Open web system of Virtual labs for nuclear and applied physics

I S Saldikov, V V Afanasyev, V I Petrov and M Yu Ternovykh

National Research Nuclear University "Moscow Engineering Physics Institute" (NRNU MEPhI), 31 Kashirskoe highway, Moscow 115409, Russian Federation

Corresponding author's e-mail address: ISSaldikov@mephi.ru

Abstract. An example of virtual lab work on unique experimental equipment is presented. The virtual lab work is software based on a model of real equipment. Virtual labs can be used for educational process in nuclear safety and analysis field. As an example it includes the virtual lab called “Experimental determination of the material parameter depending on the pitch of a uranium-water lattice”. This paper included general description of this lab. A description of a database on the support of laboratory work on unique experimental equipment which is included this work, its concept development are also presented.

1. Introduction

One of the important tasks of modern higher education is to provide equal access to knowledge, the formation of a unified educational space for kindred institutions. At the same time universities are letting specialists for a number of high-tech industries such as nuclear, should provide a high level of teaching fundamental and applied physics, supported by modern teaching laboratories. In the National Research Nuclear University "Moscow Engineering Physics Institute" (NRNU MEPhI) stuff are working on the implementation of the above objectives. As an example, the publication of papers on teaching methods in some areas of applied physics can be considered [1, 2].

The university has a number of unique experimental facilities and the accumulated experience of their use in the educational process. Such plants often have a high metal and power consumption and cost for their operation is necessary to ensure safety, obtaining the appropriate licenses and the availability of highly qualified scientific and technical personnel. This makes it difficult to implement the learning process of these plants.

As a rule, incorporate it in the educational process is preceded by many years of scientific and engineering research. This includes installation of equipment, experiments, development labs and its description. Often leading educational institutions have their own unique assemblies. It reflects the history of the specificity and the history of this institution. It is obvious that the effectiveness of training would be improved if information about the unique experimental facilities, and conduct them on labs will be available to other institutions. In this complex devices like approach to the student, the effect of presence, involvement in a major development, facilitated by simulation and activity-oriented vocational training in an obstructed area. To this end, the Faculty of Physical Engineering developed a database of Support system for laboratory work on unique experimental equipment in nuclear power plants - is unique educational project in the field of nuclear energy and training system. It is created on the basis of specialties and laboratory work at the National Research Nuclear University MEPhI and combines everything a student need for both locally and the Internet access to laboratory work in the study of nuclear power plants. With photo and video materials of real facilities it allows for conducting virtual work to enhance the effect of presence. The project is available online at http://vlr.mephi.ru/, in English and Russian versions. Figure 1 shows the main page of the project.

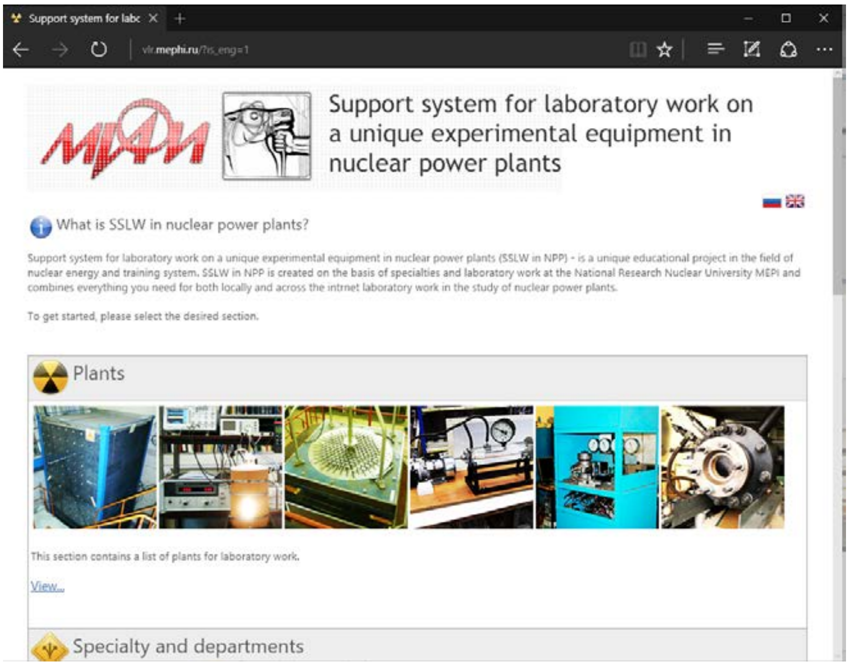

Figure 1. Main web page of support system for laboratory work on unique experimental equipment in nuclear power plant.

