

# On teaching experimental reactor physics in times of pandemic

Jan Malec<sup>1</sup>, Michael Österlund<sup>2</sup>, Andreas Solders<sup>2</sup>, Ali Al-Adili<sup>2</sup>, Anže Jazbec<sup>1</sup>, Sebastjan Rupnik<sup>1</sup>, Vladimir Radulović<sup>1</sup>, Igor Lengar<sup>1</sup> and Luka Snoj<sup>1</sup>

<sup>1</sup>Jožef Stefan Institute, Slovenia

<sup>2</sup>Uppsala university, Sweden

Corresponding author: [jan.malec@ijs.si](mailto:jan.malec@ijs.si)

**Abstract**—The COVID-19 induced restrictions have prevented reactor physics students from attending in-person reactor physics exercises which are a vital part of their education. Jožef Stefan Institute has organized remote exercises with the help of off-the-shelf technology, including multiple videoconferencing setups, remote desktop software, portable cameras, a dome camera, shared spreadsheets, and a common whiteboard. The students were encouraged to actively participate in the exercises by giving instructions to the reactor operator, asking and answering questions, logging data, operating digital acquisition systems, and performing analysis during the exercise. The first remote exercises were organized as a five-day course of experimental reactor physics for students from Uppsala University. The feedback was collected after the course using an anonymous online form and was generally positive but has revealed some problems with sound quality which were resolved later. The Jožef Stefan Institute can also organize a remote course during a full lockdown when the reactor is not able to operate using the in-house developed Research Reactor Simulator based on a point kinetics approximation and a simple thermohydraulic module.

**Keywords** — education, training, quarantine, reactor physics, nuclear reactor

## I. INTRODUCTION

The Jožef Stefan Institute (JSI) regularly organizes training [1], [2] for local and foreign students of nuclear engineering and related sciences. The exercises are very valuable for the students because they give them the opportunity to perform practical experiments on a working nuclear reactor, and in some cases represent the only link between theory and experimental research. Travel restrictions in 2020 due to the COVID-19 pandemic prevented foreign students from traveling to Slovenia, and the closure in spring 2020 meant that practical exercises at the reactor were not possible at all. This paper describes some innovative solutions that were implemented to allow participants the closest possible approximation of in-person exercises given the restrictions. This paper presents a five-day distance learning course in experimental reactor physics organized for Uppsala University

using commercially available equipment. The performance of the course was evaluated by an anonymous online survey in which all students and their mentor participated. The organizers asked both open questions and questions that were answered using a rating scale. Jožef Stefan Institute can also organize remote exercises with a specially developed simulator [3]–[5] when the nuclear reactor is not allowed to operate. In this paper we focus on the experimental reactor physics course organized for Uppsala University and its implementation, followed by an evaluation of the course and an outlook on future improvements.

## II. TECHNICAL EXECUTION

Instructors used available technology to approximate the face-to-face exercise experience as closely as possible, transforming students from passive spectators to active participants. The primary means of communication was standard videoconferencing software installed on PCs, smartphones that served as portable cameras and a dome camera mounted on the ceiling (Figure 1).

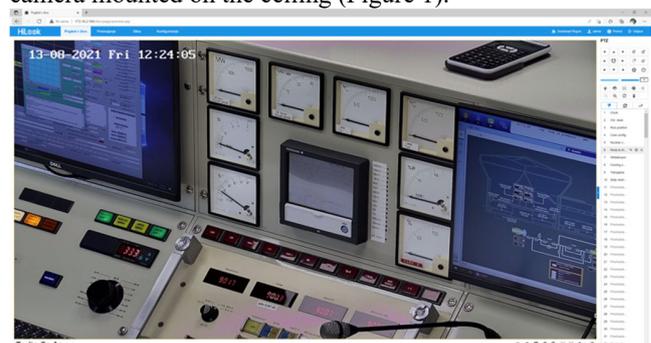


Figure 1 Dome camera pointed to the nuclear instrumentation. It could be remotely moved and zoomed-in to any point in the control room by using controls on the top right corner. Predefined positions (such as instrumentation and rod positions) could be selected in

The personal computers with video conferencing software are marked as “2.” on photo Figure 4 and diagram Figure 5. The portable cameras, marked “5.” on Figure 5 and Figure 8, could be taken into the reactor hall by the instructors to take a virtual tour, show the experimental setup or other activities at the reactor, such as the removal and re-installation of the neutron

source during criticality approach. A lecturer using the remote camera can be seen on Figure 8. In addition to the smartphone and PC cameras, a dome camera in the control room and a camera installed above the reactor core could be viewed and controlled by the students via the remote desktop software.



