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Poster

TRIGA REACTOR PC-BASED SIMULATORS FOR TRAINING AND EDUCATION

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ABSTRACT

The IPR-R1 TRIGA nuclear reactor at Nuclear Technology Development Centre (CDTN) is used for education, particularly for the needs of the Brazilian Nuclear Power Plants operators' training. Thus, a digital system was developed that simulates the behaviour of the main variables related to the routine start-up of the reactor in order to assist in the training conducted in this reactor. Students of physics and postgraduate students of nuclear engineering can carry out practical exercises on this reactor simulator system. The variables derived from the neutron multiplication that can be simulated are: the inhour curve (relationship between the reactivity and the stable period T); the control rods worth; the neutron multiplication (power). The control panel shows the reactor power in Linear and Logarithmic Channels. With the simulator, several exercises can be performed by simulating various operation scenarios, such as neutron multiplication as a function of the rod position or as a function of a given period. The program can evaluate the effect of extreme values of several variables, allowing understanding the process behaviour and its implications. This is of extreme importance for the safe operation of nuclear reactors. The use of video screens for monitoring the operational parameters is important in the normal operation and to perform basic operator training. Advanced human-system interface technology is being integrated into existing nuclear plants as part of plant modification and upgrades.

1. Introduction

The most important variable in the nuclear reactors control is the power released by fission of the fuel in the core, which is directly proportional to neutron flux [1]. It was developed a digital system to simulate the neutron evolution flux and monitor their interaction on the other operational parameters. The control objective is to bring the reactor power from its source level (mW) to a few W. It is intended for education of basic reactor neutronic principles such as the multiplication factor, criticality, reactivity, period, delayed neutron and control by rods.
The 250 kW IPR-R1 TRIGA research reactor at Nuclear Technology Development Center - CDTN (Belo Horizonte/Brazil) was used as reference. TRIGA reactors, developed by General Atomics (GA), are the most widely used research reactor in the world. They are cooled by light water under natural convection and are characterized by being inherently safe.
The simulation system was developed using the LabVIEW® (*Laboratory Virtual Instruments Engineering Workbench*) software developed by National Instruments, considering the modern concept of virtual instruments (VI's) [2]. This system use electronic processor and visual interface in video monitor, as shown in Fig. 1. The main purpose of the system is to provide training tools for students and reactor operator, allowing to study, to observe, and to analyze the behavior, and the tendency of some processes that occur in the reactor using a user-

friendly operator interface. Some scenarios are presented to demonstrate that it is possible to know the behavior of some variables from knowledge of input parameters. The TRIGA simulator system will allow the study of parameters, which affect the reactor operation.
Nuclear reactor instrumentation is designed so as to emphasize the reliability, redundancy and diversity of control systems. Power monitoring in nuclear reactors is of crucial importance with respect to safety and efficient operation. Since the first criticality of a nuclear reactor carried out by Fermi and collaborators on December 2, 1942, at the Chicago University, there has been concern about safely monitoring the parameters involved in the chain reaction.
Nuclear reactor simulation involves mainly neutronic (neutron physic) and thermal hydraulic (fluid and heat transfer). The dynamic behavior of a reactor is associated with an important property known as its reactivity. This property changes when the fuel temperatures are changed. The changes of reactivity occasioned by fuel changes of temperatures form the effect that is called the “temperature coefficient of reactivity”. For the IPR-R1 TRIGA reactor, this effect appears when the reactor operates in power above nearly 1 kW. For low operating power level, there is not the influence of temperature.

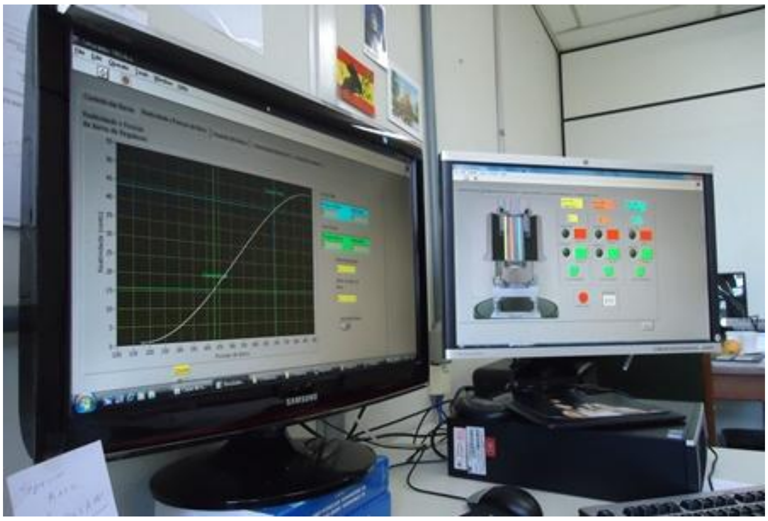

Fig. 1. Digital control system simulation for nuclear reactor parameters

2. The IPR-R1 TRIGA Reactor

The IPR-R1 TRIGA (*Instituto de Pesquisas Radiativas* - Reactor 1, Training Research Isotope General Atomic) reactor is a typical TRIGA Mark I light-water and open-pool type reactor. The fuel elements in the reactor core are cooled by water natural circulation. The heat removal capability of this process is great enough for safety reasons at the current maximum 250 kW power level configuration. However, a heat removal system is provided for removing heat from the reactor pool water. The water is pumped through a heat exchanger, where the heat is transferred from the primary to the secondary loop. The secondary loop water is cooled in an external cooling tower.
TRIGA reactors are the most widely used research reactor in the world. There is an installed base of over sixty-five facilities in twenty-four countries on five continents. General Atomics (GA), the supplier of TRIGA research reactors, since the late 1950s, continues to design and install TRIGA reactors around the world and has built TRIGA reactors in a variety of configurations and capabilities, with steady state thermal power levels ranging from 100 kW to 16 MW. TRIGA reactors are used in many diverse applications, including production of radioisotopes for medicine and industry, treatment of tumors, nondestructive testing, basic research on the properties of matter, and for education and training. The TRIGA reactor is the only nuclear reactor in this category that offers true "inherent safety,” rather than relying on "engineered safety." It is possible due to the unique properties of General Atomic’s uranium-

zirconium hydride fuel, which provides unrivaled safety characteristics, which also permit flexibility in sitting, with minimal environmental effects [3].
The prototypical cylindrical fuel elements are a homogeneous alloy of zirconium hydride (neutron moderator) and uranium enriched at 20% in ^{235}U. The reactor core has 58 aluminum-clad fuel elements and five stainless steel-clad fuel elements. One of these steel-clad fuel elements is instrumented with three thermocouples along its centerline. This instrumented fuel element was inserted in the reactor core in order to evaluate the thermal hydraulic performance of the IPR-R1 reactor [4]. The fuel rod has about 3.5 cm diameter; the active length is about 37 cm closed by graphite slugs at the top and bottom ends, which act as axial reflector. The moderating effects are carried out mainly by the zirconium hydride in the mixture and on a smaller scale by light water coolant. The characteristic of the fuel elements gives a very high negative prompt temperature coefficient and is the main reason of the high inherent safety behavior of the TRIGA reactors. The power level of the reactor is controlled with three independent control rods: a Regulating rod, a Shim rod, and a Safety rod.

3 Digital Instrumentation for Nuclear Reactors

Control and instrumentation of nuclear power plants has improved rapidly and significantly in recent years as demands for reactor safety, availability, and reliability increased. Development and design of modern, highly automated systems have become possible as new measurement and control methods were introduced together with new data processing techniques based on recent advances in electronic components, transducers, and computers. There is now a new generation of computerized nuclear power plant control systems that meet the high demands for reactor safety and decrease the risk of accidents. The experience gained using computers in reactor-control systems and in monitoring the status of safety systems has shown the benefits that can be gained from fully computerized shut-down systems. They are reliable, flexible in design, and give a better man-machine interface. Microcomputers and their software will dominate future systems. Computers and their peripherals, e.g., graphical color screens, will become the major source of information for the reactor operator. The new digital control includes automatic start-up and shut-down procedures to reduce risks for potential errors and to improve operational management. The control methods employed are mainly supervisory computer control and direct digital control [5].

4 Virtual Instruments

The rapid adoption of the PC in the last 20 years catalyzed a revolution in instrumentation for test, measurement, and automation. One major development resulting from the ubiquity of the PC is the concept of virtual instrumentation, which offers several benefits to engineers and scientists who require increased productivity, accuracy, and performance.
A virtual instrument (VI) consists of an industry-standard computer or workstation equipped with powerful application software, cost-effective hardware such as plug-in boards, and driver software, which together perform the functions of traditional instruments. The VI appearance and operation imitate physical instruments. Traditional hardware instrumentation systems are made up of pre-defined hardware components, such as digital multimeters and oscilloscopes. These systems are more limited in their versatility than virtual instrumentation systems. The primary difference between hardware instrumentation and virtual instrumentation is that software is used to replace a large amount of hardware. Virtual instruments are computer programs that interact with real world objects by means of sensors and that implement functions of real or imaginary instruments. They can acquire, simulate and analyze data. Virtual instruments represent a fundamental shift from traditional hardware-centered instrumentation systems to software-centered systems that exploit the computing power, productivity, display, and connectivity capabilities of popular desktop computers and workstations. Although the PC and integrated circuit technology have experienced significant advances in the last two decades, it is software that truly provides the advantage to build on this powerful hardware foundation to create virtual instruments, providing better ways to innovate and significantly

reduce cost. With virtual instruments, engineers and scientists build measurement and automation systems that suit their needs exactly (user defined) instead of being limited by traditional fixed-function instruments (vendor defined). The synergy between them offers advantages that cannot be matched by traditional instrumentation [2].

LabVIEW® (*Laboratory Virtual Instruments Engineering Workbench*) contains a comprehensive set of tools for acquiring analyzing, displaying, and storing data. This software is used in conventional plants and in some nuclear reactors, replacing the analog control system with modern, user-friendly digital control [6]. LabVIEW® is an amazingly intuitive software which allows to create programs using a graphics-based programming language called G. This means there are no longer lines upon lines of text-based code with hard-to-remember syntax (e.g., C++, Fortran). You just drag the functions onto the screen and wire them together. Also, LabVIEW® is equipped with some very easy-to-use functions that take care of the dirty low-level work of configuring the computer hardware to establish communication between the computer and the instrument. LabVIEW® software was used, in the work present here, to simulate the neutronic parameter evolution of nuclear reactor. LabVIEW® Vis contain three components: the front panel, the block diagram, and the icon and connector panel. In LabVIEW®, the user builds an interface, or front panel, with controls and indicators. Controls are knobs, switches, push buttons, dials, and other input devices. Indicators are graphs, meters, and other displays that simulate the front panel of a real instrument. The code and structures to control the front panel objects are added to the user interface. The block diagram contains this code. The block diagram resembles a flowchart [7]. Their most recognizable feature is user friendly human–machine interfaces (HMIs) with graphical [8].

5 Simulated Parameters

The neutronic parameters to be simulated are those that appear in the reactor startup caused by the control rods' movement, leading to neutron flux multiplication. As mentioned, the reactor reference is the IPR-R1 TRIGA research reactor. In this reactor, the reactivity control, and consequently the power level, is done by three control rods that can be inserted into or withdrawn from the core. They are: a Safety Rod, a Shim Rod and a Regulating Rod.

The front panel of the simulator system displays the responses of the two main power measure channels, the Linear Channel and the Logarithmic Channel. The reactivity (ρ) the period (T) and the inhour equation are variables derived from these two channels.

The boundary conditions are:

- The inhour equation is only valid for stable period.
- The Safety Rod can be moved from position 150 (fully inserted) to position 890 (totally removed). During reactor operation, this rod is completely out.
- The Shim Rod, during the reactor operation, normally works in an intermediate position. It can be moved from position 161 (fully inserted) to position 890 (totally removed).
- The Regulation Rod also works in an intermediate position. It can be moved from position 171 (fully inserted) to position 900 (totally removed).

The simulation is valid for operations up to a maximum of 1 kW. For higher power, the fuel temperature increase causes the appearance of a negative reactivity in the core (temperature coefficient of reactivity), not simulated by this program version.

The main VIs developed for the simulator were: the VI that relates the control rod position with the reactivity inserted in the core (calibration rod equation), the VI that relates reactor period with reactivity (inhour curve) and the VI that relates the neutron multiplication in the Linear Channel and Logarithmic Channel. Some VIs were developed to manage the program. These instruments were called "structure events."

6 Routine Startup and Shutdown of the TRIGA Reactor

The steps that are followed for the routine startup and shutdown the TRIGA reactor are described here. With the control rods of the reactor calibrated and a neutron source provided, the reactor might be taken up to power from its shutdown condition by slowly withdrawing the

Safety rod to its ready position, followed by small stepwise withdrawal of the Shim rod and the Regulating rod, maintaining approximately symmetrical positions for this two rods. The multiplication of the neutrons is followed with the period meter, the fission chamber (Startup Channel) and the ionization chamber (Logarithmic Channel), while the reactor is still subcritical. If the motion of the shim or regulation rod under withdrawal is stopped while the rector is in this condition, the meters will come to rest and the period meter will return to the infinite period position [9].
The slow adjustment of the shim rod and the regulating rod by the operator is continued. There will come a time when, with the rods stationary, the period meter not indicate an infinite period but some finite, large value. This indicates that the reactor is slightly supercritical. The shim rod positions should then be left as they are, and the regulating rod adjusted slightly to set the period to a moderate value. In this state, the reactor power is slowly rising and may be followed by the meter of the logarithmic channel and later by the linear channel. When the desired power level is obtained, the regulating rod should be slightly inserted until the power level remains constant and the period meter returns to the infinite-period position. The reactor may be shut down by one or more methods. To shutdown the reactor, the “scram” button is pressed, thereby releasing the control rods. They will then quickly insert the rods by gravity and shut the rector down [9].

7 The Control Rods Worth VI

It was created several virtual instruments (VIs) and for each VI, had developed a LabVIEW® block diagram. The determination of the reactivity worth of individual control elements and the effects of such elements on the power distribution in the core is important to the safe and efficient operation of a nuclear reactor. Once a control rod is calibrated, it is possible to evaluate the magnitude of other reactivity changes by comparing the critical rod positions before and after the change. All three-control rods are calibrated by the positive period method. The method consists of withdrawing the control rod from a known critical position through a small distance. This adds a positive reactivity to the system, and the reactor power increases in a exponential manner with time and establishes a stable period that is measured using the doubling time, that is the time required for the power to increase by a factor of two. Each successive step is compensated by lowering the other control rod just enough to reestablish criticality. The reactivity associated with the measurement is gotten from the graphical form of the inhour equation that gives the relationship between reactivity and the stable reactor period.
The experimental data obtained in the control rods’ calibration and the integral fitted worth curves of the Regulating, Shim and Safety control rods as a function of their positions are shown graphically in Figure 2, Figure 3 and Figure 4, respectively. The equations representing the fitted model, and the coefficients of determination R^2, that confirm the goodness of the fit are also shown in the figures. The integral control rod worth curve is particularly important in research reactor operation. The experimental values of the Regulating, Shim and Safety control rod worth for the IPR-R1 TRIGA reactor were 0.5, 3.1 and 2.8 cents, respectively [10].

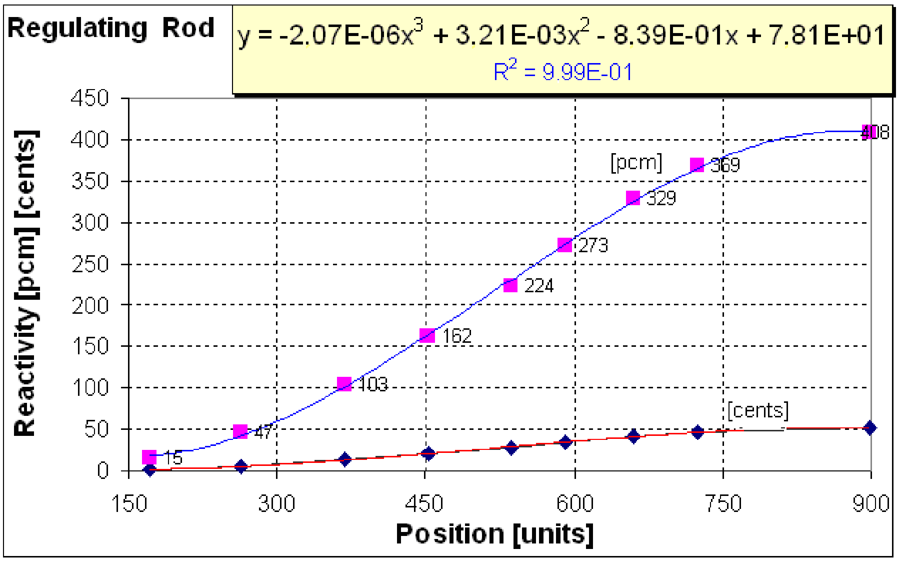

Fig. 2. Reactivity as function of insertion of Regulation control rod

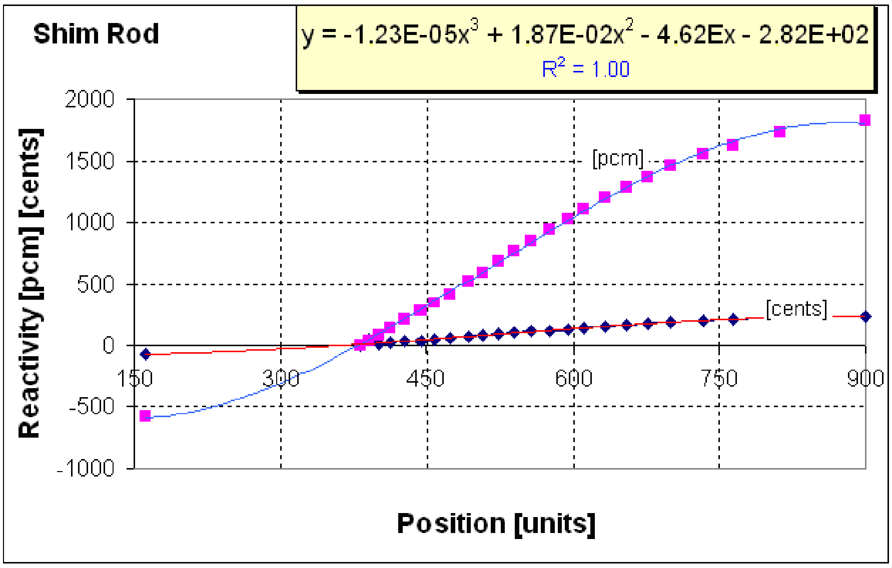

Fig. 3. Reactivity as function of insertion of Shim control rod

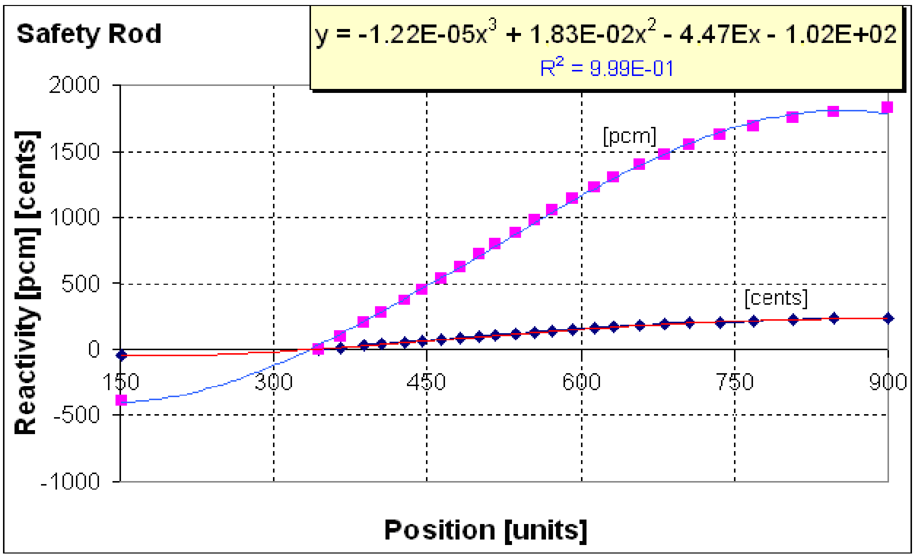

Fig. 4. Reactivity as function of insertion of the Safety control rod

It was building the VI named “Control Rods Worth” and the control rods worth curves were added to the block diagram of LabVIEW® program. In this VI there are switches and indicators that allow the user to simulate the reactivity inserted into the core as a function of the rods positions. Figure 5 shown the graphic interface for Regulating Rod and places where the user enters with the variables “delta reactivity” and “rod position step”

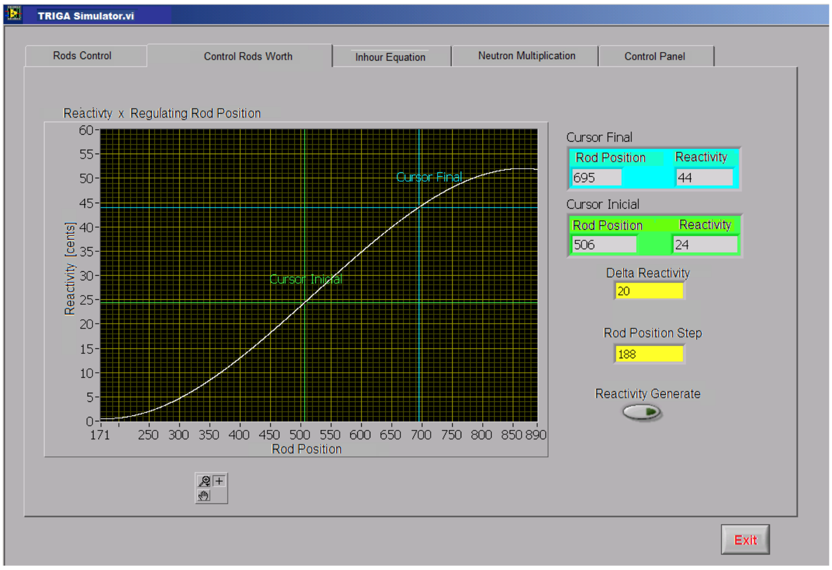

Fig. 5. Reactivity versus Regulating rod position

7.1 The Inhour Equation VI

The relationship between the reactivity (ρ) and period (T) for the IPR-R1 TRIGA reactor, which is not far above the critical condition of operation, is given by the inhour equation. This equation was inserted into the LabVIEW® simulator program.
For IPR-R1 TRIGA reactor: the neutron generation average lifetime (ℓ =100μs), the delayed neutron fraction and its decay constant, and the multiplication factor (k ≈ 1 and □k ≈ 0.001) is known so the period can be determined when the reactivity is known and vice versa. It was considered the properties of the six known groups of delayed neutrons emitted during the fission of ^{235}U. Figure 6 shows the graphic interface of the program.

