EDUCATION AND TRAINING IN MUSA PROJECT ON MANAGEMENT AND UNCERTAINTIES OF SEVERE ACCIDENTS

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ABSTRACT

The overall objective of HORIZON 2020 project on “Management and Uncertainties of Severe Accidents (MUSA)” is to quantify the uncertainties of severe accident codes when modelling reactor and spent fuel pools (SFP) accident of Gen II and Gen III reactors for the prediction of the radiological source term. The “Education and Training” programme in MUSA is focusing on raising the competence level of university students (M.Sc. and Ph.D.) and young researchers and engineers engaged somehow in severe accidents. Towards this purpose the following main actions are in progress: 1) production of public learning modules compiling the major outcomes from the project; 2) a mobility exchange programme of young researchers and M.Sc./Ph.D. students for training in the MUSA partners’ laboratories to enhance the dissemination of knowledge in the area of Severe Accident and Uncertainty tools; 3) production of a lecture on “Uncertainty Quantification in Severe Accident Analyses” for the different international Courses.

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Introduction

Numerical simulation tools are widely used to assess the behaviour of Nuclear Power Plants (NPP) during postulated accidents, including severe accidents. In addition, the development and optimization of Accident Management (AM) measures, aiming at preventing and mitigating the consequences of a severe accident, heavily rely on numerical simulations, with codes such as ASTEC [1], MAAP [2] and MELCOR [3].

Considering the complexity of the physical-chemical and thermal-hydraulic processes taking place during the different phases of a severe accident, it is mandatory to quantify their embedded uncertainties, considering the latest developments in methods and algorithms [5]. At present, many severe accident codes have reached a high enough level of maturity with regards to their modelling scope and accuracy, simulation capability of safety-relevant phenomena, and validation for many reactor types, and extensive applications in industrial, regulatory, and research areas can be found [6]. Furthermore, they are extensively employed for the development and optimization of AM measures and to provide the source term to estimate the radiological impact of an accident.

In the meantime, mathematical tools for the quantification of code uncertainties and sensitivities have been under development for many years worldwide, as DAKOTA [7], RAVEN [8] and SUNSET [9]. There is a huge accumulated experience already in the nuclear community in performing Uncertainty Quantification (UQ) with Best Estimate (BE) thermal-hydraulic system codes [10], [11] and this is being extended to other fields, like fuel

performance and neutronics. So far, this has not been the case for severe accident codes, and few investigations have been focused on severe accidents and UQ in Europe [12] and elsewhere [13].
The Management and Uncertainties of Severe Accidents (MUSA) is a 4-year HORIZON-2020 project, coordinated by CIEMAT (Spain) that moves beyond the state of the art regarding the predictive capability of severe accident analysis codes by combining them with the best available UQ tools [14]. By doing so, not only will the prediction of the timing for the failure of safety barriers and of the radiological source term in case of a severe accident be possible, but also, the quantification of the uncertainty bands of selected analysis results, considering any relevant source of uncertainty, will be provided. It should be highlighted that MUSA is not restricted to reactor accidents but SFP accidents are also addressed. A special attention has been also given to the education and training initiatives to facilitate the transfer of the project's outcomes to young researchers.

1. The MUSA Project

1.1 MUSA objective and structure

The overall objective of MUSA is to quantify the uncertainty in severe accident codes when modelling reactor and SFP accident scenarios of Gen II and Gen III reactor designs for the prediction of the radiological source term. Hence, UQ methodologies are applied where not only initial and boundary conditions and model parameters, but also AM measures are considered, to assess their impact on the source term prediction. Therefore, Figures of Merit (FOM) related to the source term are to be used in the UQ application. Consequently, the MUSA project will contribute to the determination of the state of the art on the application of the different UQ methods to severe accident codes, regarding their prediction of the source term that potentially may be released to the external environment and to the quantification of the associated code's uncertainties, applied for the analysis of these severe scenarios.
The achievement of the overall objective is assured by a consistent and coherent work program, reflected in the five technical Work Packages (WP) defined as follows (Figure 1):

1. Identification and Quantification of Uncertainty Sources (WP2, IQUS).
2. Review of Uncertainty Methodologies (WP3, RUQM).
3. Application of UQ Methods against Integral Experiments (WP4, AUQMIE).
4. Uncertainty Quantification in Analysis and Management of Reactor Accidents (WP5, UQAMRA).
5. Innovative Management of SFP Accidents (WP6, IMSFP).

