cherubini, Irmela Zentner, Vinicius Alvez-Frenandez (EDF), Matjaž Dolšek , Jure Zizmond (UL), Paolo Bazzurro (IUSS)

Uncertainty in 1D analyses does not capture all sources of variability, including the influence of lateral variability on wave scattering. It is proposed to:

- Assess and propagate uncertainty in 2D site response including spatial variability and nonlinear material behaviour
- Develop an approach to define consistent (linear) equivalent 1D columns reflecting the encountered variability
- Define a reduced set of 1D columns (and the corresponding probability distributions) that would well represent the variability for SSI

As 1D site response becomes problematic in the case of shear strain increase in one of the layers, the focus will be on the investigation of this shortcoming based on measurements and trying to develop an improved technique for 1D analysis

Actions	Start Date	Due Date	Responsible
Action 1: Develop a methodology for defining ground motion and soil columns by equivalent 1D site response	M1	M12	EDF
Action 2: Improvement of 1D site response analysis for high shear strain response	M12	M36	UL

Task 5.3.2: 2D/3D site response and spatial variability

Sub-Task Leaders: Vinicius Alves Fernandes, EDF

Contributors: Vinicius Alves Fernandes (EDF), Matjaž Dolšek (UL), Marco Pilz (GFZ)

In this Sub-task, **EDF** provides a strategy to account for 2D and 3D site response using full FEM analyses and the development of spatial variations of input motion considering ground motion input from PSHA at bedrock level.

Partner **GFZ** will develop criteria for conducting 1D, 2D, or 3D site response:

i. based on transfer function variability if site-specific information is available;

ii. using earthquake-based criteria (within-event variability, comparing changes in spectral shape and amplitude, accounting for the magnitude-distance dependency of 2D/3D effects, cf. Euroseistest), if no site-specific information is available.

Actions	Start Date	Due Date	Responsible
▪ Action 1: Report on a strategy to account for 2D and 3D site response by full FEM analyses	M12	M36	EDF (Vinicius Alves Fernandes)
▪ Action 2: Criteria for conducting 1D, 2D or 3D site response	M0	M24	GFZ (Marco Pilz)

Task 5.3.3: Empirical site effects to develop soil surface GMTH

Sub-Task Leaders: Ken Miyakoshi GRI

Contributors: Ken Miyakoshi, Kojiro Irikura, Takashi Akazawa, Masato Tsurugi (GRI), Marco Pilz (GFZ*)*

Numerical site response analyses require costly numerical computations. Empirical amplification functions are determined in the frequency domain as the ratio of observed seismic spectra to the 'bedrock spectra'. We develop an empirical method for quantitatively evaluating site effects in the time-domain, by extending the method in the frequency domain to Fourier spectra, including phase information. The resulting amplification functions are applied to correct bedrock GMTH in the Fourier domain.
The transformation of the complex amplification functions to a causal recursive filter in the time domain allows for the precise forecasting of the waveforms for rock sites free of the site effects accounting for the different durations at soft soil and rock sites.

Actions	Start Date	Due Date	Responsible
▪ Action 1: Development of empirical methods for estimating site response transfer functions	M12	M24	GRI

Task 5.4: Ground motion ensembles for METIS case study and guidelines

Start date: M24 End date: M42

Task Leaders: Paolo Bazzurro (IUSS)

Contributors: Mohsen Kohrangi, Nevena Šipčić, Pablo Garcia, Paolo Bazzurro (IUSS), Irmela Zentner, Vinicius Alves Fernandes (EDF), Maria Lancieri (IRSN), Dimitrios Vamvatsikos, Aggeliki Gerontati (NTUA)

Task 5.4.1: Application of developed methodologies to select ensembles of hazard consistent GMTHs for mainshock and clustered seismicity

Sub-Task Leaders: Paolo Bazzurro (IUSS)

Contributors: *Mohsen Kohrangi, Nevena Šipčić, Pablo Garcia, Paolo Bazzurro (IUSS), Irmela Zentner, Vinicius Alves Fernandes (EDF)*

The goal of this task is to develop ensembles of hazard consistent motions for both mainshock and clustered seismicity for the case studies addressed in WP3. These ensembles will use the methodologies defined in Tasks 5.1, 5.2. and 5.3 The ensembles of ground motions will be selected to be hazard consistent for the IMs identified in WP6 for fragility curves estimation.

The role of IUSS is to carry out the activities for both action items listed in the table below.

Actions	Start Date	Due Date	Responsible
▪ **Action 1:** Selection of ground motion record sets consistent with mainshock hazard for the site of the WP3 case study	M24	M42	IUSS
▪ **Action 2:** Development of surface ground motion for METIS case study	M24	M42	EDF
▪ **Action 3:** Selection of ground motion record sets consistent with clustered seismicity hazard for the site of the WP3 case study	M24	M42	IUSS

Task 5.4.2: Recommendations and guidelines

Sub-Task Leaders: Paolo Bazzurro (IUSS)

Contributors: Paolo Bazzurro (IUSS), Irmela Zentner, Vinicius Alves Fernandes (EDF), Maria lancieri (IRSN), Dimitrios Vamvatsikos, Aggeliki Gerontati (NTUA)

This task will produce a document containing the guidelines and procedures for record selection suitable for fragility curve calculations for mainshock and clustered seismicity conditions. This report will also include recommendations for the selection of spatially consistent ground motions.

The role of all four organizations, namely IUSS, IRSN, EDF, and NTUA, is to collaborate in the writing of the guidelines for the selection and usage of mainshock-only and mainshock-aftershock ground motions. IUSS will lead this effort.