The database has a modern interface (the system of nested menus) and provides information in a variety of file formats. The files can be viewed, printed and / or downloaded for offline use.

In preparing students for laboratory work the database can be used as an alternative to the standard "paper" tutorial, because information in it fully reflects the content. The theoretical material which is applied to each lab, as well as photo and video materials allow you to see the process of work and can be used as teaching aids in the process of lectures and seminars. Each lab is applied checklist of questions that the student should know the answers before doing the lab.

The database is an open system and can be updated with information as the acquisition and development of new facilities and laboratory work.

2. Concept development of virtual labs

It is now possible to develop mathematical models that adequately describe the physical processes taking place in many experimental systems. A scientist can simulate a set of experimental results - the results of virtual experiments for different values of "input" parameters. The simulation is sometimes carried out in real time, but it is not always possible. In the case of complex mathematical models of time getting "virtual" results may be much greater than the time of the actual experiment. In this case, the scientist can use the approximation of the 'virtual' results, with a preliminary mass calculations based on a mathematical model of the assembly. It is also possible to use an approximation of the actual experimental results. An adequate mathematical model allows obtain the 'virtual' results that are not achievable in the existing experimental assembly, which can greatly enhance the ability of a 'virtual' laboratory.

In any case, the mathematical model is needed to create a virtual laboratory facility and should precede its development.

The development of the virtual laboratory work can be carried out using a variety of means, but the structure of this work should include the following elements:

- Initial data (installation parameters of studied materials, detector parameters, etc.).

- Set of different modes for the experiment (presence or absence of a source, the heater power, etc.).
- Simulation of the measurement (animation, photo or video materials).
- Saving (exporting) the results of virtual dimensions for further processing.

Virtual lab simulates the real laboratory work. Thus the design of the experimental setup is often described schematically, making it difficult to understand the physical processes occurring in the measurement process. To demonstrate the "insides" of the experimental setup and physical processes can use the additional multimedia educational materials made on the technology of computer graphics. The development of such materials is a separate problem. Thus, the concept of the development can be represented in figure 2.

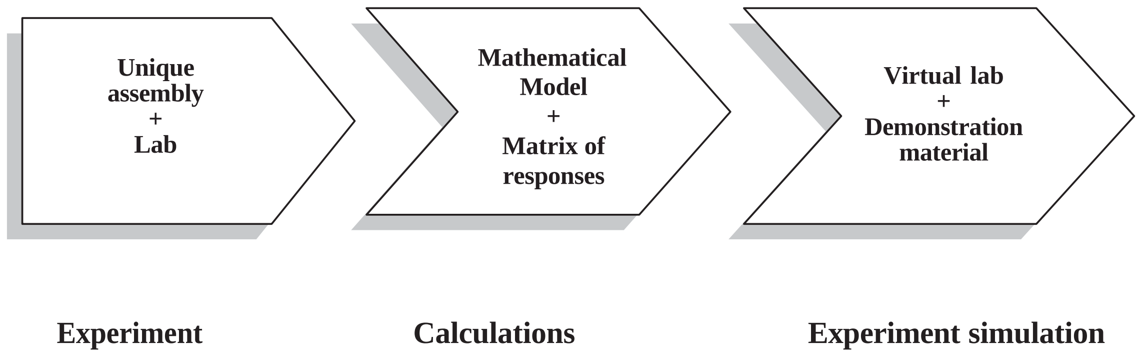

Figure 2. The development concept of virtual lab works.

3. Mathematical modelling of physical plants

The establishment and improvement of the workshop learning laboratory of the Department "Theoretical and experimental physics of nuclear reactors" NRNU MEPhI occurred simultaneously with the development of most of the department and was an integral part and a reflection of its scientific and educational work.

Lab "Experimental determination of the material parameter depending on the pitch of a uranium-water lattice" was created on the basis of uranium-water subcritical assembly that was developed in MEPhI.

To simulate a number of experimental settings, one can use a general-purpose professional programs. For example, for the simulation of systems with fissionable materials and/or sources of neutrons or gamma rays can be used Russian code MCU[3]. This program is based on the Monte Carlo method and is used for modelling the transport of neutrons and gamma rays in different systems. A scientist can adequately describe the geometry of the experimental facilities in MCU and conduct "virtual" experiment. However, the calculations are time-consuming, making it difficult to use the program MCU during laboratory work. So the following scheme in the development of "virtual" laboratory work was applied:

- Development of the model of the experimental assembly for the program MCU.
- Conduct a series of calculations for all possible "states" of the experimental plant, resulting in laboratory work.
- Filling of the "matrix of responses" of experimental values.
- Develop a program-simulator lab, in which "matrix of responses" will be used when performing a "virtual" laboratory work.