Figure 2 Screenshot of the Digital Reactivity Meter displaying data recorded during an approach criticality experiment by students of Uppsala University. The graph on the top displays the neutron flux in red, fuel temperature in green and the calculated reactivity in blue. The controls on the bottom control the plotting range, data logging and processing of the flux signal.

Students could point the dome camera at any area of the control room and zoom in or out to view the lecturer, the reactor operator's actions, or the nuclear instrumentation. The dome camera location is visible on Figure 6. The camera mounted above the reactor is used to see the bubbles being blown through the reactor core, the neutron source being removed, or the Cherenkov radiation (Figure 7). The dome camera and the camera mounted above the reactors were also both viewable from the television in the control room (marked "1." on Figure 4 and Figure 5). The remote desktop software was also used to control the digital acquisition software, the shared whiteboard, and Digital Reactivity Meter [6], an in-house developed software to monitor the neutron flux and solve inverse kinetic equations to calculate the reactivity of the reactor online. The Digital Reactivity Meter and the digital acquisition software were running on a dedicated computer ("3." on Figure 4 and Figure 5, screenshot on Figure 2).

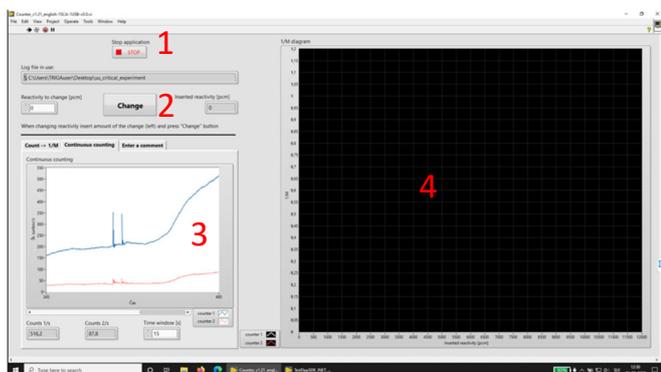


Figure 3 Digital acquisition software was remotely controlled by the students. The purpose of the application on screenshot above was to measure the number of counts in the start-up channel and assist in plotting the 1/M diagram. The students were able to start and stop the application by pressing the Start/Stop button (1), enter the inserted reactivity or differences in inserted reactivity (2) perform

timed counts or view count rate as a continuous time plot (3), and view the current 1/M diagram (4), which is not visible on the screenshot.

The exercise program made extensive use of shared online spreadsheet, which was used by multiple students with different roles at the same time. In the control room, the shared spreadsheets (Figure 9) were sometimes viewable on one of the personal computers ("2." on the diagram on Figure 5) or the common whiteboard ("4." on the same diagram).

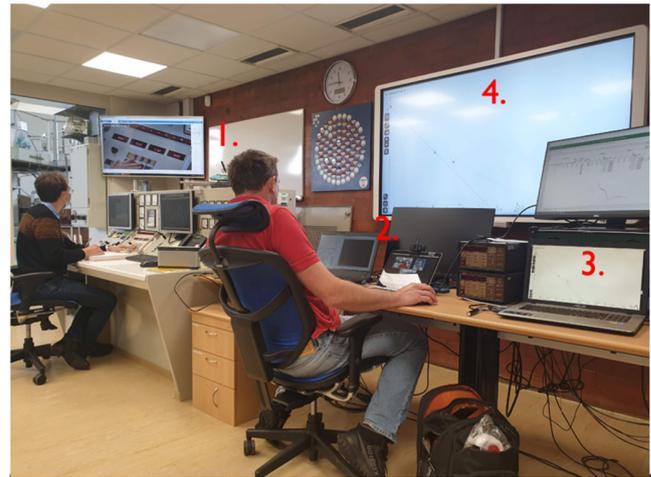


Figure 4 The students are communicating with the reactor operator and the lecturer, observing the operator movements and controlling a shared spreadsheet