Actions	Start Date	Due Date	Responsible
▪ **Action 1:** Guidelines on the use of the ensembles of ground motions for the fragility curve derivation related to the WP3 case study.	M24	M42	IUSS,IRSN,EDF,NTUA

Deliverables

Number	Title	Due Date	Responsible
D5.1	Methodology for selecting ensembles of rock-hazard consistent ground motions for fragility curve computations and datasets for WP6	M20	IUSS
D5.2	Methodology for selecting ensembles of rock-hazard consistent ground motions suitable for fragility curves computations for clustered seismicity and datasets for WP6	M24	IUSS
D5.3	Methodology for site response analysis to obtain surface ground motions from rock-hazard-consistent ground motions.	M24	UL
D5.4	Ensembles of hazard-consistent surface ground motions for mainshock seismicity	M28	IUSS
D5.5	Ensembles of hazard-consistent surface ground motions for clustered seismicity	M30	IUSS

Milestones of WP5

Number	Title	Verification me	Due Date	Responsible
MS5.1	Criteria for selecting rock-haza consistent ground motions for mainshock and clustered seismicity conditions	Report and sets o ground motions	M24	IUSS
MS5.2	Site response methodology suitable for providing surface ground motions from rock-haz consistent ground motions	Report and sets o ground motions	M28	EDF

Interaction with other WPs

Number	Interaction description	Responsible
1	**Tasks 2.4:** "Workshops and webinars" and 2.5: "Education and training" Findings of WP5 will be used as training material	LGI, NTUA, IUSS
2	**Task 3.2:** "Selection of a case study and data sharing" Information about the soil characteristics for the case study will be used in **Task 5.3**: "Site response modelling to obtain surface ground motions from rock-hazard consistent ground motions".	EDF
3	**Task 4.4.1**.: "Vector-valued PSHA and CS Approach" The methods and tools implemented in this task will be used in **Task 5.1.3** to test the selection of rock-hazard consistent ground motions for various IMs and different variants of the hazard calculations.	GEM, IUSS
4	**Task 4.4.2**: "Modelling earthquake sequences for considering aftershocks" The methods implemented in this task will be used in **Task 5.2** to test the record selection for various IMs for clustered seismicity conditions.	IUSS
5	**Task 4.5: "**Simulation of strong ground-motion on bedrock" Records simulated in this task will be used in **Task 5.1.3** to assemble DBs of ground motions.	GEM, IUSS, IRSN
6	**Task 4.7: "**Application to METIS study and guidelines" Results of PSHA analysis will be used in **Task 5.4**: "Ground motion ensembles for METIS case study and guidelines".	GEM, IUSS
7	**Task 6.3**: "Determination of damage/failure relevant ground motion intensity measures and record selection". IUSS will compute fragilities of simple SSCs using different ensembles of hazard consistent ground motions defined in **Task 5.1**.	UL, IUSS
8	**Task 6.7**: "Influence of aftershocks and clustered seismicity on seismic fragility" IUSS will use the different ensembles of hazard consistent mainshock-aftershock pairs of ground motions defined in **Task 5.2** to compute fragilities of simple SSCs and estimate the effect of clustered seismicity.	IUSS TUK
9	**Task 6.9:** "*Application to METIS case study and guidelines"* Final set of records from Task 5.4 will be used	IUSS TUK

Risk of WP5

Contractual risks (number, description, risk-mitigation), probability (1=low; 5=high) that the risk occurs and impact (1=low; 5=high) if the risk occurs. Other risks (not in GA) can be added so they can be followed during the project. Risk mitigation: P=preventive actions / C=contingency actions.

Number	Risk description	Risk mitigation	Proba	Impact
1	Simulated ground motions not passing the battery of tests for the entire oscillator period range of interest	Use hybrid (stochastic plus deterministic) methods	3	4
2	Hazard consistency difficult/impossible to implement for IMs identified in WP6	Collaboration with WP6 to make sure that the IMs considered are suitable for hazard calculations and ground motion selection	2	3

7. Description of WP6 "Beyond Design Assessments and Fragility Analysis" activities

Start date: M1; End date: M48

Work Package Leader- co-Leader: Konstantin Goldschmidt – Hamid Sadegh-Azar; Technical University Kaiserslautern (TUK)

Task 6.1.: Definition and classification of SSCs and development of reliable mechanical models

Start date: M01 End date: M21

Task Leaders: Oleksandr Sevbo, ER

Contributors: Konstantin Goldschmidt, TUK; BITAR Ibrahim, IRSN; Heitz Thomas, IRSN; Richard Benjamin, IRSN; Dimitrios Vamvatsikos, NTUA; Dzifa Kudawoo, UKC

The aim of this task is the definition and classification of SSCs according to their relative importance into Tier 1 SSCs (requiring detailed system-specific analysis) and Tier 2 SSCs (generic class-specific assessment). A hierarchy of multi-fidelity models will be developed for Tier 1 systems, involving both detailed and simpler reduced-order models, together with associated failure criteria to offer different fidelity options for both unbiased estimation of central tendencies as well as efficient variance reduction. Consideration of three typical SSCs for verification: a reinforced concrete beam, a crane bridge mock and a 1:4 scale reinforced concrete building. Only simple, class-level models will be employed for Tier 2 systems, employing both inter-SSC and intra-SSC correlation and variance to capture an entire class of similar components.

The role of partner ER is to define and classify the SSCs.

The contribution of partner UKC, TUK and IRSN is to develop the reliable mechanical nonlinear analysis models and corresponding failure criteria for three previously defined SSCs.

The contribution of partner NTUA is to investigate of the possibility to derive surrogate models to be used for fragility analysis.

Actions	Start Date	Due Date	Responsible
▪ Action 1: Define and classify SSCs (structures, systems and components) for detailed specific and for generic fragility analysis	M2	M13	ER
▪ Action 2: Develop reliable mechanical nonlinear analysis models and corresponding failure criteria of three SSCs	M7	M20	UKC, TUK, IRSN
▪ Action 3: Investigate of the possibility to derive surrogate models to be used for fragility analysis.	M7	M20	NTUA

Task 6.2: Verification and validation of models and failure criteria

Start date: M12 End date: M36

Task Leaders: Heitz Thomas, Richard Benjamin, IRSN;

Contributors: Dimitrios Vamvatsikos, NTUA; Konstantin Goldschmidt, TUK

The aim of this task is the selected mechanical models and failure criteria identified and developed in T.6.1 Tier 1 will be validated and verified based on experimental analysis and test data. Based on the results, we develop verification and validation criteria that should be fulfilled to assure meaningfulness, both for detailed and reduced-order models and associated failure criteria, targeting a multi-fidelity bias/variance reduction approach.