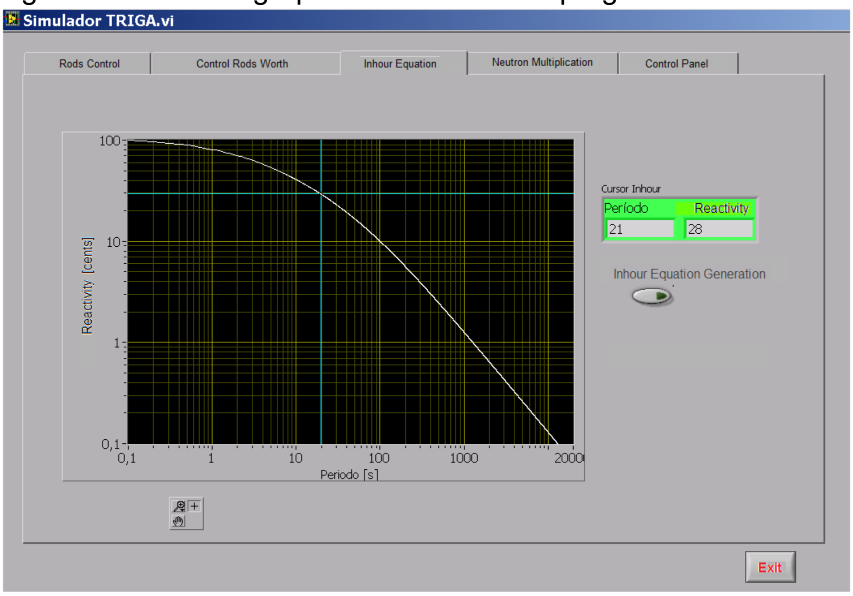

Fig. 6. Inhour equation curve

7.2 The Neutron Multiplication VI

It was developed the VI named “Neutron Multiplication”. In the graphical interface the user inserts the initial power and the period (T). Graphic presentation of the power may be in linear or logarithmic scales and other resources can also be simulated. Figures 7 and Figure 8 show the graphical interfaces available for the user.

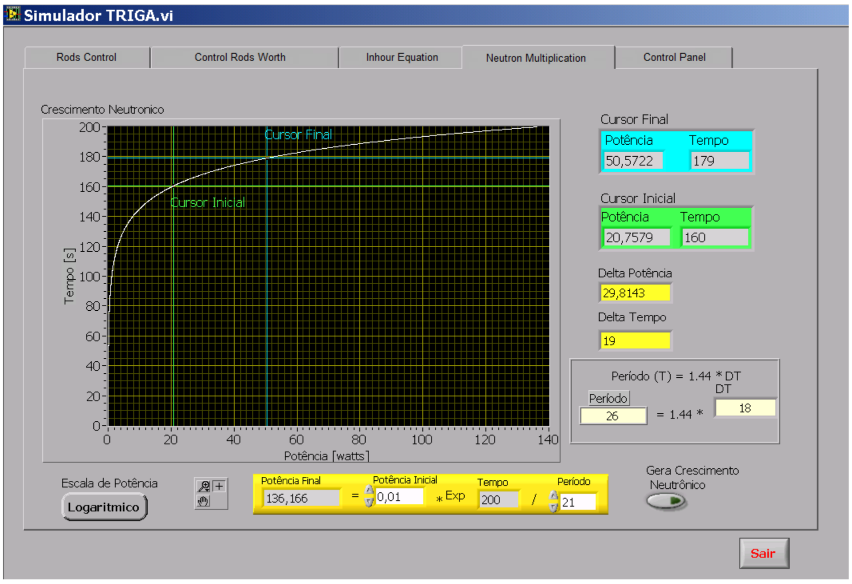

Fig. 7. Linear channel

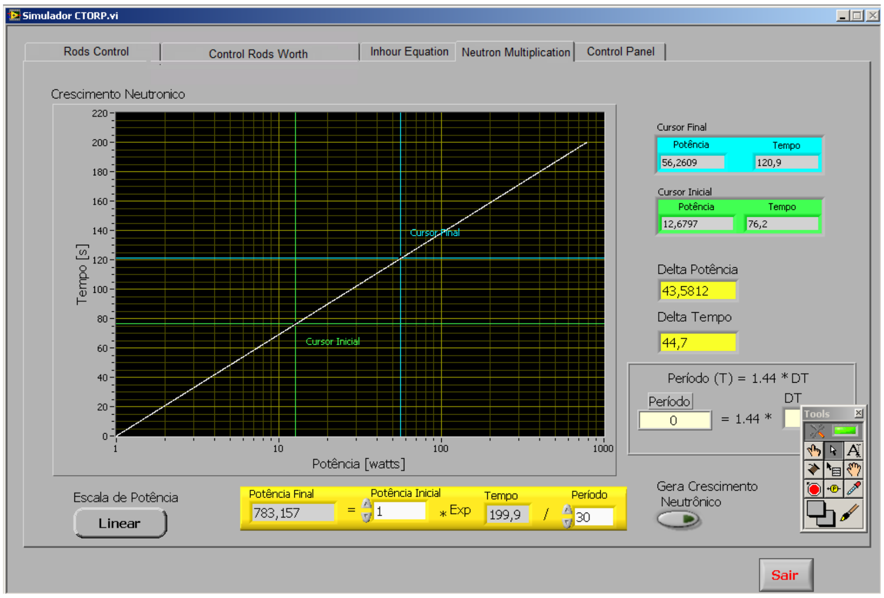

Fig. 8. Logarithmic channel

7.3 The Control Panel VI

On the VI "Control Panel" the user must enter the following variables concerning the inhour equation which is specific for the IPR-R1 TRIGA reactor:

- The excess of the multiplication factor “Delta K” which is used in the inhour equation. The default value for the IPR-R1 reactor is 0.001s.
- The neutron average lifetime “L” [s], for IPR-R1 TRIGA is 100μs or 0.0001s.

The block diagram of the control panel is shown in Fig. 9. In all other VI's of the program were developed block diagrams similar to this.

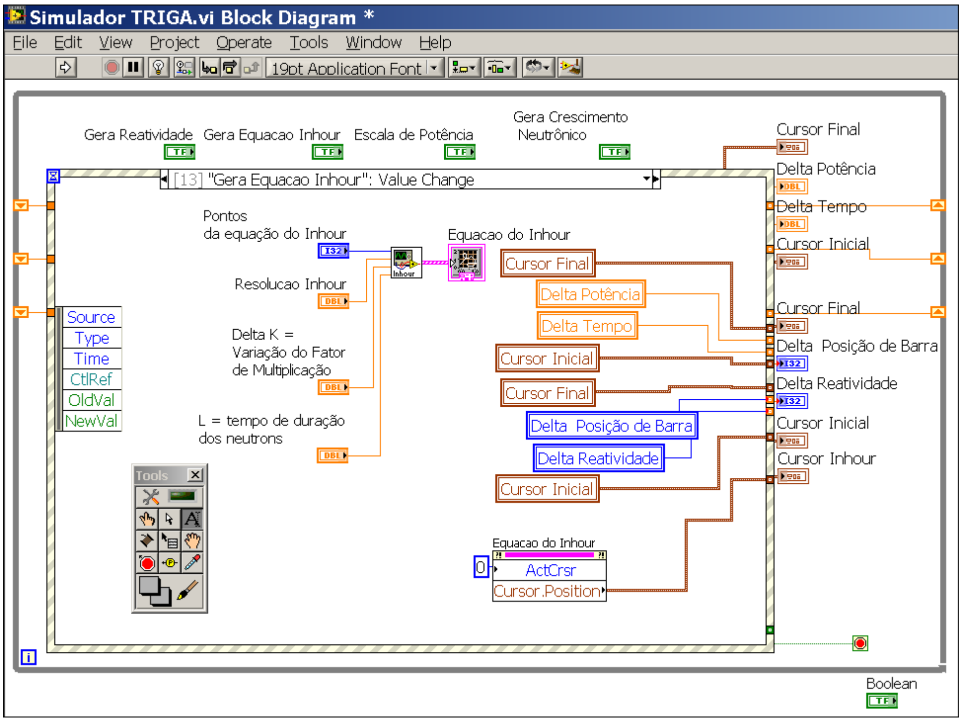

Fig. 9. Block diagram of the Control Panel

In the VI "Control Panel" is also available the button named "Help" (Fig. 10), which when clicked, presents to the user the recommendations, tips and logical sequence for using the simulator system.

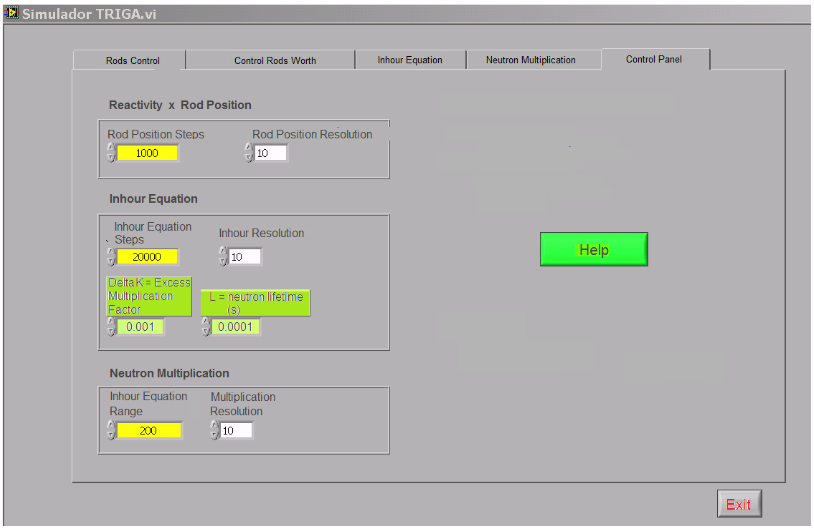

Fig. 10. Control panel user interface

7.4 The Rods Control VI

The operator performs, the control rods movement using the keys "Up" and "Down" on the VI “Control Rods”. The rods position is shown on the screen. There are buttons to cause the scram of each rod “SCRAM” or for all rods simultaneously "Emergency". This is the main program screen where the operator starts the reactor operation and visualizes the rod movement in a scheme of the TRIGA core as shown in Fig 11.

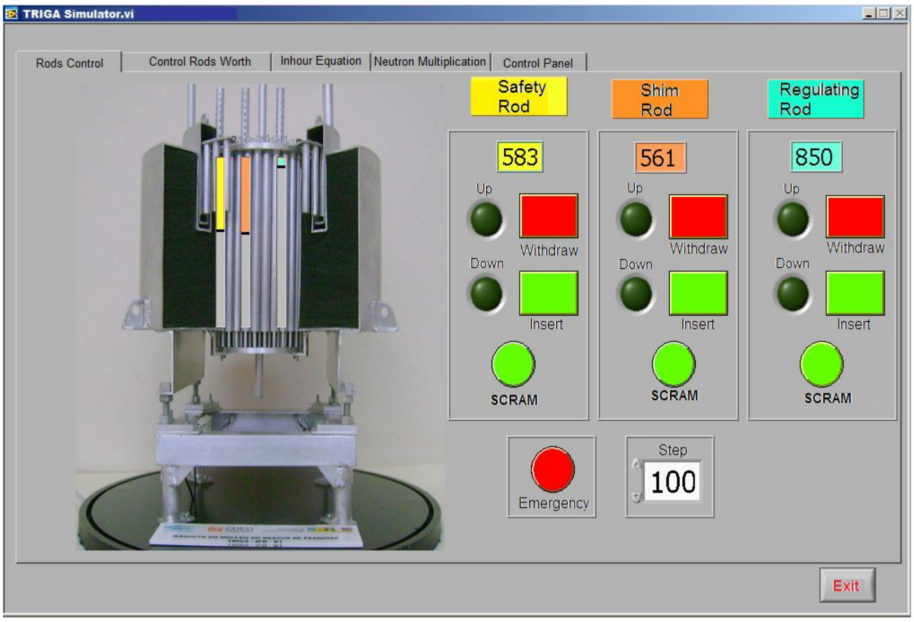

Fig. 11. Control rods front panel

8 Conclusion

The IPR-R1 TRIGA nuclear reactor at Nuclear Technology Development Center (CDTN) is used for education, particularly for the needs of the Brazilian Nuclear Power Plants operators' training. Thus, a digital system was developed that simulates the behavior of the main variables related to the routine startup of the reactor in order to assist in the training conducted in this reactor. Students of physics and postgraduate students of nuclear engineering can carry out practical exercises on this reactor simulator system.

The variables derived from the neutron multiplication that can be simulated are: the inhour curve (relationship between the reactivity and the stable period); the control rods worth; the neutron multiplication (power). The control panel shows the reactor power in Linear and Logarithmic Channels. With the simulator, several exercises can be performed by simulating various operation scenarios, such as neutron multiplication as a function of the rod position or as a function of a given period.

The program can evaluate the effect of extreme values of several variables, allowing understanding the process behavior and its implications. This is of extreme importance for the safe operation of nuclear reactors. The use of video screens for monitoring the operational parameters is important in the normal operation and to perform basic operator training. Advanced human-system interface technology is being integrated into existing nuclear plants as part of plant modification and upgrades.

The system simulator was developed using the LabVIEW® software that is the most commonly program used for monitoring, control, simulation and data acquisition. In LabVIEW®, the user builds an interface, or front panel, with controls and indicators. The use of customizable software and modular measurement hardware to create user-defined measurement systems is called virtual instruments (VIs).

Their appearance and operation imitate physical instruments. The resulting system has a user-friendly operator interface. Advanced human-system interface technology is being integrated into existing nuclear plants as part of plant modification and upgrades. A new version of the simulator is being developed to simulate the entire power range of the IPR-R1 TRIGA reactor (until 250 kW). For this upgrade a mathematical expression must be inserted that takes into account the temperature coefficient of reactivity that occurs in operation powers above about 1 kW.

9 Acknowledgments

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AUGMENTED NUCLEAR EDUCATION

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ABSTRACT

An important duty for a scientist is to correctly inform and educate people on scientific topics. In these regards several studies have shown that acceptance of Nuclear Energy strongly depends by coherent and unbiased information.
In the framework of creating a multimedia tool for Education and Training a new innovative concept was applied. The project is about explaining how a Nuclear Power Plant (NPP) works and solving some of the most Frequently Asked Questions (FAQ) that the user might have. The innovative approach consists in enhancing the end-user experience and attracting his interest through the implementation of an Augmented Reality (AR) environment hence the name "Augmented Nuclear Education". Augmented Reality is a technology that blends digital objects with reality, so that they appear in the user's real-world environment.
The user activates the game waving at the screen and is welcome by Prof. Neutronix, the interaction happens in a gesture control environment, without the need of touching any component and/or device. The information are passed to the user through the animations of different components of the NPP and through small pop-up windows appearing once we select a component while Prof. Neutronix explains with a calm and warm voice the functioning of that equipment (see Fig. 1).
The tool was developed having in mind different types of audience and their requirements and hence the system asks to select a profile (i.e. "SIMPLE" or "ADVANCED") at the beginning of the "Game". The simple profile addresses a general public audience explaining the NPP components with an everyday's language and easily comprehensible examples. The advanced profile on the other hand is directed to an audience with some scientific knowledge but yet not technical that might be not used to terms and concepts of nuclear engineering (i.e. journalists, politicians, public with higher education…).
A second part of the tool is a kind of test that requires the user to answer some Frequently Asked Questions (FAQ) grouped in three subfields: Materials, Energy, and Radiations. The questions are presented with 3 multiple choice potential solutions. The user selects an answer and Prof. Neutronix interacts with her/him either approving the answer and giving some further technical details or encouraging the user to find a different solution. At the end of the 9 FAQs the user get the score of the total correct answers.

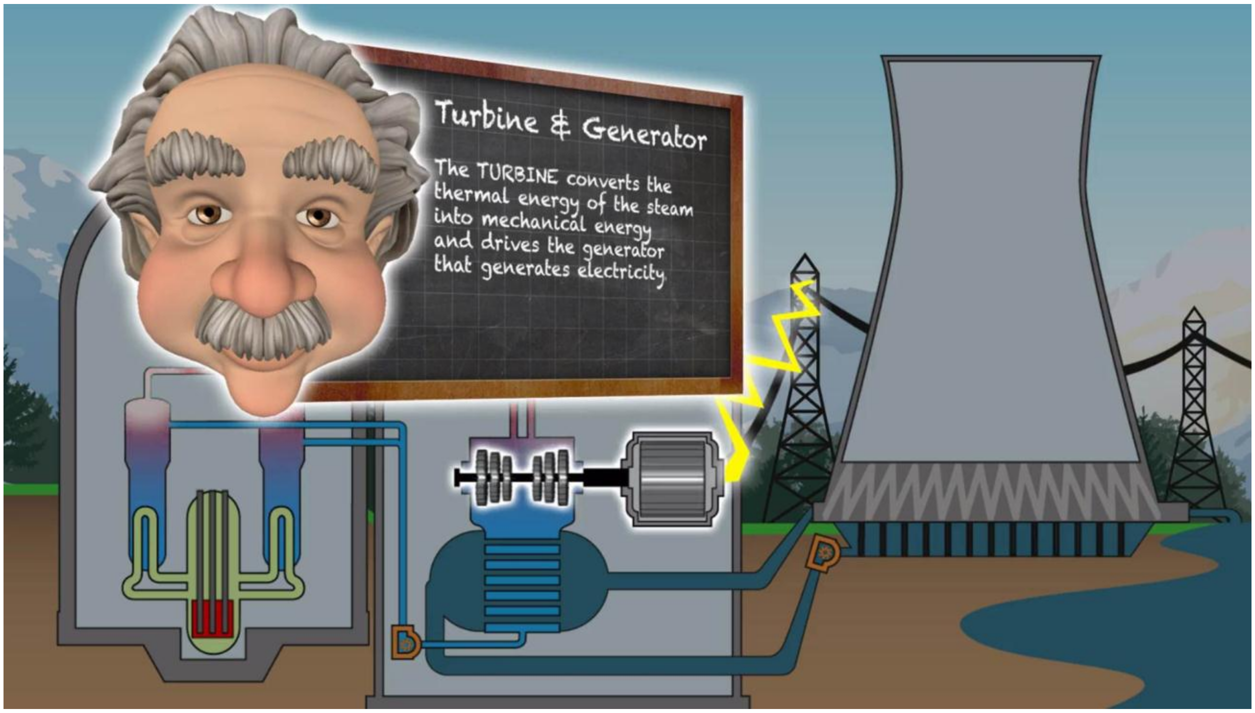

Figure 1 - Screen shot of the tool

The Nuclear Fuels School of CEA Cadarache, an experimental and theoretical approach for education and training in the field of fuel study

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Abstract

The use of fuels, plutonium and actinides implies a knowledge of their physico-chemical characteristics, the technologies specifically related to plutonium and actinide facilities and the design and safety rules that must be observed. The Plutonium School was created in 1987 at Cadarache to meet the training needs of CEA agents working within the framework of fast reactor fuel and MOX fuel development, used in Pressurized Water Reactors. The different courses are designed for all personnel working in the field of nuclear research and energy: operators, technicians, engineers, manufacturers, the operation staff and project managers,…The Plutonium school was renamed "The Nuclear Fuels School" in 2012 in order to cover the entire scope of all fuel studies. The school is a part of the Fuel Studies Department and is associated with The National Institute for Nuclear Sciences and Techniques (INSTN).

1. Introduction

The use of fuels, plutonium and actinides implies a knowledge of their physico-chemical characteristics, the technologies specifically related to plutonium and actinide facilities and the design and safety rules that must be observed. The Plutonium School was created in 1987 at Cadarache to meet the training needs of CEA agents working within the framework of the development fast reactor fuel and MOX fuel, used in Pressurized Water Reactors. The Plutonium school was renamed "The Nuclear Fuels School" in 2012 in order to cover the entire scope of all fuel studies.

2. The training and the CEA facilities

The training is based on a mixture of conferences, practical work sessions and visits dealing with safety problems, legislative aspects and all the activities involving the fuel cycle. The topics of the conferences include reviews of nuclear physics, plutonium and actinide properties, metallurgy and chemistry, biological and medical aspects, plutonium metabolism, risk assessments (contamination, irradiation and criticality) and legislation (waste and facility management, safety). The school also offers handling exercises in both inactive and active glove boxes, an introduction to radiation measurements, gamma spectrometry, dosimetry and visits to nuclear reactors and laboratories working on fuel, reprocessing and waste. The CEA fuel facilities are shown in Figure 1 (hot labs).