It should be noted that the "response matrix" can be completed without the calculations, and using only the real experimental data. However, the using of computer codes extends the "possibility" of experimental facilities. It allows enter a new "variable". For example, for subcritical assemblies containing natural uranium, it will be possible to perform the calculations for the enriched uranium and model the experimental indications of units for this event. Similarly, it will be possible to carry out computational studies on the effect of impurities in water at the experimental values. Thus, it can be argued that the use of mathematical modeling will increase the capacity of the experimental assemblies and develop "virtual" lab work with the new features.

4. Mathematical models of subcritical stands

Consider the process of mathematical modelling on the example of the uranium-water subcritical assembly diagram is shown in figure 3.

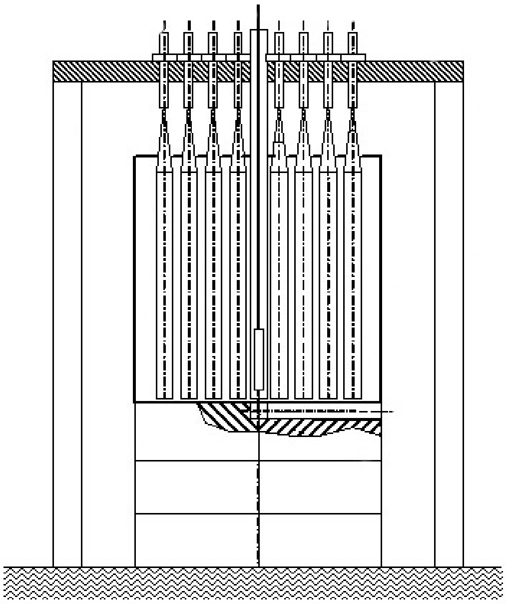

Figure 3. Uranium-water subcritical assembly scheme.

To create a virtual laboratory works on the assembly of mathematical models were developed for the program MCU. The visualization of the model is showed in figure 4. The "matrix of responses" was received for assemblies, based on calculations by MCU code. The calculations were performed for different states determined by the initial parameters.

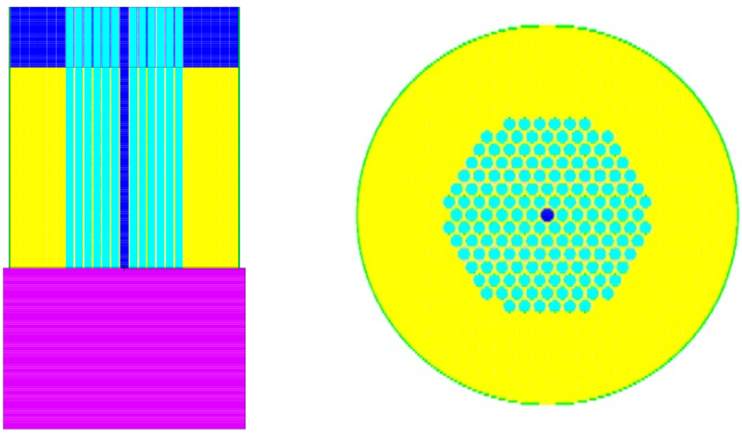

Figure 4. Visualization of the model of Uranium-water subcritical assembly (a) – left view, (b) – top view.

The number of structural elements in all the models corresponded to the number of elements in the corresponding experimental assemblies. However, the properties of model elements can differ from reality. Calculations of model assemblies with non- real parameters have been carried out to extend the range of the input data in a virtual lab, compared to the real one. Table 1 shows the values of the properties considered structural components for assembly.

Table 1. Fuel type and enrichment (%) of uranium rods in subcritical assembly for real and virtual assemblies.

	Fuel Type	Fuel Enrichment, %
Real	U_{me}	0.71
Virtual	UO_2, U_{me}	0.71, 0.9, 1.1, 1.3

5. Creating a Virtual Lab

For the development of virtual labs was created software environment Modeling of the Experiments based on the Monte-Carlo Method (MEMCM) to simulate real-world performance laboratory at subcritical assemblies. MEMCM allows you to receive experimental data as if it were actually performed by the lab, "Determination of the material parameters of the uranium-graphite assemblies" and "Experimental determination of the material parameter depending on the pitch of a uranium-water lattice" in a real experimental setup.