The contribution of partner **IRSN** is to develop and apply V&V approaches for the mechanical nonlinear models using experimental analysis and tests.

The contribution of partner **NTUA** is to perfom V&V of surrogate model (Please see also T6.4) and to discuss multi-fidelity models and approaches. In particular, we analyze how to make sure that reduction to surrogacy does not inadvertently introduce high epistemic uncertainty using spot checks with the detailed model. NTUA will also discuss the issue of record to record correlation within a generic class and how aggregation ruins the correlation that should exist for a given ground motion.

The competence of partner **TUK** is to review the V&V techniques used by IRSN.

Actions	Start Date	Due Date	Responsible
▪ Action 1: V&V of mechanical nonlinear models using experimental analysis and tests	M12	M22	IRSN
Action 2: Critical analysis and recommendations for developing surrogate models for fragility assessment	M12	M22	NTUA
▪ Action 3: Review of V&V techniques for nonlinear mechanical models, Verification and validation of surrogate models	M21	M28	TUK

Task 6.3: Determination of damage/failure relevant ground motion intensity measures and record selection

Start date: M5 End date: M28

Task Leaders: Dolšek Matjaž, UL

Contributors: Konstantin Goldschmidt, TUK; Paolo Bazzurro, IUSS; Nevena Sipcic, IUSS; Pablo Alfonso Garcia de Quevedo Iñarritu, IUSS; Mohsen Kohrangi, IUSS; R Irmela Zentner, EDF; Gloria Senfaute, EDF; Dimitrios Vamvatsikos, NTUA

The aim of this task is to identify damage/failure relevant ground intensity measures (scalar or vector) to reduce the scatter and epistemic uncertainty of response results. The structural response and the corresponding uncertainty due to different ground motion record selection schemes developed in WP5 will be investigated. The recommendation on the final methodology for IM selection, record selection and including site response in record selection will hinge on the findings of this task.

The role of partner UL, EDF is to determinate damage/failure relevant ground motion parameters together with TUK and IUSS.

The role partner TUK is to determinate damage/failure relevant ground motion and develop and implement multi-dimensional fragility evaluation.

The role of partner IUSS is the computation of the fragility of simple SSCs using ground motion from WP 5.

Actions	Start Date	Due Date	Responsible
▪ Action 1: Determination of damage/failure relevant ground motion parameters (vectors and characteristics).	M5	M21	UL, IUSS, TUK, EDF

Actions	Start Date	Due Date	Responsible
Action 2: Development and implementation of multi-dimensional (vector-based) fragility evaluation methods	M5	M21	TUK
Action 3: Fragility computations of simple SSCs using different ensembles of hazard consistent ground motions from WP5	M18	M25	IUSS

Task 6.4.: Uncertainty quantification and propagation

Start date: M8 End date: M30

Task Leaders: Dimitrios Vamvatsikos, NTUA

Contributors: Konstantin Goldschmidt, TUK; BLAIN Christophe, IRSN; RICHARD Benjamin, IRSN; Dolšek Matjaž, UL

The aim of this task is to identify and quantify all sources of uncertainty (aleatory and epistemic). For Tier 1 SSCs, special attention is paid to the use of reduced-order or surrogate models, using cross validation to make sure that the reduction to surrogacy does not inadvertently introduce errors, but instead helps reducing epistemic uncertainty by allowing a cost-effective exploration of a large parameter space. In Tier 2 SSCs, the issue of loss-of-fidelity due to aggregation within a single class fragility will be investigated, offering novel representations of fragility that incorporate record-to-record and component-to-component correlation models to reduce the associated epistemic uncertainty. Propagation via simplified approaches, machine learning, and smart sampling will be investigated, focusing on developing recommendations suitable for each SSC and uncertainty level present.

The role of partner **TUK** is to identify and quantify all sources of uncertainty and determine probabilistic analysis method for fragility analysis.

The role of partner **IRSN** is to identify and quantify all sources of uncertainty.

The role of partner NTUA is to identify and quantify uncertainty of surrogate models and determine probabilistic analysis method for fragility analysis.

The role of partner **UL** is to develop models for dispersion of limit-state intensities considering aleatoric and epistemic uncertainties for relevant SSC considering the optimal scalar/vector-valued IM.

Actions	Start Date	Due Date	Responsible
Action 1: Identification and quantification of all sources of aleatory and epistemic uncertainty	M8	M24	TUK, IRSN
Action 2: Reduced-order or surrogate models for tier 1 SSCs	M8	M24	NTUA

▪ Action 3: Determination of accurate and efficient probabilistic analysis methods for fragility analysis	M8	M21	TUK, NTUA
▪ Action 4: Models for dispersion of limit-state intensities for the optimal scalar/vector-valued IM resulting	M8	M24	UL

Task 6.5.: Seismic fragility evaluation of relevant SSCs

Start date: M15 End date: M35

Task Leaders: Konstantin Goldschmidt, TUK

Contributors:_BLAIN Christophe, IRSN; RICHARD Benjamin, IRSN; Dolšek Matjaž, UL; Dimitrios Vamvatsikos, NTUA; Dzifa Kudawoo, UKC

The aim of this task is the calibration and verification of the methods and models developed in previous tasks for the seismic fragility of SSCs identified in T6.1 using rigorous probabilistic analysis methods. Investigation of the influence of nonlinear structural behavior on the resulting floor response time-histories/spectra and on the fragility of Systems and Components Simplified approaches will be proposed for SMA based on DEE/ BEPU analyses and for fragility evaluation. The results will be verified by existing experimental test campaigns available to partner IRSN. The multi-dimensional (vector-based) fragility evaluation methods will be implemented in Open Sees (TUK, NTUA) and code_aster (UKC).

The role of partner **TUK** is to determine the fragilities and uncertainties of the previously defined SSCs. Based hereupon previously developed simplified approaches will be calibrated. Also, the influence of nonlinear structural behavior on the resulting floor response time-histories/spectra and on the fragility of SSCs will be investigated and simplified approaches will be proposed. TUK will also participate in the implementation of the multi-dimensional fragility evaluation methods in Open Sees.