Figure 1: CEA fuel facilities, hot labs

3. The training courses, trainees and trainers

The teaching levels vary according to the qualifications and profiles of the participants. Among the different training courses, the catalogue includes: “An Introduction to the Handling of Plutonium and Actinides”, “Fuels, A General Overview”, any tailor-made training course on plutonium and actinides according to specifications and courses for foreign participants as well (AIEA, KIC InnoEnergy, ITU…). A new tool for fuel modelling is now available in a 3D movie. The teachers, mostly CEA and AREVA employees, are specialists in their fields. Engineers, technicians, project managers, all share their knowledge and pass on their expertise and professional feedback. The trainees come from the world of industry, the universities, and engineering schools.

Figure 2 gives the programme of the “Introduction to the Nuclear Fuels School” training session (5 days) carried out along with The National Institute for Nuclear Sciences and Techniques (INSTN) and Figure 3 shows the “nuclear fuels overview” training session (1 day) organized in collaboration with the CEA Professional Training Office.

NUCLEAR FUELS SCHOOL / INSTN

Introduction to the handling of plutonium and actinides
REF. 020

Objectives
-to be able to describe different radiation associated with plutonium and actinides and explain the differences.
-to know about the necessary equipment, its use as well as the risks associated with the implementation of the plutonium and actinides.
-to know how to explain and reproduce the gestures and necessary controls for manipulation of the plutonium and actinides.
-to be able to specify the nuclear fuel manufacturing conditions.
-to learn and describe rules for the management of waste and alpha effluents.

Public
Technicians or engineers working in facilities or on themes related to nuclear fuel manipulated in glove boxes and wishing to acquire a basic knowledge of plutonium and actinides, manipulation in a glove box and the associated risks.

Prerequisites: Interns must obtain medical clearance allowing them to stay and work in a controlled area for the duration of the session.

Content
-Review of nuclear physics.
-Characteristics of Pu and actinides.
-Medical aspects.
-The Pu and actinide risks: contamination, irradiation, criticality.
-Rules concerning the use of the Pu and actinides: facilities and waste management.
-Implementation of the Pu and actinides: premises, gloves boxes, the nuclearisation of equipment and the manufacturing of fuel elements.

<u>Practical work</u>
-Active and inactive glove boxes involving the manipulation of Pu and actinides.

Method
Lectures, practical work sessions including actual manipulation in a glove box.
Visits: facilities at CEA Cadarache.

Group limited to 14 participants.

Regulatory: Persons subject to dosimetric monitoring must make sure their dosimeter is regularly kept up to date for the duration of the session.

Some courses include a hands-on implementation of ionizing radiation sources and/or visits

Figure 2: training session (from the INSTN e-catalogue)
"Introduction to the Handling of Plutonium and Actinides"

Th

-
various nuclear reactor types and their associated fuels,
- describe some fabrication processes for the more standard nuclear fuels,
- describe some characterization devices used for spent nuclear fuels.
- upgrade overall knowledge of in-pile nuclear oxide fuel behaviour and of its limits.

at Cadarache. The number of trainees is limited (less than 20).

➲ ATTENDANCE

Technicians and engineers intending to work on nuclear fuels or interested in this subject. Students who wish to acquire an overall view of nuclear fuels and their performance.

➲ COORDINATION

Collaboration: CEA/DEN/DEC/DIR
Pedagogical manager: Didier Paul

➲ CONTENT

This training session is an introduction to an overall knowledge of nuclear fuels (mainly oxides).
It is a full day lecture including discussion of the following items:
- The nuclear reactor types and their fuels,
- The design and fabrication of nuclear fuels,
- The post-irradiation examinations,

The in-pile nuclear fuel behaviour and its limits.

➲ PLACE

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The Nuclear Fuels School
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➲ CONTACT

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Figure 3: Nuclear fuels overview training session

4. The training facilities, means

The training facilities, located in a building near the plutonium zone of the Cadarache Centre, include a conference room with modern communication means, an equipment demonstration room, a model cell designed for practical training sessions involving manipulations of matter in glove boxes, a library and a museum. The school is part of The Fuel Studies Department in The Plutonium, Uranium and Minor Actinides Service and is associated with The National Institute for Nuclear Sciences and Techniques (INSTN) operating within the framework of a convention.

Figure 4 shows the conference room and the practical work instructors in the model cell in front of one of the two glove boxes.

Figure 4: The conference room and the model cell (for practical work sessions) of The Nuclear Fuels School

Sometimes the training session takes place in the facility itself as seen in Figure 5 with the trainees enrolled in a KIC InnoEnergy session and working in the Bernard François Laboratory also called the UO_2 lab and training programme.

Pellet characterization programme outline

Day 1
Introduction lecture
Visit of the UO2 Bernard François laboratory (security and nuclear safety)
Density determination (1): apparent density

Day 2
Density determination (2): open, close porosity
Microstructure analysis: sample preparation (cutting, polishing, surface treatment)

Day 3
Microstructure analysis: sample observation (optical analysis, SEM observation)
Phase determination (XRD analysis, FTIR surface analysis)

Day 4
CEA Cadarache centre tour and visit of the DEC facilities (LEFCA and LECA-STAR)
DEC Seminar

Day 5
Examination, presentation of the performed practical work

Figure 5: the KIC InnoEnergy training session (INEPT Project), CEA Bernard François (UO_2) lab

5. Conclusion

The Nuclear Fuels School now has new challenges facing it with a national and international outlook and new audiences. This facility of The Fuel Studies Department of the CEA has proven to be an excellent instrument in the monitoring of short, medium and long-term needs in the field of nuclear fuels and nuclear safety. Its goal is to establish links with the European Commission and the Joint Research Centre in order to reinforce the potential that the CEA's expertise and unique facilities offer to graduate and post-graduate education and training, including a close collaboration with academic and other educational organisations acting as a new member of the GENTLE (Graduate and Executive Nuclear Training and Lifelong Education) Project (FP7).

THE ROLE OF NUCLEAR CHEMISTRY AND RADIOCHEMISTRY IN THE NUCLEAR EDUCATION AND TRAINING

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ABSTRACT

Nuclear Chemistry and Radiochemistry play a fundamental role in sustainable production process of energy through nuclear power plants and in new technological solutions development.
A crucial point is the cultural and operative preparation of new operators in these fields that implies the necessity that courses like health physics and/or radiochemistry must be more present in the university curricula.

1. Introduction

In 1896 Henry Becquerel discovered a related phenomenon, thanks to a well known accidental event: some uranium salts put in contact onto a photographic film, closed in an effective shield, blackened the film itself: he deduced that the U salts did produce unknown rays more penetrating than light. At first, it seemed that the new radiation had the same characteristics of the discovered Röntgen X rays just one year before.
Moreover, Marie Sklodowska and Pierre Curie in 1898 discovered that several other chemical substances (or ores) presented the same properties of the uranium salts; thus they invented the term radioactivity to describe this new phenomenon. They discovered that the emitted rays presented different characteristics corresponding to three different types of radiation: the 1-st with a positive electric charge called α, the 2-nd with a negative electric charge called β, and the 3-rd one without electric charge called γ. In 1919 Ernest Rutherford became the first person that transmuted one element into another, when he converted nitrogen into oxygen through the nuclear reaction $^{14}N(\alpha,p)^{17}O$.
In 1933 Frédéric Joliot e Irène Curie using the α particles discovered from Irène's mother Marie, discovered more deeply the artificial radioactivity: by bombarding with these particles some light elements they observed that some elements like the natural ones but with radioactive properties were produced. The new radioactive elements were not identical to the knowing natural radioactive elements, as for their chemical properties, as for the type of the emitted particles, as for half-lives as well; in other words they understood that it was possible, by bombarding a nucleus, to transmute it in another one with particular nuclear characteristic related to its decay mode.
At the beginning of 1934 at the Institute of via Panisperna in Roma, Italy, Enrico Fermi and Co., after reading the discovery of the artificial radioactivity, by using a Ra-Be source, discovered that also the neutrons (especially if thermalised) could transmute a stable nucleus into a different radioactive one. Furthermore, become immediately evident that to produce a

large activity and a huge amount of radioactive elements it was necessary to use more intense neutron sources or intense sources of light ions (protons, deuterons, alpha) with high energy, suitable to penetrate the nucleus and produce, through a suitable nuclear reaction, the radionuclides of interest. As described by E. Fermi [1] the ways followed at that time were the use of nuclear reactors or particle accelerators like cyclotrons, Van de Graaf and/or linac. In a few months the Panisperna group was able to describe the properties of a great number of new artificial radionuclides. It was immediately clear that the application of artificial radioactivity could be a major outcome for research, industry and especially for medicine. In 1938 Fermi wrote that the main applications of artificial radioactive elements like the natural ones would be in the radiotherapeutic field. It would be possible to prepare a great number of different artificial radionuclides that could be produced in some particular chemical form, that permit to obtain specific effects. He stated also that he hoped that the huge amount of artificial radioactivity could allow experimental research in the field of biology and chemistry, using the radioelements like “indicators” (today they are called “radiotracers”). He knew very well the first experiments made in the ‘920 years by G. von Hévesy, Nobel Prize in 1943, about the dispensing of ^{32}P, isotope of the phosphorus, that thanks to its radioactive properties, could be detected even if the amount given was so small that did not modify the biological behavior. This is the basis of the “radiotracer principle” for which the labeled compound doesn’t have a pharmacological effect on the patient due to the negligible mass or molar quantity administered (ng – nmol). At that time started what today we call radiodiagnostic and radiotherapy applications with the use of “unsealed radiopharmaceutical compounds”, chemical species labeled with suitable radiotracers.
So it must be recognized that ionizing radiations play a fundamental rule in radiodiagnostics, where the radiations allow to “look” inside the human body and in metabolic radiotherapy, where the supplied energy of the radiations allow to kill the tumor cells [2]. The bio-distribution of the radiopharmaceutical is related to the chemical – physical characteristics of the compound itself, the administration *via* to living organisms, the capability to cross the biological barriers and to the evaluated patient metabolic conditions.
Moreover, induced fission promised suddenly to became a powerful and inexhaustible source of energy (both thermal and electrical) for industry, transportation and basic necessities of human life. In this scenario the novel disciplines namely Radiochemistry, Nuclear Chemistry, Radiation Chemistry (in short N&R) and Health Physics [3] started to develop quickly, up to the more update applications like: Radiopharmaceutical Chemistry (i.e. for both radiodiagnostics and metabolic radiotherapy) [4,5], curing of materials, protection of human heritage handicrafts and sterilization of different kinds of food, medical and surgical specimen as well [6], and last but not least the direct dissociation of water in gaseous H_2 (i.e. hydricity) and O_2, either pyrochemically in presence of a catalyst at temperatures much higher than 1000 °C in very high temperature nuclear reactor (VHTGR) or by thermochemical cycles at a bit lower temperatures (HTGR). The heat generated by Nuclear Power Plants - NPPs - can also solve the problem of lacking of potable water, by desalting the inexhaustible sea and ocean sources [3, 7-9].

2. Materials and Methods

The N&R and Health Physics play a crucial rule in many and different fields, related to:

- in the various steps of fuel cycle for energy production with NPPs, based on fission of either fissile (or fertile) materials, from ore mining, plant operation, decommissioning and rad-waste disposal;

• nuclear analytical techniques (NATs): Instrumental- and Radiochemical Separation Neutron Activation Analysis (INAA and RSNAA respectively) and others 1, applied to monitor environmental and biological matrices and to characterize the nuclear fuel;

• radioanalytical techniques: use of High Specific Activity Radiotracers produced by cyclotron or nuclear reactor in no-carrier added (NCA) form [10], applied to the development and calibration of the radioanalytical and radiochemical processing procedures;

• radiation protection techniques: *alpha, beta* and *gamma* spectrometries, applied to control the environmental contamination and to the health physics protection of general population and workers.

For each of these points a deeply dissertation could be reported. In this report we underline the contribution of N&R in the fields of research at LASA Laboratory, presenting some our results from which it can be understood the power of these kinds of techniques.

The INAA is a powerful multielemental technique that bombarding stable isotopes and with the successive gamma spectrometry of the activated samples reaches a high sensibility for many elements, high accuracy and precision and minimum effect of the matrix. It is excellent for environmental and biological matrices. In our laboratory we use the Research Nuclear reactor TRIGA MARC II – 250 kW (General Atomic – USA) of the Pavia University, that in the central thimble facility “Lazy Susan” can reach a neutron flux of 10^{13} cm^{-2} s^{-1}. In Fig. 1 is reported, as an example, the results obtained analyzing the human blood [11].

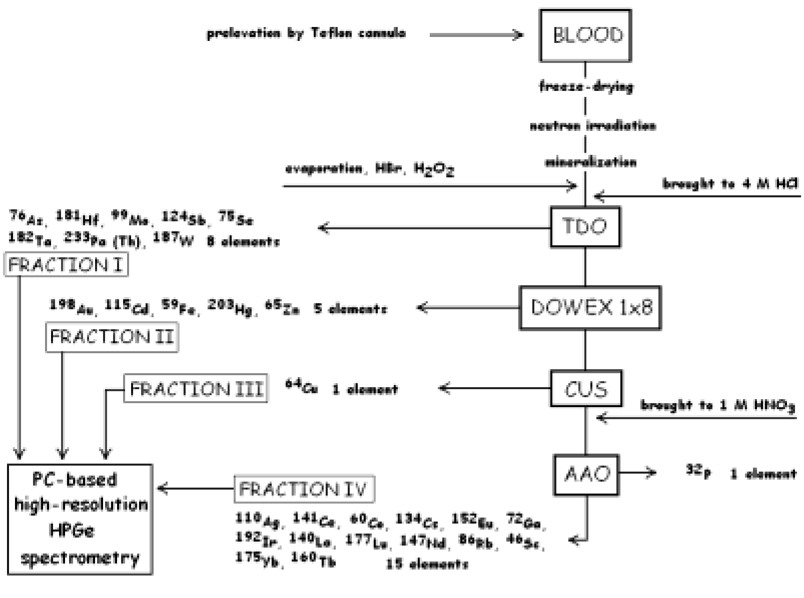

Fig. 1 Analysis of the human blood by INAA and the determination at the same time of 30 different elements [11]. Inorganic Ion Exchangers: TDO tin dioxide, CUS copper sulfide, AAO acidic aluminum oxide; the DOWEX 1x8 is an anionic organic exchanger.

With the same technique we monitor the trace element (TE) content in the atmospheric particulate in order to control and evaluate the degree of the air pollution and furnish additional information for assessing the air quality of our environment. Many TE of anthropogenic origin may be considered dangerous to the human health and their presence in the air constitutes a potential risk for the population, not only at level of threshold concentrations, but also in terms of prolonged exposure to low levels. However, the knowledge of the concentrations in the total suspended air particulate, which represents an important parameter, is nevertheless not sufficient for a more close evaluation of the possible impact onto the public health. The monitoring must be comprehensive of the concentrations in the fine particulate fractions involved in the respiratory system at alveolar and bronchial levels. By means of inertial multistage impactors, the air particulate can be collected in fractions, to distinguish among the deposition in the alveolar (particles from 0 to 1.1 mm nominal diameter), bronchial (from 1.1 to 4.6 mm) and tracheo-pharynx (from 4.6 to < 9 mm) areas of our respiratory system. After the sampling campaign consisting in the aspiration of dust upon filters, the INAA followed by high resolution gamma spectrometry measurements and the Electrothermal Atomic Absorption Spectrophotometry (ET-AAS) can be employed to evaluate the concentration in $ng{\bullet}m^{-3}$ of many elements, of toxicological interest. The concentration of the TE in the corresponding total air particulate allows us to compare the state of the air quality among the different locations investigated. The knowledge of the TE distribution trends in the different size particle fractions furnishes information about their mobility and their paths followed in the different human respiratory areas [12, 13].

The High Specific Activity Radiotracers produced by cyclotron or by nuclear reactor in No Carrier Added (NCA) form is a long tradition at LASA [10, 14, 15].
Such radiotracers are a powerful tool to label a wide variety of chemical elements and compounds present in the biosphere in ultra-trace amounts. Medium and high Z radionuclides, can be produced by irradiation in light-ions accelerator and sometimes nuclear reactor. If the nuclear reaction product has atomic number different from irradiated target, it is possible separating the radioactive nuclide from irradiated target, without addition of isotopic carrier. These kinds of radionuclides are named No Carrier Added, NCA, and their specific activity is very high and can reach values close to the theoretical Carrier Free one. The true specific activity must be determined by use of very sensitive radioanalytical techniques.
If a low isotopic dilution factor is obtained, these radiotracers are used to label inorganic species and complexes of elements, which are presently introduced into the echo-systems by human activities. The “accurate” knowledge of the behavior of thin-target excitation functions for nuclear reaction leading to cyclotron production of relevant RNs, allows increasing both radionuclidic purity and specific activity of RN itself, obviously by use of very selective radiochemical separations, without the addition of isotopic carrier.

In all these kinds of activities it is necessary to have a radioprotection system in order to guarantee the adequate protection of the personnel and of the public living outside the structure by the Qualified Expert, a professional figure with the responsibility to take under control all the aspects related to the usage of ionizing radiations.

3. Results and conclusions

Activities using ionizing radiation become each day more and more employed in every field of our life. It is very important to underline to the young people that the real risk, that only with education and training it is possible to try to stem, in the field involving ionizing radiations is related to the loss of expertise: the ageing of the workforce, limited prospects for new build and moratoria in a number of countries on the use of nuclear energy are all aspects that impact the level of skills and competence across the whole nuclear sector, particularly in the West Countries and dramatically in Italy. Emergency and post accident management is no exception to this trend. Key indicators of the nature of this problem are: declining university enrolment, closure or dilution of university departments offering nuclear education and training, demographics of the workforce resulting from retirement over a relatively short period with little or no replacement planned, major reductions in research capacities as the industry matures, reducing funding for experimental research and closure of dedicated experimental facilities, which has been accelerated by growing social distrust of experiments involving radioactive materials.

On the contrary we can have a real "protection" if there are very well trained personnel that work in this field maintaining the competence, the expertise and the skill.

So it is clear the necessity to stress the great need of education and training of young scientists in the field of N&R techniques, in order to ensure sustainable supply of qualified nuclear chemists and health physicists. This goal could be reach (time goes on in the meantime) starting to re-enter in full into the university programs, the courses of health physics, nuclear chemistry, radiochemistry and related subjects.

It is important to take in mind that the subjects related to these fields require a constructive collaboration between Physics, Chemistry, Biology, Medicine that are only different chapters of the only one great book of the life science.

4. Acknowledgements

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THE POSSIBILITY OF UTILIZATION OF «CRYSTAL» AND «GIACINT» RESEARCH INSTALLATIONS FOR NUCLEAR EDUCATION AND TRAINING

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ABSTRACT

With the start of construction of a NPP in the Republic of Belarus, the work on the development of a national training system, necessary for the operation of the future NPP, is done. At present, the Belarusian universities are training specialists in the field of nuclear energy. The Joint Institute for Power and Nuclear Research-Sosny of the National Academy of Sciences of Belarus (JIPNR-Sosny of NAS of Belarus) has organized a branch of the Chair of Nuclear Physics of the Belarusian State University. The training strategy is to complete theoretical courses and training courses on simulators with the experimental work (laboratory work) carried out on research installations «Crystal» and «Giacint». The «Crystal» and «Giacint» installations can include uranium-containing critical assemblies with water and zirconium-hydride moderators, or without moderator. The specified installations can be used for education and training of university students. The education experiments can be combined into training courses attended by students according to their study specialization and knowledge level. Research project programs can be implemented in the postgraduate courses. The training program can be focused on neutron and reactor physics, nuclear safety, and control of nuclear installations. A proposal to expand the training activities at the «Crystal» and «Giacint» installations is presented here. The description of these research installations, which after modernization can be used in the educational purposes and some data about the experiments which can be carried out during training courses on these installations, is presented.

1. Introduction

In order to develop human resources for the NPP under construction in four leading universities of the Republic of Belarus, students in nuclear power engineering and physics are educated and trained. For involving leading scientists and experts in the use of nuclear power into the process of education of human resources and development of laboratory and educational books and manuals for university students, the Joint Institute for Power and Nuclear Research – Sosny of the National Academy of Sciences of Belarus (JIPNR-Sosny), which has a huge experience in theoretical and experimental research in nuclear power, has organized a branch of the Chair of Nuclear Physics of the Belarusian State University.

The JIPNR-Sosny has a training and computational centre and a classroom of physical protection of facilities using or storing nuclear materials. The training centre of the JIPNR-Sosny has an analytical NPP simulator with a VVER reactor facility. The computational centre has a modern supercomputer SKIF K-500 and data storage systems.

Since the JIPNR-Sosny has huge experience of making experiments at critical assemblies and nuclear reactors, it is expedient that the strategy of education in the branch of the Chair of Nuclear Physics should be aimed at supplementing theoretical and training courses on simulators by experimental research at nuclear research installations. The training courses at these installations are necessary to give to students and future operating personnel a comprehensive understanding of the nuclear physics and to illustrate the principles and the operation of the nuclear reactor. The research reactors installations critical «Crystal» and «Giacint» can be used for such purposes after the necessary modifications.

The research installations «Crystal» and «Giacint» are designed for investigations in physics and safety of neutrons of multiplication systems and for development of a new generation of nuclear reactors of various uses. These installations can be used to assemble uranium-containing critical assemblies with water and zirconium-hydride moderators or without moderator. Sets of fuel rods containing with different uranium-253 enrichments (10; 19,75;

21; 36; 75 and 90%), cassettes of reflector units (based on zirconium hydride, beryllium, polyethylene, stainless steel, etc.) and controls (rods and plates) of the control and protection system (based on europium oxide, boron carbide, cadmium, etc.) are also available.