As noted in Figure 1, there is also a specific WP for managing the technical and financial aspects of the project (WP1, MUCO), and another one (WP7, COREDIS) for efficiently articulating the Communication and Dissemination (C&D) activities, including the education and training aspects, so that technical outcomes of MUSA reach as many stakeholders as possible, and the resulting enhancement of nuclear safety reaches the generic public.

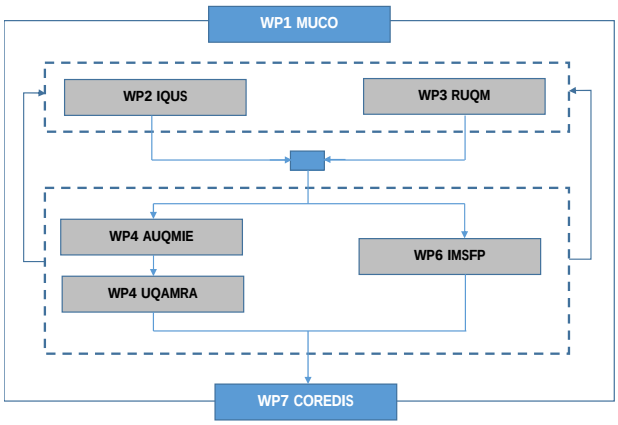

Figure 1. MUSA Work Package interlink.

These two WPs aside, the technical WPs (WP2–WP6) are distributed in two blocks. The first one, including WP2 and WP3, is meant to prepare everything necessary to conduct the second block, which can be referred to as the "application WPs block" (WP4, WP5, and WP6). As shown in Figure 2, the "application block" represents roughly two-thirds of the total workforce in the project, whereas roughly one-fourth is to be spent in the "preparatory block" and about 5% for C&D activities, including about € 130,000 for founding the M.Sc./Ph.D. mobility actions. In terms of working load, MUSA is estimated to require 625 months (about 15 scientists/engineers working full-time for 4 years).

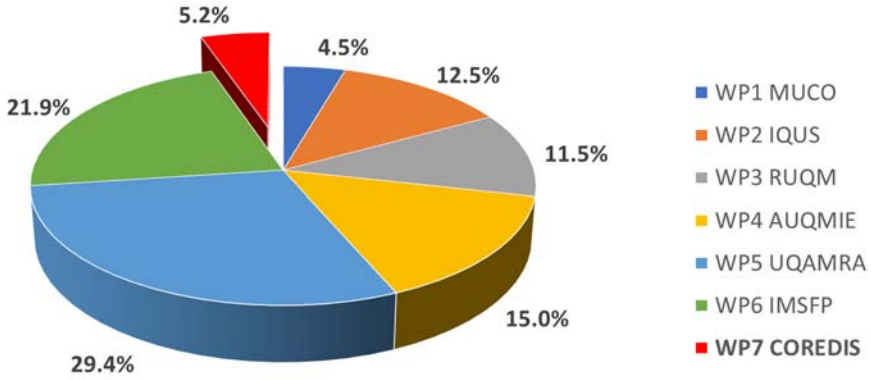

Figure 2. MUSA workforce distribution.

1.2 Major MUSA Features

Some MUSA specific features, reported in the following, strengthen the project significance in the field of nuclear safety:

- Twenty-eight organizations from three continents are MUSA partners (Figure 3). This ensures the involvement of a wide range of competencies and experience on severe accident phenomena and source term investigations all over the world with different perspectives (i.e., Technical Support Organizations (TSO), utilities, research centers, and academia). Moreover, and no less important, it guarantees a wide dissemination of the MUSA results.
- The focus on source term analysis stems naturally from the goal of severe accident codes, and it is consistent with the consequences experienced and the conclusions drawn after the Fukushima accident. The role played by source term in the emergency measures implemented at the time of the accident and in the ongoing land recovery around the Fukushima Daiichi site underlines the relevance of its realistic evaluation. Furthermore, the wide participation in MUSA will contribute to the harmonization of the degree of confidence in source term estimates.
- The integrating nature of the project is outstanding and, despite the specific application on the source term area, the project integrates all the aspects of both reactor and SFP severe accidents. In addition, it addresses a broad scope of reactor designs since its main outcomes would be generally applicable to all water-cooled reactor types.
- There is a strong link with the international communities dealing with Probabilistic Safety Assessment (PSA) level 2, emergency response, environmental consequence analysis, and AM.
- Key elements of the project are the just available experimental data and knowledge about the severe accident phenomenology from the earlier projects funded in the previous EURATOM framework, such as PHEBUS-FP [15] and SARNET [16].
- As in the previous EURATOM project in this area [17], a special attention is given to the spreading of excellence activities, including education and training initiatives to facilitate the transfer of the project's outcomes to young researchers in the severe accidents field and the M.Sc./Ph.D. students at European universities. These activities for MUSA will be presented in the following.