The role of partner **IRSN** is to verify the results based on existing experimental data.

UL evaluates seismic fragility of relevant SSCs by considering optimal scalar/vector valued IM from T6.3. These fragilities will represent point of comparison for validating simplified method for the verification of SSC fragility i.e. practice-oriented intensity-based assessment procedure for the verification of target-fragility of relevant SSCs (alternative 3R method, Dolšek and Brozovič, 2016).

NTUA implements the multi-dimensional fragility evaluation methods in Open Sees.

The role of partner **UKC** is to implement the multi-dimensional fragility evaluation methods in code_aster.

Actions	**Start Date**	**Due Date**	**Responsible**
▪ Action 1: Determination of seismic fragility and uncertainties of SSCs identified in T6.1	M20	M30	TUK

▪ Action 2: Calibration and verification of efficient simplified analysis approaches	M20	M30	TUK
▪ Action 3: Investigate influence of nonlinear structural behavior on the resulting floor response time-histories/spectra and on the fragility of SSCs	M20	M30	TUK
▪ Action 4: Simplified approaches for SMA, BEPU and fragility evaluation	M20	M30	TUK
▪ Action 5: Verification of results against existing experimental test campaigns results	M25	M35	IRSN
▪ Action 6: Evaluate the seismic fragilities of the SSCs considering previously defined IMs & vector-IMs	M20	M30	UL
▪ Action 7: Implementation of the multi-dimensional (vector-based) fragility evaluation methods in Open Sees	M25	M35	TUK, NTUA
▪ Action 8: Implementation of the multi-dimensional (vector-based) fragility evaluation methods in code_aster	M25	M35	UKC

Task 6.6.: Bayesian updating of models and fragilities

Start date: M18 End date: M41

Task Leaders: BLAIN Christophe, RICHARD Benjamin, IRSN;

Contributors: Irmela Zentner, EDF; Ludivine Saint Mard, EDF; Abhinav Gupta, NCSU; Saran Bodda, NCSU; Oleksandr Sevbo, ER; Konstantin Goldschmidt, TUK

The aim of this task is the use of Bayesian techniques to update the input parameters of SSCs nonlinear models based on experience feedback, numerical results coming from advanced simulations and measured data coming from either in-site measurements or laboratory experiments such as shaking table tests. Seismic fragilities will be updated by means of nonlinear BEPU analyses and experience feedback. For this purpose, the SQUG experience feedback database will be used.

The role of partner **IRSN** is to review the techniques for Bayesian updating on nonlinear mechanical models available in literature, in particular for nuclear engineering. Also, the methods will be applied and verified based on experimental data.

The role of partner **TUK** is to review the techniques for Bayesian updating on nonlinear mechanical models together with IRSN.

The role of partner **EDF** is to review Bayesian update of fragility curves using experience feedback.

The role of partner **NCSU** is to update of fragility curves obtained by simplified analyses by means of a reduced sets of nonlinear time history analyses. Since nonlinear analyses require a huge computational modeling effort and it is generally not feasible to directly estimate the fragility curve. This problem can be tackled by adopting a

Bayesian approach to update existing fragility curves based on a reduced number of costly nonlinear FEM model runs. This methodology can also be applied in conjunction with test data (qualification, shaking table).

The participation of partner **ER** consists in the applicate the Bayesian approach to combine SSC-specific experimental data and generic data

Actions	Start Date	Due Date	Responsible
▪ Action 1: Literature Review on Bayesian techniques to update nonlinear mechanical models and associated fragilities	M18	M40	IRSN, TUK
▪ Action 2: Method and Data for Bayesian update of fragility curves using experience feedback (incl. SQUG investigations)	M18	M40	EDF
▪ Action 3: Updating of fragility curves obtained by simplified analyses by means of reduced sets of nonlinear time history analyses.	M18	M40	NCSU
▪ Action 4: Application of Bayesian updating of nonlinear mechanical models and associated fragilities using experience feedback and available experimental data	M18	M40	IRSN
▪ Action 5: Participation in application of Bayesian approach to combine SSC-specific experimental data and generic data	M18	M40	ER

Task 6.7.: Influence of aftershocks and clustered seismicity on seismic fragility

Start date: M18 End date: M40

Task Leaders: Paolo Bazzurro IUSS;

Contributors: Nevena Sipcic, Pablo Alfonso Garcia de Quevedo Iñarritu, Mohsen Kohrangi, IUSS; Konstantin Goldschmidt, TUK

The aim of this task is to develop damage-state dependent fragility evaluation procedures for clustered seismicity. The effects of clustered seismicity on the resulting fragility curves will be determined and quantified.

The role of partner **IUSS** is to compute the fragility of simple SSCs or surrogate models developed in the previous tasks of this package, using different ensembles of ground motion records that were defined as an output of the WP5. The main objective of this task is to draw attention to the importance of clustered seismicity and hazard consistent record selection procedures for earthquake sequences.

To quantify the effect of clustered seismicity on the resulting fragility. IUSS will compare the damage-dependent fragility curves with the ones obtained using the traditional approach that assumes that structure is in the pristine state.
Furthermore, the importance of the hazard consistent mainshock-aftershock pair selection will be highlighted by comparison with the fragility estimates that exploit the set of randomly matched record pairs, current practice in the risk assessment that accounts for seismic clustering. Impact of the record selection will be investigated across all damage states defined.

The role of partner **TUK** is to analyze the influence of clustered seismicity on the resulting fragility and risk.

Actions	Start Date	Due Date	Responsible
▪ Action 1: Fragility computations of simple SSCs using different ensembles of ground motions from WP5	M22	M37	IUSS
▪ Action 2: Influence of clustered seismicity on the resulting fragility and risk (WP7)	M22	M37	TUK

Task 6.8.: Sensitivity analyses and methods and parameters for beyond design assessments (DEE/BEPU)

Start date: M24 End date: M48

Task Leaders: BLAIN Christophe, RICHARD Benjamin, IRSN;

Contributors: Konstantin Goldschmidt, TUK

The aim of this task is the determination of required parameters and simplified models for beyond design assessments (DEE/BEPU) based on the results of the detailed probabilistic seismic fragility analysis. The results are also used for the development of simplified pragmatic CDFM assessment schemes. Sensitivity analyses are performed to identify parameters with major influence on fragility and risk.