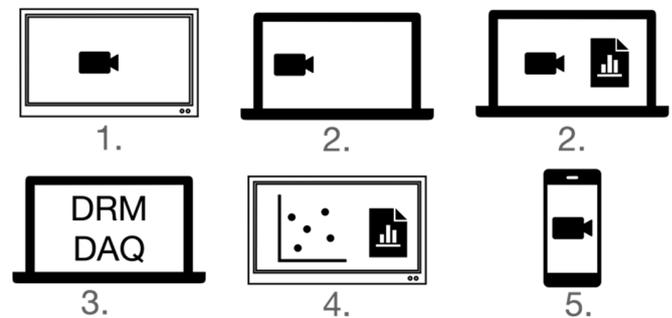


Figure 5 1. TV with dome/reactor camera, 2. Video conferencing/Spreadsheet laptops 3. Digital acquisition/Digital Reactivity Meter laptop, 4. Common digital whiteboard, 5. Portable remote cameras



Figure 6 The dome camera is mounted on the ceiling and positioned so it can see the reactor control panel, nuclear instrumentation readings, and the lecturer in front of the shared whiteboard.



Figure 8 We used smartphones with video conference software as portable cameras.

### III. UPPSALA UNIVERSITY EXERCISE SCOPE

Jožef Stefan Institute has offered a standard five-day course in reactor physics for undergraduate students from Uppsala University. The course started with an introductory session where students became familiar with the reactor. After a presentation of the facility and an overview of the course, the instructors took the students on a virtual tour of the reactor hall using portable cameras with zoom capability. The first exercise was the criticality approach, where students were asked to give step-by-step instructions to the operators on rod movements and estimate the current position at each step.

Students were assigned roles to encourage their active participation. The students participating in the exercise can be seen on Figure 10. One of the students entered the neutron count rates measured at each step into a shared online spreadsheet and estimated the current reactivity. Another student used the same spreadsheet to draw an automatic graph of the inverse count rate versus the inserted reactivity. One of the students drew the same chart on a shared whiteboard, one

used the dome camera mounted in the control room to monitor the control rod positions, and another communicated with the reactor operator. Students were able to request that the neutron source be removed from the reactor core and observe the process and the reaction of the detectors using remote

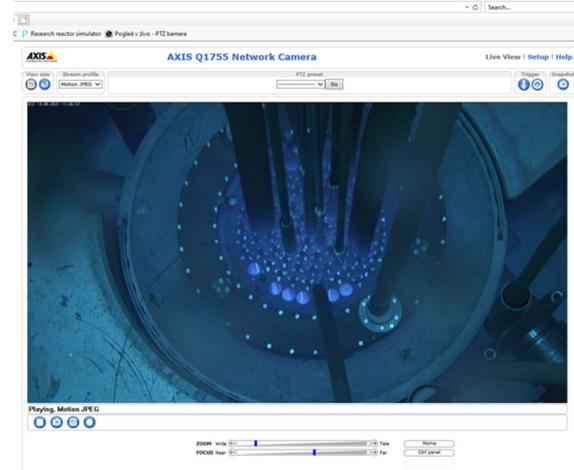


Figure 7 Cherenkov radiation is visible on the remote camera mounted above the reactor core. Students could view this camera at any time and use the zoom controls

cameras.

The second exercise dealt with the reactor's response to step changes in reactivity. As with the previous exercise, students were able to give operating instructions to reactor operators and observe the reactor's response to reactivity changes using remote cameras.

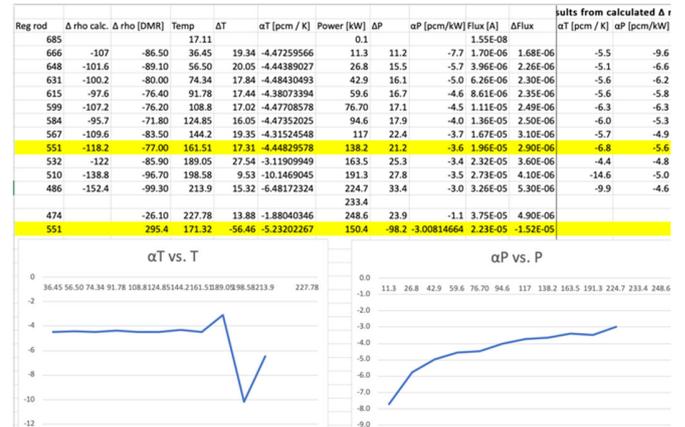


Figure 9 The shared spreadsheet was edited by multiple students with dedicated roles simultaneously. The students were entering the rod positions, changes in reactivity and temperatures and calculating the temperature and power reactivity coefficients (plots on the bottom part).