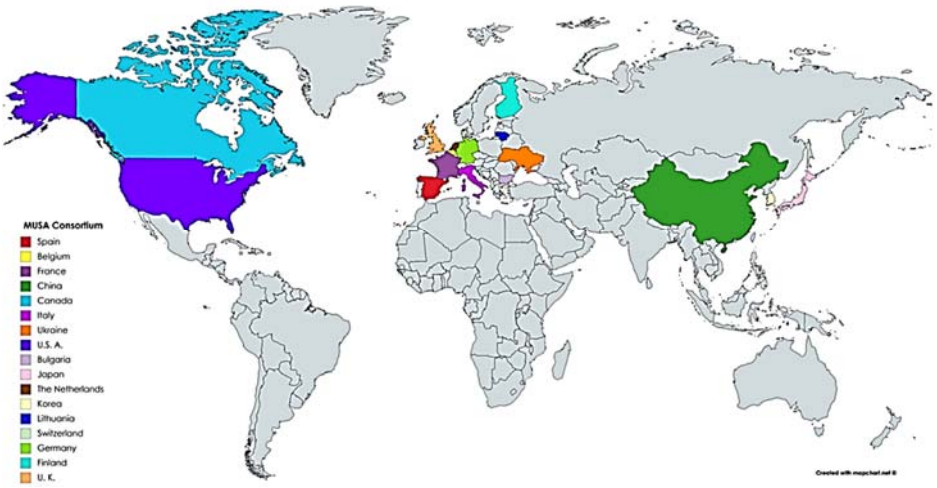

Figure 3: MUSA member countries.

2. MUSA Communication and Results Dissemination

The activities carried out in the MUSA WP7 COREDIS (Communication and Results Dissemination) are led by University of Pisa together with the Project Coordinator, with the support of LGI Consulting (France), but all MUSA partners are involved to some extent in these C&D activities. Within this WP7 different tasks can be highlighted, where education and training is one of the main target:

MUSA Public Communication (led by LGI)

A C&D strategy plan was developed at the beginning of the project, and it is being continuously updated on the basis of the evaluation of its impacts. The first action has been to determine the needs of the project and to identify the goals to be reached by the C&D actions and how to achieve them. This strategy plan includes:

- A detailed planning of all communication actions, their goals and timing.
- Key messages and defined target audiences.
- An event and publications management plan.
- Identification of C&D key performance indicators for the goals to be reached, as the number of international journal papers, the number of website views or the engagement on social media.

A series of communication tools and actions has also been implemented from the very beginning of the project and will continue for the entire 4 years period:

- A project brand, including its logo (Figure 4) and visual identity for standard presentation slides and document templates to ensure the MUSA project's visibility among all relevant stakeholders. The female figure in the logo is the ninth Muse, called Urania (daughter of Zeus), the muse of science, doing a step forward in the U (uncertainties in the project acronym). She is normally represented using blue (here is the EU colour) to represent the celestial vault and on her hands, she carries a globe and a compass.
- Communication support materials, as a general presentation, descriptive posters, and a general factsheet to communicate on the project at conferences, workshops and online. MUSA was presented in this way initially at the FISA 2019 Conference and then at the SNETP 2021 Forum (held in virtual mode for emergency reasons), plus other international and national initiatives as NUGENIA 2019 General Assembly, CSARP 2020 Meeting and EUROSAFE Forum 2021.
- A public website (https://musa-h2020.eu/), to serve as the main communication channel towards the different project's stakeholders and the target audiences. Contents, such as news and articles are published monthly, to engage with and build the MUSA community, and communicate about main initiatives related to source term area and more generally to nuclear safety.
- A social network account on LinkedIn® (https://www.linkedin.com/company/musa-h2020-project/) is managed to communicate on MUSA, promote its results, and advertise the

workshops and other initiatives, as well as the mobility opportunities, also permitting a two-way dialogue with the target groups (at the moment more than 100 followers). The main target is obviously the group of young professional users of this network, users characterized by the common interest for the MUSA related arguments.