In order to use the described facilities for education and training, they should be appropriately upgraded, including reconstruction of the control and protection system and selecting the critical assembly types and configuration for experiments. It is also required to upgrade the system of collection, processing and storage of experimental data at research installations, organize a training classroom for students, provide the required equipment, including devices for experiment observations, and to develop and test at critical assemblies methods and manuals for education and training experiments (laboratory works). The education and training experiments can be included into training courses for students according to their study specialization and the level of knowledge. Research project programs can be organized for the postgraduate courses. The training program can be focused on neutron and reactor physics, nuclear safety, control of nuclear installations, etc.

A proposal to expand the training activities at the installations «Crystal» and «Giacint» is presented in this paper. It also includes some data on the experiments to be are carried out at the facilities in the course of training.

2. Research installation «Crystal»

The research installation «Crystal» includes: a critical assembly, a control and protection system (CPS), a radiation control system, an alert system, a temporary (operational) nuclear fuel storage, a physical protection system, etc. The research installation «Crystal» is used to assemble critical assemblies with zirconium-hydride moderator. Figures 1 and 2 show photos of the critical assembly and the loading chart for one of possible core configurations.

Fig 1. Critical assembly with zirconium-hydride moderator

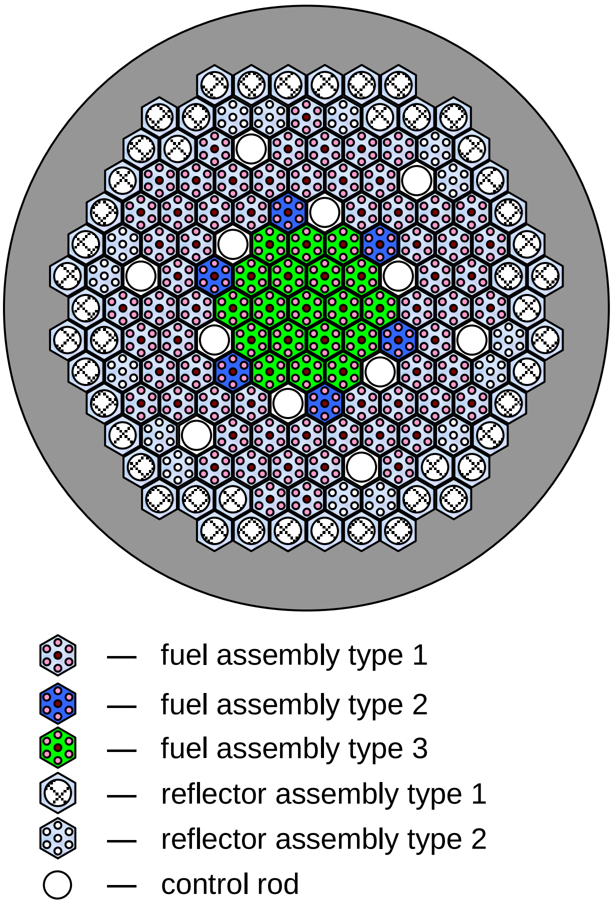

Fig 2. Loading chart of critical assembly with zirconium-hydride moderator

The uranium-zirconium-hydride critical assembly (Fig. 2) represents a hexagonal grid of fuel assemblies of type 1, 2 and 3, channels of the CPS controls and side reflector cassettes spaces at 45 mm in the basket made from, stainless steel. The moderator and inner reflector's layer are from zirconium-hydride. The critical assembly basket is surrounded by the side steel reflector. The upper end reflector units from stainless steel are put on top of the fuel assemblies and side reflector cassettes. Neutron detectors are fixed around the critical assembly.

The fuel assembly body, type 1, represents a thin-wall hexagonal stainless steel tube with the wall thickness 0.4 mm, for the 44 mm wrench. The hexagonal tube is connected to the shank, representing the mounting surface when the core is assembled. The hexagonal tube houses 12 hexagonal moderator units from zirconium-hydride $ZrH_{1.9}$, each 50 mm high, for the 42.85 mm wrench. The moderator units with the triangular grid pitch 14.5 mm, has seven holes 8.2 mm in diameter, housing the stainless steel channel tubes with the outer diameter 8 mm and the 0.25 mm walls. The fuel assembly houses one fuel rod, type 36 (in the center), and 6 fuel rods, type 21.

The fuel assembly, type 2, differs from the fuel assembly, type 1, in that three steel tapes alloyed with boron (boron-10 85% enrichment) are placed in the gaps between the hexagonal tube and the zirconium-hydride units. The tapes are arranged in the central part of the fuel assembly at the height 300 mm, on every second facet. The tape is 20 mm wide and 0.3 mm thick.

The fuel assembly, type 3, differs from the fuel assembly, type 1, in that the zirconium-hydride units arranged in the central part of these cassettes (at the height 300 mm) have recesses that increase the moderator content in this part of the fuel assembly by 17 volume percent, and the gaps between the hexagonal tube and the zirconium-hydride units include three steel tapes as in the fuel assembly type 2.

The fuel rod, type 36, includes a fuel core, its cladding and end parts. The fuel rod cladding is made from stainless steel with the 7 mm outer diameter and 0.35 mm wall. The fuel core is a fill of uranium dioxide with the density 5.2 g/cm^3. Enrichment by uranium-235 is 36%. The total core height is 500 mm. The upper and lower shanks of the fuel rod are made from stainless steel with the 60 mm length and 6.6 mm diameter. The total fuel rod length is 620 mm.

The fuel rod, type 21, includes a fuel core, its cladding and end parts, i.e., upper and lower plugs. The fuel rod cladding is made from stainless steel with the 6.2 mm outer diameter and 0.4 mm wall. The fuel core comprises tablets, 5.2-5.3 mm in diameter and 5-7 mm in height, made from uranium dioxide with the density 10.2 g/cm^3. Enrichment by uranium-235 is 21%. The total core height is 500 mm. The uranium-235 mass in the fuel rod is 20.5 g. The fuel rod has a stainless steel, 0.55 mm in diameter, wired on it with the 100 mm pitch.

The body of the side reflector cassette, type 1, is a hexagonal stainless steel tube, for the 44 mm wrench and the 0.4 mm wall thickness. The hexagonal tube is connected to the shank, representing the mounting surface when it is put into the basket. The hexagonal tube houses hexagonal zirconium-hydride $ZrH_{1.9}$ units, each 15 mm high, for the 43 mm wrench, arranged through the entire length of the cassette. These units have a 28 mm hole, with the 27 mm organic glass rod inserted through the entire length of the cassette. The zirconium-hydride reflector cassettes, type 2, are fuel rods, type 1, without fuel rods.

The critical assembly has 12 channels for the control and protection system's controls, arranged uniformly along two belts, inner and outer. The CPS control moves inside the hood, representing a stainless steel tube 42 mm in diameter and the 3 mm wall. The CPS control comprises absorbing and dissipating links, connected by a swivel. The upper absorbing link includes an outer cladding (a steel tube with the 33x1.0 mm diameter) and an inner cladding (a steel tube with the 17x0.5 mm diameter). The circular spacing between the outer and inner claddings is filled with Eu_2O_3 neutron absorber with the density of fill 5.3 g/cm^3. The absorbing part is 400 mm long. The inner cladding includes powdered Al_2O_3 with the density 2.1 g/cm^3. The lower dissipating link includes a cladding (a steel tube with the 33x1.0 mm diameter), filled with the powered Al_2O_3 with the density 2.1 g/cm^3 over the 410 mm length.

3. Research installation «Giacint»

The research installation «Giacint» is used for investigation of critical assemblies with water and zirconium-hydride moderators or without moderator. It includes: a critical assembly, a control and protection system (CPS), a hydraulic system, a radiation control system, an alert system, a temporary (operational) storage of nuclear fuel, radioactive substances and waste, a physical protection system, etc.

Figures 3 and 4 show photos of the critical assembly and the loading chart for one of possible uranium-water core configurations, which can be used for education and training purposes. The hydraulic system of the critical installation «Giacint» is designed to work only with uranium-water critical assemblies and is shown in Figure 5.

The uranium-water critical assembly (Fig. 4) represents a homogeneous hexagonal grid of fuel rods, type 20 and 20.1, arranged at 21 mm pitch in the water moderator. The fuel rods are arranged in the upper and lower aluminum spacer grids (the lower and upper edges of the lower grids match with the top and bottom of the core, respectively) and support on the steel bearing plate. The upper steel plate is installed above the fuel rods. The critical assembly is arranged in the stainless steel tank filled with water moderator and has physically “infinite” side and end water reflectors. Besides water, the core reflector includes steel shanks of fuel rods and elements of the critical assembly.

Fig 3. Critical assembly with a water moderator

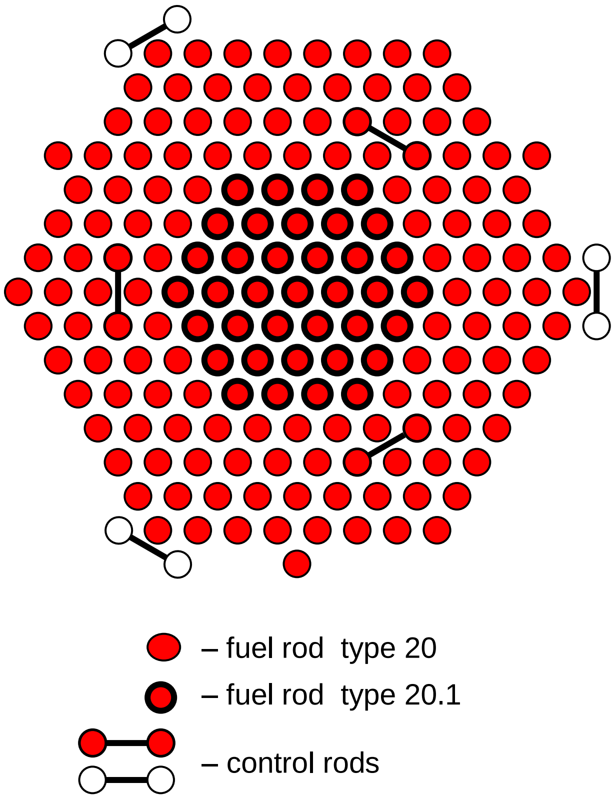

Fig 4. Loading chart of critical assembly with a water moderator

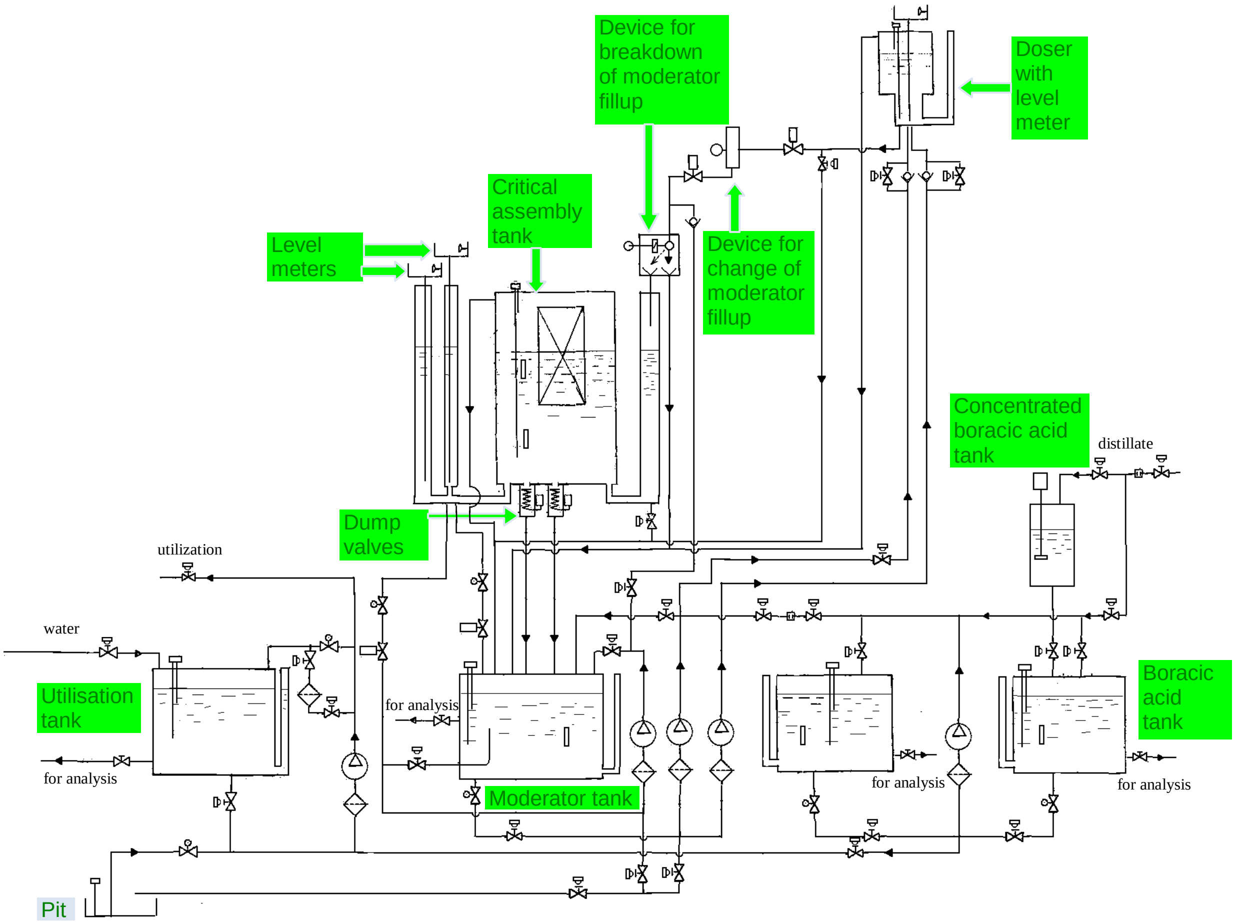

Fig 5. Hydraulic system of the critical installation «Giacint»

The core of the uranium-water critical assembly comprises fuel rods of type 20 and 20.1. The fuel rod of type 20 (20.1) comprises a fuel core, cladding and end parts. The fuel rod core has the 12 mm outer diameter and the 0.6 mm wall thickness. The fuel core comprises tablets, 10.75 mm in diameter and 14.7 mm in height, from uranium-zirconium carbonitride $U_{0,9}Zr_{0,1}C_{0,5}N_{0,5}$. The core density is 12.0 g/cm^3, and the uranium-235 enrichment is 19.75%. The gaseous He medium at ~0.11 MPa is ensured in the gaps between the tables of the fuel rod core and the fuel rod cladding. The total height of the core is 500 mm. The total length of the fuel rod is 620 mm. The cladding and end parts of the fuel rods (plugs) is stainless steel (fuel rod, type 20) or niobium alloy (fuel rod, type 20.1).

The CPS includes six controls (actuating elements): three controls are in the core and three in the moderator. The CPS control located in the core is a cluster of two composite rods representing an absorbing element and fuel rod, type 20, rigidly interconnected via an adaptor. The CPS control located in the moderator is also a cluster of two composite rods. The composite rod in this CPS control represents an absorbing element and an organic-glass rod rigidly interconnected between them.

The absorbing element is a cylindrical stainless steel cladding with the 12 mm diameter and 1 mm wall, filled with natural density (1.36 g/cm^3) boron carbide to the height of 500 mm. the total length of the absorbing element is 620 mm. The organic-glass rod is a 12 mm diameter cylinder.

Figures 6 and 7 show a photo of the critical assembly without moderator and the loading chart for one of possible core configurations without moderator that can be used for training.

Fig 6. Critical assembly without moderator

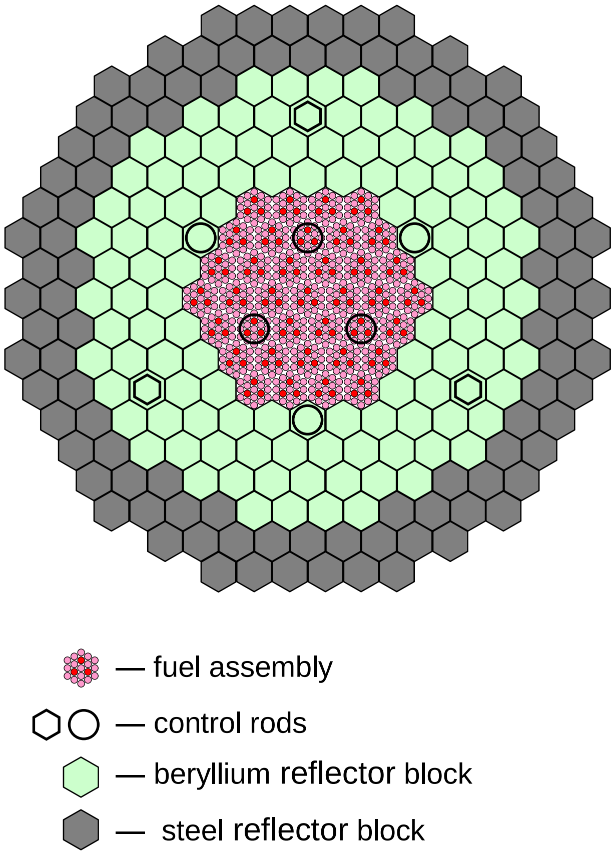

Fig 7. Loading chart of critical assembly without moderator

The critical assembly without moderator (Fig. 7) is a core, assembled from fuel assemblies, surrounded by four rows of beryllium reflector units and two rows of steel reflector units. All fuel assemblies and reflector units are placed on the critical assembly support plate. The upper end reflector units are put on top of the fuel assemblies and side reflector of the fuel assemblies. Neutron detectors are fixed around the critical assembly on special racks (poles).

The fuel assembly of the critical assembly without a jacket comprises 19 fuel rods, including 16 fuel rods, type 36.1, and 3 fuel rods, type 90. The fuel rods are arranged with the 8-mm pitch over the hexagonal grid and are fixed by means of end parts (pieces). The fuel assembly size is for the 34.8 mm wrench, and the total assembly length is 1047 mm (the length of the core is 500 mm, the fuel rod shanks are 2x60 mm, the assembly upper end parts are 216 mm, and the assembly lower end parts are 211 mm). All upper and lower end parts of the fuel assemblies are made from stainless steel.

The fuel rod, type 90, comprises a fuel core, a cladding and end parts. The fuel rod cladding is made from stainless steel, with the 7 mm outer diameter and the 0.2 mm thick wall. The fuel core comprises tables of 6.4 mm diameter and 5 mm height, made from metal uranium. The uranium-235 enrichment is 90%. The total core height is 500 mm. The upper and lower shanks of the fuel rod are made from stainless steel, with the 60 mm length and the 6.6 mm diameter. The total fuel rod length is 620 mm.

The fuel rod, type 36.1, comprises a fuel core, a cladding and end parts. The fuel rod cladding is made from stainless steel, with the 7 mm outer diameter and the 0.2 mm thick wall. The fuel core comprises tables of 6.4 mm diameter and 4-7 mm height, made from uranium dioxide, 9.8 g/cm^3. The uranium-235 enrichment is 36%. The total core height is 500 mm. The upper and lower shanks of the fuel rod are made from stainless steel, with the 60 mm length and the 6.6 mm diameter. The total fuel rod length is 620 mm.

The critical assembly side reflector represents four rows of beryllium reflector units and two rows of steel reflector units.

The beryllium reflector unit is a hexagonal beryllium prism for the 34.8 mm wrench with the 972 mm length. The lower part of the unit has a stainless steel shank attached to it, this shank is the mounting surface when the critical assembly is loaded. The upper part of the unit has a hexagonal upper stainless steel reflector for the 34.8 mm wrench and the 40 mm length.

The steel reflector unit is made from stainless steel, representing a hexagonal prism for the 34.8 mm wrench, with the 1047 mm length. The lower part of the unit includes a shank being the mounting surface when the critical assembly is placed on the support plate.

The control and protection system included nine controls (actuating elements), arranged evenly on three belts (three controls on each): one belt in the core and two belts (inner and outer) in the beryllium reflector.

The CPS control in the core represents a fuel assembly and an absorbing element located in the core rigidly interconnected via an adaptor. The CPS control located in the beryllium reflector in the inner belt is a beryllium reflector unit and an absorbing element rigidly interconnected via an adaptor. The CPS control located in the beryllium reflector in the outer belt is a beryllium reflector.

The absorbing element is a stainless steel cylindrical cladding with the 26 mm diameter and the 1 mm wall, filled with boron carbide powder, with the mean density 1.38 g/cm^3, to the 500 mm height.

4. The system for collection, processing and storage of experimental data

The research installations «Crystal» and «Giacint» have a system of hardware and software designed for collection, processing and storage of experimental data on physical neutron characteristics of critical assemblies studied by these facilities.

The system for collection, processing and storage of experimental data can be used to make the following experiments:

- loading critical mass (plotting loading charts and inverse account curves);
- measuring efficiency of the control and safety rod of control and protection system;
- calibration the control and safety rod;
- determining the reactivity margin;
- measuring reactivity effects;
- measuring axial and radial distribution of power release in the core;
- measuring the critical assembly absolute power;
- measuring the ratio of the effective share of delayed neutrons to the lifetime of instantaneous neutrons (kinetic parameter β_{eff}/l);
- nondestructive control of fuel rods and fuel cassettes with fissile material , etc.

This system can be used to understand the role of the neutron instrumentation in nuclear reactors:

- study the neutron detection systems in real conditions,
- observe the signal coming from the detector at the different stages of the electronics system (pulse, current),
- study systems similar to that used to measure the neutron flux in a nuclear reactor.