In addition to the rod positions and neutron flux monitors, students were able to use the remote camera mounted above the reactor core to observe Cherenkov radiation (visible in Figure 7) at higher powers and the remote desktop software

TeamViewer to operate and read out the Digital Reactivity Meter [Figure 3].

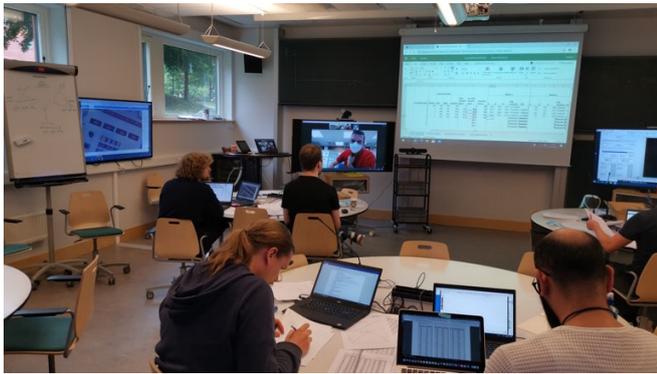


Figure 10 The students were using personal computers, larger monitors and a projector to both interact with the experiments and monitor the exercises

During reactor operation, each student starts up the reactor, brings it to full power, and shuts it down under the supervision of a licensed operator. Since direct remote control of the reactor is not possible, students use videoconferencing software to give instructions to the operator and remote cameras to monitor the reactor's response. The void reactivity coefficient is measured by blowing air bubbles into the reactor core and observing the effects on reactivity using the Digital Reactivity Meter [6]. In this exercise, the portable cameras were used extensively to show the details of the experimental setup on the reactor platform. The last two exercises were measurements of the value of control rods, where students measured and reconstructed calibration curves using either the rod swap method or the rod-in method, and a measurement of the temperature-reactivity coefficient, where students instructed operators to move the control rods over the point of active heat and recorded the change in fuel temperature and reactivity at each step.

#### IV. FEEDBACK INFORMATION

Feedback was obtained anonymously from students and their mentors using an online form. Instructors asked both choice-based questions and open-ended questions about the content of the exercises, staff performance, and technical execution of the remote exercises. Figure 11 is a summary of the results relating to the 'Technical content of the Educational Course', 'Quality of lectures', 'Quality of printed material and other material' and 'Educational Course equipment', all of which were rated as 'Excellent' or 'Good'. The responses to the open-ended questions were also mostly positive. Participants praised the content of the lectures and the opportunity to actively participate in the exercise and experience the role of the nuclear reactor operator. Some participants noted that students were sometimes not given enough time to find the answers to the questions and stated that students sometimes felt lost, especially at the beginning of the exercise. One of the

participants recommended that the lecturer should give clear, practical instructions before starting the experiments or give the students more time to solve the task themselves. The most frequently mentioned weakness was the quality of the audio. Several participants complained that they sometimes could not hear the lecturer when they moved away from the microphone.

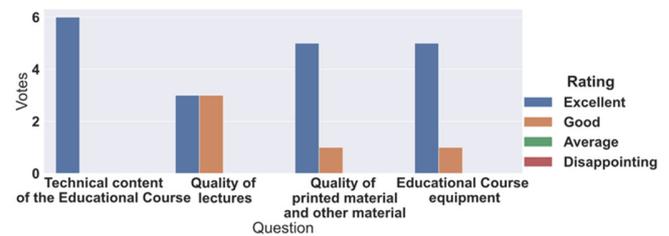


Figure 11 Survey results concerning content and quality of the lectures

The sound difficulties were also reflected in the ratings of the remote session on Figure 12, where the picture quality and latency were rated as 'Excellent' or 'Good' by all participants while the sound quality was also rated 'Average' or 'Disappointing'. Later, correction measures were taken and demonstrators wore wireless headsets.