The role of partner **TUK** is to develop efficient methods for accurate SMA/BEPU assessments and general guidelines for probabilistic fragility analysis including CDFM assessment schemes.

The role of partner **IRSN** is to develop CDFM assessment schemes and validate and verify the process.

Actions	Start Date	Due Date	Responsible

Action 1: Development of efficient methods (and parameters) for accurate seismic margin assessments SMA/BEPU assessments and general guidelines for probabilistic fragility analysis (SPSA)	M24	M36	TUK, IRSN
Action 2: Development of simplified pragmatic conservative deterministic failure margin (CDFM) assessment schemes	M24	M36	TUK
Action 3: Verification and validation process	M32	M42	IRSN

Task 6.9.: Application to METIS case study and guidelines

Start date: M1 End date: M48

Task Leaders: Konstantin Goldschmidt, TUK

Contributors: ,RICHARD Benjamin, IRSN; Dolšek Matjaž, UL; Dmytro Ryzhov, SSTC; Dimitrios Vamvatsikos, NTUA

The aim of this task is the application of previously developed models and methods to the METIS case study. The results of the simplified methods will be verified by detailed seismic fragility analysis and compared to results by applying EPRI methods/parameters. Practice oriented guidelines are developed for detailed seismic fragility analysis, simplified beyond design assessments (DEE/BEPU), SMA and simplified pragmatic CDFM assessment schemes.

The role of partner **TUK** is to coordinate the application to the case study and preparation of guidelines, verification and validation.

The role of partners **IRSN, NTUA and UL** is the preparation of guidelines, verification and validation.

The role of partner **SSTC** is to perform a comparative analysis of fragility curves achieved in the METIS project with results of calculations using EPRI method.

Actions	Start Date	Due Date	Responsible
Action 1: Coordinating application to demonstrative case study (WP3)	M1	M48	TUK
Action 2: Preparation of guidelines, verification and validation	M1	M48	TUK, IRSN, UL, NTUA
Action 3: Comparative analysis of fragility curves achieved in the METIS project with results of calculations using EPRI method.	M1	M48	SSTC

Deliverables

Number	Title	Due Date	Responsible
D6.1	Definition and classification scheme of SSCs for specific and generic seismic fragility evaluation (Technical report)	M12	ER
D6.2	Report on verification and validation of models and failure criteria	M36	IRSN
D6.3	Report on damage/failure relevant ground motion intensity measures, record selection/generation and site response analysis schemes	M28	UL
D6.4	Report on efficient uncertainty quantification and propagation techniques and implementation in open source software	M30	NTUA
D6.5	Report on scalar and multi-dimensional (vector-based) fragility evaluation methods and implementation in open source software	M35	TUK
D6.7	Influence of aftershocks and clustered seismicity on seismic fragility (Technical report)	M40	IUSS
D6.6	Application of Bayesian updating techniques (Technical report)	M41	IRSN
D6.8	Fragility curves for METIS case study	M36	TUK
D6.9	Guidelines for beyond design assessments (SMA/BEPU) and fragility evaluation (Technical report)	M48	TUK

Milestones of WP6

Number	Title	Verification mean	Due Date	Responsible
MS9	Methodology and tools to compute fragility curves available	Report and code developments + documentation	M24	TUK
MS13	Fragility curves for METIS case study available	Report and data	M36	IRSN

Interaction with other WPs

Number	Interaction description	Responsible
1	Task 6.1 Definition and classification of SSCs and development of reliable mechanical models With Task 3.2 Selection of a case study and data sharing	ER
2	Task 6.3 Fragility computations of simple SSCs using different ensembles of hazard consistent ground motions from WP5 With Task 5.1 Methodology for site-specific rock-hazard-consistent record selection for mainshock-only seismicity	IUSS
3	Task 6.7 Fragility computations of simple SSCs using different ensembles of hazard consistent mainshock-aftershock pairs of ground motions from WP5 With Task 5.2 Methodology for site-specific rock-hazard-consistent record selection for clustered seismicity	IUSS
4	Task 6.7,Influence of clustered seismicity on the resulting fragility and risk (WP7) With Task 7.3 Development of a new assessment algorithms	TUK
5	Task 6.8 Coordinating application to demonstrative case study (WP3) With Task 3.3 Supervision of analysis chain	TUK

Risks of WP6

Contractual risks (number, description, risk-mitigation), probability (1=low; 5=high) that the risk occurs and impact (1=low; 5=high) if the risk occurs. Other risks (not in GA) can be added so they can be followed during the project. Risk mitigation: P=preventive actions / C=contingency actions.

Number	Risk description	Risk mitigation	Proba	Impact
1	Data available for chosen case study does not allow to define all elements of PSA analyses chain.	Choose alternative test case (among the two options) or complement by data from other sites available to METIS partners	3	5
2	METIS study case does not allow to assess the performance and benefit of all of the new METIS methodologies or tools	Modify characteristics of test case and/or perform supplementary studies with different characteristics	3	3

	because it does not contain all features encountered in real sites.			
3	Number of GMTH required to compute fragility curves with nonlinear models exceeds the number of analyses acceptable for engineers when conducting SSCs response analyses (less than a hundred).	METIS develops two complementary approaches to tackle this problem: - metamodels to replace physical models by a cheaper representation - fragility curves determined for linear models and updated with a few nonlinear analyses	3	3
4	Difficulty to develop FEM models for SSCs chosen for METIS study because of lack of detailed descriptions	Use models/descriptions of similar SSCs already available to project partners	3	3
5	One of the international partners withdraws from proposal or underperforms due to budget problems so that all the tasks can be carried out.	NCSU has already confirmed resources for their in-kind contribution. EDF and other partners have already collaborated with the international partners and there is a positive feedback. If a problem occurs, then the main developments can still be conducted but ambitions are reduced.	2	2

8. Description of WP7 activities

Start date: M6; End date: M48

Work Package Leader: Oleksandr SEVBO (ER)

Opensource tools are available for the hazard and fragility assessment steps, but not yet for PSA computations. The generic objective of the WP7 is to develop and implement new assessment methodologies that allow to deal with vector hazard and fragility (developed in WP3, WP4 and WP6), as well as multi-unit assessment.