The system was created on the basis of the local network of PCs, a subsystem for preliminary signal processing and data collection, experimental units and devices (for determining reactivity, distribution of the neutron flow density in the core, etc.) The said system, after its proper upgrading, can be used for education and training.

5. Experiments that can be performed for education and training

The training courses, involving experiments at the research installations «Crystal» and «Giacint», can be used by a broad range of participants, including students of universities, experts in area of physics and technique of reactors (researchers, engineers, operators, etc.) as well as university teachers. Such installations can also be used by international schools for training and retraining of experts in operation of research nuclear facilities. Depending on the trainees and related education and training goals, we propose courses on various aspects of nuclear reactors in order to ensure general understanding and demonstrating the reactor's operations as well as for detailed investigations of various aspects of reactor operations.

The educational activities using the research installations «Crystal» and «Giacint» after their upgrade can include experiments for determining a number of physical neutron characteristics of critical assemblies and studying neutron detection systems in nuclear reactors. We will review six experiments that can be carried out in the education and training activities.

Critical mass measurement
The approach to criticality is the most fundamental procedure in nuclear reactor experiments. Preparation and adjustment of the critical assembly as an experimental apparatus are completed by the approach to criticality. When a reactor is first loaded with fuel, the amount of fuel needed to make the reactor critical is usually not known very accurately. Therefore, prediction of the critical mass by neutronics calculations based on the reactor theory would be necessary for the safe loading of fuel. The physical characteristics of a nuclear reactor as well as the validity of computational methods and nuclear data used may also be well understood through comparison of the predicted and measured critical mass.

Experiments on determining critical load can be made on the above-described critical assemblies with water and zirconium-hydride moderators or without moderator. The above mentioned critical assemblies are controlled by control and safety rods. The neutron counters and the ionization chambers are used for nuclear instrumentation.

The approach to criticality is based on the inverse-multiplication method. Criticality is approached by adding the fuel elements (rods or assemblies) in the core periphery. The inverse-multiplication rate (when the neutron density is stable due to the neutron source) versus the fuel mass (the number of fuel elements) is plotted after each fuel loading step, and the critical mass is estimated by extrapolating the curve to zero. Comparison of the predicted and measured critical mass, the dependence of inverse-multiplication rate curves on the relative position of the detector and the source and other reactor physics problems are to be reported.

Measurement of rod worth and control rod calibration
Various reactivity effects in nuclear reactors are usually determined by compensating the given reactivity with the control rods to maintain the critical state. Calibration of the control rod (determination of reactivity worth per unit movement of the control rod) is thus essential when the control rods are used as reactivity standards to measure the reactivity changes caused by any other perturbation in the reactor. Rod worth and control rod calibration data are also important for the reactor operation; using the control rod calibration data, the operator can estimate the reactivity caused by the control rod movement and will be able to operate the reactor safety. Furthermore, determination of excess reactivity and shut-down

margin of the reactor is one of the strictest requirements to safety reactor operation. Thus, measurement of rod worth and control rod calibration of a new core is the most essential experiment to be performed immediately after the approach to criticality prior to the experiments.

Two methods of control rod calibration are utilized in this experiment: the positive period method and the rod-drop method. In the first method, the reactor is made supercritical by withdrawing the control rod to be calibrated a certain amount, and the resulting (positive) period is determined from the measured doubling time to derive the reactivity. This technique is the basis of various reactivity measurements. The rod-drop method is to measure the subcriticality; the rod to be calibrated is dropped from a certain position at the critical state, and the resulting decay of the neutron flux is observed and related to reactivity. This method is utilized for measurement of negative reactivity, where the period method is no more applicable.

Experiments on measuring efficiency and calibration of control rods can be made for any of the above critical assemblies. Both positive and negative reactivity can be measured by the inverse solution of the point kinetics equations from the time history of the neutron flux signal (so-called reactivity meter).

Measurement of thermal neutron flux distributions

When a thermal reactor is operated with constant power, its thermal neutron flux forms a unique distribution, determined by the reactor characteristics. Since the level of this flux distribution is proportional to the reactor power, one can determine the reactor power by measuring the relative flux distribution in the reactor and the absolute flux level in a certain reactor location. Compared to detectors, such as ionization chambers and fission chambers, track detectors are insensitive to Gamma ray and can be used in locations where other detectors could not be used because of their size.

Experiments on measuring thermal neutron flux distributions can be made for any of the above critical assemblies. These measurements can be made by means of track detectors that can be placed between the fuel tablets inside the fuel rod cladding or on the aluminum plate close to uranium foil. The ratio of thermal to epithermal neutron fluxes is determined by measuring the Cadmium ratio, using the track detectors with uranium foils covered with and without Cadmium covers. A special measuring device is used to count tracks on detectors.

Experiment of Feynman-α method

The main purpose of noise experiments of a zero-power reactor is to determine the reactor kinetic parameters by measuring the fluctuation of neutron density around its mean value. It is well known that for a truly random neutron source, the number of detected neutrons in a certain interval of time forms a position distribution, where the variation-to-mean ratio becomes one. A neutron multiplying system, such as a nuclear reactor system, which is placed between the random neutron source and the detector, will cause the observed variance-to-mean ratio deviate from one. This deviation of the variance-to-mean for the observed counts from one results from the correlated neutrons born in the chain reaction of fission and is a function of kinetics parameters of a reactor.

The Feynman-α method, determining the reactor parameters from variance-to-mean ratio of neutron counts in a certain time interval, is used in this experiment to illustrate the application of reactor noise theory to measurement of reactor parameters. Neutrons emitted from a Cf-252 neutron source are detected by a few He-3 proportional counters. The pulse-rate analyzer, making part of the system for collection, processing and storage of experimental data, is used to record the neutron pulse signals from the detectors. Various reactor parameters, such as β / l (ratio of the effective delayed neutron fraction to the neutron lifetime), subcriticality and reactor power are determined by analyzing the experimental data.

Experiment of the pulsed neutron method

The basis of the pulsed neutron method is that the time rate of change in the neutron density following the neutron pulse injected into a media is closely related to the characteristics of the media. The neutron burst, generated by an external accelerator, is introduced into the subcritical reactor: due to its subcritical state, the resulting thermal neutron density in the reactor is multiplied, but rapidly decays. After a certain time from the initial neutron burst, higher order harmonics of the neutron flux decay, and the time behavior of thermal neutron density is dominated by its fundamental mode, which decays in an exponential form. The pulsed neutron method determines the reactor kinetics parameters by measuring this decay constant.

This experiment demonstrates the application of pulsed neutron theory to reactivity measurement and control rod calibrations. The experimental system consists of a pulsed neutron source, a neutron detector and a time analyzer. The pulsed neutron source used in this experiment is a shield-tube type source, which generates 14 MeV neutron pulse by D-T reaction. Time behavior of the neutron density after the initial burst is detected by fission chambers, BF_3 proportional counters and He-3 proportional counters. Reactivity of a previously calibrated control rod is measured by proposed Simmons-king, Sjoestrand and Gozani methods, compared with reactivity obtained from preceding measurements of control rod calibration.

Temperature effect
When the reactor is operated at appreciable power, the energy produced by the fission reaction induces the increase in temperature of the fuel, the moderator and other material present in the core of the reactor. This, in turn, leads to a modification of the core reactivity. In order to study the temperature effects, the following experiment on uranium-water critical assembly can be carried out.

The reactor is stabilized in the critical condition. The critical position of the regulation rods and the water and fuel rods temperature is measured. The core is heated by an external heat source to a temperature not higher than 90 ºC. The new critical position of the regulation rods is defined. The water and fuel rods temperature is measured. The regulation rods graduation data are used to determine the reactivity temperature effect.

For a possibility of carrying out of experiments on measurement of temperature effect of reactivity the system of external heating of critical assembly should be created.

6. Conclusions

The JIPNR-Sosny has huge experience in theoretical and experimental research in nuclear power, including experiments on nuclear reactors and critical assemblies. This experience can be used to train university students to work at the NPP under construction in the Republic of Belarus. The strategy of education should be aimed at supplementing theoretical and training courses on simulators by experimental (laboratory) research at nuclear research installations, such as the critical facilities «Crystal» and «Giacint». It requires relevant modernization and upgrade of these installations (the control and protection system, the collection and processing of experimental data, etc.), development and experimental testing of laboratory operations, and organization of a classroom having all facilities for presenting experimental data at the critical assemblies. Implementation of such training courses ensures a practical and comprehensive understanding of the reactor physics, design and safety of the reactor operation.

EDUCATION AND TRAINING ON ISIS REACTOR

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ABSTRACT

Located in the south of PARIS, the ISIS research reactor is operated by the French Alternative Energies and Atomic Energy Commission (CEA). ISIS reactor is an essential tool for the Education and Training programs organized by the National Institute for Nuclear Science and Technology from CEA. A large set of training courses have been developed on the ISIS reactor, focusing on the operational and safety aspects, both in normal and incidental operation. The courses are addressed both to students and professionals. In 2012, about 40 % of these courses were carried out in the frame of international academic or vocational programs. This paper presents the ISIS research reactor and the practical courses that have been developed on ISIS reactor. We also discuss the development of Internet Reactor laboratories (IRL) on ISIS reactor, which consists in broadcasting the training courses via internet.

1. Introduction

Part of the French Alternative Energies and Atomic Energy Commission (CEA), the National Institute for Nuclear Science and Technology (INSTN) is a higher education institution [1]. Its objective is to provide students and professionals a high level of scientific and technological qualification in all disciplines related to nuclear energy applications. In this frame, INSTN carries out education and training (E&T) programs on nuclear reactor theory and operation. Its strategy is to complete theoretical courses by training courses and laboratory works carried out on an extensive range of training tools that includes software applications, simulators, as well as the use of research reactors [2, 3]. For all of the practical exercises, specific emphasis is given to the safety issues aspects of reactor design and operation, both in normal and incidental operation [4].

From 1961 till 2007, the INSTN was operating its own reactor, an Argon type 100 kW reactor called ULYSSE. In 2007, the E&T activity was transferred to the ISIS research reactor which is operated by the Nuclear Energy Division. For this purpose, the ISIS reactor went through a major refurbishment from 2004 till 2006.This paper presents the characteristics of the ISIS reactor. It describes the curricula of the academic and vocational courses in which the practical courses are integrated. Finally, this paper presents the Internet Reactor Laboratories (IRL) that is under development and will consist in broadcasting the training courses via internet to remote facilities or institutions.

2. The ISIS research reactor

The ISIS research reactor is located on the CEA Saclay site. It belongs to the same nuclear facility as OSIRIS reactor and is operated by the Nuclear Energy Division. Both reactors are open core pool type reactors and exhibit the same core characteristics (size and configuration of the core, fuel and rod characteristics).

The schematic of the reactor pool and the water primary and secondary circuits is shown in figure 1. The pool of ISIS reactor is 7 meters deep. At the bottom of the pool, a big metallic piece called the base sustains the core of the reactor. The core, with a section of 62 cm x 70 cm, is composed of an Aluminum box with 56 cases. It contains 38 fuel assemblies, 6 control rods, 7 Beryllium assemblies, as well as 5 experimental boxes. The MTR fuel, in silicide U_3Si_2Al form, is enriched at 19.75%. The beryllium assemblies are used both as neutron reflector, to reduce neutron leakage on one side of the core, and as the starting neutron source, through (γ, n) reactions.

The experimental boxes can be used to place devices to be irradiated or tested (instrumentation, samples to be activated, test fuel, …). Above the core a stainless steel chimney separates the water from the primary water loop from the rest of the pool. A gate, which is place on one side of the chimney, can be removed to load or unload fuel assemblies of experimental devices between the poll and the core. Figure 2 is a photograph of the top of the pool in the reactor hall.

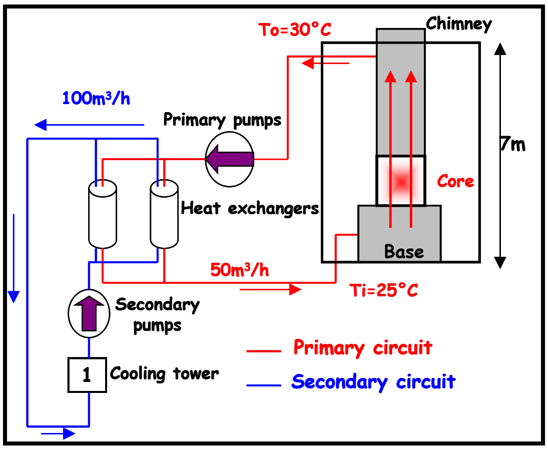

Figure 1: ISIS reactor pool and water circuits.

Figure 2: Photograph of the reactor hall

For the E&T activity, a supervision software has been specifically developed. The logic of the safety system, the control system hardware, the ergonomics of the control board and control room have been adapted to this specific activity. For example, the logic of the safety system was modified to enable the individual drop of each rod during standard reactor operation, and a specific operation mode was created for E&T activities, with a power limit fixed to 50 kW allowing the reactor operation in natural convection.

Figure 3 shows the information displayed by the supervision system that extracts the signals measured during reactor operation. For each experiment, the parameters to be displayed are chosen by the instructor: the power, the core temperature and the position of the rod used to control the reactor for the study of the temperature effect.

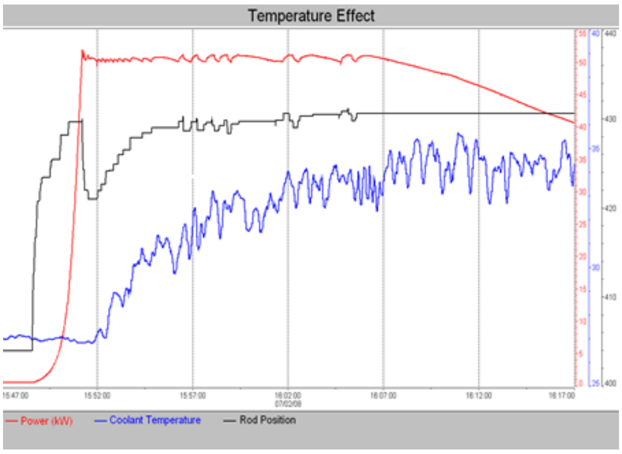

Fig 3. Supervision screen during the study of the temperature effect.

3. Courses on the ISIS reactor and associated curricula

A large set of experiments, which are shown in figure 4, have been developed for the E&T programs organized by the INSTN. These experiments are integrated in nine courses, each course with duration of 3 hours.

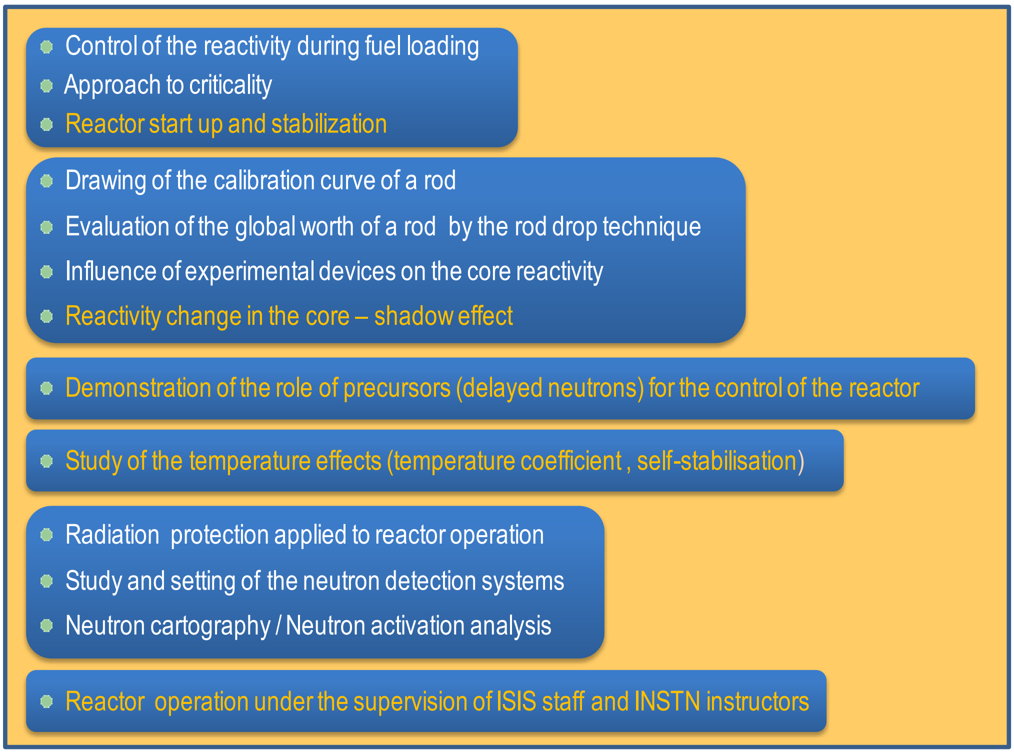

Fig. 4 : Content of the training courses developed on ISIS reactor.

Training courses on ISIS reactors are addressed to students and engineers from different institutions at a national and international level. This includes training courses carried out in the frame of:

- an international master in Nuclear Energy organised by the INSTN in collaboration with other universities and engineer schools [5],
- a one year specialisation course in Nuclear Engineering which was developed by the INSTN in 1956 and contributed to the qualification of up to 140 engineers every

year since this date [6],

- nuclear engineering modules of various master and engineer degrees in which the INSTN is involved,
- a collaboration agreement between Sweden and France that ensure the financial support for 2,5 day training sessions for students from three Swedish universities (Chalmers University of Technology, KTH Royal Institute of Technology, Uppsala University).

Concerning continuing education for professionals, training courses on ISIS reactors are addressed to a very wide public including researchers, engineers and technicians. This includes training courses carried out in the frame of:

- a 8 weeks course which is compulsory in the qualification process of the operators of the French research reactors,
- different courses (taught in English or French) organised on a regular basis (at least once a year) and related to the principle, the operation, the safety and the neutronics of nuclear reactors,
- different courses organised by INSTN to respond to the specific need of the nuclear industry and nuclear programs, which includes courses for the personal of the French regulator body, for young engineers from the Italian company ENEL, for project managers of the Vietnamese company EVN (Electricity of Vietnam), or for teachers and professors from several Polish Universities (training of the trainees).

Depending on the pedagogic and qualification goals, the trainees follow different training programs (3 to 27 hours) on ISIS reactor that can be completed at INSTN by training courses carried out using other tools such as software applications (APOLLO, FLICA, TRIPOLI, MCNP, …) and reactor simulators (normal and accidental PWR operation).

All the experiments carried out on the ISIS research reactor focus on the practical aspects of reactor design, principle and operation. Emphasis is given to the safety aspects both in normal and incidental conditions. The feedback from the participants shows that practical exercises, as well as hands on reactor operation, are very efficient in going deep inside the understanding of the theoretical courses on reactor physics. Indeed, training courses on a real nuclear facility is the only way participants can approach and understand how different taught subjects (reactor design, principle, operation, safety, radiation protection …) are taken into account to ensure the safe operation of a nuclear facility. The feedback from the trainee's, even years after they went through training courses on a research reactor, also shows that the impact of such course ensures comprehensive, and long standing, understanding of the reactor principle and operation that cannot be gained only with theoretical courses associated with the use of simulators.

Thus the INSTN is continuously promoting the use of the training courses on ISIS reactor in its E&T programs as they appear to be a very powerful tool for the development of the human resources needed by the nuclear industry and the nuclear programs.

4. Internet Reactor Laboratory

At an international level, a small number of research reactors are available for nuclear education programmes and human resource development. Thus, since the ISIS reactor has been specifically dedicated for education and training, CEA is promoting the use of the reactor at an international level. This is done in the frame of bilateral agreements, specific contracts or through the international courses that are organised by the INSTN.

When the supervision system of ISIS reactor was developed in 2003, the specifications were established taking into account remote access and data transmission. Nevertheless for pedagogical reasons, in-reactor training courses where promoted up to now by the INSTN. After the experience of “virtual reactor laboratory,” which linked the PULSTAR research reactor at North Carolina State University with the Jordan University of Science and Technology (JUST) as a guest institution [7] and the demand for Internet Reactor Laboratories (IRL) at an international level, CEA decided to develop the remote access to the training courses carried out on the ISIS reactor.

Keeping in mind that IRL cannot replace real hands on a research reactor, IRL can be seen as a cost-effective way to expand the nuclear education for groups of students or trainees that would not normally have access to a research reactor during their education. With this limitations and expectations, CEA has decided to develop IRL broadcasted to guest institutions. Using a system based on Visio conference equipment, the following information can be sent from the ISIS reactor (host reactor) to the remote classroom at the guest institution(s):

(1) Power point presentations,

(2) Pages from the supervision system used by the operator to follow the state of the different systems of the reactor (control rods, neutron detection systems, cooling system, safety system…),

(3) Interactive white board were the lecturer can present and explain the experiments and results,

(4) Graphs from the supervision system showing the time evolution of selected parameters for each experiment,

(5) Tables of selected data recorded by the supervision system,

(6) Curves plotted using the recorded data after calculation,

(7) Movies to be shown to introduce or illustrate some experiments or phenomena,

(8) Video signals from four cameras looking at: the lecturer, the reactor hall, the core, the operator at control desk.

Out of this information, according to the pedagogic needs during the training courses, the lecturer on the ISIS will choose to broadcast the relevant information at each stage of the course. By interacting through video conference, the remote classroom will also be able to ask for the display of particular information. At the guest institution, the information will be displayed on two screens, one dedicated to the information selected out of (1) to (7) and the other one dedicated to the video signal selected out of the camera signals (8). Concerning the interaction with and the feedback from the remote classroom, at least one camera will be installed in the remote classroom and its signal will be sent to the ISIS control room to be visible par the lecturer and the operators. IRL broadcasted from ISIS reactor will be available in 2014.