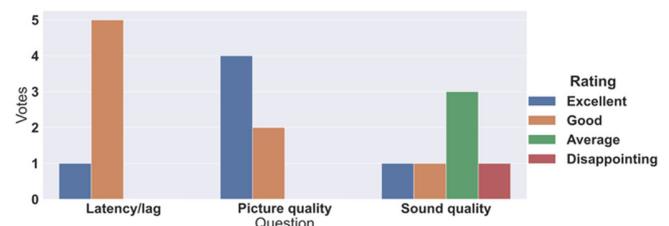


Figure 12 Survey results about the remote session

The participants agreed that such course should be organized routinely and that other nuclear workers and students could benefit from similar exercises. Five participants described the organization and administration of the Education Course as "Excellent" and one as "Good". When asked about the staff and their readiness to help with resolving their problems five participants answered again "Excellent" and one "Good".

#### V. RESEARCH REACTOR SIMULATOR

Jožef Stefan Institute also organised remote exercises in times of complete lockdown, when the reactor was not allowed to operate. This was done for students of physics at the University of Ljubljana with the help of the Research Reactor Simulator developed [3]–[5] by Jožef Stefan Institute. It solves point kinetic equations and contains a simple thermohydraulic model, which is well suited for simulating a research reactor with a small core and homogeneous neutron flux distribution. Students were able to perform all of the exercises that undergraduate students are expected to perform on a real reactor, i.e.: Approach to criticality, response to reactivity changes below the point of active heat, measurement

of the temperature reactivity coefficient, and measurement of the power decay after rod drop.

## VI. CONCLUSIONS

Students were able to perform all the planned exercises in the full scope in times of restricted travel and even during a full lockdown when the reactor was not allowed to operate. The authors of this article believe that this is incredibly important as the live exercises give students a different insight into reactor physics from the theoretical lectures. The remote exercises even have some advantages over the in-person exercises, especially lower cost because there is no need to travel, and the time agenda can be more flexible. Additionally, the simulator-based exercises guarantee that the measurements will be perfectly reproducible. Despite the advantages of remote exercises and simulator-based exercises, the instructors believe that they should be used exclusively as a backup option when in-person exercises are not possible. The lecturers observed that the students were asking fewer questions and did not participate as actively at the remote exercises compared to in-person exercises. The full predictability of the simulator output also takes away some of the educational value that comes from the exercises. Phenomena such as non-ideal neutron detector response or uncertainty in rod calibration curves are problems that nuclear reactor designers and operators have to recognize and know how to mitigate.

## ACKNOWLEDGMENT

The successful execution of the exercises in given conditions is the result of a quick response to circumstances and active collaboration of multiple departments from different institutions. Special thanks go to the staff of the Reactor Infrastructure Center of Jožef Stefan Institute for adapting to the new exercise format and installing the necessary equipment, and to the students and professors from Uppsala University for working closely with the staff from Jožef Stefan Institute and making the exercises possible.

## REFERENCES

- [1] L. Snoj, S. Rupnik, and A. Jazbec, 'New practical exercises at the JSI TRIGA Mark II reactor', in *PHYSOR 2014 International conference Proceedings*, vol. 2014, p. 12 str.
- [2] L. Snoj, M. Kromar, G. Žerovnik, and M. Ravnik, 'Advanced methods in teaching reactor physics', *Nuclear Engineering and Design*, vol. 241, no. 4, pp. 1008–1012, Apr. 2011, doi: 10.1016/j.nucengdes.2010.02.040.
- [3] J. Malec, D. Toškan, and L. Snoj, 'PC-based JSI research reactor simulator', *Annals of Nuclear Energy*, vol. 146, p. 107630, Oct. 2020, doi: 10.1016/j.anucene.2020.107630.
- [4] 'Research Reactor Simulator official website', *Research Reactor Simulator official website*. <http://reactorsimulator.ijs.si/> (accessed Oct. 01, 2019).
- [5] D. Toškan, J. Malec, and L. Snoj, *Research reactor simulator : User manual*, vol. 12332. Ljubljana: Inštitut Jožef Stefan, 2017.
- [6] I. Lengar, A. Trkov, M. Kromar, and L. Snoj, 'Digital meter of reactivity for use during zero-power physics

tests at the Krško NPP = Uporaba digitalnega merilnika reaktivnosti pri zagonskih testih na ničelni moči v NE Krško', *Journal of energy technology.*, vol. 5, pp. 13–26, 2012.