The WP7 activities are directed to address such challenges in seismic PSA that are not satisfactory treated in the commercial PSA tools used in the nuclear industry. This would entail to achieve the following: to push forward an opensource initiative for PSA based on the opensource tool SCRAM; and to address technical issues of seismic PSA by improving the existing tools and technology.

Task 7.1: Development of an open-source representation format for PSA models

Start date: M6; End date: M24

Task Leaders: Mohamed HIBTI (EDF)

Contributors: Nicolas DUFLOT (IRSN), Oleksandr SEVBO (ER), Pierre-Alain NAZE (GDS), Dmytro GUMENYUK (SSTC)

The aim of this sub task is to develop new representation format for probabilistic safety assessments models. Regarding more specifically seismic PSA, it will be an essential tool to exchange models, to incorporate fragility curves and to implement model rewriting techniques. The Open PSA format is adopted for this:

- Identify and detail modelling issues, gaps and shortcomings to be resolved in new seismic PSA tool;
- Develop technical requirements (specification) to new seismic PSA tool;
- Incorporate in the format all what is needed to perform seismic PSA, Including hazard curve, seismic fragilities, seismic correlations and their variability parameters;
- Revisit the format to incorporate recent results of model-based systems engineering.
- Update modelling environments and calculation engines to take into account the new version of the format.

GDS will focus on integration of the new format into the calculation engine SCRAM. SCRAM is a command-line Risk Analysis Multi-tool allowing for fault and event tree analyses used for PSA of NPP. It is not yet used for in industrial studies except some prototype application conducted by EDF. METIS will further improve and develop SCRAM tool regarding the industrial needs for seismic PSA computations.

ER and **SSTC** elaborate technical requirements (specification) to new seismic PSA tool and contribute to the identification and specification of modelling issues, gaps and shortcomings to be resolved in new seismic PSA tool based on Ukrainian view and experience

IRSN elaborates technical requirements (specification) to new seismic PSA tool and contribute to the identification and specification of modelling issues, gaps and shortcomings to be resolved in new seismic PSA tool based on the French view and experience.

EDF is responsible for the integration of the new format into the integrated modelling environment Andromeda (calling SCRAM calculation engine).

Actions	Start Date	Due Date	Responsible
Action 1: Coordination of data gathering and reporting, identification and specification of modelling issues, gaps and shortcomings to be resolved in new seismic PSA tool – French view and experience	M2(6)	M10	EDF

▪ Action 2: Identification and specification of modelling issues, gaps and shortcomings to be resolved in new seismic PSA tool – French view and experience	M2(6)	M10	IRSN
▪ Action 3: Identification and specification of modelling issues, gaps and shortcomings to be resolved in new seismic PSA tool – Ukrainian view and experience	M2(6)	M10	ER, SSTC
▪ Action 4: Coordination and development of technical requirements (specification) to new seismic PSA tool	M6	M18	EDF
▪ Action 5: Development of technical requirements (specification) to new seismic PSA tool - French view and experience	M6	M18	IRSN
▪ Action 6: Development of technical requirements (specification) to new seismic PSA tool - Ukrainian view and experience	M6	M18	ER, SSTC
▪ Action 7: Integration of the new format into the integrated modelling environment Andromeda	M6	M24	EDF
▪ Action 8: Integration of the new format into the integrated modelling environment SCRAM	M6	M24	GDS

Task 7.2: Development of a dedicated seismic database management tool

Start date: M6 End date: M24

Task Leaders: Nicolas DUFLOT (IRSN),

Contributors: Dimitrios VAMVATSIKOS (NTUA), Konstantin Goldschmidt (TUK)

In order to have a clear, exact and unified expression of each component's seismic failure probability, a dedicated opensource database standalone tool, based on Open-PSA format, is developed.

This tool allows for the implementation of any mathematical expression to define seismic basic event (BE) failure probability including shared parameters between different BE probability and direct matrix values. With a clear and intuitive interface (no line code writing), it allows for expressing each BE seismic failure probability as a function of laws (lognormal, etc.) and parameters, that may be shared between several BE, to fit these laws. This tool is also able to compute the data base to define either a single set of seismic BE probabilities for a given seismic level, or Mont Carlo generated seismic sets of BE probabilities with a complete and correct integration of all possible correlations. The scope of Task also includes development of a module in charge of MCS set requantification (for Mont Carlo sampling) will be studied.

IRSN will develop open-source seismic database management tool and implement it in METIS tool.

TUK will perform review and validation of the seismic database management tool.

NTUA will perform review and validation of the seismic database management tool.

Actions	Start Date	Due Date	Responsible
▪ Action 1: Coordination of reporting. Development of seismic database management tool	M2(6)	M18	IRSN
▪ Action 2: Review and validation of the seismic database management tool	M18	M24	NTUA, TUK
▪ Action 3: Resolution of review comments, updating of seismic database management tool (if needed)	M18	M24	IRSN

Task 7.3: Development of new assessment algorithms

Start date: M6 End date: M48

Task Leaders: Mohamed HIBTI (EDF)

Contributors: Dmytro GUMENYUK (SSTC), Oleksandr SEVBO (ER), Nicolas DUFLOT (IRSN), Pierre-Alain NAZE (GDS), Konstantin Goldschmidt (TUK)

The aim of the task is to develop new set of algorithms for the assessment of PSA to cope with the following bottlenecks with the current technology:

- the ability to handle basic events with a high probability;
- the ability to handle dependencies amongst basic events;
- the ability to perform at an acceptable computational cost uncertainty propagation and sensitivity analyses;
- other issues defined at Task 7.1 (if any).

Task 7.3.1: Development of PSA tool

Sub-Task Leaders: Pierre-Alain NAZE (GDS)

Contributors: Mohamed HIBTI (EDF), Konstantin Goldschmidt (TUK)

The goal of this sub-task is to develop new set of algorithms for the assessment of PSA and to incorporate it into one integrated modelling PSA tool, developed under Task 7.1.