MEMCM opportunities for modeling subcritical assemblies:

- Calculation of the count rate (flux density in a given period of time) of neutrons in the assembly.
- Displays the number caught in the neutron detector in real time (figure 4).
- Measurement of the neutron count rate with cadmium filter on the detector.
- Measurement of background.
- View information about the performed laboratory work locally (without the Internet connection).

MEMCM opportunities for simulation of virtual assembly for virtual lab "Experimental determination of the material parameter depending on the pitch of a uranium-water lattice":

- Changing the fuel enrichment in the assembly of 0.72% to 1.3%;
- Change fuel type of U metal and UO_2;
- Changing the measurement time of 15 to 45 seconds.

The main working area of the program is presented in figure 5. Here a user can set the channel number for the detector. Channel selection is displayed on the diagram. The neutron source can be set or removed (for background measurements). The cadmium filter can be put on source for removing the thermal flux. When the user starts the experiment the number caught in the neutron detector is showed in the area. At the completion of the virtual measuring its results can be recorded and viewed in the table of the results.

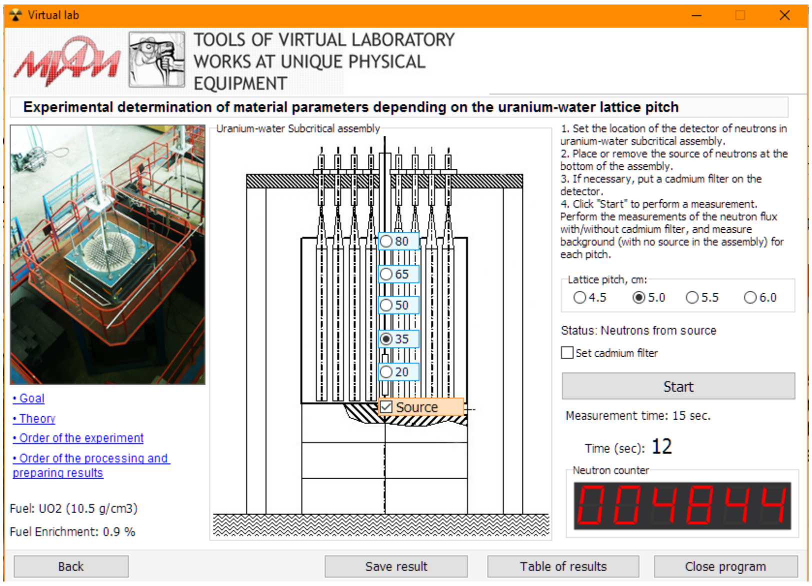

Figure 5. Main area of virtual experiment.

A general view of real experimental assembly is showed in figure 6.

Figure 6. Uranium-water subcritical assembly.

6. Conclusions

A similar scheme was applied for a database of laboratory works of engineering and physical training on the unique experimental equipment, the Faculty of Physical Engineering: 16 units, 24 labs. Mathematical models in English are built for six units and three prototypes of virtual labs:

- Uranium-graphite subcritical assembly [4].
- Spherical combustion research chamber.
- Thermophysical stand.
- Uranium-water subcritical assembly (described above).
- Spherical combustion chamber.
- Atmospheric shock tube.

Developments have been successfully used in the educational process NRNU MEPhI. Students not only learn good theoretical material, but also gain valuable engineering competencies neat course and prepare the final projects. Anyone can try to do the virtual lab in his/her University.

This work was carried out within the framework of 5-100.

References

[1] Petrov V I, Samossadny V T and Shalnov A V 1997 Training nuclear physics engineers in Moscow. Nuclear Europe Worldscan. No. 9-10, p 44.

[2] Sysoev A A, Sysoev A A, Petrov V I, Poteshin S S (2012). Engineering education technique based on professional activity imitation. Procedia. Social and Behavioral Sciences. London, vol 55. pp 707-709.

[3] Kalugin M A, Oleynik D S, Shkarovsky D A 2015 Overview of the MCU Monte Carlo Software Package. Annals of Nuclear Energy. vol 82 pp 54-62.

[4] Afanasyev V V, Kryuchkov E F, Petrov V I, Saldikov I S, Ternovykh M Yu, Tikhomirov G V (2014) Virtual labs on unique experimental equipment. Procedia. Social and Behavioral Sciences. vol 128 pp 482-488.