5. Conclusion

Since 1956, the National Institute for Nuclear Science and Technology provides students, engineers and researchers a high level of scientific and technological qualification in nuclear reactor theory and operation. The adopted strategy is to complete theoretical courses by training courses on training reactors. A large set of training courses have been developed on ISIS research reactor in the frame of the education and training programmes from the INSTN. The experience gained shows that such training courses bring tremendous benefits for all trainees since they ensure a practical and comprehensive understanding of the reactor physics, design and operation. With this feedback, the implementation of the Internet Reactor Laboratory, which will be operational in 2014, appears to be a powerful tool, complementary to in reactor training courses, for the development of the human resources needed by the nuclear industry and the nuclear programs.

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IMPLEMENTING PUBLIC PARTICIPATION APPROACHES IN RADIOACTIVE WASTE DISPOSAL IN POLAND

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ABSTRACT

The new approach to public participation in environmental decision making methods is presented in case of radioactive waste management. Some consequences of the plans of nuclear energy introducing in Poland and necessity to build a new repository for low and intermediate radioactive waste repository are discussed. Preparing the future dialogue with the public, the various actions take place. In this work the results of first public hearing and technical training for local community administrations are shown as an example of influence of nuclear knowledge broadening to environmental opinion about nuclear energy implementation and the radioactive waste repository to be built.

I. Introduction

The implementation of nuclear power in Poland will force a new approach to the current procedures and systems related to the management of radioactive waste and spent nuclear fuel. Due to the fulfillment of disposal volume in the National Radioactive Waste Repository in Różan it will be necessary to build a new repository for low and intermediate radioactive waste with a capacity of about 170 000 m^3 .(Ref.1) In the operation of nuclear power plants with a capacity of 6 GWe over its lifetime 60 years, the discharged spent fuel will contain up to 6 800 tHM. Considering the possibility of nuclear energy introducing in Poland the following questions should be solved:

1.spent nuclear fuel management,

2.radioactive waste management produced during:

- nuclear power plant operation period,
- NPP and spent fuel decommissioning,
- application of isotope techniques in health protection, industry, science and during operation of experimental nuclear objects and connected with them isotope facilities,
- improvement or decommissioning of nuclear and isotope facilities.

All these questions should be solved based on dialogue with society of our country and trans border communication.

Regulation and international agreements in the form of conventions have been established. The nuclear and radioactive waste management industries work to well established safety standards for the management of radioactive waste. International and regional organizations such as the International Atomic Energy Agency (IAEA), The Nuclear Energy Agency (NEA) of the Organization for Economic Cooperation and Development (OECD) the European Commission (EC) and the International Commission on Radiological Protection (ICRP) develop standards, guidelines and recommendations under a framework of co-operation to assist countries in establishing and maintaining national standards. National policies, legislation and regulations are all developed from these internationally agreed standards, guidelines and recommendations. These standards aim to ensure the protection of the public and the environment now and in the future. International agreements in the form of conventions have also been established such as the Joint Convention on Nuclear Safety and the Joint Convention on the Safety of Spend Fuel Management and on the Safety of Radioactive Waste Management. This convention was adopted in 1997 by a diplomatic conference convened by the IAEA and came into force in June2001 following the required number of ratifications. Other international conventions and directives seek to provide for interim alia the safe transportation of radioactive material, protection of the environment (including the marine environment) from radioactive waste and control of imports and exports of radioactive waste and trans boundary movements. In July 2011 the European Union adopted a directive for the disposal of used nuclear fuel and radioactive wastes which require member countries to develop national waste management plans for European Commission revive by 2015. The plans must include firm timetables for the construction of disposal facilities, descriptions of needed implementation activities, cost assessments and financing schemes. Safety standards promulgated by the IAEA will become legally binding within the EU-wide policy framework.

In Poland such plan is elaborated step by step and it is expected to be presented in 2013. All plans regarded to surface or geological disposal or other reprocessing possibilities have to be based on the voluntary involvement of potential host communities and IMPLEMENTING PUBLIC PARTICIPATION APPROACHES IN RADIOACTIVE WASTE DISPOSAL (IPPA project)ref.2, which become the urgent tasks.

Using scientific methods elaborated as RISCOM model, RISCOM Reference Group in Poland was established July 1 2011 with satisfactory representation of Governmental Bodies, Scientific Institutes, Radioactive Waste Managements, the local Community of Różan. In this work the description of hearings , trainings, workshops and meetings is presented and the questionnaire methods of communication with the society is discussed showing the influence to public opinion.

II. IPPA research project as a first step towards public participation approaches in radioactive waste management.

II.1. Goals of the IPPA project.

The aim of the IPPA research project is to promote the idea of participation of the society transparency in decision-making processes at various stages of implementation of repositories for the radioactive waste in European countries. The project involves the establishment of a safe arena for all stakeholders, which will allow better understanding of problems of radioactive waste disposal through active exchange of views between the interested parties. This goal can be achieved in Poland by implementing so-called RISCOM process allowing clarification and explanation of the arguments from interested parties, based on scientific grounds. The RISCOM process involves establishing a reference group as a platform for effective public participation in the decision-making process. The Reference Group in Poland was established on July 1st, 2011. Its activity is based on an agreement accepted by all its members. The Group fulfils the project objectives through participation in the implementation of 8 work-packages (WP).

The actions carried out within the project are aimed to improve the quality of decisions in the field of radioactive waste management, by strengthening the transparency and trust between all stakeholders. Recognising the importance of the radioactive waste management issues in a wider social perspective will make it possible to avoid unnecessary conflicts resulting in blocked decisions or hindered programmes of great importance for the country in the future. Correct communication with the public is a necessary condition for the success of both building new radioactive waste landfills and the Polish Nuclear Energy Programme.

II.2. Hearing

The hearing is one of the tools used within the RISCOM process, which has been applied in the IPPA in order to discuss plans to build a new repository of radioactive waste. According to the model adopted within the RISCOM process, the hearings are a form of communication with the public, carried out at the various stages of the project implementation, beginning from the very early construction plans, through the stage of research on location and its final choice, up to completion of the controversial investment. The hearings are intended to ensure public participation in the decision-making process at the earliest stages of the

implementation of the idea through active exchange of views and explanation of all the facts known at the specific stage.
At its meeting on January 24th, 2013 the Reference Group made a decision on arranging the first hearing, the subject of which was:
Do we need a new repository for radioactive waste?
According to the assumptions made, the hearing was intended to inform all the stakeholders of status preparations for the construction of a new landfill and the complexity of the related issues. Participants of the meeting were to find the answers to the nurturing questions, allay the concerns about the risks as well as to present their own views and expectations to the bodies responsible for the preparation of the investment.

II.3. The RISCOM hearing

The aim of the RISCOM hearing was to initiate an open debate on the need to build a new repository for low and medium radioactive waste in Poland and the choice of its location.
The hearing was supposed to be an opportunity to exchange views and experience between the various groups of stakeholders, who see the need to build a repository or see the risks connected with this fact. The hearing was supposed to give an answer to frequently asked questions: What is the current state of technology in the field of storage of the radioactive waste? What are the public concerns about locating the landfills in the direct neighbourhood of homes? What to do in order that a repository will be safe and acceptable to the local community?
130 people representing various communities: researchers, practitioners dealing with waste and nuclear power engineering, local communities interested in building a future landfill in its area and representatives of the public administration, were present at the hearing, which was held on May 8th, 2013 in Hotel Radisson Blue in Warsaw. In addition to the groups of supporters of the nuclear energy and people supporting construction of new landfills in Poland there were people sceptical about those programmes as well as the declared opponents. The hearing was accompanied by a panel of experts, who presented the current state of knowledge about the repository of waste as well as issues regarding the social participation in the decision-making process and the related legal aspects. The moderator of the discussion was journalist Krzysztof Bobiński.
The participants gained extensive information about state of implementation of the project of the repository, they also had an opportunity to get familiar with the opinion of the representatives of the ecological environments, reporting a number of concerns about costs, impact on the environment and way the dialogue with the public is carried out. These doubts were answered by experts from ICHTJ, NCBJ, PIG-PIB, PAA, ZUOP and DEJ.
The hearing was an opportunity to express own views on storing waste, safety of repositories and manner of preparations for the construction of the new facility. The discussion was vivid and very instructive. Course of the hearing demonstrated the need to organise meetings that are an opportunity not only to present a substantive knowledge and exchange views, but also give an impulse to groups of stakeholders, strengthening their influence on the decisions made in the broadly-meant social interest.

II.4. Conclusions of the hearing

The hearing was the first event of such a scale, dedicated to plans of constructing a new repository for the radioactive waste in Poland. Until today such issues were discussed at the governmental level (Department of Nuclear Power, Ministry of Economy) in purely expert environments relating to the technical aspect of project execution. All groups of stakeholders both interested in construction of the repository and skeptics about this project participated. In fact, there were no declared opponents of construction of the repository for the low and medium radioactive waste produced by industrial and medical activities. However a severe conflict arouse about building a nuclear power plant in Poland. Majority of ecological organisations in the country is opposed to develop nuclear power plants and express it loudly. There is a fear that the construction of the repository is just an element of the larger plan to build a nuclear power plant, and even a deliberate action supporting this plan, which is alleged to enable introducing nuclear power plants on the sly. Therefore the opponents of the nuclear power plants also disapprove of possible construction of the deep repositories for spent nuclear fuel and highly radioactive waste. Very often they complain about manipulations on the public fed only with information about advantages of the nuclear power plants. In their opinion the facts about the risks are unsaid.

The ecologists stress lack of discussion in wide groups of experts, representing also themselves as well as the parties more sceptical about the nuclear energy programme and see the hazards resulting from storage of the radioactive waste. In their opinion, it is commonly assumed that the term "expert" is used only when speaking of the representatives of atomists, but nobody invites the experts in the ecological law, environmental sciences and sustainable development to any debates. The ecologists complain about low relevance of the arranged meetings and debates. Also a huge mistrust of the experts representing the atomists, who not always are neutral, even when they show results of the research and commonly accepted approaches to risk analysis, was seen.

From its part, the expert side of atomists, not always sees the necessity and sense of engaging wide groups of the society into the decision-making processes. In the atomists' opinion (confirmed by research) status of public knowledge of nuclear fission and operation of the modern power reactors is very poor, and first of all, educational campaigns should be conducted in various social groups, and only then ask for expressing an opinion. The voices of the whole society, also of the uneducated people, should be heard according to the sociologist.

The participants in the meeting had an opportunity to learn of main assumptions of the Aarhus Convention and rules of applying the Convention to the radioactive waste management. Many of them, heard about the main pillars of the Convention for the first time and realised the onerous consequences for a country which does not respect the Principle of the Aarhus Convention, which are echoing in the new Directive of the EU Council 2011/70/EURATOM, which imposes transparency and social participation in the decision-making process related radioactive waste and used nuclear fuel management.

In the same time all the participants in the hearing assessed positively the attempts of organising the meetings like this one and stressed their willingness to participate in similar meetings in the future. The topic of the hearing, as well as the presentations made, received high rates. Extensive treatment of construction of the repository with consideration of its legal and social aspect as well as its implications for the environment met a particular assent. It seems that such events meet social expectations and are of much need, when the project of development of nuclear power engineering is executed in Poland with lack of interest of the public in participation in the decision-making process. The participation involves not only right to participate in this process, but also imposes obligations on the participating societies as well as implies distribution of responsibility for the decisions made.

With presence of public media (press, radio) the information about the hearing reached wide social groups. The public could get familiar not only with opinions on construction of the repository, but also with wide range of works, which must precede its construction, including in the areas of communication with the public. The society could learn that appropriate social communication is a subject of care of the state, and transparency of the decision-making processes is an indispensable element of correct operation of the civil society.

III. Technical training

III.1. Education level added to RISCOM

Technical tracing is a new approach to communication, starting from presentation the basic scientific questions related to radioactivity in environment, nuclear waste origin and management and visiting nuclear facilities.

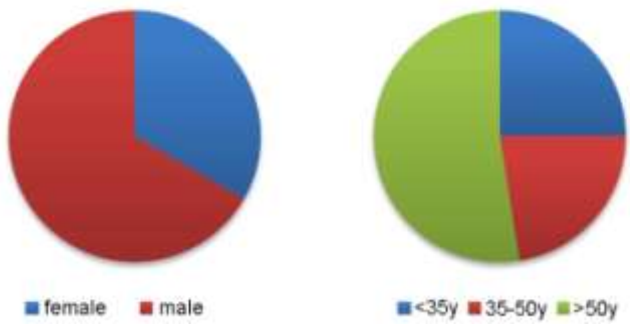

Figure 1. Division of survey participants by gender and age.

Due to fruitful international collaboration, participation in trainings, exchange of experience about RISCOM implementation in different countries, Reference Group in Poland gained a lot of experience and knowledge how to start public participation initiative in nuclear waste management questions. In order to check the result of introduction the educational level to RISCOM, the technical for community representation was done.
As a first group of listeners (Fig. 1) selected for training was the Society "Dolina Pilicy" were the local community representation, administration employees, elected mayors are organized. The selected region up to now it was not exposed to any kind of antinuclear of pronuclear action. It is typical region in central Poland without industry, with rather poor farming and no dense population, looking for new possibilities and new challenges.

III.2. Methodology

The technical training was arranged 6-7 June 2013, in National Centre for Nuclear Research [3] and Radioactive Waste Management Plant [4] at Świerk where the main nuclear facilities of Poland are located and at National Radioactive Waste Repository at Różan about 150 km aside. During the training the lectures were followed by visiting installation. Before and after training the questionnaires opinions were collected and simultaneous hearings were kept.
The main points of visit were following:

- Introduction about NCBJ, ZUOP, IPPA-project.
- Information about radioactive waste management in Poland.
- Ionizing radiation and humans.
- Nuclear facilities in Poland. Reactor MARIA its history and future (visit).
- Radioactive waste management facility (visit).
- Dept. of Education and Training -experimental presentation about detection of ionized radiation and basic nuclear facilities(visit).
- Former NPP Żarnowiec model and exhibition (visit).
- National Radioactive Waste Repository -Różan(visit). Meeting with Różan Meir
- Questionaire opinion studies. Hearings during the visits.
-

III.3. Results

The general presentation of participants is show on Fig.1 where the gender and age are summarized. One should stress that participant had very matter of fact approach to the visit. They came with ready questions and they have the filing of lack of knowledge about nuclear matters, in spite of the fact that the education level of that participants was high. 30 persons of 40 taking part in training, had higher education and among them 9 had technical education.
The knowledge of the respondents, according their opinion, about conditions and consequences of radioactive waste repository is not satisfactory what is shown at Fig 2.

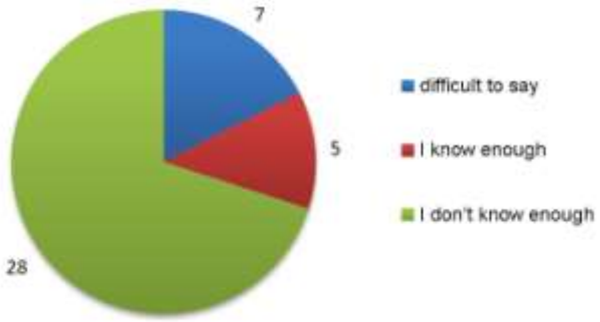

Figure 2. Knowledge of the respondents about conditions and consequences of the construction of radioactive waste repository; measure 1.

The main sources of knowledge about radioactive waste management are presented at Fig.3. One can see that media and internet are the most powerful tool of education for adult from small communities. The approach to the radioactive waste repository was changed after training, what is shown at Fig.4

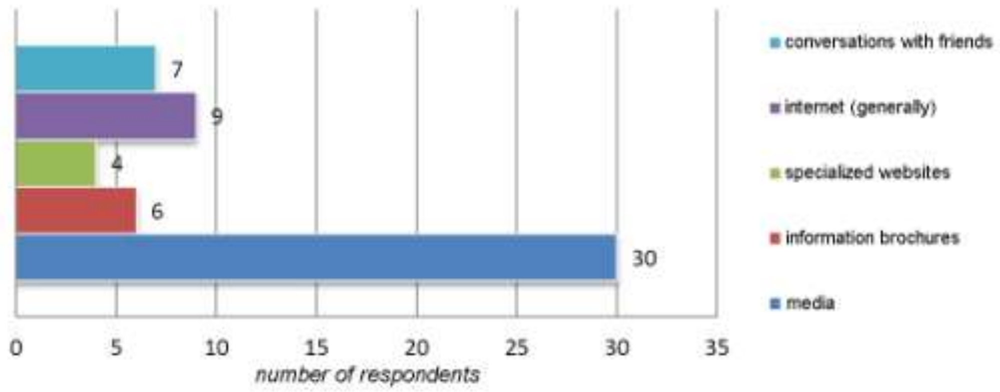

Figure 3. Sources of knowledge about radioactive waste repositories (possible to mark more than one answer); measure 1.

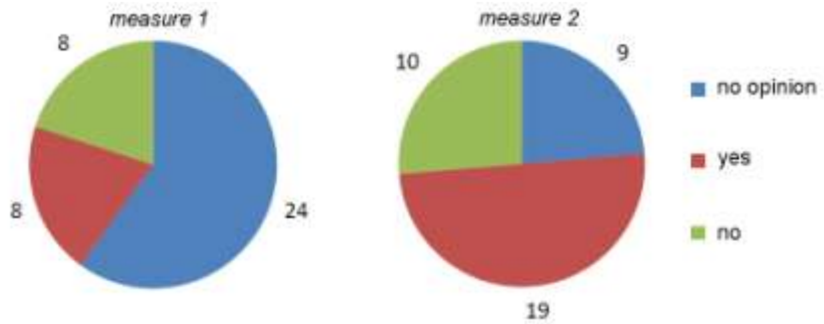

Figure 4. The answer the question: Do you think that in Poland there is a need to build a new radioactive waste repository?

Significant fraction of participants undecided before training stated that there is necessity of repository construction. The more detailed analyze one can make using correlation between proposed distance to the repository and living place. The typical approach is NIMBY(Not in My Backyard). The estimation of the advantages and disadvantages ratio regards the plan of repository built in selected region are summarized at Fig.5 where some added value approach is evident. Economical profit is pointed out but some risk was stressed as well, first of all the following negative aspects were stated during hearing:

-risk of investors lost,

-decrease of real estate value,

-possible conflict with touristic development of village ,

-social conflicts possibility.

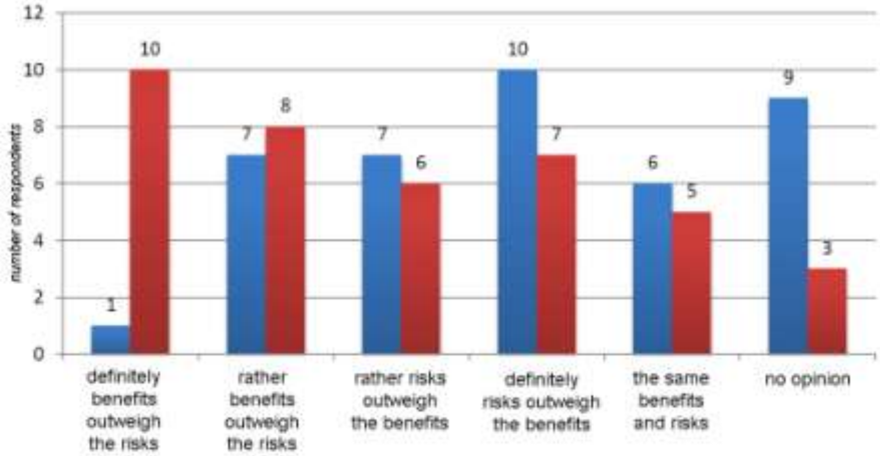

Figure 5. Benefit-risk ratio in case to build a nuclear waste repository; blue – measure 1, red – measure 2.

Fig.6 illustrates approach to the risk and profit distribution. The useful discussion were about who should decide about radioactive repository location. The consultation forms were pointed out and following preferred consultation forms were proposed: referendum, meeting with experts, habitants reunions, excursions to other existing repositories, trainings, conferences, medial information, internet. One should point out that proposed actions contain educational and information character.

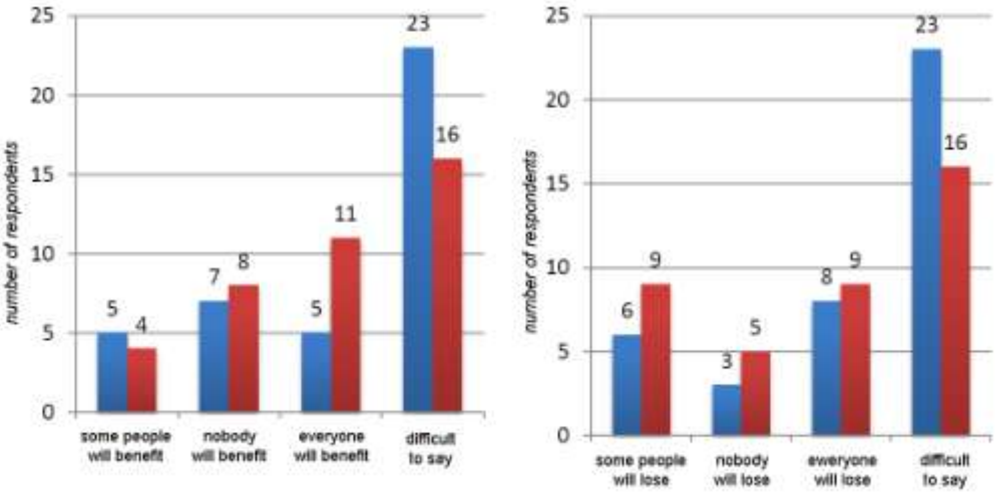

Figure 6. Respondents' opinion about the benefits and risks within the local community; blue – measure 1, red – measure 2.