The new assessment algorithms will include the application of vector-based ground motion intensity measures (alternatively to scalar ones). The feasibility and the overall influence of applying vector-based ground motion intensity measures on risk and the corresponding uncertainty will be determined.

All Task 7.3 partners will participate in development of the algorithms.

GDS improves SCRAM to deal with correlated events and high probabilities in seismic PSA.

EDF develops parallel computing functionalities with Andromeda and integrates all developments into one modelling environment, the METIS tool.

TUK will develop a strategy for the application of vector-based ground motion intensity measures in PSA.

Actions	Start Date	Due Date	Responsible
▪ Action 1: Coordination of reporting. Development of assessment algorithms and modification of SCRAM to deal with correlated events and high probabilities in seismic PSA	M2(6)	M26	GDS
▪ Action 2: Development of assessment algorithms and enhancement parallel computing functionalities with Andromeda (draft)	M2(6)	M12	EDF
▪ Action 3: Integration of all developments into one modelling environment, the METIS tool. Development of final report on enhanced version of the PSA integrated modelling environment	M12	M30	EDF
▪ Action 4: Strategy for the application of vector-based ground motion intensity measures	M12	M30	TUK

Task 7.3.2: Strategy for consideration of aftershocks in seismic PSA

Sub-Task Leaders: Dmytro Ryzhov (SSTC)

Contributors: Oleksandr Sevbo (ER), Nicolas DUFLOT (IRSN)

The goal of this sub-task is to develop strategy for consideration of aftershocks in seismic PSA. Activities will include survey of the state-of-the-art methods and the best practice for consideration of aftershocks in seismic PSA, accounting for results of WP4 related to consideration aftershocks, and development of a strategy and recommendations.

SSTC and TUK will develop a strategy for consideration of aftershocks in seismic PSA.

IRSN will provide example application of PSA considering aftershocks to assess its impact on risk.

ER will perform review of the strategy.

Actions	Start Date	Due Date	Responsible
▪ Action 1: Coordination of data gathering and reporting. Development of draft strategy for consideration of aftershocks in seismic PSA	M12	M24	SSTC
▪ Action 2: Development of draft strategy for consideration of aftershocks in seismic PSA	M12	M24	TUK
▪ Action 3: Definition of example application of PSA considering aftershocks to assess its impact on risk	M18	M24	IRSN
▪ Action 4: Review of the strategy for consideration of aftershocks in seismic PSA	M24	M30	ER
▪ Action 5: Development of final strategy for consideration of aftershocks in seismic PSA	M30	M36	SSTC

Task 7.4: V&V and benchmarking of the new tools

Start date: M12 End date: M36

Task Leaders: Dmytro GUMENYUK (SSTC)

Contributors: Oleksandr SEVBO (ER), Pierre-Alain NAZE (GDS), Nicolas DUFLOT (IRSN), Konstantin Goldschmidt (TUK)

Task 7.4.1: Representative benchmark

Sub-Task Leaders: Dmytro GUMENYUK (SSTC)

Contributors: Andrii Kornitsky (ER)

The goal of this sub-task is to perform representative benchmark calculations for the METIS tool developed at Task 7.3.1, using proven PSA commercial codes. Scope of activities will include:

- Selection of representative hazard scenario(s);
- Model testing and conducting benchmark calculations using METIS tool vs commercial PSA tools.
- Development of recommendations for improvement of the METIS tool, based on benchmark results and test calculations.

SSTC will perform representative benchmark of models related to Seismic PSA level 1 for reactor and/or spent fuel pool and perform benchmark calculations using the METIS tool and SAPHIRE or Risk Spectrum codes.

ER will contribute to assessment of new modelling approaches for the propagation of epistemic uncertainties, vector valued analyses, and consideration of multiple units and multiple radiation sources at a site.

Actions	Start Date	Due Date	Responsible
▪ Action 1: Coordination of data gathering and reporting. Preparation of probabilistic models for selected hazard scenarios for benchmarking purposes. Conduction of preliminary and final quantification of risk metrics (core damage frequency and/or fuel damage frequency), taking into account uncertainties. Development of recommendations for improvement of the METIS tool, based on benchmark results and test calculations ▪	M12	M32	SSTC
▪ Action 2: Performing of assessment of new modelling approaches for the propagation of epistemic uncertainties, vector valued analyses, and consideration of multiple units and multiple radiation sources at a site	M12	M36	ER

Task 7.4.2: Compliance with seismic PSA requirements and benefits of new PSA tool

Sub-Task Leaders: Nicolas DUFLOT (IRSN),

Contributors: Pierre-Alain NAZE (GDS), Konstantin Goldschmidt (TUK)

The goal of this sub-task is to assess benefits of new PSA tool and compliance of new PSA tool with seismic PSA requirements. The following activities are envisaged:

- Performing of limited scale test case and applications to ensure that developed tools comply with seismic PSA requirements.
- Fulfillment of feasibility checks, assessment of benefits of vector valued PSA and PSA considering aftershocks using the METIS tools
- Analysis of the influence of epistemic uncertainty from simplified/surrogate/generic analysis and verification of the classification scheme of systems, structures and components from task 6.1 is verified based on risk estimates.
- Assessment of the relative influence of fragility parameters on total risk.

IRSN will complete limited scale test case and applications to ensure that developed tools comply with seismic PSA requirements and will be compatible with WP3.

TUK will determine the influence of increased epistemic uncertainty from simplified/surrogate/generic analysis and verify the classification scheme of SSCs based on risk relevance. TUK will also determine the relative influence of fragility parameters on total risk.

