High-Performance Advanced Methods and Experimental Investigations for the Safety Evaluation of Generic Small Modular Reactors

Research and Innovation Actions

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D6.5: Report on training course

Summary

This report provides a description of the second McSAFER training course titled ‘SMR neutronics and thermal hydraulics’ which was held at LUT University in Finland on March 22-24, 2022. The course consisted of lectures by experts from the McSAFER project, a tutorial to the Kraken reactor analysis framework and laboratory activities at the LUT nuclear safety research laboratories. The course was participated by 17 students on-site and it involved a total of 44 people including lecturers and remote participants.

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High-Performance Advanced Methods and Experimental Investigations for the Safety Evaluation of Generic Small Modular Reactors.

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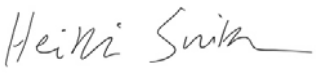
Signatures			

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11	TRACTEBEL	Private company	Belgium
12	KTH	University	Sweden
13	CNEA	Research Centre	Argentina

Distribution to the partners will be through the project SharePoint.

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1. Introduction

As part of the educational activities developed within the McSAFER project framework, the second training course entitled as 'SMR neutronics and thermal hydraulics' was organized by the Lappeenranta-Lahti University of Technology (LUT, Finland). According to the DoA, the course was supposed to take place in February but due to internal scheduling issues it was decided to postpone the course to March. At that time there were no such COVID-19 related restrictions in Finland or at LUT that would have prevented the realization of the course on-site, provided appropriate precautionary measures, such as wearing face masks, were taken. In fact, the course was physically held at LUT on the dates from March 22nd to 24th, 2022, although several lectures of the first day were performed virtually. The course was offered free of charge, but it was limited to max. 20 participants due to the limited laboratory capacities.

Regarding the course contents, it should be noted that this course was closely related to the first McSAFER training course, in which the most relevant theoretical issues inherent to the functioning and the safety systems of the SMR designs involved within the McSAFER project along with the development of the accidental sequences to be modelled were explained to the course attendees (197 attendees), see Table 1.

Table 1: Contents of the first McSAFER training course

Time	Lecture's topics	Speaker
Monday		
14:45-15:30	Introduction to SMR LWR Technologies: Main Characteristics, Applications and Comparisons	John LILLINGTON (Jacobs)
15:40-16:25	SMART SMR Reactor Core & Coolant System	Bart VERMEEREN and Simon VERDEBOUT (TBL)
16:35-17:20	SMART reactor safety systems	Victor Hugo SANCHEZ-ESPINOZA (KIT)
Tuesday		
14:30-15:15	NuScale reactor core and primary circuit	Ville VALTAVIRTA (VTT)
15:25-16:10	Safety systems of NuScale reactor	Marek BENČÍK (UJV)
16:20-17:05	NuScale reactor. Safety Analysis	Cesar QUERAL (UPM)
Wednesday		
14:30-15:15	CAREM reactor main features	Darío DELMASTRO (CNEA)
15:25-16:10	CAREM core main features	Edmundo LOPASSO (CNEA)

2. Course contents and implementation

The course was designed and implemented as a post-graduate / continuing education course within the curriculum of LUT with 2 ECTS credits awarded to the students completing it. Although it was made possible to participate only parts of the course, for example, the first day via remote connection, the full completion to obtain the credits required participation on-site, completion of a course quiz and returning a report of the laboratory work after the contact teaching days.

The course was promoted with a flyer (Annex-1) that was posted to the project website and via email in relevant contact networks of the project participants. A total of 18 students enrolled to the course of which 17 participated the course on-site. The first day of the course was streamed online and the stream was followed by 14 additional students. Teaching at LUT was given by 9 lecturers and 4 via remote connection. Thus, the course involved a total of 44 people.

The detailed schedule of the course is shown in Annex-2 and the contents of the three contact teaching days as well as the self-study parts of the course are described in the following.

2.1. Day 1 – Lectures by project experts

The course was opened by professor Juhani Hyvärinen (LUT) followed by a brief introduction to the McSAFER project presented by Heikki Suikkanen (LUT). The first day of the course consisted of lectures on various analysis methods and tools applied for SMRs within the context of the McSAFER project. Following the introductory part of the course, a total of six lectures were given with four of them via remote connection. The first day was streamed via Zoom to the interested McSAFER partners as well as those who had expressed their interest to participate but could not travel to Lappeenranta. The lectures by the project experts were the following.