III.4. Conclusions

The improvement of the knowledge does not transfer to increase of acceptance but the way of training help to polarize the opinion of people previously undecided. In the selected group it was strong feeling that the decision about radioactive waste repository location should be done by whole local community. (Fig. 7) The necessity of education, training, information, before consultations are stated. It is almost impossible to separate the radioactive waste management question and approach to nuclear energy development in Poland. The attitude to nuclear energy implementation in Poland is shown at Fig.8.

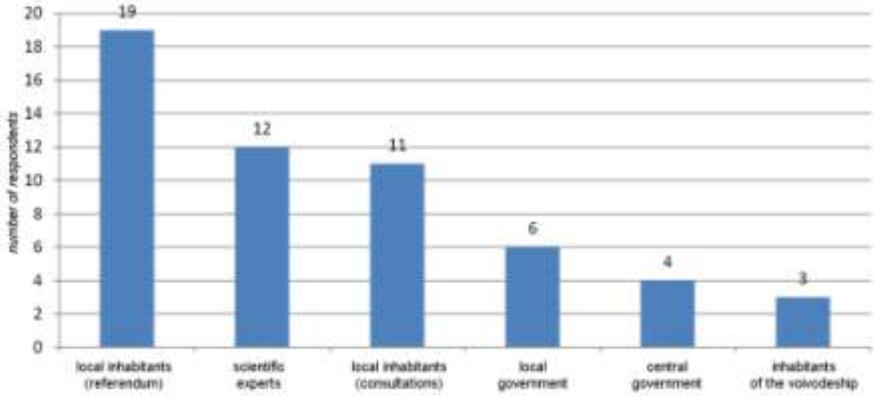

Figure 7. Who has the final say on the location of the new radioactive waste repository – opinion of the respondents.

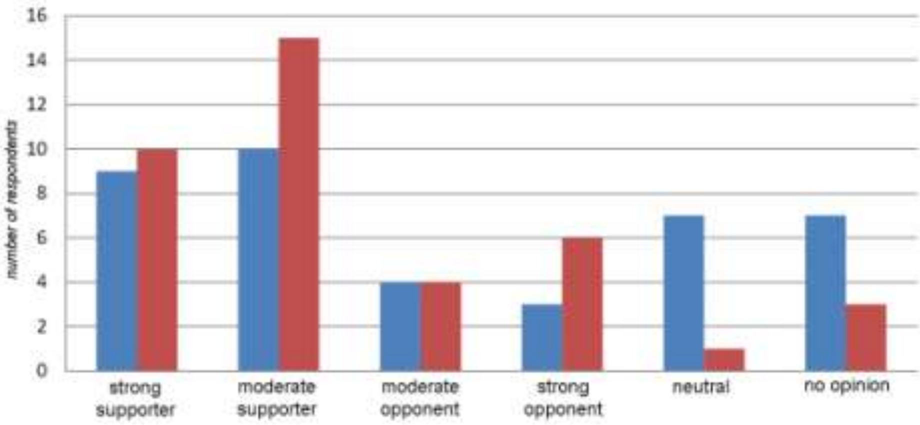

Figure 8. Attitude to nuclear energy development in Poland, blue – measure 1, red – measure 2.

One could presume that negative attitude is not the result of lack of information because these opponents did not change their attitude after training, so the source of this prejudice is somewhere else, but in other groups the acceptance increases. The organized training gives the new suggestions for future action.

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NEW PATHWAYS TO EDUCATION AND TRAINING IN THE NUCLEAR ARENA

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Much has changed in the arena of nuclear training and education in the recent decade. Traditionally, brick and mortar schools were the only paths to attaining a college degree in nuclear engineering and technology. Students would enroll at public or private institutions of higher education, pay their tuition, attend classes and several years later attain their degree. In many ways, education was a guarded commodity and metered out only to those that could afford the high cost of admission to the elite ranks of the college educated. Increasingly, these "traditional" institutions of higher education have been relinquishing their premier position as sources of knowledge to non-traditional schooling. Non-traditional schools may also be brick and mortar, but more and more of these institutions are based on online learning. The introduction and evolution of the personal computer and the growth of the World Wide Web/Internet have played a major role in the establishment of new paths to education and degree attainment.

Two of the leading paths to education are now online schools and the most recent development of MOOCs (Massive Open Online Courses). An online institution offers the courses it has developed to students for a fee, the students then partake in online learning. This form of learning involves readings, discussions, assignments and tests all done via the Internet. The learning can be both synchronous as well as asynchronous learning depending on the format developed by the institution for that particular course. A number of colleges offer online courses, but the premier example of an online or non-traditional school is Excelsior College in Albany, NY which offers a host of Associate, Bachelor and Master Degrees including a Bachelors degree in Nuclear Engineering Technology. Currently, the college has approximately 36,000 enrolled students from throughout the United States and the world, has graduated more than 150,000 students, and is one of the most respected distance learning institutions of higher education in the United States. The college provides multiple venues for earning college credit and a degree, with the focus on what students know, rather than on where or how they learned it. Undergraduate and graduate credits may be earned through a variety of accredited sources. Those include for-credit examinations, credit aggregation of course work, military and corporate training, online course work, courses offered through CD-Rom, as well as through portfolio assessment.

One of the most important aspects is the credit aggregation of course work. In many instances learners take courses at numerous colleges because of household moves or military deployments. In so doing they attain the knowledge but never have enough credits at one particular college to qualify for a degree. Once students submit their transcripts to Excelsior College, those transcripts are then evaluated regarding the courses and credits earned. Based on the assessment, credits are then awarded to the student toward one of the Excelsior College degrees. If there are gaps in the student's knowledge, the institution offers online courses to fill the gaps. Students may also earn credit based on their life experiences by completing a portfolio assessment course or take for-credit exams to earn credits.

What quality education is free, available to anyone, anytime, around the world? The answer is MOOCs. MOOCs – Massive Open Online Course – are a recent phenomena and addition to the educational and training mix. MOOCs are online courses that anyone can register for, free of charge. There is no limit to enrollment size as there are no classrooms; hence, thousands of people can be taking the same course at the same time. Current estimates place approximately 6 million students as enrolled in these online courses worldwide. MOOCs are developed from traditional courses and are considered the very best offerings from such distinguished schools as MIT, Harvard, Princeton, Stanford, and UC Berkley. They include such courses as Introduction to Engineering Mechanics, Chemistry, Material Behavior, and many others, spanning a host of educational disciplines. Learners take these courses online and the ultimate goal is to receive college credit upon completion. There have been some teething pains with MOOCs including a higher than normal dropout rate and no way to validate if actual learning has occurred, and by whom. Promoters of the MOOC concept contend that once or if certification or degrees are offered based on MOOCs, the dropout rate will be similar to traditional institutions. Regardless of these startup problems, it appears that this innovative and wildly embraced mode of learning is here to stay.

Much has changed in education in recent years. The slide ruler gave way to the handheld calculator, and the personal computer, linked with the Internet, has opened doors to education that could only be dreamed of a scant few years ago. Education is no longer secreted and locked behind ivy walls. Nor is it reserved for the socially elite. Non-traditional schools provided learners with alternative means to attain a college degree through, at one time paper based courses, and in recent years, online courses. Now, the entire educational system may be on the verge of a dramatic upheaval of how learning occurs, and how recognition is awarded to students through the MOOC system of transmitting knowledge. MOOCs are unhindered by the size of classrooms, geographical borders, and the financial condition of the learner. They also offer the many benefits of any online course including the flexibility that most adults need.

However the knowledge is attained, through online courses, MOOCs, or any of the paths that Excelsior College offers, the goal is the same--to provide quality education to those willing to study, assimilate and embrace the information that is there for the taking. The nuclear industry is poised for the long-awaited renaissance, and the educational tools that can help to supply experienced, safety minded individuals to staff those new plants, is now in place and ready to do its part as the industry moves forward in the 21st century.

COLLABORATIVE NUCLEAR SAFETY TRAINING EFFORTS TO MEET THE NEEDS OF A SMALL COUNTRY

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ABSTRACT

In Finland, the Ministry of Employment and the Economy (MEE) launched a project in late 2010 to survey the know-how in the nuclear field in Finland. The task was started with a comprehensive questionnaire sent to all stakeholders, including regulators, industry, research organisations and the academia, and projected the personnel needs in the field up to 2025. The demand for new experts in the nuclear energy field in Finland was estimated to be 2400 persons in 12 years, when the current workforce is 3300 experts.
Experts on the non-nuclear areas need to be educated on the specific requirements of nuclear safety when employed in the nuclear energy field. To tackle this challenge, the Finnish nuclear energy organisations have arranged basic professional training courses on nuclear safety since 2003. The syllabus was planned according to the IAEA model, adjusting it for domestic conditions. We have completed ten courses and have started the eleventh one in October 2013. The length of each course has varied between 19 and 30 working days in 5-6 modules scattered from October to March. The number of expert lecturers on each course has been around 100 and the average number of participants about 60.

1. Introduction

The presently operating nuclear power plants have been designed, built, and operated by a generation of experts in various fields. The transfer of their know-how to a new generation is a prerequisite for a continued safe and economical operation of NPP's. Besides replacing retiring experts, Finland alike many other countries are planning or already building new NPP units, and this increases the need for new experts.
The replacement of the experts in the nuclear energy field is a challenge, because the current plants were mainly built in the 1970's and 1980's, after which there were few new-builds for about two decades. This period of stagnation led to fewer new job opportunities in the organisations and, thus, a smaller need for education capacity.
The so-called nuclear renaissance started about 10 years ago. The new interest that has led to new NPP projects also in Europe, together with the aging of the personnel that built and operates the existing plants, have brought all stakeholders to a new situation: new experts

must be employed in unexpectedly increasing numbers. Universities and polytechnics need to re-focus their curricula onto engineering of power systems, and nuclear engineering in particular, as well as other fields relevant to NPP's like radiochemistry, automation and project governance. As a parallel effort, nuclear energy organisations need to strengthen the training of their new personnel. The effect of the Fukushima Daiichi accident in March 2011 is not yet clear, but already now its influence varies a lot from country to country.

2. Survey of competence needs

In Finland, the Ministry of Employment and the Economy (MEE) launched a project in late 2010 to survey the know-how in the nuclear energy field in Finland (the so-called Competence Committee). The task was started with a comprehensive questionnaire sent to all stakeholders, including regulators, industry, research organisations and the academia. The goal was to map the current situation and to obtain a reliable estimate of the personnel needs in the field up to 2025.

The coverage of the questionnaire was ensured with several reminders and replies were finally obtained from all significant stakeholders, which make the results as reliable as any projection to the future can be. In the final report of the project [1] the replies are displayed from various perspectives. The current workforce is classified according to the area of competence, education level and the number of years in the nuclear field. These data are also displayed separately for power companies, regulators, and research organisations and universities. Then the needs of experts on various fields are projected to 2015, 2020 and 2025 collectively for all organisations. For illustration, Fig. 1 shows the estimated need for personnel in various competence areas that require a higher university or polytechnic degree.

When taking into account the multidisciplinarity of the nuclear energy field, the need for new experts in the nuclear energy field in Finland was estimated to be 2400 persons in 12 years, when the current workforce is 3300 experts. Roughly half of the new recruits replace retiring experts and the other half are needed in the new projects: one new reactor is being built in Finland, two more are being planned, and the nuclear waste repository for spent nuclear fuel is also being commissioned. Altogether this means a total of 200 new recruitments per year, all of whom should have at least a basic understanding of nuclear safety.

Answers to this need are also given in the final report of the MEE project that broadly covers education and training, research, and infrastructure as well as participation in international projects and plant construction projects. As seen in Fig. 1, the demand is not only for experts on specific nuclear issues like reactor physics or nuclear fuel, but also more generic issues like structural materials, power electronics, automation, and radiochemistry.

One aim of the project was to reveal any bottlenecks in the education and training system. No severe difficulties were noted, but a clear need for improved cooperation and coordination of activities between universities and polytechnics was observed. Fortunately, the contacts between the academia on one hand and the other stakeholders on the other hand are functional in Finland, an advantage of being a small country. Even though the end-user needs are readily taken into account in the academia, the inherent education delays must be remembered: usually it takes five years to educate a master or engineer and additional five years to get a doctoral degree.

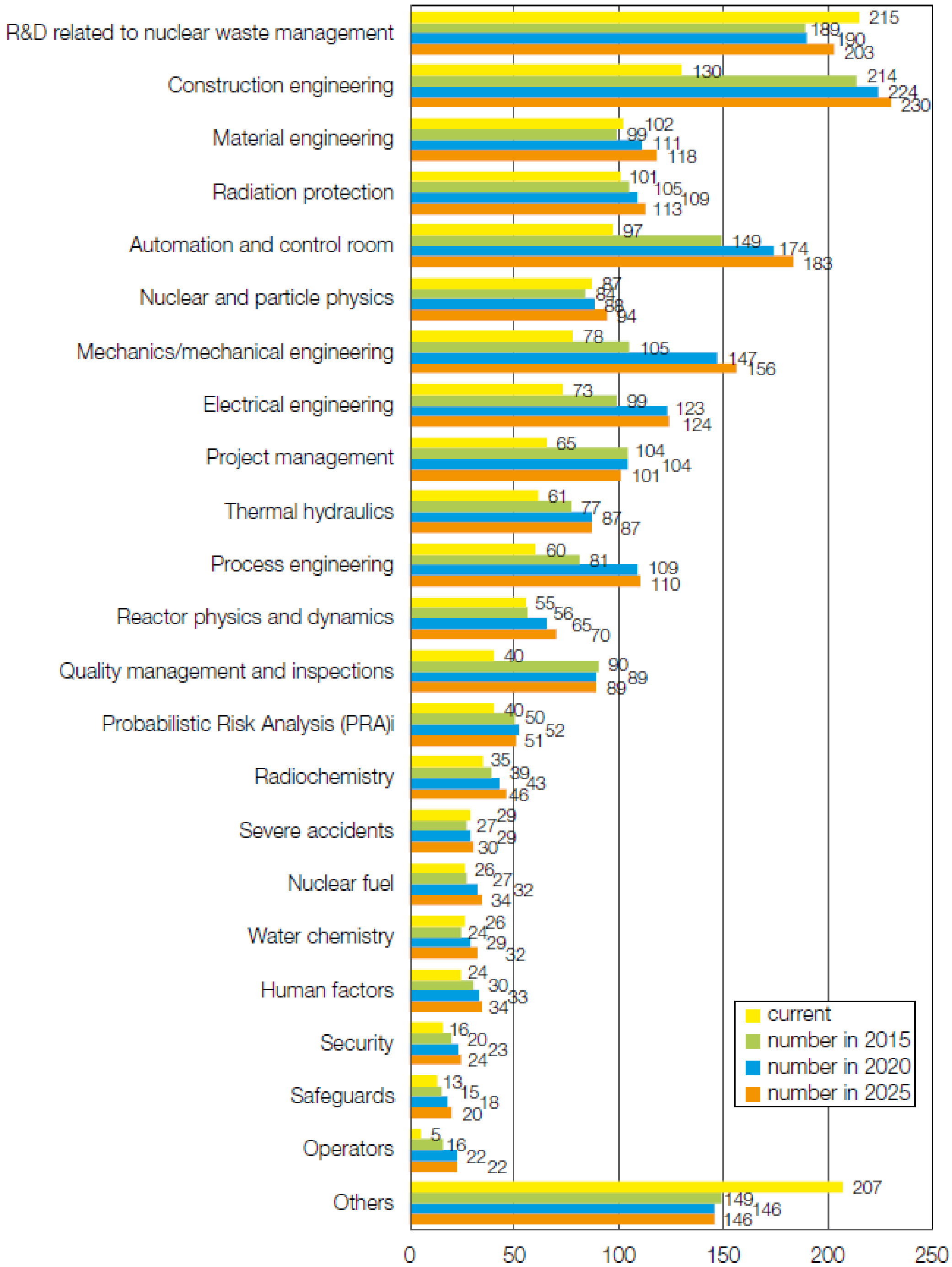

Fig. 1. The estimated need for personnel in various competence areas that require a higher university or polytechnic degree [1].

3. Basic professional training: the YK course

Experts on the non-nuclear areas need to be educated on the specific requirements of nuclear safety. Aalto University (Aalto) and Lappeenranta University of Technology (LUT), the main educational institutes in this field in Finland, are giving basic courses on nuclear energy to an increasing number of engineering students; a minority of them will finally major in nuclear engineering. Additionally, Aalto is currently planning a minor subject in nuclear energy for Master level students with any engineering major, thus implementing one of the recommendations of the MEE report [1].

However, the industry, regulators and research organisations are also recruiting many science and engineering professionals from other universities than Aalto and LUT, and they must receive at least basic training on nuclear safety. In-house training courses are the traditional solution in the nuclear energy field. As an additional means to tackle this challenge, the Finnish nuclear energy organisations have collectively arranged basic professional training courses on nuclear safety since 2003, known as the YK course[1] that is a joint endeavour of all major stakeholders [2]:

- Ministry of Employment and the Economy (MEE)
- Radiation and Nuclear Safety Authority (STUK)
- VTT Technical Research Centre of Finland
- Aalto University
- Lappeenranta University of Technology (LUT)
- Fennovoima Oy
- Fortum Oyj
- Posiva Oy
- Teollisuuden Voima Oyj

The planning of the YK course was started in the autumn of 2002, just a few months after the Parliament had ratified the positive decision-in-principle for Finland's fifth nuclear power unit, Olkiluoto 3. The syllabus of the YK course was originally planned according to the IAEA model [3], but it was adjusted for domestic conditions already on the first course YK1 that started in October 2003. Over the years, the contents have evolved from the original model course in order to utilize the time resources most efficiently. Table 1 displays the themes and their current volumes. The adaptation of the nuclear safety course to Finnish conditions is emphasized by the choice of Finnish as a working language.

The YK course is planned, developed and implemented by a steering group where all participating organisations have their representative. Now that the course is relatively mature, the steering group meets 4-5 times per year. The organisation responsible for all practical arrangements is LUT. However, each course module is hosted by a different organisation. This adds another important dimension to the course besides new knowledge, namely networking and becoming acquainted with the whole field.

We have completed ten courses by the spring 2013 and celebrated this with the YK1-10 Anniversary in March, collecting some 250 participants and lecturers of the past courses. YK11 started in October 2013 with 72 participants. The length of each course has varied between 19 and 30 working days in 5-6 modules scattered from October to March. The average number of participants on each course has been about 60, so by now over 600 persons have taken the YK course. Most of these participants are recently recruited university or polytechnic graduates, but also some more experienced professionals have refreshed their knowledge.

It should be noted that the YK course is utilised for dual purposes. Namely, it is possible to include the course in the doctoral studies at Aalto and LUT. Participating in the course and doing the home exercises gives 8 ECTS. This opportunity has been used by several course participants each year. YK may also be accredited in the participant’s learning portfolio. These aspects are discussed in more depth in Ref. [4].

The number of expert lecturers on each course has been around 100. Many lecturers have a single lecture on the course on the subject where he/she is the top expert in Finland. This has led to some challenges to keep the course as a whole consistent and to avoid excess overlapping of lecture contents. Progress has been made in these respects, not least thanks to participant feedback over the years.

A very special feature of the YK courses is that there are no course fees to the participants or their employees. Each organisation obtains a number of seats on the course on the basis of the number of lectures that the organisation is giving on the course. Some running expenses are paid collectively by the participating private companies.

[1] YK comes from the Finnish word ”Ydinturvallisuuskurssi”, i.e., a Nuclear Safety Course.

Table 1: Themes in YK11. The total hours include lectures, group works and excursions.

Part	Theme	Total hours
0	Orientation	3
1	Nuclear reactor principles	17
2	Principles of nuclear safety	4
3	Starting and implementing a NPP project	4
4	Radiation protection	4
5	Design of a nuclear power plant	12
6	Safety classification	2
7	Deterministic safety analyses	13
8	PRA/PSA principles	7
9	Human performance	3
10	Research infrastructure	3
11	Plant operational safety	14
12	Surveillance and maintenance programs	6
13	Fuel cycle, waste management, decommissioning	10
14	Plant life management	5
15	Limiting conditions for operations	2
16	In plant accident management	14
17	Regulatory control	7
18	Emergency preparedness	4
19	Safety culture	3
20	Quality management	2
21	Public communications	2
YK11	Total	141

Despite the no-fee-principle, the YK courses are, of course, a significant investment for all participating organisations. The lost working days of the participants during the course as well as the lecturers preparing their slides can be estimated, at least on the rough level, and it is easy to see that the total sum becomes large. One can also add in costs due to traveling and accommodation. Yet, the YK course is a cost-effective way to introduce newcomers to the safety culture in this field. Each YK course has a finite number of seats and the candidates are competing of entrance.

One interesting aspect is that less than 5% of the course participants have changed their field after the course. There are naturally more people who have changed organisation, but they have remained in the field, so the YK investment has still served the nuclear energy community in the country. One can speculate whether the training course also leads to increased loyalty.

4. Conclusion

In our opinion a real safety culture presumes that nuclear safety is a common goal, so the regulator/licensee role or the competition for market shares are no obstacles for cooperation in training activities. With true collaboration, the best expertise is made available to all stakeholders and the costs can be kept very reasonable. This kind of collaboration can be achieved when there is a real need.

The basic professional training course that is currently given for the 11th time has filled a real need in the Finnish conditions. In the beginning, it was thought that a couple of courses would be sufficient, but now it seems that the YK course has an established position in Finland and will be running annually in the foreseeable future.