- Participation in the European Researchers' Night event is planned for 2022 (in Pisa and/or other partners' cities) to engage mainly with the public and raise awareness of nuclear in general and of the MUSA project more specifically.

Figure 4: The MUSA logo.

MUSA Internal Dissemination

Different activities enhance the internal communication among the project's partners and encourage/coordinate the common actions, in particular the preparation of joint technical papers for conferences and journals. Furthermore, an internal annual newsletter is released by LGI in between the two public annual newsletters, having a strong link with the WP leaders for its contents.

This internal communication action is facilitated thanks to a dedicated platform, restricted to the ,partners that allows them to easily share technical and administrative documents and manage MUSA's various events, such as workshops, or internal actions (as the mobility exchange programme).

MUSA External Dissemination)

The dissemination actions to the project's stakeholders, including audiences who are not nuclear researchers by a wider nuclear community, are the key activities to widely promote and exploit the different results generated during MUSA and the accumulated knowledge in severe accident area. These dissemination actions include:

- The organization of a final open workshop, in collaboration with the OECD and IAEA, to present and share the main MUSA outcomes to the nuclear community.
- Relevant public events have been initially identified by each partner with the definition of a publication planning, update each year to cope also with unforeseen problem linked to the sanitary emergency.
- The consortium's participation in submitting papers, presenting, promoting, and disseminating the project's results at international conferences (such as the European Review Meetings on Severe Accident Research ERMSAR) as well as in fora such as the annual SNETP Forum, ETSON annual meetings and/ or IAEA workshops, is continuously coordinated in WP7.
- The publication of scientific articles in peer-reviewed journals (about 2 common journal papers per each technical WP are expected: status of their activities after about 2 years and final achievements at the end of the project) plus 2 general papers on the project results, as [14].
- The use of the Zenodo open-access repository to archive and make publications accessible to a wider research community, as request by the EU rules on the open access to the peer-reviewed scientific publications produced in Horizon 2020 projects, together with the research data needed to validate the results presented in the deposited scientific publications.
- An electronic newsletter at the end of each year of the project to inform the different stakeholders about the project's progress; it includes a word from the MUSA coordinator, a specific highlight per work package, relevant news, relevant workshops, publications, and conferences.

A close collaboration has been just realized with different organizations, existing initiatives, and related projects, to use their communication channels and build on their established

external visibility, as SNETP (Sustainable Nuclear Energy Technological Platform) and OECD/NEA WGAMA. These strong links with other international organizations, that might address in specific ventures the same MUSA subject but with different scope, are also useful for research collaborations, as for the IAEA CRP on "*Advancing the State-of-Practice in Uncertainty and Sensitivity Methodologies for Severe Accident Analysis in Water Cooled Reactors*".

2.1 MUSA Education and Training Activities

The background of these education and training initiatives is that in EU and worldwide demographic factors pose potentially difficult challenges to the continued safe and reliable design, operation, and maintenance of NPPs. Many of the personnel currently working in the different areas on nuclear are reaching retirement eligibility and, at present time, when some of the knowledge acquired in the severe accident field is at risk of being lost (as many specialists are just retired or are retiring) and new approaches for their assessment (as the Uncertainties and Sensitivity Analysis) are being explored. So, it seems an appropriate timing to articulate the most efficient ways possible to bring young generation on board to face the new research challenges in this field and, at the same time, preserving the high level of European expertise.

To contribute to this goal, the ongoing MUSA education activities are focused on M.Sc. and Ph.D. students of European institutions involved in nuclear education, but they are open also to young researchers in the severe accident field. The main actions of this part of the project are reported in the following.

<u>Production of public learning modules</u>

At least three learning modules, compiling the major outcomes from the project, will be built towards the end of the activities to be freely published in the MUSA public website. It is planned to produce three presentations and/or mp4 videos of max. 45 minutes each, realized to disseminate the MUSA outcomes to nuclear students, as a support for the courses related to nuclear safety, and young researchers in the field but also to a generic audience. They will address the following topics:

1. Major sources of uncertainties in Severe Accidents, with particular emphasis on the radiological source term.
2. Methodologies for uncertainty assessment in Severe Accidents, with particular emphasis on the source term estimates.
3. Assessment of Source Term Uncertainties in Fukushima-like scenarios.