- Juan Blanco (KIT) gave a remote lecture on PARCS-SCF calculations of the Argentinian CAREM reactor.
- Anthime Farda (CEA) gave a lecture on simulating a cold water injection transient in the F-SMR design with the coupled codes of CEA.
- Jorge Sanchez (UPM) gave a remote lecture on modelling the NuScale reactor with TRACE.
- Ladislav Vyskocil (UJV) gave a lecture on CFD and its application to simulations of the NuScale reactor (see Figure 1).
- Manuel Garcia (KIT) gave a remote lecture on the coupled multiscale analyses applied on the transient analyses of the SMART reactor.
- Hector Lestani (CNEA) gave a remote lecture on the fuel cycle design optimization.

After the lectures of the first day the participants were served dinner at the Kehruuhuone restaurant.

Figure 1: Lecture by L. Vyskocil (UJV).

2.2. Day 2 – Kraken workshop

The second day of the training course was devoted to a workshop on the Kraken multi-physics framework and its application for SMR analyses. Kraken is a multi-physics framework developed by VTT. The workshop was organized by Ville Valtavirta (VTT), and it consisted of the following parts.

- Introduction to multi-physics code coupling in the Kraken framework
- Introduction to the physics solvers
- Python level introduction to the coupled calculation schemes used in the NuScale REA analyses
- Running and analysis of introductory coupled simulation
- Constructing input models for NuScale REA analyses
- Constructing coupled calculation models for NuScale REA analyses
- Running and analysis of NuScale REA scenario

2.3. Day 3 – Laboratory activities

The focus of the third day was in thermal hydraulics experiments. The day started with a lecture by Juhani Hyvärinen (LUT) providing insight to the SMR test facility MOTEL and the results obtained with the facility so far within the McSAFER project.

The participants were divided into 4 smaller groups for the rest of the day consisting of activities at the nuclear safety research laboratories. Each group circulated through the four different laboratory activities in turns. Each activity had a duration of 1 hour. The laboratory activities were the following.

- **Natural circulation experiment**
  Supervised by Eetu Kotro (LUT)
  Students performed measurements with a small-scale natural circulation test facility. The measurement data was later analysed by the students in their lab reports.
- **Measurement uncertainties lecture**
  Given by Joonas Telkkä (LUT)
  A lecture was given on measurement uncertainties and how they should be incorporated to the measured data.
- **Laboratory tour**
  Given by Markku Puustinen (LUT)
  The various test facilities at the nuclear safety research laboratories including the SMR facility MOTEL were visited and introduced to the students.
- **Advanced measurement techniques**
  Given by Lauri Pyy (LUT)
  Several advanced measurement techniques utilized in the LUT research laboratory were introduced, including PIV, wire-mesh sensors, optical fibres, and high-speed cameras.

2.4. Quiz and laboratory report

In addition to the participation in the contact teaching days at LUT, the students were required to complete a quiz and return a report of the laboratory exercise to officially pass the course and be awarded by the ECTS credits by LUT University.

Course lecturers provided several multiple choice and true/false type questions from their lecture topics from which a quiz was compiled to the course digital learning environment Moodle (see Figure 2).