Actions	Start Date	Due Date	Responsible
▪ Action 1: Coordination of data gathering and reporting. Development of limited scale test case and applications to ensure that developed tools comply with seismic PSA requirements and are compatible with WP3	M12	M36	IRSN
▪ Action 2: Determination of the influence of increased epistemic uncertainty from simplified/surrogate/generic analysis and verify the classification scheme of SSCs based on risk relevance	M32	M36	TUK

Task 7.5: Risk testing

Start date: M30 End date: M42

Task Leaders: Vitor SILVA (GEM),

Contributors: Vitor SILVA (GEM), Emmanuel VIALLET, Irmela ZENTNER (EDF)

The confrontation of outcomes of risk analyses with observations will be assessed. The annual core damage frequency is an extremely rare event, and to some extent, there are currently insufficient data to empirically validate a PSA. Therefore, other risk metrics such as annual fatalities and repair costs (similar to what is practiced in the insurance industry), will be used to verify risk models to observations. Another quantity more directly linked to the plant is the annual probability of shutdown (NPP are shut down if the acceleration measured at the basement exceeds a given threshold). The probability shutdown moreover constitutes a quantity relevant for cost reduction in NPP. The output of the PSHA models will be compared to observations such as the number of shutdown within a given time span. The OpenQuake-engine will be used to compute risk in terms of fatalities, damages and repair costs and compare the computations to past observations.

Actions	Start Date	Due Date	Responsible
▪ Action 1: Coordination of data gathering and reporting. Selection of risk metrics other than core damage frequency. Risk analyses for case	M30	M42	GEM

study with OQ tools and comparison with observations			
▪ Action 2: Risk Testing methodology. Comparison and confrontation of outcomes of risk analyses with nuclear practice and observations	M30	M42	EDF

Task 7.6: Application of new assessment methods to METIS study case

Start date: M36 End date: M48

Task Leaders: Oleksandr SEVBO (ER),

Contributors: Mohamed HIBTI (EDF), Pierre-Alain NAZE (GDS), Nicolas DUFLOT (IRSN), Dmytro GUMENYUK (SSTC), Konstantin Goldschmidt (TUK)

This Task is dedicated for resulting application of the METIS tool validated for the METIS study case. Integrative PSA modelling and quantification of risk metrics for study case the will be performed in order to demonstrate capabilities of the METIS tool, to formulate the tool advantages as well areas for further improvements and developments. The results of the previous tasks and to identify future needs with regard to METIS code and model improvements, and future seismic PSA researches will be analyzed and summarized. The Task will provide a clear view about the METIS tools and their applicability to seismic PSA developments and researches..

ER is responsible for this task and will contribute to modeling of the METIS study case using METIS tool.

Integrative PSA modeling and quantification of risk metrics for study case the will be performed together with **EDF, GDS, IRSN, SSTC, TUK** in order to demonstrate capabilities of the METIS tool, to formulate the tool advantages as well areas for further improvements and developments

Actions	**Start Date**	**Due Date**	**Responsible**
▪ Action 1: Coordination of data gathering and reporting.	M36	M42	ER
▪ Action 2: Preparation of input and supporting data from WP6 (list of SSC, their reliability and fragility data, etc.) for modelling of METIS study case using the Metis tool.	M36	M42	TUK
▪ Action 3: Preparation of supporting data for modelling of METIS study case using the METIS tool.	M36	M42	EDF, GDS
▪ Action 4: Preparation of input and supporting data (list of SSC, their reliability and fragility	M36	M42	SSTC

data, etc.) for modelling of METIS study case using the Metis tool.			
Action 5: Development of METIS study case using the Metis tool. Test and quantification of risk metrics	M36	M42	ER
Action 6: Evaluation of the previous tasks results and identification of future needs with regard to METIS code and model improvements, and future seismic PSA researches	M42	M48	ER

Task 7.7: Recommendations on seismic PSA

Start date: M42 End date: M46

Task Leaders: Oleksandr SEVBO (ER),

Contributors: Mohamed HIBTI (EDF), Pierre-Alain NAZE (GDS), Nicolas DUFLOT (IRSN), Dmytro GUMENYUK (SSTC)

This Task is devoted to analyze and summarize the results of Tasks 7.1, 7.2, 7.3, 7.4, 7.5 and 7.6; as well as to identify future needs with regards to METIS code and model improvements, and future seismic PSA research

All partners will contribute to analysis of the WP7 previous tasks, to development recommendations of the future needs and associated conclusions.

Actions	Start Date	Due Date	Responsible
Action 1: Coordination of analysis and reporting, analysis and summarization of the results of Tasks 7.5 and 7.6. Identification of future needs with regards to METIS code and model improvements, and future seismic PSA research.	M42	M46	ER
Action 2: Analysis and summarization of the results of Tasks 7.1 and 7.3. Identification of future needs with regards to METIS code and model improvements, and future seismic PSA research.	M42	M46	EDF
Action 3: Analysis and summarization of the results of Task 7.3.1. Identification of future needs with regards to METIS code and model improvements, and future seismic PSA research.	M42	M46	GDS
Action 4: Analysis and summarization of the results of Task 7.2 and 7.4.2. Identification of future needs with regards to METIS code and model improvements, and future seismic PSA research.	M42	M46	IRSN

▪ Action 5: Analysis and summarization of the results of Tasks 7.3.2 and 7.4. Identification of future needs with regards to METIS code and model improvements, and future seismic PSA research.	M42	M46	SSTC

Deliverables

Number	Title	Due Date	Responsible
D7.1	Specification of the PSA format	M18	EDF
D7.2	Development of seismic database management tool	M24	IRSN
D7.3	Enhanced version of the PSA calculation engine SCRAM	M28	GDS
D7.4	PSA considering aftershocks	M36	SSTC
D7.5	Enhanced version of the PSA integrated modelling environment Andromeda	M30	EDF
D7.6	Benchmark of PSA models	M32	SSTC
D7.7	Assessment of new or improved PSA approaches	M36	ER
D7.8	Report on Risk Testing methodology and outcome	M42	GEM
D7.9	Application to METIS study case (WP7)	M42	ER
D7.10	Recommendations to conduct seismic PSA	M46	ER

Milestones of WP7

Number	Title	Verification mean	Due Date	Responsible
MS10	METIS PSA tool available	Report and PSA tool developments with documentation	M26	GDS
MS12	Benchmarking of new PSA tool SCRAM	Report and data	M32	SSTC
MS14	PSA computations for METIS case study performed	Report and data	M42	ER