<u>A mobility exchange programme for young researchers and M.Sc./Ph.D. students</u>

This mobility program aims at training European young researchers and M.Sc./Ph.D. students through delegation in the MUSA partners' laboratories to enhance the exchanges and the dissemination of knowledge in the area of severe accident codes and Uncertainty tools. The related Mobility Manual, explaining the procedure and the eligibility criteria, is available on the MUSA public website from the beginning of the project.

These mobility actions could be also useful for European M.Sc. students at the different universities where nuclear course are given, to achieve the requirements for the European Master of Science in Nuclear Engineering (EMSNE) Certification. In these EMSNE requirements, 20 European Credit Transfer and Accumulation System (ECTS) credits must be taken at a "foreign" institution with respect to that in which the student is based but member of the ENEN Association. The MUSA mobility actions could be useful to promote these educational and training periods in its members' laboratories and also to economically support these actions, in parallel with others more general mobility actions, as the past ENEN+ or NUGENIA-PLUS grants.

Additionally, the presence of MUSA young researchers in international conferences, workshops, and seminars to present some MUSA results, is supported. Supporting the inclusion in external educational or training Courses on areas related to MUSA will be also considered.

The total economical budget for these mobility actions (€ 128,000.00), as stated in the Project Grant Agreement, has the following distribution:

- conferences, seminars, or MUSA workshops participation € 20,000
- course participation € 20,000
- mobility cost € 88,000

It was foreseen to attribute a grant of max € 6,000 as financial contribution per long visit (about € 1,000 for month) and max 4 long visit are planned each year. This amount is not fixed and will be approved by the MUSA Executive Board after being re-assessed on a case-by-case basis by the leaders of WP1 and WP7. About the participation to conferences, seminars, MUSA workshops and courses, the MUSA grant will cover the registration fees plus travel and subsistence expenses, with a maximum of € 2,000 for each action, again with the evaluation of the application by the MUSA ExB.
According to the above budget distributions and planning, it is foreseen that the total number of participations sponsored by MUSA in conferences and workshops would be between 8 and 12, and this same number is foreseen for courses participation. As for mobility, about 15 “long” actions might be allocated within the MUSA budget. However, the 2019-2020 sanitary context has forced a complete stop to this MUSA mobility program, with a very slow restart only in the second half of 2021, based on the European sanitary situation and the different countries’ rules, with huge difficulties to push on this particular action.

Production of a lecture on “Uncertainty Quantification in Severe Accident Analyses”
The production of this UQ related lecture for the different international Courses that might be given on severe accidents and/or on "uncertainties" is foreseen. This lecture will be also utilized for the next editions of the NUGENIA TA2 Course on Severe Accident Phenomenology (SAP), where the main insights gained in MUSA will be embedded in this specific lecture.
It should be highlighted that an established collaboration exists with this well-established NUGENIA TA2 SAP Course, where MUSA partners have often given the lectures in the several Course editions from 2005 (organized in the past in the SARNET framework [18]), gathering from 40 to 100 young participants for each course edition.

3. Conclusions

After a first phase of 2 years, characterized by some delays linked to the sanitary emergency, the MUSA project continues from June 2021 for two years more. It aims both at solving the latest pending issues for current NPPs safety and at consolidating the sustainable integration of the European SA research capacities.
By conducting MUSA, the European Union will take a step forward with regards to severe accident analyses by proposing systematic methodologies for a thorough application of BEPU in SA analyses. Such methods will have been vastly tested and will be spread all over Europe and beyond (as Asian and American organizations also participate in the project). In addition, the leadership of the European Union in the source term area will be even further consolidated by assessing the accuracy of the current source term predictions with severe accident codes and by identifying which variables are worth further investigation in terms of achieving a significant reduction of uncertainty bands.
Efforts will also continue on the transfer of knowledge in the severe accident area to younger generations through the different on-going education and training activities. It will allow preservation of knowledge produced by past thousands of person-years of R&D and the dissemination of this knowledge to end-users, and will contribute in strengthen the position of Europe in the area of severe accident codes. Links with OECD/NEA activities and other research programmes co-funded by the EC will be maintained and reinforced, in particular with the initiatives originated in the Sustainable Nuclear Energy Technology Platform (SNETP).

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