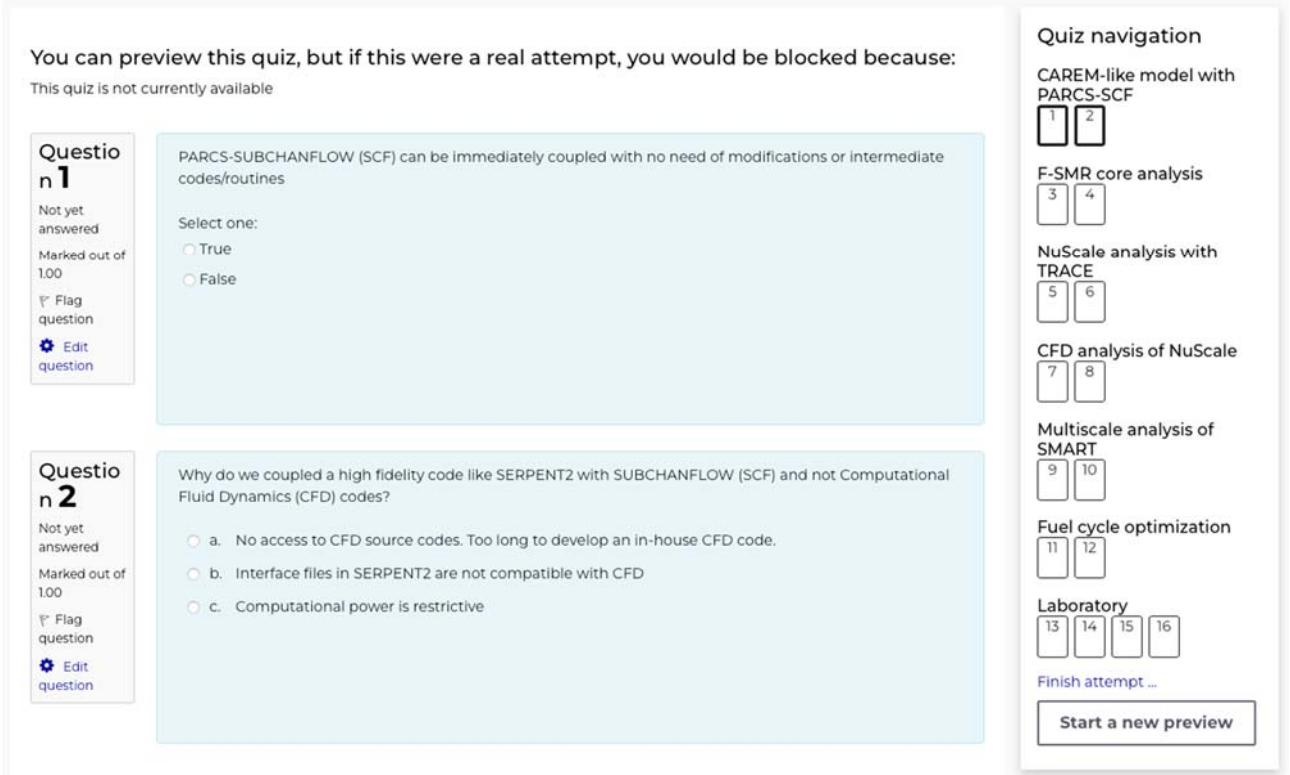

Figure 2: A preview of the course quiz.

3. Conclusions

The main conclusions drawn from the described training activity are listed below:

- The training course focused on the core neutronics and thermal hydraulics of light water SMRs. The three contact teaching days at LUT consisted of lectures by experts from the McSAFER project, a tutorial to the new Finnish computational reactor analysis framework Kraken developed at VTT and an experimental thermal hydraulics session at the LUT research laboratories. Additionally, the participants wishing to attain 2 ECTS credits granted by LUT University needed to complete a quiz and return a report on the laboratory work after the contact teaching days.
- During the first-day of the course, all lectures were successfully presented. In fact, important feedback between the audience and the lecturers took place during the Q&A period after each lecture resulted in very interesting discussions. Therefore, it is considered that the theoretical explanations were given properly by the lecturers and the modelling issues regarding SMRs involved in the project correctly described.
- In the second day the new reactor analysis framework Kraken was introduced and demonstrated with practical examples of its application to SMR analyses.
- Finally, during the last day course, the experimental thermal hydraulic session included a hands-on experiment and measurements related to natural circulation and introduction to advanced measurement techniques as well as the LUT test facilities including the SMR model MOTEL.
- 17 students participated the course on-site and including lecturers and remote participants the course involved a total of 44 participants

Overall, the course was successfully delivered and the planned objectives were met.

Annex-1: Course flyer

McSAFER Training Course on

"SMR neutronics and thermal hydraulics"

Lappeenranta-Lahti University of Technology LUT (Finland)

March 22 - 24, 2022

PROJECT OVERVIEW

The aim of the **McSAFER project** (*High-Performance Advanced Methods and Experimental Investigations for the Safety Evaluation of Generic Small Modular Reactors*) is to advance the safety research for SMRs by combining experimental investigations and numerical simulations. McSAFER has received funding from the Horizon 2020 Euratom Research and Training Programme.

COURSE THEME AND STRUCTURE

The training course focuses on core neutronics and thermal hydraulics of light water SMRs. It will consist of lectures by experts from the McSAFER project, a tutorial to the new Finnish computational reactor analysis framework Kraken developed at VTT and an experimental thermal hydraulics session at the LUT research laboratories.

Day 1: **Lectures**
The course lectures will present various McSAFER neutronic and thermal hydraulic analysis tools and methods applied for SMRs, such as CAREM, F-SMR, NuScale and SMART.

Day 2: **Kraken**
The new reactor analysis framework Kraken is introduced and demonstrated with practical examples of its application to SMR analyses.

Day 3: **Laboratory**
The experimental thermal hydraulic session will include a hands-on experiment and measurements related to natural circulation and introduction to advanced measurement techniques as well as the LUT test facilities including the SMR model MOTEL.

After the contact teaching, the participants are expected to complete on-line quizzes and return a short report on the laboratory work in the course digital learning environment.

ADDITIONAL INFORMATION

Venue: LUT University, Yliopistonkatu 34, Lappeenranta, Finland

Participation: The course is **free of charge** but **limited to 20 participants**.