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UTILIZATION OF BRAZILIAN RESEARCH REACTOR TRIGA FOR EDUCATION AND TRAINING

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ABSTRACT

With the revival of the Brazilian nuclear program, it is anticipated a large demand for training in nuclear technology. The Nuclear Technology Development Center (CDTN), a research institute of the Brazilian Nuclear Energy Commission (CNEN), offers the Operator Training Course on Research Reactors (CTORP). This course has existed since 1974 and about 258 workers were certificated by CTORP. This article describes the activities of CTORP and presents a proposal for expansion of its activities in order to meet the current demand in the nuclear technology. Experimental research projects programs would be created in the postgraduate course at CDTN. In addition to the normal reactor physics topics addressed by CTORP, new subjects such as thermal hydraulic and instrumentation should be added and discussed in more detail.

1. Introduction

Nuclear reactor technology play a number of significant roles in improving the quality of our environment while at the same time has the potential to generate virtually limitless energy with no greenhouse gas emissions during operations. In recent years there has been a growing interest in nuclear energy, leading to a “nuclear power renaissance” in countries the world over. In Brazil, the nuclear renaissance can be seen in the completion of construction of its third nuclear power plant and in the government's decision to design and build the Brazilian Multipurpose research Reactor (RMB). The role of nuclear energy in Brazil is complementary to others sources. Presently two NPPs are in operation (Angra 1 and 2) with a net output of 2000 MWe. A third unity (Angra 3) is under construction. Even though with such relatively small nuclear park (approximately 3% of electric power consumed), Brazil has one of the biggest world nuclear resources being the sixth resource of natural uranium in the world, and has a fuel cycle industry capable to provide fuel elements.

Brazil has four research reactors in operation: the MB-01, a 100 W critical facility; the IEA-R1, a 5 MW pool type reactor; the Argonauta, a 500 W Argonaut type reactor; and the IPR-R1, a 100 kW TRIGA Mark I type reactor. They were constructed mainly for using in nuclear research, education and radioisotope production.

With the revival of the Brazilian nuclear program, it is anticipated a large demand for training in nuclear technology. The Nuclear Technology Development Center (CDTN), offers the Operator

Training Course on Research Reactors (CTORP). This course has existed since 1974 and so far about 258 workers were certificated by CTORP. It is a three-week practical training course using the IPR-R1 TRIGA research reactor which emphasizes basic nuclear reactor neutronic principles. Subjects such as the neutron multiplication factor, criticality, delayed neutrons, reactivity, period, control rods calibration, and poisoning are discussed in such a manner that even someone not familiar with reactor physics and kinetics can easily follow it. Few mathematical equations are used and several tables and graphs illustrate the text.

This article describes the activities of CTORP and presents a proposal for expansion of its activities in order to meet the current demand in the nuclear technology. Experimental research projects programs would be created in the postgraduate course at CDTN. In addition to the reactor physics and instrumentation topics addressed by CTORP, new subjects such as thermal hydraulic should be added and discussed in more detail. Among the new items that should be studied, may be cited: reactor thermal power calibration, fuel and water temperatures, heat transfer, fuel thermal conductivity, temperature coefficients, Design Basis Accident, etc. Validation and verification of neutronic and thermal-fluid dynamics computer codes such: Monte Carlo, WIMS, RELAP and CFD. Theoretical and experimental burn-up calculations and introduction to reactor control and safety system based on the microprocessor.

2. The IPR-R1 TRIGA Reactor

The IPR-R1 TRIGA reactor at Belo Horizonte is a typical TRIGA Mark I light-water and open pool type reactor. The fuel elements in the reactor core are cooled by water natural convection. The heat removal capability of this process is great enough for safety reasons at the current maximum 250 kW power level configuration. However, a heat removal system is provided for removing heat from the reactor pool water. The basic parameter which allows TRIGA reactors to operate safely during either steady-state or transient conditions is the prompt negative temperature coefficient associated with the TRIGA fuel and core design. The IPR-R1 was designed for training in reactor operation, neutronic and thermal-hydraulic researches and isotope production, but has been used practically only for characterization of samples by neutron activation analysis technique. Figure 1 shows one photograph of the reactor core.

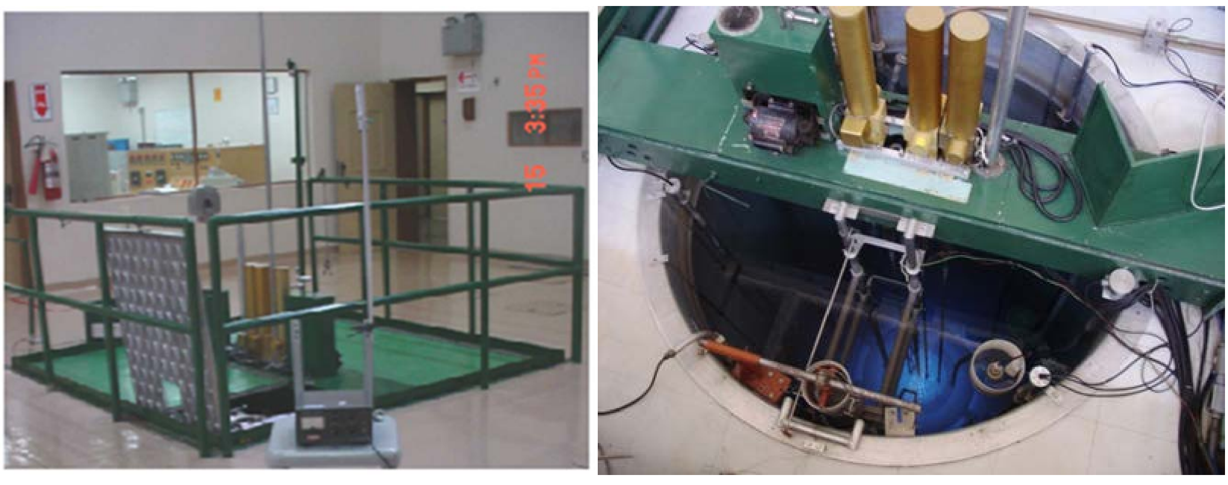

Fig. 1: Nuclear reactor IPR-R1 TRIGA view of the pool and core

3. THE OPERATOR TRAINING COURSE ON RESEARCH REACTORS (*CTORP)*

One of the requirements for the commissioning of the Angra 1 Power Station, the first Nuclear Power Plant in Brazil, was the training program for future nuclear reactor operators [1]. In general, training programs in countries with experience in the nuclear area included training in research reactors operation or in reactor simulators [2], [3]. At that time, Brazil had three research reactors in operation. The IEA-R1 located in São Paulo, reached its first criticality in 1957, while the Argonauta, in Rio de Janeiro, reached it in 1965. The IPR-R1 at Nuclear Technology Development Center (CDTN) situated at Belo Horizonte, state of Minas Gerais, reached its first criticality on November 11th, 1960.

The possibility of using the IPR-R1 TRIGA reactor in the training of the Admiral Álvaro Alberto Nuclear Power Station – CNAAA operators was one of the factors which stimulated the creation of CTORP. The content of this training program was first drawn by experts from the Nuclear Utilities Services Corporation, an American company, working in behalf of FURNAS, the reactor operator, together with Brazilian staff from the Radioactive Research Institute – IPR (later its name changed to Nuclear Technology Development Centre – CDTN). During several days, the requirements for the training program were quoted with the experimental installations available at CDTN, and adaptations were provided, either to adjust the texts to the existing equipment or to make them match the practical character intended for the training.

In the middle seventies the Operator Training Course on Research Reactors CTORP [4] was structured with the aim of filling part of the reactor operators training for Angra 1, which started its commercial operation in 1985. Since then, CTORP has been given 25 times and has certified around 258 professionals for the Brazilian nuclear sector.

Additional requirements of the program for the first applications were that the operators had some experience in the operation of thermal power stations and that they should get in advance the written description of the experiments to be made at the TRIGA research reactor existing at CDTN.

The CTORP is structured as a three-week intensive course. It is inherently practical and the experiments are divided into three categories: Reactor Experiments, Laboratory Experiments and Radiological Protection Experiments.

The material for this course is divided into two volumes. The experiments in each volume are divided into two categories: Reactor Experiments and Laboratory Experiments. The Reactor Experiments cover topics related to reactor kinetics and operation, while the Laboratory Experiments cover subjects as health physics (radiological protection) and reactor instrumentation. Volume 1 deals with the basic theoretical training and a facility description section. This material should prove very helpful to the trainees and should be read before the start of the course. This way, this volume is sent in advance to the trainees. Each experiment described in Volume 2 is further divided into several sections. These sections are: purpose, discussion, procedure, questions, and references. In order to obtain maximum benefit from the program, it is important that the student read the experiment before performing it. Tables 1 and 2 present the summaries of the Volume 1 and 2, respectively.

Tab. 1. Summary of CTORP Part 1

CTORP - PART 1: INTRODUCTION TO EXPERIMENTS
Chapter I: Revision of Fundamental Topics I.1 Nuclear Radiations – Radioactive Decay - Activity I.2 Interaction of Radiation with Matter I.3 Radiation Detection
Chapter II: Introduction to Reactor Experiments II.1 Introduction to IPR TRIGA Reactor Mark1 II.2 Instruments Response – Instruments Reliability II.3 Subcritical Approach – 1/M curves II.4 Inhour Equations – Period and DPM II.5 Critical Mass Determination II.6 Control Rods Worth II.7 Temperature and Void Coefficients II.8 Flux Mapping II.9 Full Power Operation – Recovery Startup II.10 Blind Startup – Automatic Control – Control Rods Permutation II.11 Xenon and Samarium Poisoning
Chapter III: Introduction to Laboratory Experiments III.1 Reactor Instrumentation: Startup Channel III.2 Reactor Instrumentation: LogN and Power Channels III.3 Geiger Müller Tubes – Radioactive Decay III.4 Radiation Shielding III.5 Neutron Activation Analysis III.6 Ion Exchangers
Chapter IV: Radiation Protection IV.1 Introduction IV.2 Biological Effects of Radiations IV.3 Radiation Protection Standard Rules IV.4 Radiation Protection Instruments
Chapter V: Introduction to Radiation Protection Experiments V.1 Characteristics and Operation of Radiation Protection Instruments V.2 Radiometrics Survey V.3 Decontamination V.4 Distance Effect for Point and Liner Sources

Tab. 2. Summary of CTORP Part 2

CTORP - PART 2: EXPERIMENTAL PROCEDURES
Chapter I: Startup, Operation and Shutdown Procedures for IPR-R1 Reactor
Chapter II: Reactor Experiments II.1 Introduction to IPR TRIGA Reactor Mark1 II.2 Instruments Response – Instruments Reliability II.3 Subcritical Approach – 1/M Curves II.4 Inhour Equation – Period and DPM II.5 Critical Mass Determination II.6 Control Rods Worth II.7 Temperature and Void Coefficients II.8 Flux Mapping II.9 Full Power Operation – Recovery Startup II.10 Blind Startup – Automatic Control – Control Rods Permutation II.11 Xenon and Samarium Poisoning
Chapter III: Laboratory Experiments III.1 Startup Channel III.2 Reactor Instrumentation: LogN and Power Channels III.3 Geiger Müller Tubes – Radioactive Decay III.4 Radiation Shielding III.5 Neutron Activation Analysis III.6 Ion Exchangers
Chapter IV: Radiation Protection Experiments IV.1 Characteristics and Operation of Radiation Protection Instruments IV.2 Radiometrics Survey IV.3 Decontamination IV.4 Distance Effect for Point and Linear Sources

The application methodology of the course consists of:

I. The trainees are divided into two groups. The first one conducts the reactor experiments in the morning, and the laboratory and radioprotection experiments in the afternoon, while the other group performs the training in inverse order;
II. Each practical class is preceded by a presentation, which last approximately thirty minutes, in order to give a basic theoretical background about it with particular emphasis on the Purpose and Discussion. With a thorough understanding of these sections, the student will be in a better position to pay full attention to the dynamics of the experiment and to obtain the data necessary to write it up;
III. Finished the oral presentation, students follow the teachers in implementing the proposed experiment;
IV. After the practice, the students together write up a report which should contain the experimental data, graphs and analysis of the results;
V. Finally, questions about the experiment must be answered individually by the students.

After the first and the second weeks, the trainees do written tests to measure their progress in learning the fundamental principles. At the end of the third week of the course a written and oral exams will be administrated to each student to evaluate the student's knowledge at the end of the program. The practical test is necessarily applied by two experts who did not teach in the course. This procedure aims to avoid any prejudgment that could occur due to the student-teacher interaction during the course.

The final evaluation of the trainees is done on the basis of individual questionnaires, partial tests and final exams. Approval is given to the trainees who obtain final grade equal or greater than 70 %.

The CTORP is applied indiscriminately to professionals with high school and also with higher levels (Fig. 2). For this reason, this course avoids the application of differential and integral calculus, using only elementary mathematics. A few equations are used and several tables and graphs illustrate the text. This approach does not diminish the level of the course. The physical concepts which could be masked by a more elaborate mathematical treatment are better understood and assimilated by the trainees.

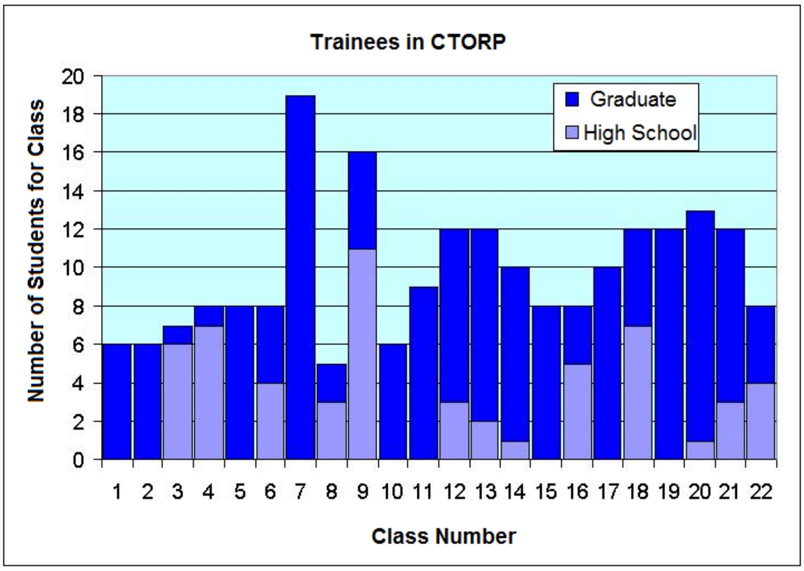

Fig. 2. Number of trainees in CTORP until the 22th class

During the practical classes, special attention is given to each trainee to participate effectively in the experiment, and everyone in the class is expected to participate in the discussions. Another important point in the philosophy of this course is the student-instructor relationship. It is our intention to treat all students as equals, regardless of their company position or academic background. Further, although the students will perform many startups and other operations on the Reactor Control Console, it is essential to remember that the licensed Reactor Senior Operator is fully responsible for the reactor at all times and no action affecting the reactor shall be performed without his knowledge and consent.

4. PROPOSAL FOR A PROGRAM IN REACTOR TECHNOLOGY USING THE IPR-R1 TRIGA

Nuclear Technology Development Centre (CDTN) was the first nuclear research institute in Brazil. In the sixties there was the pioneer project conducted by a research group called Thorium Group. The aim of the project was to develop a thorium fueled reactor. This project realized several progresses in conceptual design (fuel technology, reactor physics, thermal hydraulics, reactor vessel and materials). In the early seventies, with the Brazilian Government's decision to build a Westinghouse PWR (Angra1) in a turn key bases, the Thorium Group discontinued its activities. However, the human power and knowledge developed under the frame work of this initiative were very useful for the future Brazilian nuclear program [5]. Until the late eighties the CDTN provided reactor technical support to the Brazilian nuclear power plants.

During the last decade there was a recovery in several areas of research in CDTN, leading to the creation of the Postgraduate Course in Science and Technology of Radiation, Minerals and Materials. With the conclusion of Angra 3, the RMB design and construction, and the resumption of the Brazilian nuclear program, it is anticipated a large demand for training in nuclear technology.

Then, the aim of this paper is to propose the expansion of training activities in the IPR-R1 TRIGA reactor with the creation of research programs in the reactor technology area in the CDTN postgraduate course. To perform this aim, it is in progress the update of the reactor instrumentation that will be used to monitor its operational parameters. The new system will be microprocessor based, and will be used large LCD displays that are typical of state-of-the-art control rooms.

A digital system is being developed to monitor, store and simulate the behavior of operating parameters [6]. Figure 3 shows two user-friend interface of the system in two computer video screens. In the foreground can be seen the integral curve of a control rod. The graphical interfaces will provide greater reliability and transparency in IPR-R1 TRIGA reactor operations. Besides allowing online reactor parameters visualization and transmission through the internet or in the networks, the data can be stored and made available for exercises.

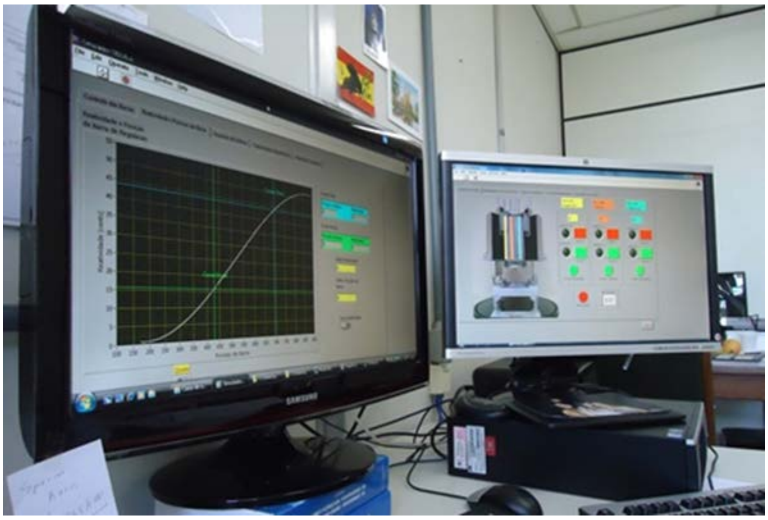

Fig. 3. Digital control system simulation for nuclear reactor parameters [6]

In addition to the neutronic, instrumentation and radiation protection topics addressed by CTORP, new items as thermal hydraulic should be added and discussed in more detail, in the proposed postgraduate program at CDTN. Among the new items that should be studied, may be cited:

- Validation and verification of reactor physics and kinetics computer codes, such as: MCNP, WIMS-D and TRIGLAV-W.
- Validation and verification of thermal-fluid dynamics computer codes, such as RELAP and CFX.
- Development of codes, including coupling of neutronic and thermal-hydraulic codes.
- Calculation of various research reactor physics parameters and models.
- Burn-up calculations and experiments.
- Core optimization.
- Safety requirements, strategic planning and IAEA standards for research reactors.
- Design Basis Accident (DBA).
- Reactor thermal power calibrations and heat transfer.
- Fuel and water temperatures, and heat transfer.
- Reactor instrumentation, digital control and safety system based on the microprocessor.

5. CONCLUSIONS

The CTORP so far has been applied 25 times, and about 258 trainees received Research Reactor Operator certificates. The efficiency and success of the course have been confirmed over the years by the good performance of the workers in the later stages of the training program. The experience of the CTORP certifies that it is possible to provide an effective training on research reactors using only elementary mathematics.

With the revival of the Brazilian nuclear program, it is anticipated a large demand for training in nuclear technology. The IPR-R1 TRIGA research reactor at Nuclear Technology Development Center (CDTN) has been used particularly for the needs of the Brazilian nuclear power plants operators training. This paper proposed the expansion of training activities at the IPR-R1 reactor. Research projects programs would be created in the postgraduate course at CDTN. In addition to the normal neutronic and instrumentation topics addressed by CTORP course, new fields as thermal hydraulic should be added and discussed in more detail. In order to perform a research program and training using the IPR-R1 reactor, it is needed the update of its instrumentation for control of its operational parameters.

6. Acknowledgments

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CENEN - NET - New generation nuclear energy partnership

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CENEN-NET project is solved of Operational Program Education for Competitiveness in priority axes no.2 - Tertiary Education, Research and Development and area of support no. 2.4. - Partnership and networking. The goal of project is to intensify collaboration between involved universities which offer education in field of nuclear energy and the members of CENEN (Czech Nuclear Education Network).

Involved organisations:
Czech Technical University in Prague
Istitute of Chemical Technology Prague
University of West Bohemia Pilsen
VŠB-Technical University of Ostrava
Brno University of Technology
Technical University of Liberec
State Office for Nulear Safety
CEZ GROUP
Nuclear Research Institute Řež
ŠKODA JS a.s.
VÍTKOVICE ÚAM a.s.

Fundamental activities of the project are interships among individual working compartment, together with workshops and conferences which are important to strengthen and foremost making new contacts in national and international academic, state and even industrial bodies. Key part is foundation of project support office aimed to help CENEN members to prepare domestic and international projects.

Activities are focussed to transfer of knowledge and moreover forwarding of contacts to industrial institutions home and abroad from Prague universities to universities outside of Prague. Another part is to arrange sharing of contacts between regional universities themselves.

The main output of the project is than tighter collaboration between universities, state and industrial bodies and creating of contacts.

Target group of project are academic workers and students from out off-Prague universities involved in nuclear education. Particulary it covers 7 workplace at level of departments from 7 different faculties at 4 universities (University of West Bohemia in Pilsen, Technical University of Liberec, VŠB - Technical University of Ostrava and Brno University of Technology). Information about project and state of its solution can be found at project web site: **www.cenen.net** and homepage of CENEN: **www.cenen.cz**

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