ECTS: LUT University will grant **2 ECTS credits** for students who pass the course.

COVID-19: The course is planned to be organized as contact teaching at LUT but is subject to the current corona virus regulations. See https://www.finentry.fi/en/ for up-to-date guidelines for traveling to Finland.

Web page: https://mcsafer-h2020.eu/news-and-events/

REGISTRATION AND FURTHER INFORMATION

Contact: Dr. Heikki Suikkanen (heikki.suikkanen@lut.fi)

Annex-2: Course program

McSAFER Training Course on SMR Neutronics and Thermal Hydraulics

March 22-24, 2022, LUT University, Lappeenranta, Finland
Final Program

Day 1 – Tuesday, March 22, 2022
Lecture room 7443

Time	Lecture	Lecturer
9:00-9:10	Opening the course	Juhani Hyvärinen, LUT
9:10-9:25	Course practicalities and a brief introduction of the McSAFER project	Heikki Suikkanen, LUT
9:25-10:25	CAREM-like model with PARCS-SCF	Juan Blanco, KIT (remotely)
10:25-10:45	Coffee break	
10:45-11:45	F-SMR core analysis	Anthime Farda, CEA
11:45-12:45	NuScale analysis with TRACE	Jorge Sanchez, UPM (remotely)
12:45-13:40	Lunch break	
13:40-14:40	CFD analysis of NuScale	Ladislav Vyskocil, UJV
14:40-15:40	Multiscale analysis of SMART	Manuel Garcia, KIT (remotely)
15:40-16:00	Coffee break	
16:00-17:00	Fuel cycle optimization	Hector Lestani, CNEA (remotely)

19:00-22:00	Dinner at the Kehruuhuone restaurant

Day 2 – Wednesday, March 23, 2022
Lecture room 7443

Time	Lecture	Lecturer
9:00-9:30	Introduction to multi-physics code coupling in the Kraken framework	Ville Valtavirta, VTT
9:30-10:00	Introduction to the physics solvers	Ville Valtavirta, VTT
10:00-10:20	Coffee break	
10:20-11:20	Python level introduction to the coupled calculation schemes used in the NuScale REA analyses	Ville Valtavirta, VTT
11:20-12:20	Running and analysis of introductory coupled simulation	Ville Valtavirta, VTT
12:20-13:10	Lunch break	
13:10-14:10	Constructing input models for NuScale REA analyses	Ville Valtavirta, VTT
14:10-15:10	Constructing coupled calculation models for NuScale REA analyses	Ville Valtavirta, VTT
15:10-15:30	Coffee break	
15:30-16:30	Running and analysis of NuScale REA scenario	Ville Valtavirta, VTT

Day 3 – Thursday, March 24, 2022
Lecture room 7443 and Nuclear Safety Research Laboratories

Time	Lecture		Lecturer	
9:00-9:45	Experimental investigations of SMRs with the MOTEL test facility		Juhani Hyvärinen, LUT	
9:45-10:00	Lab works briefing and division into groups		Heikki Suikkanen, LUT	
10:00-10:15	Moving to the laboratories			
10:15-11:15	**Group A** Natural circulation experiment (E. Kotro, LUT)	**Group B** Measurement uncertainties lecture (J.Telkkä, LUT)	**Group C** LUT laboratory tour including MOTEL (M. Puustinen, LUT)	**Group D** Advanced measurement techniques (L. Pyy, LUT)
11:15-11:20	Changing groups			
11:20-12:20	**Group A** Measurement uncertainties lecture (J.Telkkä, LUT)	**Group B** LUT laboratory tour including MOTEL (M. Puustinen, LUT)	**Group C** Advanced measurement techniques (L. Pyy, LUT)	**Group D** Natural circulation experiment (E. Kotro, LUT)
12:20-13:20	Lunch break			
13:20-14:20	**Group A** LUT laboratory tour including MOTEL (M. Puustinen, LUT)	**Group B** Advanced measurement techniques (L. Pyy, LUT)	**Group C** Natural circulation experiment (E. Kotro, LUT)	**Group D** Measurement uncertainties lecture (J.Telkkä, LUT)
14:20-14:25	Changing groups			
14:25-15:25	**Group A** Advanced measurement techniques (L. Pyy, LUT)	**Group B** Natural circulation experiment (E. Kotro, LUT)	**Group C** Measurement uncertainties lecture (J.Telkkä, LUT)	**Group D** LUT laboratory tour including MOTEL (M. Puustinen, LUT)
15:25-15:40	Moving back to the lecture room			
15:40-16:00	Concluding the course		Heikki Suikkanen, LUT	